Towards a Behavioural Foundation of Macroeconomics

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Executive Summary

This thesis strives to enrich macroeconomic theories with behavioural components. For this purpose, laboratory experiments are conducted to investigate effects of individual decision making in a macroeconomic context. First, the interlinks between economic policy and the labour market are investigated. Employment and wages react on policy changes mainly according to theory. Fiscal policy is applied adequately if employment goals are not met, price policy focuses on stability goals. A behavioural explanation for a relatedness of inflation and employment is derived. The second emphasis lies on exchange rate uncertainty and currency trade in a laboratory experiment. Subjects fail to predict the direction of exchange rate movements with more than random accuracy. Therefore currency trade is mainly guided by interest differences and this kind of speculation is profitable on average. The third scope is on a Tobin tax on an experimental asset market as a scheme to cope with excess volatility. Markets with a low tax rate achieve best results compared with untaxed and highly taxed markets in terms of efficiency, volatility, and trade volume. The last part derives practical ways of measuring statistical significance of differences in experimental data. (188 words)

Abstract

Traditional macroeconomic theories often assume that aggregate economic figures originate in the behaviour of individuals who optimise their utility. In doing so, it is casually taken for granted that all agents act self-centered, profit maximising, and risk neutral. A growing number of studies, mainly from the areas of microeconomics and psychology, contradicts this presupposition. Through data gathered by laboratory experiments it is possible to explore whether humans behave according to theoretical predictions. In order to lay a behavioural foundation to macroeconomic theories, such laboratory experiments can be conducted with a macroeconomic scope. In this dissertation thesis, three different macroeconomic topics are investigated experimentally.

One focus is put on the interlinks between economic policy and the labour market. In a laboratory experiment where players in the role of various institutions interact, the policy decisions of governments and central banks, their motivations, and their consequences are analysed with respect to wages and employment. The reactions of the labour market are mainly in line with theory. If the official sector's employment goals are not met, governments tend to increase expenditures, whereas the decisions of central banks seem rather to be motivated by the attainment of price goals. The total of the effects observed deliver a new explanation for the existence of a relationship between employment and the inflation rate.

The second emphasis is on the currency trade decisions of firms in the same experiment. The players are guided by interest rate differences rather than by expected exchange rate movements since they are unable to predict exchange rate changes correctly and thus are ambiguity averse. This results in the absence of technical trade, highest profits for interest-conforming traders, and pessimistic expectations concerning the exchange rate. The firms engage in hedging their production-incurred foreign debts against exchange rate risks. A simple decision rule is described on the base of which players would have made profits on average.

A transaction tax as proposed by James Tobin is studied in the third part. Experiments have been conducted with an asset market model that includes equally endowed traders. In another variant of the model, a transaction tax is levied on the asset. The trade volume decreases with an increasing tax rate, and so do the fiscal revenues. Price volatility is reduced drastically under a tax regime. Although the market efficiency is higher on taxed markets, there is evidence for lower efficiency with higher tax rates. Concluding it can be said that the Tobin tax has volatility reducing effects on the market, but the tax rate should be low to limit a negative impact on trade volume and market efficiency.

The last part derives efficient ways to calculate significance levels of differences in two independent and in two matched samples. This is done with Fisher-Pitman permutation tests, which are frequently used throughout this thesis. (470 words)

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1 On Experiments in Macroeconomics

"[...] the only relevant test of the validity of a hypothesis is comparison of prediction with experience."

– Milton Friedman (1953b, p. 8–9)

1.1 Introductory Comments

One of the criticisms on traditional Keynesian macroeconomic theories is their lack of microfoundations (see for example Bruun 1999 and Lucas 1976). Modern neokeynesian approaches try to compensate this flaw by deriving microeconomic theories on individual behaviour to explain aggregate effects. In doing so, it is generally assumed that individuals make only rational decisions and that deviations from fully rational behaviour disappear in the error term of the respective regressional model tracelessly. On the other hand, a growing number of economic and psychological studies demonstrates that economic behaviour is often far from being rational, self-centred, and risk-neutral. Laboratory, class room, and field experiments are frequently used to gather data to derive theories that explain the boundedly rational behaviour. The relatively young discipline of experimental macroeconomics closes the gap between theories and actually observed macroeconomic phenomena by taking into account individual behaviour measured in the abstract context of an experiment.

When and why is the means of a laboratory experiment useful? It is difficult at best, if not even impossible, to confirm *external validity* of a model by the means of a laboratory experiment. The participants of experiments, or experimental subjects, are usually confronted with decision situations that do not capture the complexity of such situations in practice. This holds true especially for macroeconomics, where a great diversity of agents interacts to generate the aggregates which are investigated. It is beyond the scope of the thesis at hand to compare results gathered by experimental models with empirical data from the field.

However, when it comes to confirming the *internal validity* of a model, that is, the consistency of human behaviour with theoretical predictions, laboratory experiments are a useful method to augment rational theories with behavioural elements. In situations where the actual behaviour of experimental subjects deviates systematically from game-theoretical and thus rational predictions, the data can be used to create new theories that are founded not only on rational but also on boundedly rational behavioural aspects. This also applies to macroeconomics. A recent example is the study by Heinemann et al. (2004), who investigate the outcome of speculative attacks. They use the model by Morris and Shin (1998) to experimentally implement a speculative attack on a currency peg as a coordination game: If one expects a devaluation of the currency, one should short-sell it in order to increase the pressure on the central bank to abandon the peg. The attack is successful only if a sufficient number of traders engages in this behaviour. Heinemann et al. find among other things that public information implies a higher prior probability of a successful attack, that is, the devaluation of the currency.

Another example for the use of the experimental method in the field of macroeconomics is the investigation of the emergence of money as a medium of exchange by Duffy and Ochs (1999). They derive a laboratory experiment from a search-theoretic model, originally designed by Kiyotaki and Wright (1989). In the model, there are three types of goods and three types of players, the latter ones being defined by a pair of goods: the good they consume and the good they produce. Each player can hold one good at a time. If a good is not consumed (resulting in the production of another good), storage costs are implied. Every period, players are randomly paired and decide whether they want to exchange the goods they currently hold. Duffy and Ochs find that the subjects' trading decisions are mainly motivated by past experiences and not, as theory predicts, marketability considerations.

There have also been successful attempts to create more complex economic systems in the laboratory. Lian and Plott (1998) ran experiments with a complex economy in which producers and consumers interact. Two goods exist in the model, namely labour and a consumption good. Furthermore, the model includes a financial market on which both types of agents, producers and consumers, can borrow money in the form of bonds. Lian and Plott find that the behaviour of the experimental subjects converges to general competitive equilibrium in the long run. They cannot find evidence for the existence of Phillips curves, that is, a negative correlation between unemployment and inflation. Nevertheless, the data speaks out strongly for a relatedness between real GNP and unemployment, an interlink known as Okun's law (see Okun 1962; newer estimates for the US economy can be found in Prachowny 1993). The authors conclude that an implementation of a complex macroeconomic setting in the laboratory can help in finding relevant results. Other works that strive to do so are mentioned in the survey of the relevant literature of chapters 2 and 3.

While the dissection of empirical field data is an appropriate instrument to confirm the external validity of a model, it is nearly impossible to show causal connections between variables that way. If a positive correlation between two variables A and B is found in field data, it is difficult to determine whether A causes the change in B, B causes the change in A, or if changes in both A and B are caused by a change in a third – possibly unobserved – variable C. The controlled environment of a laboratory experiment allows for explicitly investigating not only correlations, but also *causality* between the occurrences of certain data patterns by conducting variants of the experiment with only one parameter modified.

The dissertation at hand investigates different macroeconomic models from a behavioural point of view. In three self-contained chapters, it is shown how boundedly rational behaviour of individuals in decision situations influences the outcome of macroeconomic aggregates. Furthermore, theories are derived to explain the behaviour of economic subjects. In an additional chapter, ways to computationally carry out some statistical significance tests are outlined and used as a tool to demonstrate the relevance of the theories found.

The study described in chapter 2 investigates how changes in economic policy influence the labour market and vice versa. To do so, a complex macroeconomic two-country model by Pope et al. (2003) is used to conduct laboratory experiments with human players. A game-theoretical solution to this model exists in the paper mentioned before. Additionally, it is derived how the labour market – that is, employment and wage – should *ceteris paribus* react on changes in fiscal policy determined by the government and target price policy determined by the central bank. The experimental data speak in favour of policy decisions causing reactions of the labour market mainly in the direction of theory. However, reactions are stronger if target price policy and expenditure policy are coordinated. If target price and expenditure changes are opposite, reactions of the labour market are much weaker. The majority of policy pairs are coordinated. Furthermore, it is shown how governments and central banks fail to achieve their employment goals although they are endowed with instruments which are suitable for that purpose. One reason for this phenomenon is that central banks rather focus on price than on employment goals. Additionally it can be observed that governments irrationally try to reduce the difference between nominal home and foreign expenditures. The total of the discovered effects delivers evidence on the existence and mechanisms to a correlation between employment and the rate of inflation.

Chapter 3 is based on the same model. It grew from a collaborative paper (joint work with Sebastian Kube) entitled "Currency speculation behaviour of industrial firms: evidence from a two-country laboratory experiment". A condensed version of this paper has been published by the *Journal of Behavioral Finance*[1]. The behavioural components of a firm's currency trade decisions are investigated. Contrary to the situation in game-theoretical equilibrium, currency trade takes place and exchange rate variation arises. It is shown how both exchange rate variation and interest rates can influence a firm's currency trade behaviour and how exchange rate uncertainty is incurred. The uncertainty results in highest profits for traders who don't base their decisions on individual exchange rate estimates but solely on interest differences. As a consequence of the uncertainty, technical trade does not have a big influence on the trade decisions. Instead, the individuals try to compensate their inability to predict exchange rate changes correctly by hedging and pessimistic expectations. The traders would have made the highest profits if they had used a decision rule that postulates – simply put – always to offer the same amount of the cheapest currency. One can observe that central banks can curb the influence of speculation on exchange rate volatility if they are powerful enough and collude.

Chapter 4 deals with the influence of a transaction tax on markets and is derived form an earlier version of the paper "The Tobin tax: A game-theoretical and an experimental approach" (joint work with Thorsten Chmura and Thomas Pitz)[2]. In the 1970's, James Tobin suggested the introduction of a transaction tax on the currency market to cope with exchange rate volatility. In spite of his proposal being discussed frequently and very controversial ever since by economists and policy makers, the so-called Tobin tax has never been imposed on any currency market. The consequences of the introduction of such a tax are hence investigated on an asset market model from a game-theoretic and an experimental point of view. The

[1] see Kaiser and Kube (2009)
[2] see Kaiser et al. (2006)

main results imply that in this model the Tobin tax has in fact consequences on trader's actual behaviour, contrary to the situation in game-theoretic equilibrium. Although the overall trade volume is reduced by a tax, the trade turnover – that is, the money paid in exchange for the asset – stays uninfluenced. This happens because prices are higher on taxed markets on average. The demand is negatively correlated with the tax rate, and the overall supply of the asset is higher on taxed markets. This can be seen as evidence for a propensity of traders to prefer cash over the asset under the tax condition. Volatility gets reduced drastically by a tax as such, but the market inefficiency increases with a growing tax rate. So do the fiscal revenues. This might also be caused by the non-existence of tax escape routes in the model. Furthermore, earnings inequality is lower on taxed markets. Overall, a low tax rate seems to achieve best results in the experiment.

The econometric methods applied in this dissertation are not part of the standard set of tools in the field of experimental economics. Chapter 5, which has been published independently[3] in a peer-reviewed journal, describes the Fisher-Pitman tests for paired replicates and independent samples. After theoretically outlining the exact tests, Monte Carlo simulations for both of them are derived. Simulations can be useful if one deals with a large number of observations because the exact algorithms possess a high complexity in regard to sample sizes. The tests are designed to be a more powerful alternative to the Wilcoxon signed ranks test and the Wilcoxon-Mann-Whitney rank sum test if the observations are given on an interval scale at least. By the means of comparative simulations it is demonstrated that the results gained by Monte Carlo versions of the tests are sufficiently accurate in comparison to the exact versions. In the end, the application of both tests is exemplified with a notional data set.

All chapters have originally been written as independent research papers. How-

[3] Johannes Kaiser (2007): "An Exact and a Monte Carlo Proposal to the Fisher-Pitman Permutation Tests for Paired Replicates and for Independent Samples", *Stata Journal* **7** (3), p. 402–412

ever, the versions included in this dissertation thesis have been edited and enriched compared to the research papers, the latter ones presenting the essential points in condensed form.

2 Economic Policy and the Labour Market

"There is wide agreement about the major goals of economic policy: high employment, stable prices, and rapid growth. There is less agreement that these goals are mutually compatible or, among those who regard them as incompatible, about the terms at which they can and should be substituted for one another."

– Milton Friedman (1968)

2.1 Aims of Economic Policy

Economic policy is used by governments and central banks to achieve a variety of economic goals. For this purpose, institutions have several different instruments at hand. Some important objectives of economic policy are an acceptable inflation rate, a high employment, stable exchange rates, and economic growth. In practice, the instruments which are applied to achieve these goals differ, like the goals themselves, across countries. They include monetary ones like interest rates and open market operations, and fiscal ones like taxation and expenditure setting. This experimental study focuses on how governments and central banks miss their employment goals and explores reasons for this failure.

Both empirical and theoretical evidence on the interlinks of economic policy and the labour market exists in a broad variety. As a supplement, methods from experimental economics are applied to test macroeconomic theories in the lab and to enrich them with behavioural components. In this study, a game-theoretical two-country model by Pope et al. (2003) is used to conduct experiments with human players in the role of various institutions and firms. In their model the government fixes the total expenditure of the economy. It is assumed that this is done by fiscal policy in a way which is not explicitly modelled. Central banks have several instruments at hand to fulfil their goals: the interest rate, exchange rate aims, and the price target. The objectives of governments and central banks are largely identical and include several goals for price stability (as McDonough 1997 postulates), employment, exchange rate stability, interest rates, and international competitiveness. Identical objectives on output and inflation for governments and central banks help the institutions to attain their policy goals better – see Dixit and Lambertini (2001) for a study on this topic.

The data gained by the experiment already have been investigated in other respects. It has for example been shown that in the experiment a currency union improves the achievement of institutions' goals for international competitiveness (Pope et al. 2006). Kaiser and Kube (2009) find strong effects of exchange rate uncertainty on currency trading decisions of firms in a way that the firms rely in their trade decision rather on interest rates than on individual exchange rate estimates. This paper is the base for chapter 3 of this dissertation. Exchange rate volatility has also a negative influence on the attainment of the official goals (Pope et al. 2006). Over time, the exchange rates move in the direction of a relation of 1:1 (Pope et al. 2006b) – a phenomenon labelled nominalism. Furthermore, one can observe that gradual expenditure changes have better effects on firm profits and government goals than short sharp shocks (Pope et al. 2006a).

Experiments in macroeconomics have been established and used before to analyse behavioural components of macroeconomic phenomena and to test macroeconomic theories. Some of these experiments are described in a literature survey by Ricciuti (2005). Duffy (1998) gives a review on some laboratory experiments done on monetary theory. Noussair et al. (1997) describe a complex model with two economies, how they interact and how the exchange rate is determined. In an earlier study, Noussair et al. (1995) investigate how international trade happens and that a big fraction of economic activities happens in disequilibria. Deriving a laboratory experiment from the theory of global games, Heinemann et al. (2004) find that thresholds for successful speculative attacks on currencies are lower if central banks disclose information publicly.

Of course, most of the academic work on the interlinks between the labour market and economic policy is not of an experimental nature. Much has been written on the connection between monetary instruments and wages and employment. For example, Holden (2003) derives from a theoretical model that the existence of the monetary instrument of the exchange rate target is likely to induce lower wages in traded and higher wages in the non-traded sector than does a price target. It has been outlined theoretically by Gylfason and Lindbeck (1994) how labour unions adjust wages to prices following changes in monetary policy and that the interplay of governments and unions thus creates a persistent tendency towards stagflation. Under a currency union regime, exchange rate rigidity induces problems in wage setting when demand shocks occur asymmetrically. Calmfors (1998) finds that variations in payroll taxes can be used as a substitute for exchange rate changes under a currency union regime. The degree of independence of a central bank from a government is negatively correlated with inflation rates, but seems to have no impact on employment in a country (Bleaney 1996).

Not only monetary policy influences the labour market, but also fiscal policy. Fatás and Mihov (2006) show theoretically and empirically that positive changes in government expenditures are followed by increases in employment. The study at hand confirms this result experimentally. A higher effectiveness of fiscal policy in improving employment if the exchange rates are flexible than if the exchange rates are fixed is found by Mundell (1961). Our experimental data, however, cannot reproduce this finding. There exists also evidence in line with the new neoclassical synthesis[1] for an impact of government demand on labour demand and thus employment: Linnemann and Schabert (2003) rule out that price stickiness is the main reason for this relationship.

It is crucial for economic policy institutions to align fiscal with monetary policy in regard to their goals. While Mishkin (2000) reports that coordinating fiscal and monetary policy yields a better price stability, it will be demonstrated in this chapter that equidirectional fiscal and monetary policy decisions result in stronger reactions of the labour market to the instruments.

In 1958, Alban W. Phillips revealed an astonishing property of British employment data from 1861 to 1957: Without a macroeconomic model, he fitted annual data point pairs of money wage rate changes and the rate of unemployment into a curve with a negative slope. He argued that in phases of high employment the demand for labour is high and so employers are willing to pay more to attract workers and employees from other firms and industries. In times with low employment, workers are only hesitatingly accepting wage rates below the prevailing ones. This explains a non-linear negative relation between changes of the money wage rate and the unemployment rate according to Phillips (1958). Two years later, Samuelson and Solow (1960) introduced the price-level modified Phillips curve: They found a non-linear negative relation between the inflation rate and the unemployment rate. The model fitted real data of inflation and unemployment rates well – remember the unforgettable quote of Germany's minister of economic affairs and finance Helmut Schmidt that he prefers an inflation rate of five percent over an unemployment rate of five percent[2] –, but only until the nineteenseventies, when

[1] The New Neoclassical Synthesis is a concept coined by Goodfriend and King (1998) that merges features of both postkeynesian and neoclassical models.

[2] see Richter (1999, p. 36). The original quote can be found in an interview with Helmut Schmidt in the German periodical *Süddeutsche Zeitung* from 28th of July 1972, where he said on page 8: "Mir scheint, daß das Deutsche Volk – zugespitzt – 5% Preisanstieg eher vertragen kann, als 5% Arbeitslosigkeit.". This roughly translates to: "To put it bluntly: it seems to me that the German people can rather accept a price increase of 5 % than an unemployment rate of

stagflation began to paralyse European economies. Stagflation, often nicknamed as the "two-headed monster", describes the situation where missing economic growth (and thus a high unemployment) goes hand in hand with a high inflation rate.

Nowadays, the theory of Edmund S. Phelps (1967) is regarded as a model that matches the data observed so far best. He augmented the approach by Samuelson and Solow (1960) with the inflation expected by the subjects. Thus, an increased inflation can only have an employment-increasing effect if this inflation was not expected beforehand. Policy implications for Phelps' model have been tested experimentally: Arifovic and Sargent (2002) use an expectation-augmented Phillips curve model to confront subjects with a time-consistency problem (see Kydland and Prescott 1977) in order to investigate policy maker's behaviour in inflation setting. They conclude that regarding inflation rates, a majority of policy makers gradually reaches for the optimal inflation rate with regard to unemployment. In this chapter, more evidence is revealed on the correlation of inflation rate and employment and how this mechanism applies to the model investigated.

The remainder of this chapter is organised as follows. First, features of the model are outlined. Some theoretical implications of the structure of the model are derived thereafter. Afterwards, the observed behaviour of the participating players is analysed. It is demonstrated how the labour market reacts on policy changes and how the interplay of economic policy instruments works. The analysis of the institutions on missed goals suggests a novel behavioural explanation of the negative correlation of unemployment and inflation rate.

5%"

2.2 An Experimental Macroeconomic Two-Country Model

The model used in this investigation was developed by Pope et al. (2003). Their study, yet unpublished, describes not only the complete features of the model. It also describes a new game-theoretic equilibrium concept and applies it to the model. It would go beyond the scope of this chapter to illustrate both the model and its game-theoretical solution, so the interested reader may find details in the paper mentioned before and in the English translations of the written instructions in appendix D.1 or in Pope et al. (2007).

2.2.1 Features of the Model

In the model, there are two countries (A and B) and a discrete, finite time horizon. In each country, there are markets for labour, intermediate materials, and a consumption commodity. Furthermore, there exists one market for currency. The model is symmetric, so one country will by called the home country and everything will be described from its perspective. Variables from the foreign country will be denoted with an asterisk. There are nine players in each country: One government, one central bank, one employers' association, one labour union, and five firms.

Time Structure of a Period

Every period consists of nine steps with each step carried out simultaneously in both countries (confer to fig. 2.1 for a schematic diagram). In the first four steps, the players make their decisions. First, the government fixes the size of the total expenditures D of the economy. It is assumed that this is done by means of fiscal policy. The details are not explicitly modelled. In the second step, the central bank decides on the interest factor r (defined as one plus one hundredth of the percentage interest rate), next period's target price p_+, and an exchange rate aim f. When this has been done, the labour union and the employers' association bargain on the nominal wage rate w in step 3. In the fourth step, each firm i decides on the size of its production Q_i. Additionally, firms have the opportunity to engage in currency trade.

The Labour Market

The labour union and the employers association have only limited time to agree on a wage rate w. They can bargain by exchanging text messages. If they are able to settle on a wage, the labour union's payoff U is given by the wage rate divided by current period's target price (as set by the central bank in the previous period):

$$U = \frac{w}{p} \tag{2.1}$$

The employers' association receives a payoff V that is proportional to the expenditure deflated profit of all firms Π:

$$V = \frac{\Pi}{D} \tag{2.2}$$

If they fail to agree on a wage in the given time, a strike is imposed in the concerned country and the wage is fixed to a statutory minimum wage of $w_0 = \frac{7}{50}p$. In this case, neither labour union nor employers' association receive a payoff.

The Consumption Commodity and the Intermediate Materials Market

The firms produce a consumption commodity. They decide on how many units of the good Q_i (with $20 \leq Q_i \leq 45$ in the case of strike and $20 \leq Q_i \leq 60$ else) they want to produce. The commodity is sold only domestically on a Cournot market; the country's expenditures are spent completely and solely on the commodity (in the case of strike, only 60% of the expenditures are spent on the consumption commodity). Thus, the commodity's price q is equal to

$$q = \frac{D}{\sum_{i=1}^{5} Q_i} \tag{2.3}$$

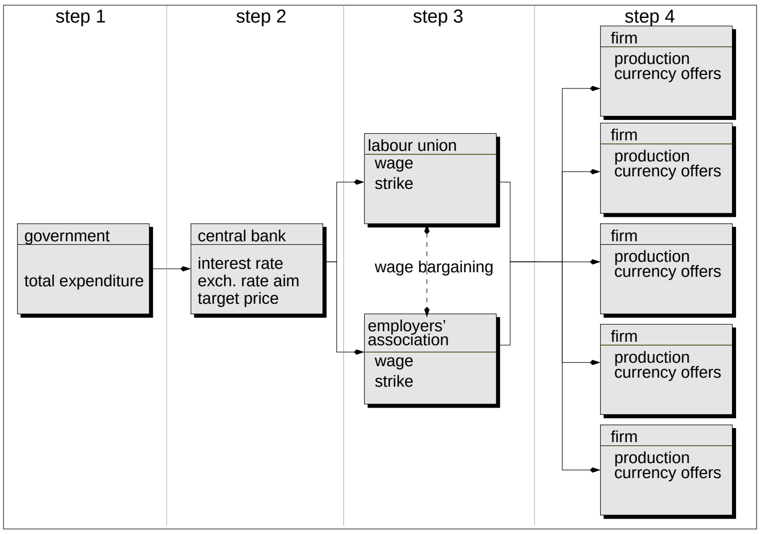


Figure 2.1: Time structure of one period

For producing one unit of the consumption commodity, a firm needs one unit of labour (bought from the domestic labour market at price w), one unit of the intermediate material from the home country available at price m, and one unit of the intermediate material from the foreign country at price m^*. Consequently, the need for home materials M_i and foreign materials M_i^* are equal to the produced number of units Q_i. The materials industry is modelled implicitly: one unit of material is produced at price w times interest factor r, that is, $m = wr$ and $m^* = w^*r^*$. Additionally, 15 units of fixed labour are needed to run the firm, so the total amount of labour to be paid by the firm totals to $L_i = Q_i + 15$. Let M be the total demand for home material by domestic firms, M^* the total demand for home material by foreign firms, Q the aggregate production of the home country, and Q^* the total production of the foreign production good. Then, the total employment of one country thus is equal to

$$L = Q + M + M^* + (5 \cdot 15) = 2Q + Q^* + 75 \tag{2.4}$$

since it incorporates labour induced by the production of the consumption commodity, the fixed labour needed by five firms, and the labour induced by the production of the intermediate material needed by firms in both home and foreign country.

Firm Accounts and Currency Market

Each firm has two bank accounts: one in the home country and one in the foreign one. In the beginning of each period, both accounts have a balance of 0. In the further proceeding of the period, costs for foreign materials are deducted from the foreign bank account and costs for labour and home materials are deducted from the domestic bank account. Sales revenues are transferred to the home account. All accounts (be their balance positive or negative) are subject to interest payments at the interest factor r or r^*. At the end of the period home and foreign accounts are transferred to the owners. Profits for this period are calculated in home currency units and therefore depend on next period's exchange rates. Consequently this period's profits become known in the next period only.

The firms have the opportunity to engage in currency trade. They can decide on whether they want to borrow an amount[3] of money X_i^* from their foreign account and transfer it to their home account at the exchange rate e (with $e = \frac{1}{e^*}$). The exchange rate e is the price of one unit of the foreign money in home currency. Alternatively, they can borrow an amount of money X_i of their home account and transfer to their foreign account at the exchange rate e^*. It is not allowed to do both at the same time, but they are free to refrain from currency trading. Thus, their home (S_i) and foreign (S_i^*) account balances total to

$$S_i = Q_i q + r(X_i^* e - L_i w - X_i) - M_i m \tag{2.5}$$

$$S_i^* = r^* \left(\frac{X_i}{e} - X_i^* \right) - M_i^* m^* \tag{2.6}$$

A schematic draft of the account structure is shown in fig. 2.2. In the end of a period, the account balances of the firms are transferred to their owners. They receive all profits and bear all losses. The foreign account balance gets transferred to the owner only at next period's exchange rate e_+. However, e_+ is not yet known at this stage, so the foreign account balance is implicitly offered on the currency market in the next period. Therefore, this period's profits are consumed by the

[3]in this case, the asterisk denotes foreign currency, and not the foreign country

owners of the firms in the next period.

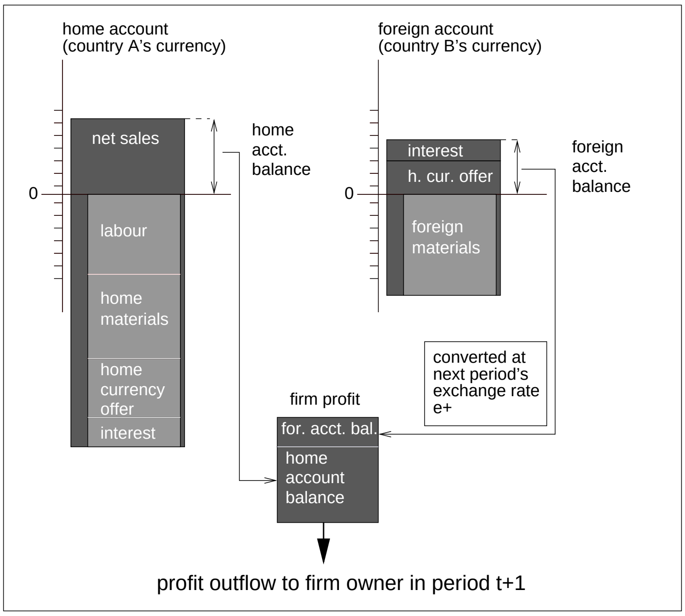


Figure 2.2: A firm's account and payoff structure if home currency is offered

A firm's payoff Π_i equals its profit:

$$\begin{aligned}\Pi_i &= (S_i + e_+ S_i^*) \\ &= [Q_i q + r(X_i^* e - L_i w - X_i) - M_i m] + \\ &\quad e_+ \left[r^* \left(\frac{X_i}{e} - X_i^* \right) - M_i^* m^* \right]\end{aligned} \tag{2.7}$$

Exchange Rate Determination

The exchange rate mechanism is completely endogenous with neither stochastic components nor external shocks. The exchange rate e is influenced by total currency supply and the central bank's exchange rate aim f. The latter one is the exchange rate which the central bank is willing to defend as far as this is within its capability. If both central banks choose the same exchange rate aims ($f = \frac{1}{f^*}$), the exchange rate e is set to f. Otherwise, the exchange rate resides somewhere between f and $\frac{1}{f^*}$ depending on the total currency offers of the firms, their foreign bank account balances from the previous period, and implicitly determined central bank interventions. Details on the exchange rate determination are beyond the scope of this chapter, but can be found in Pope et al. (2003), Kaiser and Kube (2009), and Pope et al. (2007) or in chapter 3 of this dissertation.

Government and Central Bank Goals

The government and central bank of a country receive identical payoffs. Altogether, they have seven goals to fulfil to receive their maximum payoff. The goals regard inflation, interest policy, materials price parity, exchange rate stability, and employment. Employment L is defined as the sum of labour needed by the firms producing the consumption commodity and labour incurred by the materials industry (confer eq. 2.4). This includes the home material needed by foreign firms. Governments and central banks are penalised if the employment lies out of the normal employment range defined by a lower border L_a and an upper border L_b. The payoff function is split into several components.

Each term in the payoff function represents a specific goal. Goal (2.9) penalises the institutions for deviations in the target price from previous period's target price, (2.10) penalises for deviation of this period's target price as fixed in the previous period from the actual price. These two goals focus on the central bank's target price policy. Goal (2.11) penalises for deviations of the interest rate from an ideal interest rate of 5%, goal (2.12) penalises for a materials price parity that is not equal to 1. Goal (2.13) penalises for exchange rate volatility. The remaining two goals penalise under- (2.14) and overemployment (2.15). The weight b_6 for underemployment is twice as high as the weight b_7 for overemployment.

$$
\begin{aligned}
(2.8)\qquad B_C = B_G &= b_0 \\
(2.9)\qquad &-b_1\left(\frac{p_+}{p}-1\right)^2 \\
(2.10)\qquad &-b_2\left(\frac{q}{p}-1\right)^2 \\
(2.11)\qquad &-b_3\left(r-1.05\right)^2 \\
(2.12)\qquad &-b_4\left(\frac{m}{em^*}-1\right)^2 \\
(2.13)\qquad &-b_5\left(\frac{e}{f}-1\right)^2 \\
(2.14)\qquad &-b_6\cdot\max\left\{0;L_a-L\right\} \\
(2.15)\qquad &-b_7\cdot\max\left\{0;L-L_b\right\}
\end{aligned}
$$

Currency Unions

The game has two variants. The first, as described in the previous subsections, deals with the situation of one currency in each country. In a second variant, a currency union is imposed. The model differs in some key aspects. At first, there is a fixed exchange rate of $e = 1$. There is only one central bank whose policy decisions affect both countries. Thus, governmental (B_G) and central bank (B_C) payoff functions differ:

$$
\begin{aligned}
(2.16)\qquad B_G &= b_0 \\
(2.17)\qquad &-b_1\left(\frac{p_+}{p}-1\right)^2 \\
(2.18)\qquad &-b_2\left(\frac{q}{p}-1\right)^2 \\
(2.19)\qquad &-b_3\left(r-1.05\right)^2 \\
(2.20)\qquad &-b_4\left(\frac{m}{m^*}-1\right)^2 \\
(2.21)\qquad &-b_6\cdot\max\left\{0;L_a-L\right\} \\
(2.22)\qquad &-b_7\cdot\max\left\{0;L-L_b\right\}
\end{aligned}
$$

There is no penalty for exchange rate volatility, since it does not exist anymore. Second, the materials price parity goal is no more corrected by the exchange rate.

The central banks' payoff function differs in more aspects:

$$B_C = b_0 \tag{2.23}$$

$$-b_1 \left(\frac{p_+}{p} - 1 \right)^2 \tag{2.24}$$

$$-b_2 \left(\frac{q + q^*}{2p} - 1 \right)^2 \tag{2.25}$$

$$-b_3 \left(r - 1.05 \right)^2 \tag{2.26}$$

$$-b_4 \left(\frac{m}{2m^*} + \frac{m^*}{2m} - 1 \right)^2 \tag{2.27}$$

$$-b_6 \cdot \left(\frac{1}{2} \max\{0; L_a - L\} + \frac{1}{2} \max\{0; L_a - L^*\} \right) \tag{2.28}$$

$$-b_7 \cdot \left(\frac{1}{2} \max\{0; L - L_b\} + \frac{1}{2} \max\{0; L^* - L_b\} \right) \tag{2.29}$$

The penalty for deviations of the target price from the actual price (2.25) now penalises deviations of the target price from the average price in both countries. The penalty for materials price imparity (2.27) is now symmetrised so that the central bank's penalty is identical for deviations in both directions. Furthermore, the central bank is penalised for under- (2.28) and overemployment (2.29) in both countries.

The firm players have no longer the opportunity to engage in currency trade: no profits could be reaped with a single interest rate and a single currency. Their payoff functions adjust accordingly.

Parameters are set as described in table 2.1.

Table 2.1: Parameter calibration

parameter	b_0	b_1	b_2	b_3	b_4	b_5	b_6	b_7	L_a	L_b
value	5	6	6	3	3	1	0.02	0.01	600	720

2.2.2 Theoretical Considerations

The game-theoretic solution to this completely endogenous model is derived by Pope et al. (2003) as an incomplete equilibrium. Some features of the solution relevant to this investigation will be briefly outlined here. For complete coverage of the concept of an incomplete equilibrium and the game-theoretic nature of this model, confer to this article. Questions of interest are in particular how employment and wages react to changes in fiscal and target price policy.

Wages

Recall that a labour union receives a payoff of the wage divided by the target price for the actual period if there is no strike. Equation (2.1) describes this objective. The payoff an employers' association receives is the expenditure deflated profit of the firms – see equation (2.2). Pope et al. (2003, p. 27) use cooperative bargaining theory (see Nash 1950) to select the equilibrium wage. On the equilibrium path, labour union and employers' association should agree on a wage of

$$w = \frac{16}{63}p \tag{2.30}$$

Assume that in a period t, the parties agree on a wage of w_t while the target price for this period has been set to p_t in period $t-1$. If the target price p_{t+1} for the next period increases by $\Delta p = p_{t+1} - p_t$, the new equilibrium wage is

$$w_{t+1} = \frac{16}{63}(p_t + \Delta p) \tag{2.31}$$

Consequently, the wage should increase by $\Delta w = \frac{16}{63}\Delta p$. It can be deducted that an increase of the target price should *ceteris paribus* result in an increase of the wage.

Production and Employment

Let Q_i denote the production decision of firm i and Q_{-i} the total production of other firms in its country. The price for one unit of the consumption good would then yield $q = \frac{D}{Q_i + Q_{-i}}$. The firm's operating profit can be derived from equation (2.8) to:

$$\Pi_i = Q_i(q - c) - C \tag{2.32}$$

For reasons of simplicity, the structure of the unit variable costs c and the fixed costs C are not explicitly derived here. In the following, let us neglect the capacity constraints of the firms. The best response production quantity Q_i^{BR} that maximises the profit function of a firm i given the production quantity of others Q_{-i}, the expenditures D, and the variable costs c is given by

$$Q_i^{\mathrm{BR}} = \sqrt{\frac{DQ_{-i}}{c}} - Q_{-i} \tag{2.33}$$

For five firms, the Cournot-Nash equilibrium production quantity[4] on this market is equal to:

$$Q^{\mathrm{C}} = \frac{4D}{5c} \tag{2.34}$$

In the following Q_t^{C} denotes the Cournot quantity at period t:

$$Q_t^{\mathrm{C}} = \frac{4D_t}{5c_t} \tag{2.35}$$

If in $t+1$ the expenditures adjust by $\Delta D = D_{t+1} - D_t$ and all other variables remain constant, the increase of the Cournot-Nash quantity in $t+1$ is equal to

$$\Delta Q^{\mathrm{C}} = Q_{t+1}^{\mathrm{C}} - Q_t^{\mathrm{C}} = \frac{4(D_t + \Delta D)}{5c_t} - \frac{4D_t}{5c_t} = \frac{4\Delta D}{5c_t} \tag{2.36}$$

From (2.4) it follows that employment increases with increasing production. We have

$$\frac{\partial L}{\partial Q} > 0 \tag{2.37}$$

An increase of the expenditures thus results *ceteris paribus* in an increased employment. Accordingly, a decrease of D results in a decreased employment.

[4] Due to demand depression, this quantity reduces to 60% of the original value in the case of strike. However, this plays no role for the directions of changes in employment and expenditures being the same in equilibrium.

The opposite holds true for the wage.Unit variable costs increase with w:

$$\frac{\partial c}{\partial w} > 0 \tag{2.38}$$

Consequently, an increase in the wage results *ceteris paribus* in a lower Cournot-Nash production quantity and thus in a lower employment and the other way round. From this and from what is known from subsection 2.2.2, an increase of the target price between two consecutive periods should result in a decreased employment.

2.2.3 Experimental Setup

The experiments were conducted as computer-based laboratory experiments in the Laboratory for Experimental Economics of the University of Bonn between January 2002 and June 2005. The software was first programmed in Pascal with the Ratimage library (Abbink and Sadrieh 1995), but has been completely rewritten in Java at a later point by the author of this dissertation. The latest version of the software included about 30000 lines of code for the server (including SQL statements and comments) and about 23000 lines of code for the client. Screenshots can be found in appendix A.3.

All participants have been students of economics for at least two years. Before the game was started, written instructions were handed out to the participants. For an English translation of the German instructions, confer to Pope et al. (2007) or to appendix D.1. Thereafter, an introduction of about one hour was given to them including example calculations of various figures. Some test questions were posed, and after the subjects gave the right answers, the roles were assigned at random. Then the game was started. One session lasted about 8 hours, including a lunch break of one hour. After a short debriefing session and the handing out of an ex-post questionnaire, the participants were given their converted cumulative round payoffs in Euro. Each student was furthermore given a show-up fee of €5, totalling to an equilibrium payoff of €72.50. The average payoff per hour was approx. €10.23 in the case of no currency union and €10.88 under a currency union. 15 sessions were conducted, thereof the first 6 with and the following 9 without a currency union.

The game starts in an existing world with all decision variables being in equilibrium, but the players are not aware of that.

2.3 Observed Behaviour

How does the labour market react to changes in policy decisions? Or, more precisely, how do wages and employment react to changes in fiscal and price policy? How do governments and central banks react on deviations from employment of an acceptable size? In the following, findings answering these questions are presented. Details on the econometric and statistical methods applied can be found in appendix A.1, actual data in appendix A.2.

2.3.1 Policy Changes and Their Influence

As derived in subsection 2.2.2, employment should increase if the government increases the expenditures. Comparing the changes in D with the changes in L, it is evident that a majority of governmental decisions significantly influences employment in this direction (details in table A.1). Even if this is the case, in some sessions (e. g., session 8) the opposite is the true. This can be considered first evidence that fiscal policy is not always effective. No treatment effects between the currency union treatment and the non-currency union treatment can be confirmed.

Some note on the graphical representation used here and in the following: Boxplots have been utilised to draw a distributional graph of the investigated variables. In a box plot, the median of the sample is denoted by a vertical line. Around this line, a box is drawn that represents the interquartile range (IQR): The left limit of the box is given by the .25 percentile, the right one by the .75 percentile. Outliers, that is, values that are smaller than the left quartile minus 1.5 times the IQR or greater than the right quartile plus 1.5 times the IQR, are denoted by dots. The whiskers describe the observations in the sample that are no outliers but reside outside the IQR.

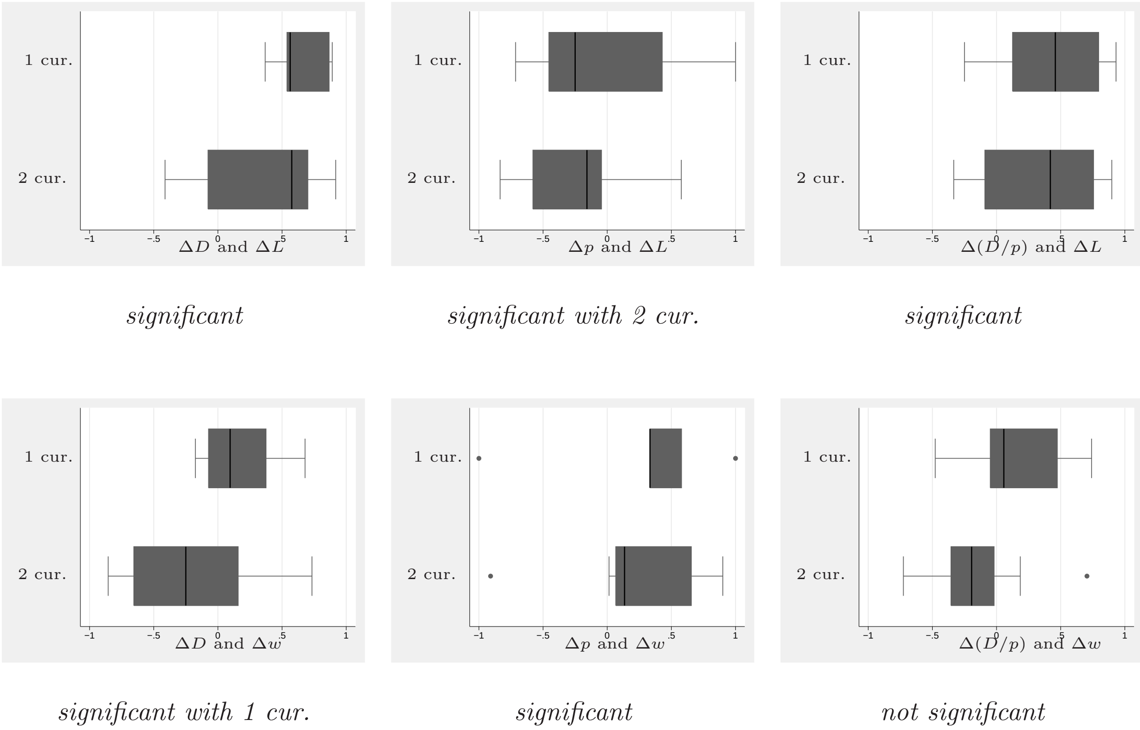


Figure 2.3: Box plots of Yule coefficients over treatments

Does an increase in the target price influence the employment negatively as predicted? Table A.2 shows the association measures of changes in p and changes in L (of both countries in the currency union treatment and of the respective home country in the treatment without a currency union). Astonishingly, no significant influence can be found in the one-currency case. A weakly significant negative influence can be observed in the two-currency case.

An association between wage changes and employment changes can be confirmed (see table A.3), but only directional. Neither the product moment nor the Spearman rank correlation nor the linear regression coefficient are significantly below zero. However, the Yule coefficients are significantly below zero. Thus, there exists a negative association between wage changes and employment changes: an increasing wage tends to be connected to a decreasing employment in a country.

The wage seems to react to changes in expenditure only weakly, but only in the currency union treatment. Also, there is some evidence that this effect is stronger under a currency union (see table A.4). The reactions of the wage to changes in target price p seem to be stronger (see table A.5). The reactions of employment and wage to policy changes are depicted in figure 2.3.

Note that a positive Yule coefficient indicates a positive association between two categories and a negative Yule coefficient indicates a negative association. A combined measure which incorporates both expenditures and target price, the target price deflated expenditures D/p, has a significant influence on employment (table A.6), but not on wage (table A.7).

Summarising the findings regarding labour, one can observe

- *positive* reactions of employment to both changes in expenditures and target price deflated expenditures,

- *negative* reactions to changes in the target price in the case of two currencies and to changes in the wage rate.

Regarding the wage rate, it is evident that it reacts

- *positively* to changes in expenditures in the case of a currency union and to changes of the central banks' instrument of the target price.

Although the majority of the observed reactions are in line with theory, there is still a high fraction of decisions that do not cause the predicted changes in wage and employment. In the following, reasons for this behaviour are given.

2.3.2 Dissecting the Interplay of Fiscal and Price Policy

As shown in subsection 2.2.2, an increase of expenditures should *ceteris paribus* result in an increased employment (and vice versa). The opposite should hold true for the target price, because an increased target price induces higher wages and thus higher variable production costs. Consequently, the instruments D and p should have contrary effects on employment changes.

How does the labour market react if the changes of D and p in two consecutive periods have the *same* sign? If this is the case, target price policy and fiscal policy set incentives for opposite effects on the labour market. Henceforth, any combination of either positive or negative changes in both target price and expenditures will be termed an *uncoordinated* decision pair. If the signs of the changes are not identical or if both D and p remain constant, decision pairs are labelled to be *coordinated* in the following. This terminology is illustrated in table 2.2.

Table 2.2: Categories of policy decision pairs

Δp \ ΔD	> 0	< 0	$= 0$
> 0	uncoordinated	coordinated	not considered
< 0	coordinated	uncoordinated	not considered
$= 0$	not considered	not considered	coordinated

Note that uncoordinated policy decisions are not necessarily irrational *per sé*: central banks and governments have more goals to fulfil than keeping employment in an optimal corridor. Coordinated policy decisions might have opposite effects on other goals. Recall furthermore that the central banks fix the target price for the current period one period ahead. This has two implications. At first, governments already know the target price at the time of their decision, thus having the opportunity to adjust the expenditures to imply equidirectional effects on the labour market. Second, the central bank's target price decision for the actual period is made when only employment and wage from two periods before are known. The government's decision on expenditures for the current period is however made when employment and wage from the preceding period are known. Hence, the central bank's information on the labour market is one period older than the government's information. This is a possibility for uncoordinated decision pairs to arise in spite of both institutions reacting rationally with respect to the labour market.

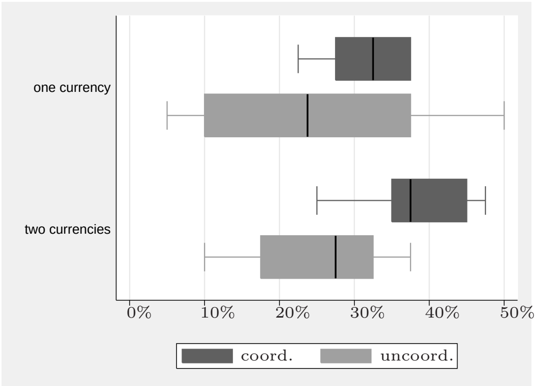


Figure 2.4: Fractions of decision pairs by category over treatments

In the experiment, decision pairs of both categories can be observed (see figure 2.4). On average, 24.8% of the decision pairs are uncoordinated with regard to the labour market, whereas 35.7% are coordinated. The remainder of the decision pairs is not considered. The latter ones outnumber opposite ones on session level ($p = 0.0317$ two-tailed permutation test, $p = 0.0464$ two-tailed Wilcoxon signed rank test). In the treatment with a currency union, the central bank has to keep the employment of two countries in the optimal employment range by the means of one single target price. In the treatment without a currency union, each central bank has to keep the employment of only one country within the optimal employment range. This yields a more complex decision situation in the one-currency case. It would thus be plausible that the share of coordinated decision pairs is higher in the two currency case. Exactly this phenomenon can be observed. The difference is also significant at $p = 0.0601$ (one-tailed two-sample permutation test) and $p = 0.0851$ (one-tailed Mann-Whitney ranksum test).

How efficient are the institutional instruments to influence wages and employment if they are coordinated and if they are uncoordinated in respect to the labour market? Let us take a look at the association of changes in target price deflated expenditures and employment or wages, respectively, in both categories of decision pairs. Note that investigating expenditure and target price changes separately under the condition is not valid here, because a change in employment could be due to target price or expenditures.

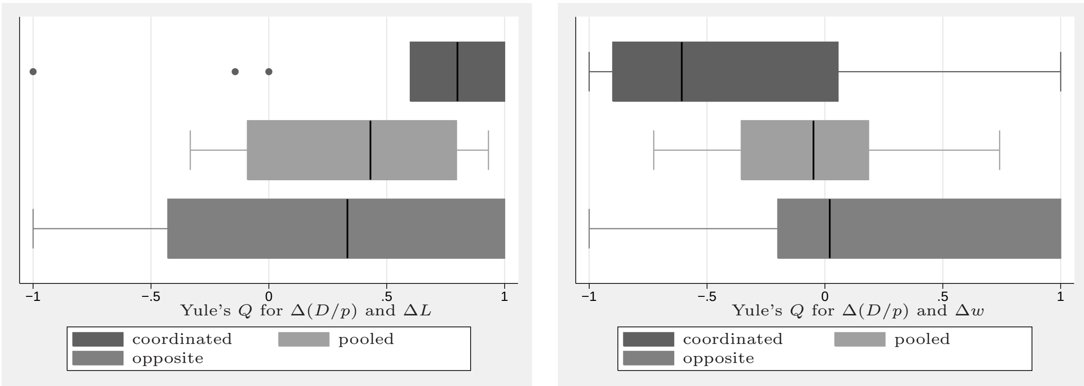


Figure 2.5: Yule's Q by both decision pair categories and all pooled decisions for D/p and L resp. w.

Figure 2.5 shows the distribution of Yule coefficients for changes in employment (or wages, respectively) and changes in D/p. Recall that a positive Yule coefficient is associated with concurrent positive and concurrent negative changes in both variables observed, whereas a negative one stands for negative changes of one measure that come with positive ones of the other. The data gives strong evidence for the importance of coordinating policy decisions for them being effective on the labour market:

Regarding employment, the positive influence of a change in D/p on employment is significantly higher if the decision pair is coordinated compared to pooled ($p = 0.0392$, Wilcoxon two-tailed signed rank test) and uncoordinated ($p = 0.0914$) decision pairs. A contrary effect can be observed for wages: If the decision pair is coordinated, an increasing D/p has a higher influence in lowering w than for pooled (significant at $p = 0.0342$) and for uncoordinated decision pairs (evidently by mean and median, but not significantly). Moreover, changes in target price deflated expenditures only influence employment and wage significantly if the decision pairs are coordinated in respect to the labour market (confer tables A.8, A.9, A.10, and A.11 in the appendix).

Concluding, it has been shown that

- due to the increased complexity of the coordination problem of the central bank in a currency union (i.e., considering two labour markets instead of only one in the two-currency case), decision pairs that are coordinated with regard to the labour market are smaller in number in this case. In general however, coordinated decision pairs outnumber uncoordinated ones in both currency union and two-currency case,

- if the decision pairs are *coordinated* with regard to the labour market, the effect of changes in target price deflated expenditures on both wages and employment is strongest,

- if the decision pars are *uncoordinated*, these effects are weaker and even contrary for the changes in wage.

One can see that the institutions are endowed with the right instruments to effectively fight both over- and underemployment. However, they seem not always to coordinate their policy decisions with regard to the labour market. The next subsection reveals how governments and central banks react to employment penalties.

2.3.3 Institutional Reactions on Unfulfilled Employment Goals

If the current employment L resides out of the boundaries of a range $[L_a, L_b]$, the objective functions of both government and central bank deteriorate. As was shown in the previous subsection, the instruments at hand can help institutions to improve their employment goals. To test whether these instruments are used to keep employment in the corridor for which institutions are not penalised, a measure incorporating penalties for missing any of the employment goals is used. The measure ε is derived directly from the payoff functions of the institutions. It denotes the employment change necessary for achieving all employment goals weighed with employment penalty constants, or shorter, the weighed necessary employment change:

$$\varepsilon_G = \varepsilon_{C2} = b_6 \cdot \max\{0; L_a - L\} - b_7 \cdot \max\{0; L - L_b\} \tag{2.39}$$

$$\varepsilon_{C1} = b_6 \cdot \left(\frac{1}{2}\max\{0; L_a - L\} + \frac{1}{2}\max\{0; L_a - L^*\}\right) - b_7 \cdot \left(\frac{1}{2}\max\{0; L - L_b\} + \frac{1}{2}\max\{0; L^* - L_b\}\right) \tag{2.40}$$

Index G denotes this necessary weighed employment change for governments; index $C2$ marks the necessary weighed employment change for central banks in the two-currency case. Index $C1$ denotes a measure for the central bank in the currency union case. This measure averages the necessary weighed employment changes for both countries. For overemployment, ε_G and ε_{C2} is negative; in the case of underemployment, both are greater than zero. If the employment lies within the range of $[L_a; L_b]$, ε_G and ε_{C2} equal zero. In the one-currency treatment, the central bank can be penalised for over- and underemployment simultaneously. Hence, the measure ε_{C1} is positive if the unemployment penalty outweighs the overemployment penalty, negative if the overemployment penalty outweighs the underemployment penalty, and 0 if the employment of both countries lies in the range of $[L_a; L_b]$.

The association between a government's expenditure changes and weighed necessary employment changes is significantly positive (see table A.12). Consequently, the governments seem to react on employment-induced penalties: If they are penalised for underemployment, the expenditures are increased. If they have to pay a penalty for overemployment, the expenditures are decreased. This behaviour is rational in respect to the labour market. Overall, this effect is strong. Interestingly, the effect is significantly weaker under a currency union. Reasons for this treatment effect will be explored in subsection 2.3.4.

Surprisingly, opposite effects can be observed in central bank behaviour. According to section 2.2.2, a central bank should increase its target price if it observes overemployment and decrease it in the case of underemployment. The central bank players in the experiment behave exactly the other way round: They decrease the target price in the case of overemployment and increase it in the case of underemployment. Evidence is presented in table A.13. The Yule coefficient, Spearman's rank correlation coefficient, and Bravais-Pearson's product-moment correlation coefficient are significant for a positive association of the weighed necessary employment change ε_C and the change of p_+ in the next period.

It seems that the application of the government's expenditure instrument is at least partially driven by the wish to achieve the employment goals. The central bank however applies the target price instrument in the opposite direction than would seem appropriate. What else drives the decisions of governments and central banks? The next subsection outlines other factors.

2.3.4 Determinants of Institutional Behaviour

How can the central banks' and the governments' behaviour be explained? Recall from subsection 2.2.1 that governments and central banks have several conflicting goals to achieve. In the following, the aggregate penalties for deviations of the target price from the actual price (2.10), (2.25), (2.18) and for deviations of the actual target price from next period's target price (2.9), (2.24), (2.17) are labelled the price penalty, whereas the aggregate penalties for underemployment (2.14), (2.28), (2.21) and for overemployment (2.15), (2.29), (2.22) are labelled the employment penalty. Figure 2.6 shows the mean absolute penalties for both institutions. The heavier burden of the employment penalty compared to price penalty is obvious and significant (central banks: $p = 0.0106$ two-tailed Wilcoxon signed-rank test, p =0.00632 two-tailed permutation test; governments: $p = 0.0106$

Wilcoxon, $p = 0.01056$ permutation test).

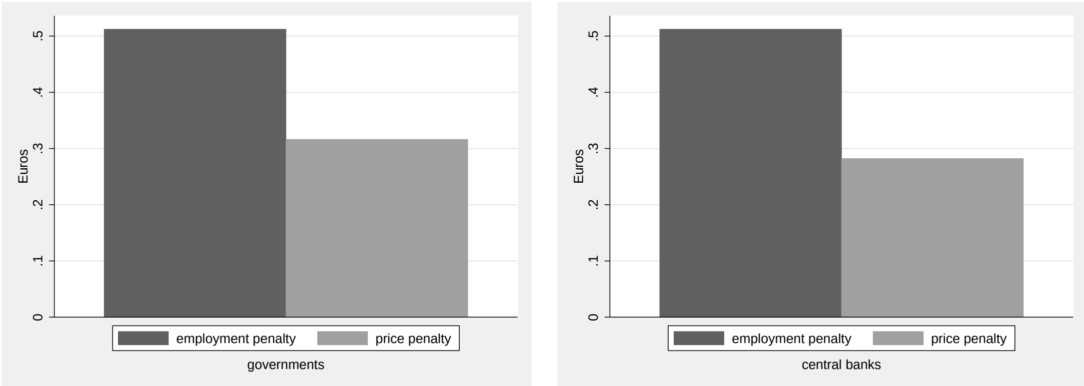


Figure 2.6: Average penalty of institutions for missing employment and price goals

One can see that the institutions fulfil their price goals better than their employment goals. At the point of its decision, a central bank could, if it is trying to minimise the price penalty, track the reference price $\bar{q}_- = q_{t-1}$ (the average price $\bar{q}_- = \frac{q_{t-1}+q^*_{t-1}}{2}$ in the currency union treatment) from the last period. Although this would minimise the penalty for an inaccurate target price (confer equation 2.10 in the two-currency case and equation 2.25 in the currency union case) if the actual price q (or $\frac{q+q^*}{2}$, respectively) in the following period was equal to the reference price in the previous period, the penalty for target price instability (2.9) would increase. To minimise both target price instability penalty and target price inaccuracy penalty, a central bank should set a target price between the actual period's target price and the reference price observed in the previous period if it believes that next period's actual price equals the reference price. Figure 2.7 displays the reference price observed and the target price decision of a central bank in an example period.

The target price line looks like a smoothed version of the reference price line. Quantitatively, it can be shown that the central banks significantly behave in this way

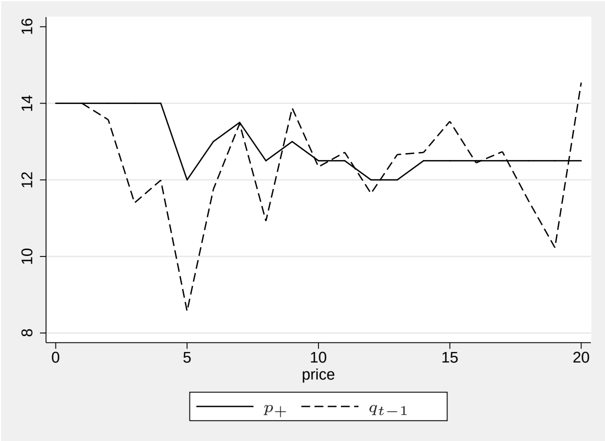


Figure 2.7: The central bank's next target price and previous period's price in session 9, country B

by deriving a tracking condition from the central banks' payoff functions. If one counts how often the tracking condition

$$\left(\frac{\bar{q}_-}{p} - 1\right)^2 \geq \left(\frac{\bar{q}_-}{p_+} - 1\right)^2 \tag{2.41}$$

is fulfilled, one comes to the conclusion that on average 76.50% of the decisions can be explained by this theory. The session average is greater than 50% ($p = 0.0006$ two-tailed Wilcoxon signed-rank test; $p = 0.0001$ two-tailed permutation test).

Governments do not have the possibility to set or modify target prices, so they have no influence on the target price stability goal. However, they can try to use the expenditures to influence the price. This affects the target price accuracy goal. Increased expenditures lead *ceteris paribus* to an increased price. If the government is aware of that, it should act in the following way: if it expects the target price for the next period be equal to the target price in this period, they should increase D under the condition that q_{t-1} is smaller than p and decrease it when q_{t-1} is greater than p. All measures of association computed except the Yule coefficient are significantly smaller than zero in the currency union case (see table A.14) and thus in favour of this hypothesis. In the case without a currency union, they are not. A possible explanation for the absence of this behaviour in the latter case and for a verifiable presence in the currency union case could be that it is inevitably harder for the central bank to minimise the target price inaccuracy penalty in the one-currency case. The governments are conscious about that and try to support the target price policy of the central bank.

In the two-currency case, the governments do not support the central bank in fulfilling the target price accuracy goal. Instead, a different phenomenon can be observed: a government tries to minimise the nominal difference between its own country's' expenditures and the expenditures of the foreign country. Note that the nominal difference of both expenditures has no meaning in real terms since both expenditures are stated in their respective currency. In terms of their payoff function, minimising the nominal difference does not make any sense at all. The collected evidence nevertheless speaks in favour of this hypothesis: In most cases, the nominal percentage difference between both countries' expenditures in the last period of the game is smaller than in the beginning of two-currency sessions (in period 0 or equilibrium, the percentage nominal difference is 28%, whereas at the end, the average percentage nominal difference of the expenditures is 12.8%). This effect is significant (two-tailed Wilcoxon signed-rank test $p = 0.0152$, two-tailed permutation test $p = 0.0117$). Further evidence for this behaviour is that on average 67.8% of the decisions satisfy the nominalism condition:

$$\left|D_{t-1} - D^*_{t-1}\right| \geq \left|D_t - D^*_{t-1}\right| \tag{2.42}$$

The share of expenditure decisions that conform to equation (2.42) is significantly greater than 50% (two-tailed Wilcoxon signed-rank test $p = 0.0707$). At a first glance, this seems to be a rather perplexing result from a macroeconomic point of view. Although easily explained with cognitive effects, e. g. the theory of prominent numbers by Albers and Albers (1983), it does not strike the economist to be convincing on a macroeconomic level. There are however many examples for nominalism in macroeconomics. In an investigation that considers both field and laboratory data, Pope et al. (2006b) outline occasions where nominalism could be observed in historical exchange rates.

Summarising, it is demonstrated that

- both institutions achieve their price goals better than their employment goals,
- central banks use their target price instrument rather for tracking the prices observed than for improving their employment goals
- governments try to influence the price for achieving the target price accuracy goal in the currency union case
- governments irrationally decrease the nominal difference of their respective country's expenditures to the foreign country's expenditures

2.3.5 Inflation and Employment

In the 1950's and 1960's, it has been discovered that there is a negative correlation between the unemployment rate and inflation (confer Samuelson and Solow 1960). Theories describing the mechanisms that cause this relation have been modified over time, and nowadays, the Nobelprize winning theories of Edmund Phelps (1967) are considered to describe the machinery most accurately. He augmented the traditional Phillips curve with inflation expectations and concluded that only unexpected inflation can in the short run reduce unemployment. Nevertheless, inflation and unemployment have been correlated negatively over a long period of time.
The existence of similar patterns in the experimental data can be shown: a positive percentage change in prices comes with a positive percentage change in employment in the period thereafter and a negative percentage change in prices comes with a negative percentage change in employment in the period thereafter . More precisely, the association between $\frac{q_t - q_{t-1}}{q_t - 1}$ and $\frac{L_{t+1} - L_t}{L_t}$ is significantly positive in the data for all four association measures (confer table A.15 in the appendix). Figure 2.8 shows a scatter diagram of the relationship in one session.

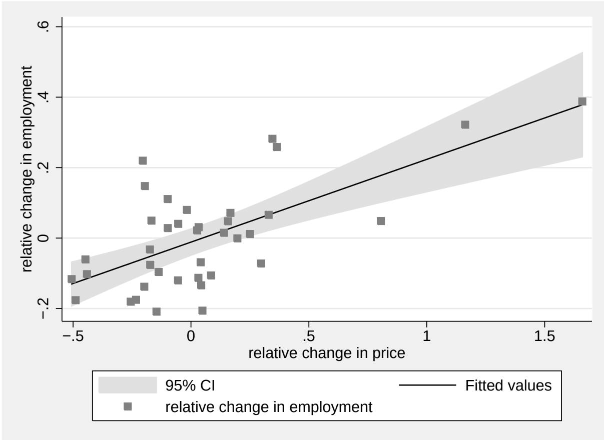


Figure 2.8: Relative changes of employment in $t$and of prices in $t-1$, regressional fit of session 3

A similar connection exists between $\frac{q_t - q_{t-1}}{q_t - 1}$ and $\frac{Q_{t+1} - Q_t}{Q_t}$ (see table A.16). A behavioural explanation can be derived for the occurrence of increasing employment after prices have increased and decreasing employment after prices have decreased.

Imagine the following constellation and refer to figure 2.9 for an illustration of the items denoted by Roman numbers: For whatsoever reason, the production quantity in one country drops from period $t-1$ to period t.

(I) Of course, a reduced production results in a lower employment (Spearman's ρ for session averages of total production and total employment is 1, two-tailed $p < 0.0001$). This becomes also clear if one takes into account that the total employment of one country as described in equation (2.4) includes twice the production of the home country.

(II) As a consequence of (I), the price of the consumption commodity increases. This would be a mathematical necessity if D_t was kept equal to D_{t-1}, for the price q is equal to $q = D/Q$. It can however not be assumed that this is *always* the case. Nevertheless, there is a strong empirical connection between a decrease in Q and an increase in q (see table A.18).

(III) The government observes in $t+1$ that the employment has dropped from L_{t-1}

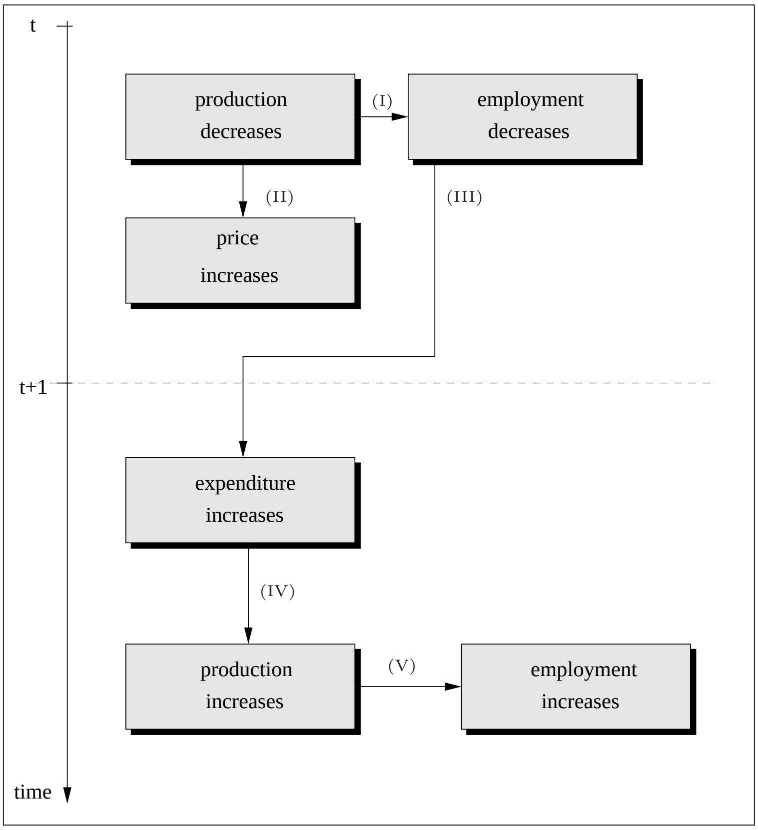


Figure 2.9: Interrelation between changes in prices and employment

to L_t. Having been penalised for underemployment or fearing, if the optimal employment range has not been violated, a further decline of employment to a point out of the optimal employment range, it increases expenditures and thus the demand for the consumption good. It has been shown in subsection 2.3.3 that governments tend to react this way on unfulfilled employment goals (confer also table A.12). But even if the underemployment avoidance goal is in fact achieved, there is a general and significant negative correlation between the relative change in employment and the relative change in expenditures in the period thereafter (confer table A.17). Consequently, the governments engage in fiscal policy that is anti-cyclical with regard to employment.

(IV) Observing the increase in D, the firms step up their individual production quantities. This effect is significant (as demonstrated in subsection 2.3.1 and visualised in figure 2.3 on page 25).

(V) For the same reasons as described in (I), the boosted production results in a higher employment compared to t.

This effect is also valid in the opposite direction. Note that in the case of an increased production, the motivation for the government to cut down expenditures in step (III) lies not in the underemployment avoidance goal, but in the overemployment avoidance goal.

This evidence sheds new light on the mechanisms at work when Phillips curves can be observed. In the model investigated, an observed price increase is often caused by production decreases, which cause employment cutbacks. This employment cutback is not in the interest of the government, so it strives to increase employment by elevating expenditures. The tactic of the government works out: The firms increase their productions and employ more people. This way, price increases and consequent employment increases are connected. Although inflation and employment are associated, this association is not due to a causal influence of one onto the other. An association is due to a third factor, a very low or very high production. If one introduced an *ad valorem* tax to artificially increase prices in order to increase employment, this plan would fail in the boundaries of this model.

2.4 Concluding Remarks

This study investigates how governments and central banks interact to achieve employment goals. In a complex laboratory experiment under controlled conditions, two macroeconomies are simulated by human players. A variation of the experiment imposes a currency union on the two countries. Governments and central banks have several goals to fulfil. To achieve minimal penalties for unfulfilled policy goals, governments can use the fiscal instrument of the expenditures. Central banks' decisions include stating a price target for the consumption good that is produced domestically by five firms. Both institutions have objective functions as such that they receive their maximum payoff only if they keep employment between a minimum and a maximum accepted employment, if the central bank's target price is equal to the actual price, if the target price does not change in regard to the period before, and if they achieve three more goals that are not relevant for this study. Before firms make their production decision, labour unions and employers' associations bargain on a wage. Unions receive a payoff depending on the wage and the target price, whereas the employers' association's payoff is proportional to the firms' profits. Theory predicts positive reactions of production and employment on changes in expenditures and negative ones on changes in the target price. Additionally, changes in the target price should influence wage positively.

A significant fraction of policy decisions influence the labour market as described by theory. However, there are many reactions of employment and labour that cannot be explained by variations of the instruments. It is shown that the effects of policy decisions are stronger if changes in expenditures and the target price have unequal signs and are thus coordinated. Moreover, the influence of the policy instruments on wage is even opposite to theoretical predictions if the decisions are uncoordinated.

One can observe that governments adjust the expenditures correctly to reduce over- and underemployment penalties in the majority of cases. This does not hold true for central banks and their target price instrument. Instead, they use the target price to track the previously observed price to minimise their target price penalties. Besides reacting on over- and underemployment penalties, governments try to influence the actual price with their expenditure instrument in case of a currency union. In case of two currencies, governments irrationally try to minimise the nominal difference between their own country's and the foreign country's expenditures. The observed phenomena also deliver a new explanation for a non-causal negative correlation between unemployment and inflation: An increased price is caused by decreased production amounts. The latter ones come with a decreased employment on which the government reacts counter-cyclical with an increase of expenditures because they experience or fear underemployment. The firms adapt to the increased demand for the consumption good by enhancing their production amounts, thus increasing employment.

In this chapter, it is demonstrated how the relatively young discipline of experimental macroeconomics can be applied to study labour market reactions on economic policy decisions and how employment influences economic policy decisions. The controlled environment of the laboratory allows to abstract from problems that are prevalent when using field data: In practice, the goals of governments and central banks are either defined in an inaccurate manner or not revealed to the public. Furthermore, it is almost impossible to quantify to which extent policy institutions achieve their goals. Although price targets find application in practice, their height is usually not common knowledge.

However, there is still room for future work. Interrelations between the labour markets of the two countries are not yet investigated. One could also think of a model that features not only two but more different countries. Also, a tie between wage and unemployment could possibly exist. The model and the experimental data gained might thus be used to test the theories of Phillips (1958) and of Lipsey (1960): They assume a negative correlation between the wage change rate and unemployment. It would also be interesting to check whether the idea of the expectations-augmented Phillips curve by Phelps (1967) applies to the observed behaviour. There have been experimental approaches to deliver a behavioural explanation, e. g. Arifovic and Sargent (2002), but none with a model that indeed features players in important roles of macroeconomic entities. In order to do so, it would be necessary to change the model to include consumers. With some modifications, the model by Pope et al. (2003) could be used as a workhorse for a whole series of macroeconomic studies on wage setting and employment.

3 Currency Trade and Exchange Rate Uncertainty

"It's important to remember, when economists are asked to forecast, they divide themselves into two camps: those who don't know, and those who don't know that they don't know."

– John Kenneth Galbraith

3.1 The Currency Market

Foreign exchange trade has always had a vast influence on systems of flexible exchange rates. A large variety of empirical, experimental, computational, and theoretical investigations deal with this topic. For example, Evans and Lyons (2002) fit a model in which order flow in the foreign exchange market plays a strong role in exchange rate determination.

But what determines the currency trade decision of a firm? Why do non-financial firms engage in currency trade? How do they deal with exchange rate uncertainty? In this study, evidence is described from a computerised laboratory experiment under controlled conditions, in which industrial firms have the opportunity to produce a consumption good as well as to offer currency on the currency market. This is the first approach in behavioural finance to cover this topic. To investigate the trading behaviour of subjects, it is necessary to utilise an appropriate experimental model which describes an exchange rate mechanism.

In traditional economics, currency trade behaviour is usually explored by evaluating empirical field data. As a complement, the controlled environment of a laboratory experiment allows to abstract from problems that are prevalent when using field data. In the lab, every trader has identical sources and channels of information, the prevailing circumstances are the same, the endowments of the traders can be kept at equal level, and external shocks can be controlled for. Yet it is important to utilise an appropriate experimental model which describes an exchange rate mechanism.

There exist some experimental designs of international economies in literature that describe the mechanism of exchange rate determination. For example, Noussair et al. (2003) derive the exchange rate from the flow of funds theory of exchange rates and use the import and the price of goods as components of the exchange rate in a complex three-country model. In an earlier paper, Noussair et al. (1997) use the same model of exchange rate determination in a two-country model with less agents and less markets. The model of Arifovic (1996) utilises a purchasing power parity model for the calculation of the exchange rate. In contrast to exchange rate determination based on international trade of goods or purchasing power parity, Fisher and Kelly (2000) let traders buy or sell two foreign currencies and one home currency in a double auction. Thus, the exchange rates are the average relative prices paid by currency traders. Note that these models take into account either international trade of goods, purchasing power parity, or currency trade. Pope et al. (2003) create a synthesis of external key features in which currency trade, international trade of goods and materials, and central bank interventions determine the exchange rate. Using this model allows to focus on the influence of different economic variables on the currency trade decision of firms.

This experimental investigation focuses on the influence of different economic variables on the currency trade decision of firms. Mundell (1960) describes a model in which speculators base their actions on the observed size of the monetary reserve of central banks. Professional traders might take this figure into account, but it seems unlikely that industrial firms, whose demand for foreign currency is mainly caused by international trade of goods and secondarily caused by currency trade, consider the central bank's monetary reserve. Keloharju and Niskanen (2001) investigate the decision of firms to raise foreign currency debts. Their findings include that firms whose exports constitute a significant fraction of net sales are more likely to raise currency debts and that the firms tend to borrow in periods when the nominal interest rate for the loan currency, relative to other currencies, is lower than usual. The results described in this chapter fall in line with the latter finding. It is also demonstrated that firms who only produce goods for the domestic market and who need foreign materials for the production tend to borrow money in their own country rather than in the foreign one. In a market survey study, Cheung and Chinn (2001) show that technical analysis of exchange rates is used as a means of determination of currency trade decisions by only thirty percent of the the US foreign exchange traders at most. It is confirmed in the study at hand that at least in the laboratory the influence of technical analysis on the currency trade decision is rather weak compared to other determinants.

Cheung et al. (2004) describe a survey of UK-based traders in 1998 regarding their beliefs on the importance of macroeconomic factors on exchange rates. They conclude that the traders think that exchange rates are determined in the long run by economic fundamental values and in the short run by overreaction, speculation, and bandwagon effects. The data gathered through our experiment suggests that a large proportion of subjects indeed adapt their trade behaviour to economic figures besides interest and exchange rates. Moreover, subjects who neglect the variation of previous consecutive exchange rates and instead base their decision solely on the difference of the interest rates in the countries scoop in the highest currency trade profits in our experiment. The literature partially states that different determinants of stock market speculation decisions don't influence their profits. For example, Malkiel (1973) conjures up the image of a blindfolded monkey throwing darts at financial pages and doing just as well as expert stock-pickers. Chakrabarti (2004) describes how the Wall Street Journal picked up this idea and let leading stock analysts compete against dart shooting employees of the journal. Over the years, the analysts won – but only slightly. The evaluation of the Wall Street Journal's experiment undertaken by Liang et al. (1995) concludes that in the long run the dartboard picks were even more profitable than the professional picks.

The remainder of this chapter is organised as follows. First, a brief introduction on the experimental model as well as the procedures used is given. Thereafter, a short descriptive review of currency trade and incurred profits and losses as taken place in the experiment is given. Determinants of the firms' currency trade behaviour are identified in the following section and the existence of exchange rate uncertainty is shown. Afterwards, implications of the firms' incapability of predicting the exchange rate correctly are lined out as well as ways of how the subjects tried to cope with exchange rate uncertainty. The section closes with a short evaluation of the influence of currency trade on the exchange rate volatility. In the final section, the findings are discussed before concluding. A condensed version of this thesis chapter has been published in the *Journal of Behavioral Finance*[1].

3.2 Experimental Setup and Procedure

As a vehicle for the experimental investigation, a symmetric and deterministic two-country model as described in Pope et al. (2003) is used. Originally designed to investigate the economic effects of currency unions, it provides all features necessary for this evaluation. The model consists of two treatments. In the following, the focus is set exclusively on the case without a currency union – the details of the currency union case are omitted since currency trade does not exist in the latter condition. The model has an identical game-theoretical equilibrium solution for both versions which will not be discussed here. Since this model displays a high degree of complexity, its description will be limited to the mechanisms which are

[1] see Kaiser and Kube (2009)

related to currency trade and exchange rate determination[2]. The game was set up as a computer-based laboratory experiment under controlled conditions as follows:

In each of the two countries A and B, nine players act as economic entities in a round-based experiment: one government, one central bank, one labour union, one employers' association, and five firms. The model is symmetric, so in the following a 'home' country (for example A) will be looked upon. Everything will be viewed from its perspective. Parameters of the 'foreign' country (B in the example) are denoted by an asterisk. Two types of goods exist in each country: a domestic consumption good Q that is produced by the firms in the country, and a material M. The material is traded internationally because a firm needs materials from *both* countries, M and M^*, for the production of the domestic consumption good. The firms have two bank accounts each to their disposal: one in the home country and one in the foreign country. The account in the home country is denoted in domestic currency, the account in the foreign country in foreign currency.

The model spans over multiple periods. Each period has a number of steps which follow a certain structure. In each step, the active players choose their decision variable(s) simultaneously in each country. After each step, the decisions are made public.

In step 1, the government chooses the total nominal expenditures D of the economy. It is assumed that this is done by means of fiscal policy. The details are not explicitly modelled. All of the expenditures will be spent completely on the domestic consumption good Q in a later step.

In step 2, the central banks have to decide on three variables (see fig. A.2): they set the interest factor r (defined as 1 plus a hundredth of the interest rate

[2] The interested reader can find the details of the solution and of both cases of the model in Pope et al. (2003). Furthermore, the English translation of the instructions of the experiment as handed out to the participants can be found in appendix D.1.

percentage) for their country, fix an exchange rate aim f and choose next period's target price p_+ for the domestic consumption good. The exchange rate is defined as the price of one unit of foreign currency in home currency. The actual target price p equals p_+ in the preceding period, and is exogenously given in the first period.

In step 3, the union representative and the employers' association of each country bargain on the nominal wage rate w that has to be paid for one unit of local labour. This is done by exchanging text messages in a computer-based chat system. If at the end of a fixed period of time (10 minutes) the union wage offer w_u differs from the employers' association wage offer w_e, there will be a strike in the corresponding country. A strike causes not only a reduction of the firms' maximum production capacity Q_c to $Q_0 < Q_c$, but also a decrease of the demand D for the produced consumption good to σD. Furthermore, the wage is set to a statutory minimum wage $w_0 = \eta p$.

In step 4, the firms decide on the quantity of the consumption good they want to produce. The firms interact in a Cournot market (as defined in Cournot 1834) for consumption goods. Now that the firms know how much they have to pay for interest and labour and the amount of total nominal expenditures to be spent on the consumption good, it is their turn (see fig. A.3). A firm i can choose its production quantity Q_i above a minimum production quantity Q_m and below the capacity constraint Q_c. A firm needs labour, home materials (M), and foreign materials (M^*) to produce the good. The market for materials is modeled to be competitive. For producing one unit of material, one unit of local labour is needed at cost w. Wage payments are paid before interest, so the marginal costs of one unit of material are wr. In a competitive market the price equals the marginal costs, so the price for the material is $m = wr$, resp. $m^* = w^*r^*$. The labour L_i consists of the two components fixed labour F, which is needed to run the company, and variable labour, which is equal to Q_i.

Besides producing, a firm may borrow money for one period either from its home or foreign account at the interest factor r resp. r^* and offer it on the currency market. X_i (X_i^*) denotes the amount of home (foreign) currency offered[3]. The money borrowed must be paid back in the next period including interest. This will be labelled currency trade in the following. Note that only the overall production quantity Q will be revealed to the firms in the next period, whereas neither individual production quantities and currency offers nor total currency offers are made public.

At the end of each round, the firm home (S_i) and foreign (S_i^*) accounts total to:

$$S_i = Q_i q + r(X_i^* e - L_i w - X_i) - M_i m \tag{3.1}$$

$$S_i^* = r^*(X_i e^* - X_i^*) - M_i^* m^* \tag{3.2}$$

Two credit constraints limit the firm accounts: The sum of labour costs and the amount of home currency offered must not exceed $C_1 = \gamma_1 w$, furthermore the maximum amount of foreign currency offered is $C_2 = \gamma_2 w^*$. This limits the currency offers to:

$$\bar{X}_i = \gamma_1 w - L_i w \tag{3.3}$$

$$\bar{X}_i^* = \gamma_2 w^* \tag{3.4}$$

The next steps don't require player interaction. All costs and revenues incurred by production and currency trade of a firm i get deducted from, and transferred to, respectively, the corresponding home or foreign account. The price q for one unit of the consumption good Q is defined as $q = \frac{D}{Q}$ ($q = \frac{\sigma D}{Q}$ in case of strike). The final account balances (positive as well as negative) are taken over by the firm's owner, clearing the account for the next period. They consume their profits in the next period in their home country, so they have to trade the money from the foreign account back into their home currency at next period's exchange rate e_+. The currency trade mechanism and the payoff and account structure of a firm is

[3]Note that here the asterisk denotes the currency rather than the country.

illustrated in figure 3.1 with the example of a home currency offer.

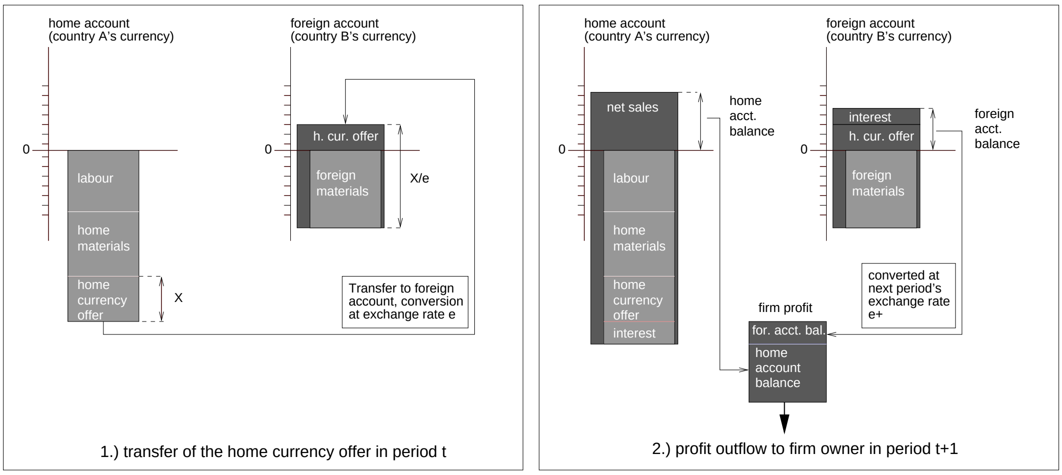


Figure 3.1: Schematic display of the account and payoff structure if home currency is offered

The exchange rate itself is determined by a mechanism which also takes the central banks' exchange rate aims f and f^* into account. In sessions 7 to 12, the exchange rate aims were publicly announced, but in sessions 13 to 15 they were not known to the firms, which makes guesses on the height of the future exchange rate even more inaccurate. If both exchange rate aims are the same ($f = \frac{1}{f^*}$), then the central banks jointly intervene on the currency market in order to realise their common exchange rate aim. The exchange rate is then f. Now assume $f \neq \frac{1}{f^*}$. In this exchange rate conflict both central banks intervene on the currency market, each in favour of its own exchange rate aim. One has to distinguish two kinds of exchange rate conflicts, a low aim conflict with $f > \frac{1}{f^*}$ and a high aim conflict with $f < \frac{1}{f^*}$. In a low aim conflict each central bank wants a smaller value for its currency than the other bank and in a high aim conflict each of them wants a higher value of its own currency than the other bank. Therefore in a low aim conflict both central banks intervene by offering their own currency, whereas in a high aim conflict each of them offers the currency of the other country.

Let m_- and m_-^* be previous period's material prices of the home country and the foreign country, respectively. In the case of a low aim conflict the home country bank offers $I = \zeta_1 m_-$ and the foreign bank offers $I^* = \zeta_1 m_-^*$. In case of a high aim conflict the foreign bank offers $I = \zeta_2 m_-$ and the home bank offers $I^* = \zeta_2 m_-^*$. Here, ζ_1 and ζ_2 are positive constants with $\zeta_1 > \zeta_2$. This inequality is based on the idea that central bank interventions in own currency are less restricted than those in the other country's currency. What has been said about I and I^* leads to

$$I = \begin{cases} \zeta_1 m_- & \text{if } f > \frac{1}{f^*} \text{ (low aim conflict)} \\ \zeta_2 m_- & \text{if } f < \frac{1}{f^*} \text{ (high aim conflict)} \end{cases} \tag{3.5}$$

and

$$I^* = \begin{cases} \zeta_1 m_-^* & \text{if } f > \frac{1}{f^*} \text{ (low aim conflict)} \\ \zeta_2 m_-^* & \text{if } f < \frac{1}{f^*} \text{ (high aim conflict)} \end{cases} \tag{3.6}$$

Other components of the exchange rate are the foreign accounts of foreign firms from the previous period (K_-), the foreign accounts of domestic firms from the previous period (K_-^*), the aggregate currency offer X of the currency of country A, the aggregate currency offer X^* of the currency of country B. and The tentative exchange rate $\bar{e}$ is defined as the ratio of the total currency offers:

$$\bar{e} = \frac{X + K_- + I}{X^* + K_-^* + I^*} \tag{3.7}$$

This measure is the base for the determination of the actual exchange rate e of the next period:

$$e = \begin{cases} \min(f, \frac{1}{f^*}) & \text{for } \bar{e} \leq \min(f, \frac{1}{f^*}) \\ \bar{e} & \text{for } \min(f, \frac{1}{f^*}) < \bar{e} < \max(f, \frac{1}{f^*}) \\ \max(f, \frac{1}{f^*}) & \text{for } \bar{e} \geq \max(f, \frac{1}{f^*}) \end{cases} \tag{3.8}$$

This model of exchange rate determination is new in economics literature, because its interpretation of currency offers is not limited to either currency trade, purchasing power parity, or international trade. As can be seen, it includes central bank intervention, international trade, and currency trade as influence factors on the exchange rate.

The objective of a firm v_i is its expenditure deflated profit. Thus, the payoff of a firm i is defined as

$$v_i = \frac{S_i + e_+ S_i^*}{D} \tag{3.9}$$

Each firm has the possibility to utilise a profit calculator (see fig. A.3). The player can enter an estimate for this period's expected exchange rate (which is unknown to him at the moment of his decision) $\hat{e}$, next period's expected exchange rate $\hat{e}_+$, his own production quantity $\hat{Q}_i$, and the total production quantity of the other firms in his country $\hat{Q}_{-i}$. The firm then selects a grid constant $\hat{s}$ for the profit table, which displays the own production quantity on the ordinate, the total production of the other firms on the abscissa, and the corresponding expected profits in the fields. The table is centred[4] around the chosen quantities $\hat{Q}_i$ and $\hat{Q}_{-i}$. Furthermore, the profit calculator gives an advice on which currency offer would be the most remunerative if the exchange rate estimates are correct. This speculative advice also takes the differences of the interest factors of both countries into account. Let $h := \frac{\hat{e}_+}{\hat{e}} r^* - r$. The speculative advice will then be:

- "offer home currency" if $h > 0$
- "offer foreign currency" if $h < 0$
- "don't offer currency" if $h = 0$

The experiments were conducted as computer-based laboratory experiments in the Laboratory for Experimental Economics of the University of Bonn between January 2002 and June 2005. All participants have been students of economics

[4] In session 14, the table was not centred but $\hat{Q}_i$ and $\hat{Q}_{-i}$ were the lowest quantities for i and the competitors of i, respectively.

for at least two years. Before the game was started, written instructions were handed out to the participants; an English translation of these instructions can be found in appendix D.1. Thereafter, an introduction of about one hour was given to them including example calculations of various figures. Some test questions were posed, and after the subjects gave the right answers, the roles were assigned randomly. Then the game was started. One session lasted about 8 hours, including a lunch break of one hour. After a short debriefing session and the handing out of an ex-post questionnaire, the participants were given their converted cumulative round payoffs in Euro. Each student was furthermore given a show-up fee of €5, totalling to an equilibrium payoff of €72.50. The average payoff per hour was approx. €10.23. 9 sessions (namely sessions 7 to 15) were conducted without a currency union. In each session, 10 players acted as firms. A total of 18 players took part in each session. Hence, a total of 90 of 162 subjects have taken part in the experiments as firm players. No subject was allowed to participate more than once in the experiment.

3.3 Analysis of the Trade Decisions

The results will be enumerated in four subsections. Firstly, a brief descriptive summary of the exchange rate variation, the currency trade behaviour, and the profitability of the firms's trade decisions will be given. After that, the findings concerning the determinants of a firm's trade behaviour are described and the existence of exchange rate uncertainty is demonstrated. The next subsection outlines the behavioural implications of exchange rate uncertainty. The remainder of the result section shows the effects of currency transactions on exchange rate volatility.

3.3.1 Descriptive Summary of the Currency Trade Behaviour

According to the game theoretical solution of the model, no firm should offer currency in equilibrium. Nevertheless, the aggregate currency offer of all firms is never zero for any currency in any period. The following paragraphs give a brief descriptive overview on the currency trade decisions and exchange rate development.

Although the exchange rate stays stable according to the game theoretical solution of the model, exchange rate variations can be observed in the experiment. As an illustration, the exchange rate development of session 13 is displayed in figure 3.2. The figure includes markers for the exchange rate aims of the central banks as well as the actual exchange rate.

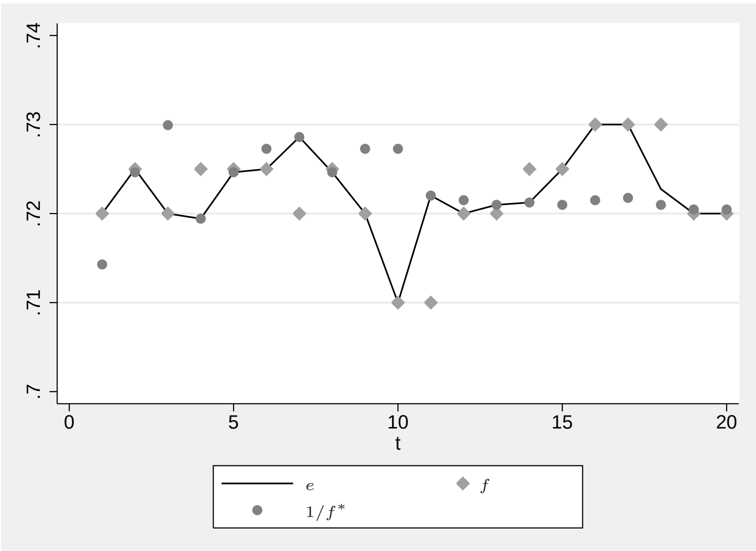


Figure 3.2: Exchange rate development in session 13

Altogether, there have been 1800 currency trade decisions in 9 sessions with 20 periods by 10 subjects each. In 1327 of those, a positive offer of either home or foreign currency was placed. If there was a positive offer of home currency, the subject offered 65.17% of the maximum home currency offer $\bar{X}$ (see equation 3.3) on average, whereupon the size of the foreign currency offer was on average 61.96% of the maximum foreign currency offer $\bar{X}^*$ if not 0. In 549 cases, foreign currency was offered, whereas in the remaining 778 cases home currency was offered. This seeming tendency to offer home currency more often and to a higher extent than foreign currency will be investigated further in subsection 3.3.3. The mean share of home currency offers to total home expenses was 15.38%, the mean share of foreign currency offers to total foreign expenses was 21.49%. The higher share of foreign offers to total foreign expenses can be explained by lower production costs in foreign currency, since no labour has to be paid from the foreign firm account.

As a measure of the profitability of individual currency trade decisions, the currency trade profit is an appropriate figure:

$$v_{\text{curr}} = \frac{(\frac{r^* e_+}{e} - r)(X_i - X_i^* e)}{D} \tag{3.10}$$

Table 3.1 displays a summary of the cumulative currency trade profits $\sum v_{\text{curr}}$ of the players in all sessions.

Table 3.1: Descriptive summary of cumulative currency trade profits

session	agg.	players with	
	$\sum v_{\text{curr}}$	$\sum v_{\text{curr}} < 0$	$\sum v_{\text{curr}} > 0$
7	.6046015	3	7
8	.0559865	5	5
9	.4795765	3	7
10	.1411873	2	8
11	.6395505	2	8
12	.6581888	1	9
13	.0619988	1	9
14	1.429293	4	6
15	-.0894841	5	5
mean	0.44232	2.89	7.11

As can clearly be seen, a majority of 71.1 % of the players makes profits on average by trading with currencies. A share of 28.9 % of the players incurs losses by currency trade, but in most sessions, the cumulative aggregate currency trade profits are positive. Statistical support for positive cumulative aggregate currency trade profits by a two-tailed Fisher-Pitman permutation test for paired replicates ($p = 0.0156$) is found. This significance test is a powerful alternative to the rank-based Wilcoxon test traditionally used in experimental economics. Details on the methodology can be found in chapter 5.

3.3.2 Determinants of Currency Trade

In the previous subsection, it has been shown that firms tend to engage in currency trade and make profits on average by doing so in spite of no currency trade taking place in equilibrium. How can the existence of non-zero currency offers be explained? In this subsection, the determinants of the currency trade behaviour are investigated.

Interest Differences

The most obvious motivation for placing currency offers would be the difference in interest rates in both countries. This behaviour can also be observed by looking at the data. Let

$$\Delta r_t := r_t - r_t^* \tag{3.11}$$

be the difference in interest rates in both countries. A firm determining its currency trade decision solely by the interest difference should offer home currency if $\Delta r_t < 0$, foreign currency if $\Delta r_t > 0$, and no currency if $\Delta r_t = 0$. Instead of determining the decision by Δr_t, a firm could also consider the speculative advice h given by the profit calculator. The profit calculator could be used arbitrarily often per period, so there is the possibility of entering more than one guess for actual and upcoming exchange rates. However, 75.67 % of the profit calculator utilisations were done with only one estimate for the exchange rates, and 94.45 % were done with three estimates at most.

Due to computer failure, parts of the profit calculator data of one session have been lost. This is why there has been a total of 1600 instead of 1800 trade decisions of which profit calculator estimates have been collected. In 958 cases of these, either home or foreign currency was offered, and interest differences existed. A special interest arises in the propensity of the players to trade either conforming to the speculative advice or conforming to interest differences. Table B.1 and figure 3.3 show a direct comparison of those cases.

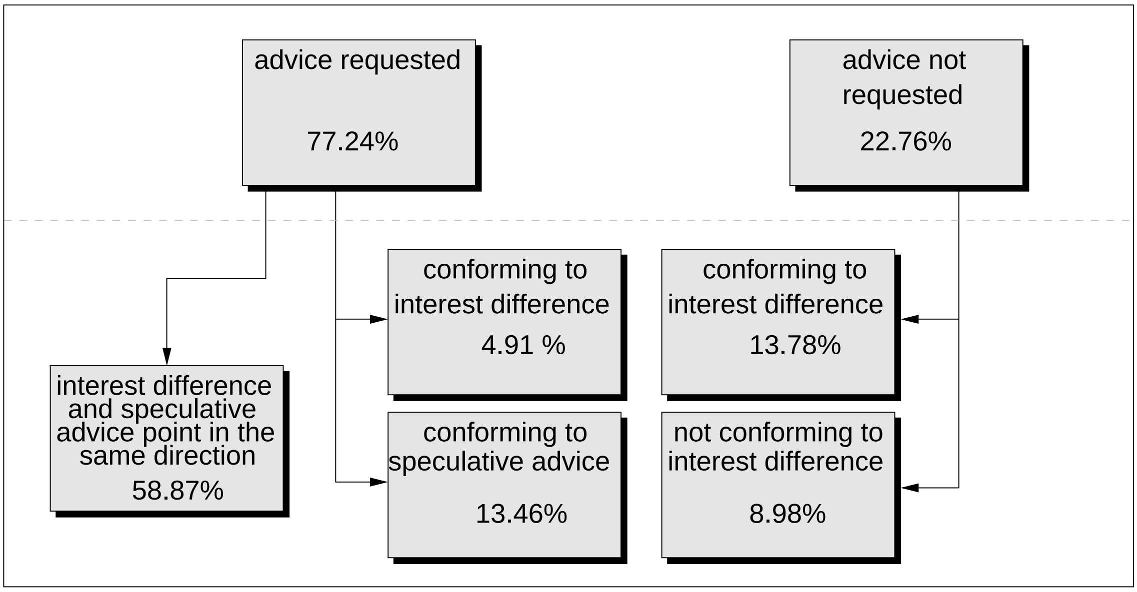


Figure 3.3: Conformance to trading motive

What can be deducted from those figures? If the speculative advice was requested and if it recommended to offer the currency which was the cheaper one in terms of interest rates, about five times more of the currency trade decisions followed both the advice and the interest difference instead of speculating against it. This is a strong indication for an influence of the interest rate on the currency trade decision, because the interest rates are taken into account by both the interest difference and the speculative advice.

But which both determinants is relied on more often? If the speculative advice was requested and it recommended to offer the opposite currency than the interest difference did, then a majority of the decisions followed the recommendation of the speculative advice rather than interest rates. It can be inferred that subjects prefer basing their decisions on the speculative advice over basing them on interest rates. Contrary to that, subjects tend to rely rather on interest rates than on other determinants if the speculative advice is not requested. Concluding, it can be stated that interest differences do matter, but people tend to take into account also individual exchange rate estimates when placing their currency trade decisions.

Do subjects usually offer the right currency with regard to Δr_t? Recall that in case of a constant exchange rate a profit-motivated subject should offer home currency if $\Delta r_t < 0$ holds true, foreign currency if $\Delta r_t > 0$, and no currency at all if there is no difference in interest rates in both countries.

To check whether the experimental participants behave like this, one looks at all periods in which a difference in interest rates arose and a firm traded currency. One then counts how often home or foreign currency was offered. This results in a 2×2 table for each firm player as shown in table 3.2.

Table 3.2: 2×2 table for the computation of Yule coefficients

	offer foreign currency	offer home currency
$\Delta r_t > 0$	y_f^+	y_h^-
$\Delta r_t < 0$	y_f^-	y_h^+

A firm can either offer home currency or foreign currency. If subjects base their currency trade decisions on interest differences, then they should offer foreign currency when the home interest rate exceeds the foreign interest rate (y_f^+), or offer home currency when the foreign interest rate is greater than the home interest rate (y_h^+), but not vice versa.

For each firm, such a 2×2 table has been determined to calculate a Yule coefficient Y as follows:

$$Y = \frac{y_f^+ \cdot y_h^+ - y_f^- \cdot y_h^-}{y_f^+ \cdot y_h^+ + y_f^- \cdot y_h^-} \tag{3.12}$$

The Yule coefficient ranges from $-1 \leq Y \leq 1$. More details on the Yule coefficient can be found in appendix A.1. In this case, Y equals 1 for subjects who offer the cheaper currency in terms of interest.[5] For some players, a Yule coefficient could not be determined because of four possible reasons. One subject did not trade at all in periods with interest rate differences. Eleven subjects were 'home-currency-biased': five subjects only offered currency when their home interest rate exceeded foreign interest rate but not otherwise, and six subjects only offered home currency and never foreign currency. Another five subjects were 'foreign-currency-biased'. They only offered currency when the foreign interest rate exceeded the home interest rate. These subjects have not been considered in the following evaluation of Yule coefficients. This effect will be investigated further later on.

The median of the Yule coefficients' distribution is 1. Table B.2 displays the session averages of Y, whereas a distributional graph of Y is shown in figure 3.4. The average Y is .72, or .8 if just the strictly positive ones are considered. The distribution is modal, with 47 times $Y = 1$. Only eight subjects have $Y < 0$, four of them at the extreme $Y = -1$. If firms with $Y \geq .5$ are classified as interest difference oriented subjects, 84% of the firms belong to this group. All session averages of Y are positive, and a two-tailed Fisher-Pitman permutation test for paired replicates on these averages for $H_0 : Y \leq 0.5$ and $H_1 : Y > 0.5$ implies the rejection of H_0 at a significance level of $p = 0.0078$.

Summarising, there exists a significant influence of interest rates on a firm's decisions of which currency to offer. Given that there is a difference in interest rates between the two countries, subjects usually offer the right currency to reap the benefits of this situation. Although this behaviour seems sensible, there are are also other

[5] Note that this does not imply that all other subjects behave irrationally. It does neither mean that subjects with $Y = 1$ necessarily act rationally. It is possible that subjects with a Yule coefficient smaller than 1 are considering different aspects when placing their currency offer.

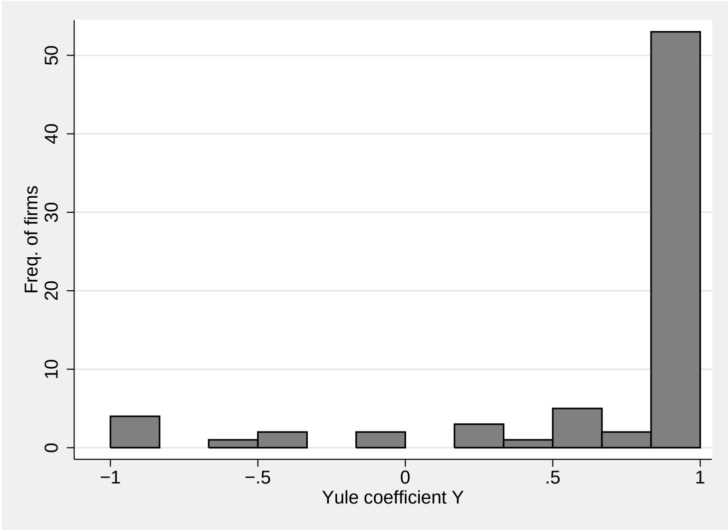


Figure 3.4: Distribution of the Yule coefficient

factors which influence the currency trade profits. The exchange rate variation can be so high that all benefits of the interest difference are eliminated. It would be wise to take the development of the exchange rate into account when placing the currency offer, but this is not an easy task to do: current and future exchange rates are not known to the players, so an estimate of the exchange rate risk is only possible by looking at other figures with only indirect effects on the exchange rate. The estimate is likely to be not very accurate, and so it is plausible to assume that subjects tend to base their currency offers rather on the difference in interest rates than on the expected percentage change of the exchange rate.

Simple Trend Extrapolation

The objective function of central banks punishes the central bank player if the interest factor in the own country is not equal to an ideal interest factor $r_0 = 1.05$. Hence, the likelihood of a high difference in interest rates in both countries is low. Usually, only marginal currency trade gains can be made by simply exploiting the interest rate difference in both countries. Contrary to that, the variation of the exchange rate between two consecutive periods might be high (see table 3.3).

Table 3.3: Summary statistics on absolute interest rate differences and absolute exchange rate changes

variable	n	average	std. dev.	max.
$\lvert\Delta r_t\rvert$	175[a]	.0106883	.0146039	.096
$\lvert\frac{e_+}{e} - 1\rvert$	180	.0531488	.1190195	.7682168

[a] 5 observations have been excluded due to obvious typing errors

This phenomenon can also be observed by the firms. It would seem plausible that the players try to extrapolate a trend from exchange rate variations observed in the past because they lack the capability of computing the real value of the exchange rate: the firm players don't know the size of central bank interventions, total firm currency offers, and foreign firm accounts.

Note that a subject could also take a great variety of other factors with only an indirect influence on the exchange rate into account. The answers given by some subjects in the ex-post questionnaires[6] indicate that players also consider wages, expenditures, material's prices, this and previous period's total amount of production, and the target price. However, a visible correlation between these figures and the currency offers could not be found.

A simple measure for estimating upcoming exchange rates is the difference between the previous period's exchange rate and the exchange rate in the period therebefore. Although this can be seen as a chartist approach and a means of technical analysis – methods applied in the currency exchange market in practice, confer Frankel and Froot (1990) and Neely (1997) –, this figure is not the only way to use technical analysis. In spite of that, the investigation will be limited to this form of simple trend extrapolation because an all-embracing evaluation of technical analysis in the currency market is not subject of this essay. Let Δe_{t-1} be the difference between

[6] In particular, it was asked: "Which variables influenced your currency trade decision?"

the exchange rate of the previous period and the period therebefore:

$$\Delta e_{t-1} = e_{t-1} - e_{t-2} \tag{3.13}$$

For testing the correlation between Δe_{t-1} and the currency offers of the firms, a standardised measure ψ of the latter needs to be created for each firm and each period. This can be done by dividing the actual currency offers by the maximum currency offers (see eq. 3.3 or eq. 3.4, respectively). ψ ranges between 0 and 1; the lower ψ is, the lower the relative offer has been:

$$\psi_i = \left(\frac{X_i}{\bar{X}_i} + \frac{X_i^*}{\bar{X}_i^*} \right) \tag{3.14}$$

Now, Spearman's rank correlation coefficient ρ for each player's standardised currency offer (ψ_i) and the possible currency trade determinants Δr_t and Δe_{t-1} is calculated. The correlation coefficient would be positive if trends were extrapolated and negative if a return to the second last value is expected. In the following, the absolute value of ρ is used, since only the strength of the correlation matters and not its direction. If a player did not take an active part in currency trade, this figure could not be determined. Figure 3.5 displays the session averages of the absolute values of the correlation coefficient for each player. The actual values can be found in table B.3. A Fisher-Pitman permutation test for paired replicates applied to the session averages with $H_0 : |\rho^{\psi_i,\Delta e_{t-1}}| \geq |\rho^{\psi_i,\Delta r_t}|$ and $H_1 : |\rho^{\psi_i,\Delta e_{t-1}}| < |\rho^{\psi_i,\Delta r_t}|$ rejects H_0 with a significance of $p = 0.0566$.

Although the exchange rate differences have a much higher influence on currency trade profits than interest differences, firms rather use the difference in interest rates than the difference in historical consecutive exchange rates as a tool for determining the size of their currency offers. This behaviour seems to be naïve at first sight and is likely to be caused by the incapability of predicting changes in exchange rates. As will be shown in section 3.3.3, the neglect of the exchange rate change is by no means unsophisticated. In order to find evidence for the existence of exchange rate uncertainty, the exchange rate estimates entered into the profit

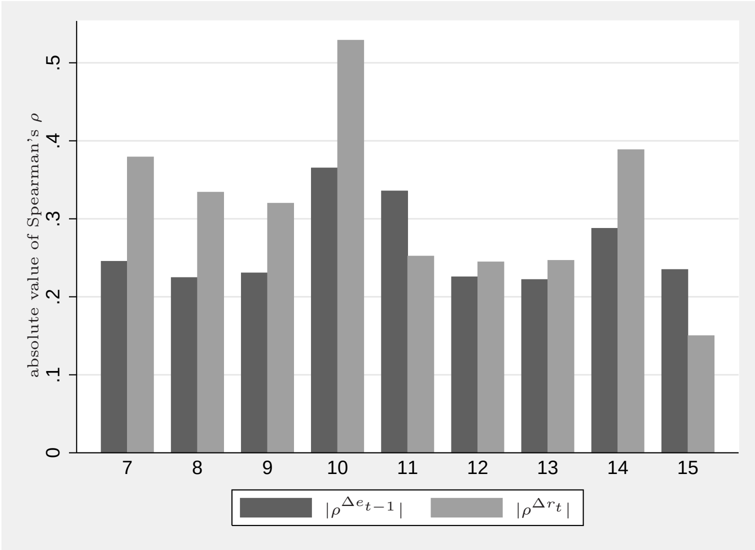


Figure 3.5: Correlation between standardised currency offer and exchange rate variation and interest rate difference, respectively

calculator are compared with the actual exchange rates.

Exchange Rate Uncertainty

Recall that the speculative advice h takes into account only the relation of $\hat{e}$ to $\hat{e}_+$ but not their absolute values. The estimated percentage change of the exchange rate $\tilde{e}_g := \dfrac{\hat{e}_+}{\hat{e}} - 1$ and the real percentage change of the exchange rate $\tilde{e}_r := \dfrac{e_+}{e} - 1$ can thus be compared to gather information on the accuracy of exchange rate estimates. If the estimated change in the exchange rate is correct, $\tilde{e}_r = \tilde{e}_g$ holds true. Figure 3.6 shows a scatterplot of both measures.

In only 158 of 1262 profit calculator utilisations, the estimated percentage change of the exchange rate has been correct. This figure seems rather high at first sight, but it really is not: There have been experimental sessions with long phases of a constant exchange rate, and 155 out of the 158 correct estimates have been true predictions of no exchange rate change at all. No obvious correlation between $\tilde{e}_r$

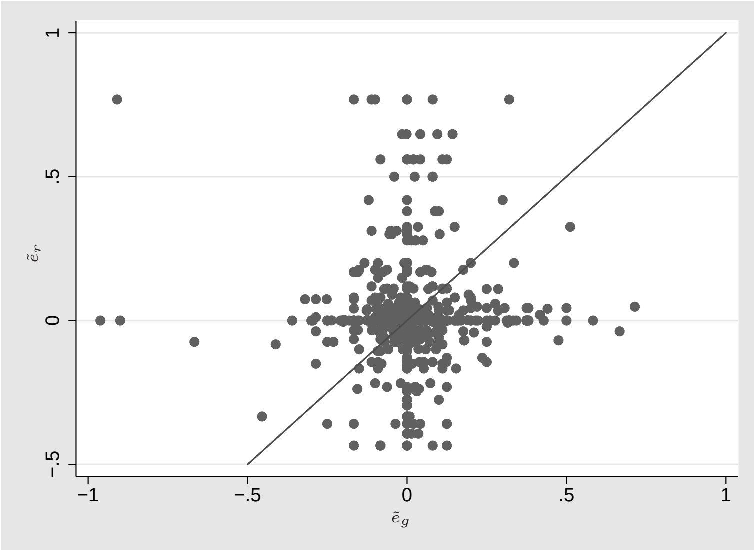


Figure 3.6: Scatterplot of real and estimated percentage change of the exchange rate. The line denotes correct estimates

and $\tilde{e}_g$ can be observed in figure 3.6. A OLS regression for the model

$$\tilde{e}_g = b_0 + b_1 \tilde{e}_r \tag{3.15}$$

shows an extremely low R^2 value of 0.0002. Spearman's rank correlation coefficient for both figures equals 0.0017. All these figures let it seem safe to assume that the subjects' exchange rate estimates have no connection with actual exchange rates.

Table B.4 displays the session values of these measures. A one-tailed Fisher-Pitman permutation test for paired replicates implies that the absolute value of Spearman's rank correlation coefficient is lower than 0.15 on a significance level of $p = 0.05$. The same test states that the R^2 value is lower than 0.03 on the same significance level. This is very strong evidence for the existence of exchange rate uncertainty. In many cases, subjects were not able to predict the change of the exchange rate correctly. If only the cases are considered in which there was a change in the exchange rate, only three exchange rate estimates have been correct. The share of correctly predicted directions of exchange rate changes (on average, 32.5% – see table B.5 for session values) is significantly lower than 50% (one-tailed Fisher-Pitman permutation test for paired replicates, $p = 0.0058$). Combined with the result of the previous subsection, it can be assumed that firms know or at least learn that their estimates are likely to be wrong. This is the reason why they don't rely on their own predictions and rather base their decisions on interest differences.

So far, the determinants of the currency trade behaviour of firms have been investigated. It was shown that subjects base their currency trade decisions rather on differences of the interest rates than on the change of the exchange rate and that subjects also tend to borrow money rather in the country with the lower interest rate. It seems that the firms do not always trust their own exchange rate estimates, because they ignore the speculative advice provided to them by the profit calculator. The reason for this behaviour is likely to be the observed incapability to predict the change in the exchange rate precisely. Using the terminology employed by Ellsberg (1961), the firms don't face risk (because the distributional parameters of the exchange rate are not known) but ambiguity. This has consequences for the behaviour of the players.

3.3.3 Consequences of Exchange Rate Uncertainty

The results gained suggest that subjects are incapable of predicting exchange rate changes correctly and thus base their currency trade decisions rather on interest differences. In this subsection, the consequences of this exchange rate uncertainty will be outlined and ways of how the firms try to cope with it will be explored.

Profitability of Trade Decisions

In the previous subsection, three different classes of trade decisions have been distinguished: Some decisions rigorously followed the speculative advice h, some of them went in the opposite direction because the difference in interest rates Δr_t was in favour of the other currency, and the rest were based on unknown heuristics. In the following, these three classes will be termed h, Δr_t, and u (with the possibility of one decision being counted in more than one class). A special interest arises in the profitability of the currency transactions in the different classes. The most profitable decision class would be h if the percentage exchange rate variation was guessed correctly. If this variation estimate was wrong, the other two classes could scoop in higher profits. The previously gained results suggest that currency trade decisions taking individual exchange rate estimates into account lead to less revenue than currency trade decisions based on interest rate considerations alone.

The average values of the currency trade profit v_{curr} for each class of currency trade decisions are shown in figure 3.7 whereas the actual values can be seen in table B.6.

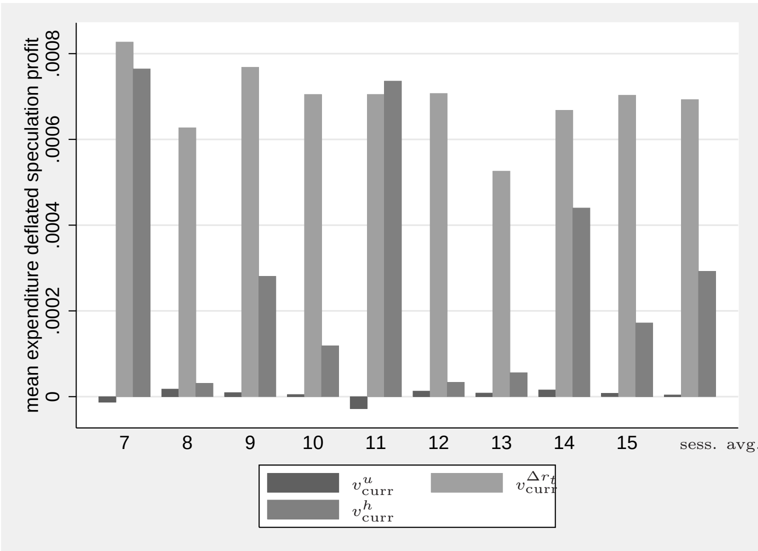


Figure 3.7: Average profitability of different classes of trade decisions

To check whether the resulting trade profit differs between these cases, a Friedman two-way analysis of variance by ranks has been conducted. At least two of the cases have different profits with significance at 0.1% level. A two-tailed Fisher-Pitman permutation test for paired replicates shows that the payoffs of classes h and u as well as the payoffs of Δr_t and u differ at a significance of $p = 0.0039$. The difference in payoffs between Δr_t and h is also significant at a level of $p = 0.0078$. The results of the statistical tests imply that trade decisions which are in line with

Δr_t are most profitable on average, followed by the decisions in line with h. The lowest currency trade profits were earned by subjects who base their decisions on determinants that could not be classified.

So far, only the trade *decisions* have been classified to investigate the profitability of different currency trade determinants. The line of reasoning will now be extended by classify the *players* according to their conformance to the three possible trading motives. Firstly, it is counted how often each player's trade decision was conform to Δr_t, h, and u. Then, a classifying variable κ is created for each player with the following rule:

$$\kappa = \begin{cases} 1 & \text{if } (\#u > \#h) \wedge (\#u > \#\Delta r_t) \\ 2 & \text{if } (\#\Delta r_t > \#h) \wedge (\#\Delta r_t > \#u) \\ 3 & \text{if } (\#h > \#\Delta r_t) \wedge (\#h > \#u) \end{cases} \tag{3.16}$$

Altogether, there have been 18 subjects who mostly traded conforming to Δr_t, 26 to h, and 41 subjects who preferred other heuristics. 5 subjects could not be classified with this rule: in one case the subject equally preferred h and u over Δr_t, and in 4 other cases the subject equally preferred h and Δr_t over u. To make the profits of the players comparable, the standardised currency trade profit is utilised:

$$\bar{v}_{\text{curr}} = \begin{cases} \dfrac{v_{\text{curr}}}{X_i} & \text{if} X_i > 0 \\ \dfrac{v_{\text{curr}} \cdot e_{-}}{X_i^*} & \text{if} X_i^* > 0 \\ 0 & \text{otherwise} \end{cases} \tag{3.17}$$

The standardised currency trade profit $\bar{v}_{\text{curr}}$ describes the profit of one unit of currency offered. Furthermore, the currency trade profit has to be multiplied with the previous period's exchange rate to make the currency offers comparable. The actual session averages are displayed in table B.7. Note that a dash ("–") in a column denotes that there has been no player of this class in this session. Figure

3.8 illustrates the mean standardised currency trade profits per session and trader class[7].

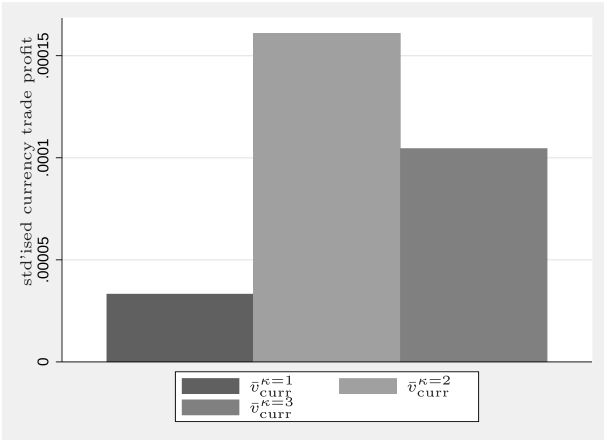


Figure 3.8: Mean standardised currency trade profits per trader class

Fisher-Pitman test for paired replicates are applied on all combinations of two currency traders' classes. Table 3.4 shows the results of the tests. It is important to mention that not every trader class was present in each session. The amount of tested sessions is displayed in the column labelled n.

Table 3.4: Test results for the profits of different trader classes

H_0	H_1	n	p-value
$\bar{v}_{\text{curr}}^{\kappa=1} \geq \bar{v}_{\text{curr}}^{\kappa=2}$	$\bar{v}_{\text{curr}}^{\kappa=1} < \bar{v}_{\text{curr}}^{\kappa=2}$	6	0.015625
$\bar{v}_{\text{curr}}^{\kappa=1} \geq \bar{v}_{\text{curr}}^{\kappa=3}$	$\bar{v}_{\text{curr}}^{\kappa=1} < \bar{v}_{\text{curr}}^{\kappa=3}$	7	0.03125
$\bar{v}_{\text{curr}}^{\kappa=3} \geq \bar{v}_{\text{curr}}^{\kappa=2}$	$\bar{v}_{\text{curr}}^{\kappa=3} < \bar{v}_{\text{curr}}^{\kappa=2}$	4	0.125

How can the significance levels be interpreted? It is obvious that subjects whose decisions conform to motives other than interest differences and the speculative advice make the least profits by currency trading. Although there is a tendency of subjects mainly motivated by the speculative advice not to make as high

[7] For reasons of readability, aggregate values are shown. Data points are only considered if all three of them were present in a session

profits as subjects motivated by interest differences solely, the significance level of $p = 0.125$ cannot be considered low enough to be convincing evidence. However, only 4 sessions exist in which there have been mainly speculative advice motivated *and* mainly interest motivated subjects – a sample size usually not sufficient for non-parametric testing. Nevertheless, if one combines this result with the highest profitability of interest difference motivated trade decisions (confer p. 65), the evidence demonstrates that higher profits are plausible if one relies on interest differences.

The previously discovered evidence of the superiority of interest rate motivated currency trade decisions can be confirmed for player types, too, albeit to a lesser extent. Remember that the speculative advice h differs from Δr_t only by the consideration of the estimated percentage change of the exchange rate. Hence, the only reasonable explanation for the supremacy of Δr_t-based decisions over h-based decisions is the incapability of subjects to estimate the variation of the exchange rate correctly.

A Simple Decision Rule

So far, it has been outlined that the difference of interest rates not only seems to have the highest influence on the currency trade decision of individuals, but also that decisions based solely on the interest difference make the highest profits on average. In the following, a decision rule will be created on which base a firm realises most likely currency trade gains. Following the approach of Gigerenzer and Todd (1999), this decision rule is kept simple on purpose.

Assume that a subject always offers the currency that is the cheapest in terms of interest. To normalise the size of the currency offer, assert that an individual always offers the same absolute amount of home currency $\dot{X}$ if it offers home currency at all. The corresponding height of the foreign currency offer if $\Delta r_t > 0$ would be

$\dot{X}^* = \frac{\dot{X}}{e}$. Since the current exchange rate e is not known to the firm player, one has to replace it by the exchange rate in the previous period e_-. Formally expressed, this decision rule postulates the currency offers to be:

$$X = \begin{cases} \dot{X} & \text{if } \Delta r_t < 0 \\ 0 & \text{else} \end{cases} \tag{3.18}$$

$$X^* = \begin{cases} \dfrac{\dot{X}}{e_-} & \text{if } \Delta r_t > 0 \\ 0 & \text{else} \end{cases} \tag{3.19}$$

Now, this simple decision rule is evaluated. For reasons of simplicity, $\dot{X}$ is set to 1. In doing so it is avoided that the credit constraints are exceeded. The theoretical cumulative currency trade profits $\sum v_{\text{curr}}$ for one firm in each country is calculated in all sessions. The influence of the currency offer on the exchange rate will be neglected in this case. It is safe doing this because the influence of the currency offer of a single firm on the exchange rate is only marginal at best. The results of this evaluation are shown in table 3.5. For this purpose, the hypothetical standardised hypothetical currency trade profit has been computed according to the following formula:

$$v_{\text{curr}}^{\text{hyp}} = \begin{cases} 0 & \text{if } \Delta r = 0 \\ \dfrac{1}{D} \cdot \left(\dfrac{e_{t+1} \cdot r^*}{e_t} - r \right) & \text{if } \Delta r < 0 \\ \dfrac{1}{D} \cdot \left(\dfrac{e_{t+1} \cdot r^*}{e_t} - r \right) \left(- \dfrac{e_t}{e_{t+1}} \right) & \text{if } \Delta r > 0 \end{cases} \tag{3.20}$$

Note that the profits shown in table 3.5 are only *hypothetical* profits. The trade decision of a firm has few but existing influences on the exchange rate of the next period, on the own currency offer in the following periods, on the height of next period's exchange rate aims of the central banks, and probably even on the production decision of the firm. By neglecting these influences the results might be less accurate, but it is likely that the general direction of the decision rule is correct because of the marginal relevance of these influences. Nevertheless, the profitability of this decision rule would probably change if every firm in both countries made use of it.

Table 3.5: Hypothetical cumulative currency trade profits for a firm if the decision rule was applied

session	avg. $v_{\text{curr}}^{\text{hyp}}$ for a firm in		
	country A	country B	avg (A&B)
7	0.000014	0.00000817	0.0000111
8	-0.000000497	0.000000448	-0.0000000247
9	0.00000433	0.00000379	0.00000406
10	0.00000353	0.00000185	0.00000269
11	0.0000048	0.00000486	0.00000483
12	0.0000129	0.0000114	0.0000122
13	0.00000132	0.000000873	0.0000011
14	0.0000222	0.00001	0.0000161
15	0.0000192	0.0000133	0.0000163

There was only one case in which a firm would have made overall losses by trading currency as proposed by this decision rule. Session 8 is marked by an almost monotonic increasing exchange rate for country A: In only 3 non-consecutive periods the exchange rate decreased weakly. This explains the failure of the decision rule in session 8. In every other case, the decision rule seems to be a successful way of deciding which currency to offer. The decision rule is thus a profitable one ($p = 0.0078$, two-tailed Fisher-Pitman permutation test for paired replicates).

To compare how this decision rule competes against actual decisions by traders, the currency trade profit made by firms is standardised with the size of the currency offer (in units of the home currency). The resulting figure $v_{\text{curr}}^{\text{std}}$ is identical in dimension to $v_{\text{curr}}^{\text{hyp}}$:

$$v_{\text{curr}}^{\text{std}} = \begin{cases} \dfrac{v_i}{X_i} & \text{if } X_i > 0 \\ \dfrac{v_i}{X_i^* \cdot e} & \text{if } X_i^* > 0 \\ 0 & \text{else} \end{cases} \tag{3.21}$$

The session averages and country averages of this measure are displayed in table B.8 in the appendix, an illustrative figure of the session averages can be found in figure 3.9.

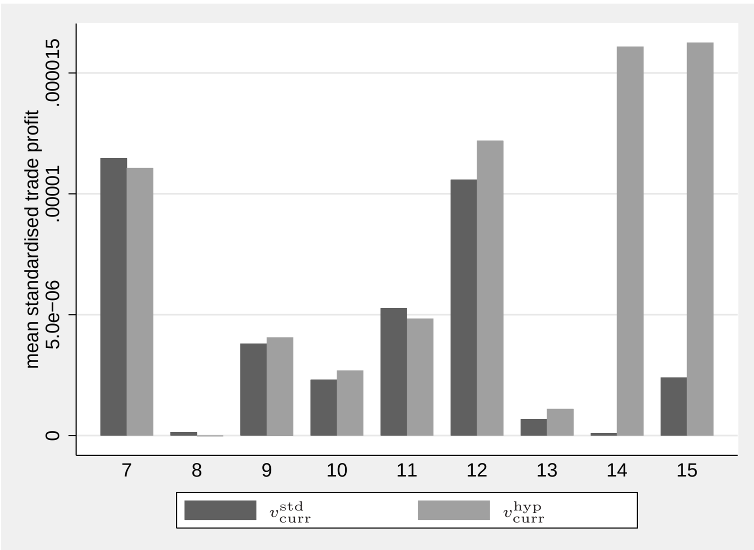


Figure 3.9: Hypothetical (if decision rule was applied) and standardised trade profits

The findings so far insinuate that the real standardised profits should be smaller than the hypothetical profits that could have been realised if the decision rule was applied. Comparing the average session values of the hypothetical decision rule and the actual decisions, it turns out that the former is significantly higher (one-tailed Fisher-Pitman permutation test for paired replicates ($p = 0.0605$). This further strengthens the assumption of supremacy of this rather simple decision rule which currency to offer if future exchange rates are unknown.

Concluding the case for the decision rule, it can be stated that the firms would make profit on average if they relied on interest differences only and always offered a fixed amount in the respective currency on the market. Even stronger conclusions can be drawn: the profits made by the decision rule outperform the profits made on average by the players. The main cause for this shown superiority of interest based decisions lies in the incapability of subjects to predict exchange rate changes correctly.

Exchange Rate Volatility and Currency Offers

Does the ambiguity sparked of by exchange rate uncertainty lead to a change in the currency trade behaviour of the players? If subjects are aware of their limited ability in predicting exchange rate changes, it is likely that they reduce the size of their currency offers with an increasing experienced volatility.

As a figure for the cumulative exchange rate volatility per period, a symmetric measure seems appropriate. Hence, the value of

$$\bar{\delta}_t = \sum_{j=1}^{t} \left(\frac{e_j}{e_{j-1}} + \frac{e_{j-1}}{e_j} - 2 \right)^2 \tag{3.22}$$

is computed for each period in each session. The value of $\bar{\delta}_t$ increases monotonically over time; the more it increases in one period, the higher the exchange rate volatility has been. To test the correlation between $\bar{\delta}_t$ and the currency offers of firms, the aggregate value of the standardised currency offers (confer p. 61) is used:

$$\psi = \sum_{i=1}^{10} \left(\frac{X_i}{\bar{X}_i} + \frac{X_i^*}{\bar{X}_i^*} \right) \tag{3.23}$$

Now, Spearman's rank correlation coefficient $\rho^{\psi,\bar{\delta}_t}$ between aggregate standardised currency offer ψ and cumulative exchange rate volatility per period $\bar{\delta}_i$ gives further information (see table B.1 and figure 3.10). As later will be shown in table 3.8, the overall volatility was extremely small in session 13. This explains the relatively high correlation in this period.

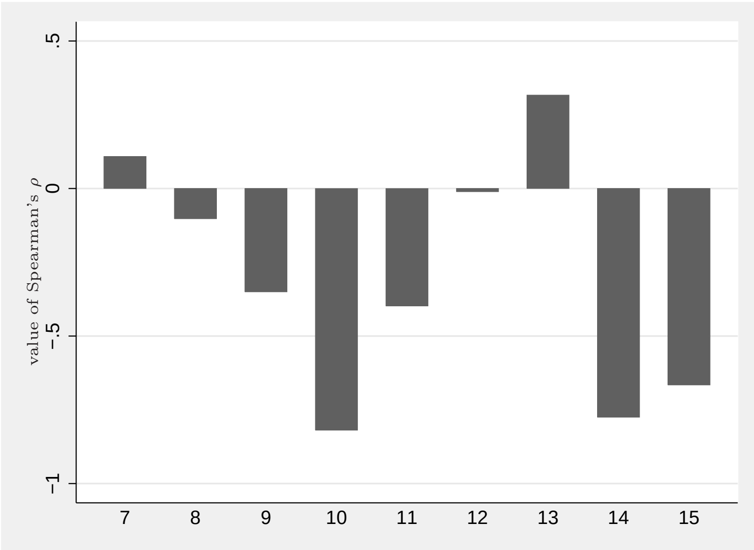


Figure 3.10: Spearman's rank correlation coefficient ρ of cumulative exchange rate volatility and aggregate standardised currency trade volume

Running a one-tailed Fisher-Pitman permutation test for paired replicates for $H_0 : \rho^{\psi,\bar{\delta}_t} \geq 0$ and $H_1 : \rho^{\psi,\bar{\delta}_t} < 0$, a positive correlation can be rejected at a significance level of $p = 0.0292$. This shows that experience with volatility over time seems to matter. One might object the explanatory power of testing a monotonically growing measure against the aggregate standardised home currency offer, because the latter one could also be correlated with the time. However, neither time nor a normalised volatility figure are significantly correlated with it.

This rather strong result is completely in line with the other findings: the subject's currency offers decrease with increasing experienced exchange rate volatility. The high volatility in the past leads to a higher exchange rate uncertainty. More profits could be earned with a higher volatility, but since the firm owners find it hard to predict the direction of the changes, they decide to decrease their currency offers: a great disadvantageous change of the exchange rate will certainly destroy the gains made by exploiting the interest differences.

The Home Currency Bias Explained

In section 3.3.1, it was mentioned that subjects tend to offer home currency more often and to a higher extent than foreign currency. In behavioural finance literature, a home bias is known as the phenomenon which lets investors prefer to buy domestic assets over foreign (see Fellner and Maciejovsky 2003, Lewis 1999, and Cooper and Kaplanis 1994). Note that the opposite occurs in this context: subjects *offer* home currency to *buy* foreign currency. In the following, this phenomenon will be labelled a *home currency bias*. Before possible reasons for this behaviour are outlined, the significance of the tendency towards higher home currency offers compared with foreign currency offers is shown.

As a tool for measuring the relative size of home and foreign currency offers, the cumulative aggregate standardised home and foreign currency offers

$$\psi_{\mathrm{h}} = \sum_{t=1}^{20} \left(\sum_{i=1}^{5} \frac{X_{i,t}}{\bar{X}_{i,t}} + \sum_{i=6}^{10} \frac{X^*_{i,t}}{\bar{X}^*_{i,t}} \right) \tag{3.24}$$

$$\psi_{\mathrm{f}} = \sum_{t=1}^{20} \left(\sum_{i=1}^{5} \frac{X^*_{i,t}}{\bar{X}^*_{i,t}} + \sum_{i=6}^{10} \frac{X_{i,t}}{\bar{X}_{i,t}} \right) \tag{3.25}$$

are used for each session, whereas the firms in the home country are numbered from 1 to 5 and those in the foreign country from 6 to 10. Since the standardised home and foreign currency offers range between 0 and 1 in each period and since there are 10 firms and 20 periods, both ψ_{h} and ψ_{f} range between 0 and 200. The session averages of these values can be found in table B.10 in the appendix, whereas a graphical representation of the values is displayed in figure 3.11.

The standardised home currency offers have always been higher than the standardised foreign currency offers. Support for this thesis is gathered through a one-tailed Fisher-Pitman permutation test for paired replicates with a significance

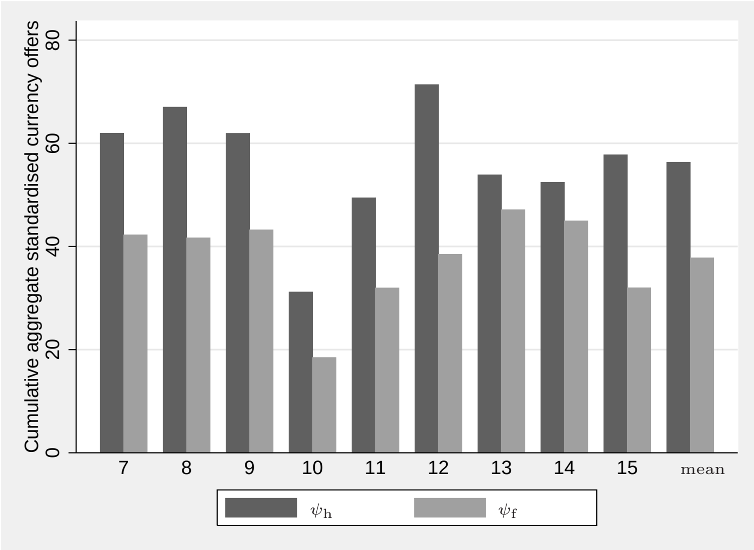


Figure 3.11: Cumulative aggregate standardised home and foreign currency offers

of $p = 0.0019$.

This behaviour could also be explained by exchange rate uncertainty. A home currency offer is transferred to the foreign account at this period's exchange rate ($X_i er^*$). This is the only positive component of the firm's foreign account balance. Expenses for foreign currency offers ($-X_i^* r^*$) and costs of foreign materials ($-M_i m^*$) are deducted from the foreign account. In the following period, the account balance gets transferred to the firm owner at the actual exchange rate. If a subject wants to pay parts or all of its foreign account debts rather now than in the next period, it should place a positive home currency offer. This makes only sense if the subject does not want to risk a higher debt caused by a possibly smaller exchange rate in the following period. The propensity to settling the foreign account debts in the actual period rather than in the following can be regarded as a very simple and primitive form of hedging against exchange rate risks. To investigate the hedging behaviour of firms, the relation of currency offers to foreign account debt

$$\Psi := \frac{r^*(\frac{X_i}{\hat{e}} - X_i^*)}{M_i^* m^*} \tag{3.26}$$

is used as a measure. A Ψ greater than zero expresses the percentage of foreign account debts settled by the home currency offer at the estimated exchange rate, a Ψ smaller than zero equals the increase of foreign account debt by foreign currency offers. Table 3.6 shows the session averages of Ψ.

If one compares Ψ for positive home currency offers ($\Psi_{X_i>0}$) with the absolute value of Ψ for positive foreign currency offers ($|\Psi_{X_i^*>0}|$), it yields that the mean percentage increase of foreign account debt is smaller than the mean percentage decrease of foreign account debt on average. A two-tailed Fisher-Pitman permutation test for paired replicates of $H_0: \ \Psi_{X_i>0} \leq |\Psi_{X_i^*>0}|$ and $H_1: \ \ \Psi_{X_i>0} > |\Psi_{X_i^*>0}|$ is significant for $p < 0.01$. If a subject feels secure about its own prediction and if this subject wishes to hedge against an increasing exchange rate, a Ψ of 1 would be the ideal value. $\Psi < 1$ can be interpreted as an expression of uncertainty about the own exchange rate estimate. In most cases, Ψ is even smaller than 0.5 if $X_i > 0$. If subjects do follow the thesis of hedging, they still don't feel very secure about their exchange rate estimates.

What at first seems to be a result of medium importance appears in a new light when one compares the session average of the relation of currency offers to foreign account debt with the respective overall session's exchange rate volatility: Spearman's rank correlation coefficient between the session exchange rate volatility and the relation of currency offers to debt has the high value of $\rho = 0.6667$. This means that the hypothesis that those two figures are not at all or negatively correlated can be rejected at a significance level of $p = 0.0499$ (two-tailed). One might object that increasing currency trade activities destabilise the exchange rate and that the reason might be the consequence in this case. As later will be shown, currency trade has no significant influence on exchange rate volatility.

It can be inferred that a higher exchange rate volatility increases the propensity of firms to engage in hedging activities to safeguard exchange rate risks which might influence the height of production profits. Although this finding also includes that

Table 3.6: Relation of currency offers to debt (session averages) and overall session exchange rate volatility δ (see eq. 3.22)

session	Ψ if $X_i > 0$	Ψ if $X_i^* > 0$	Ψ	δ
7	.36552487	-.30605193	.06577762	.0363223
8	.44483818	-.3111075	.02944369	.000035
9	.48100904	-.33237057	.07760347	.0010411
10	.46563531	-.23704799	.10555662	.0009401
11	.40150467	-.30142939	.04477621	.0125613
12	.37167138	-.24952556	.11123972	.0023613
13	.24726002	-.27796907	.03284282	.0000001
14	1.2918399	-.47550419	.35278018	.3426598
15	.41020969	-.29141708	.11093025	.0709927

firms only seldomly settle their foreign account debts to their full extent, it seems to be one way of how firms deal with exchange rate risks.

Pessimistic Expectations

How does a firm cope with exchange rate uncertainty if it engages in hedging only to a relatively small extent? Another way of doing so would be to enter rather pessimistic exchange rate estimates into the profit calculator.

If a firm expects the exchange rate to rise in the next period with no difference in interest rates in both countries in this period, it would be profitable to offer home currency. More home currency is offered in almost each session, so it is plausible to assume that subjects have expectations of growing exchange rates more often than they expect falling exchange rates.

To confirm this hypothesis, the gathered profit calculator data can be used. Like on page 55, only the last estimate for the exchange rate is taken into account. Firstly, a measure is created to describe the exchange rate expectations in each session. For each session, let

$$\epsilon^{+} := \frac{\#(\hat{e}_{+} - \hat{e} > 0)}{\#(\hat{e}_{+}, \hat{e})} \tag{3.27}$$

$$\epsilon^{-} := \frac{\#(\hat{e}_{+} - \hat{e} < 0)}{\#(\hat{e}_{+}, \hat{e})} \tag{3.28}$$

$$\epsilon^{=} := \frac{\#(\hat{e}_{+} - \hat{e} = 0)}{\#(\hat{e}_{+}, \hat{e})} \tag{3.29}$$

In general parlance, ϵ^{+} is the relation of the number of expectations of a growing exchange rate to the number of all existing exchange rate estimates. Similarly, ϵ^{-} ($\epsilon^{=}$) denotes the percentage of falling (constant) exchange rate estimates. The sum of ϵ^{+}, ϵ^{-}, and $\epsilon^{=}$ equals always 1 in one session. Figure 3.12 shows the ϵ values for each session. The actual values are displayed in table B.11.

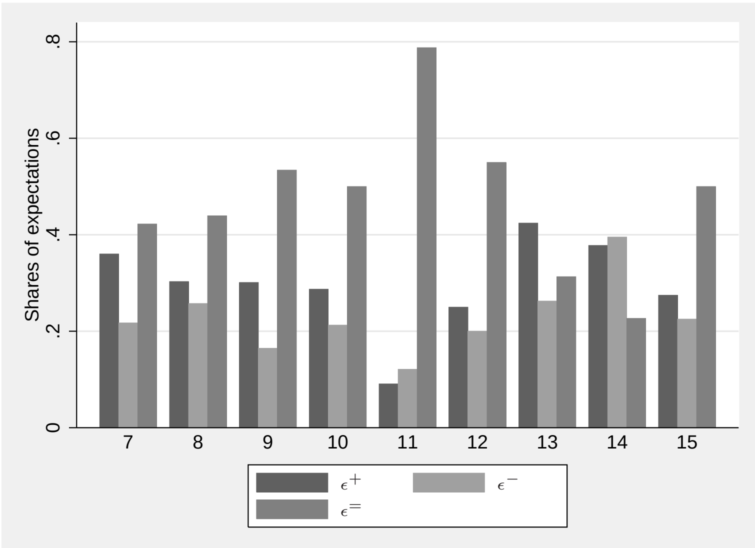


Figure 3.12: Shares of growing, falling, and constant exchange rate expectations

They demonstrate that constant exchange rate estimates have the greatest share in most sessions, and that in 2 of 9 sessions rising exchange rates are expected more frequently than falling ones. Fisher-Pitman permutation tests for paired replicates have been run for different hypotheses to gain some significant conclusions. The test results are shown in table 3.7.

Table 3.7: Results of permutation tests for paired replicates

H_0	H_1	p
$\epsilon^+ \leq \epsilon^-$	$\epsilon^+ > \epsilon^-$	0.00976
$\epsilon^= \leq \epsilon^-$	$\epsilon^= > \epsilon^-$	0.00585
$\epsilon^= \leq \epsilon^+$	$\epsilon^= > \epsilon^+$	0.02539
$\epsilon^= \leq \epsilon^+ + \epsilon^-$	$\epsilon^= > \epsilon^+ + \epsilon^-$	0.32812

The significance levels of the tests imply that firms rather have expectations of constant exchange rates than either growing or falling exchange rates, but also that they rather have expectations of growing exchange rates than falling, and that a tendency towards expectations of constant exchange rates being more frequent than *both* expectations of growing or falling exchange rates cannot be supported.

What can be deduced from this finding? Taking a look at the production profit structure of a firm

$$v_{\text{prod}} = \frac{1}{D}\left(Q_i q - L_i w r - M_i m - e_+ M_i^* m^*\right) \tag{3.30}$$

and neglecting the currency trade profits, it becomes clear that a growing exchange rate lowers the production profit by $(e_+ - e)M_i^* m^*$. Consequently, firms have rather *pessimistic* expectations concerning the development of the exchange rate. The pessimism is likely to be caused by exchange rate uncertainty – subjects are feeling insecure in predicting changes of the exchange rate, so they tend to calculate with rather downbeat expectations to obtain a worst-case profit estimate by the use of the profit calculator.

3.3.4 Consequences of Currency Trade

The existence of macroeconomic consequences of currency trade cannot be denied in practice. Neoclassical theory states that currency trade must have a stabilising effect on exchange rate volatility. Friedman (1953a) asserts that stabilising speculation is equivalent to profitable speculation: If speculators buy an asset when its price is low and sell it when its price is high, this will drive the asset's price towards its equilibrium. This view of the relation between speculation and stabilisation seems tenuous. 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 destabilising the price. In general, most post-Keynesian authors assert the opposite of Friedman's theory.

The model used endows central banks with enough power that they are able to rein back the influence of currency trade by implicit cooperation. Is there nevertheless an influence of currency trade on exchange rate volatility?

The measure already used in section 3.3.3 is taken as a descriptor for the volatility of one session:

$$\bar{\delta} = \sum_{t=1}^{20} \left(\frac{e_t}{e_{t-1}} + \frac{e_{t-1}}{e_t} - 2 \right)^2 \tag{3.31}$$

The higher $\bar{\delta}$ is, the more volatile e has been. Now, the actual exchange rate e is compared with a hypothetical exchange rate e_h, which is defined as the exchange rate which would have prevailed if no firm had placed currency offers and the rest of the parameters stayed constant (central bank interventions, exchange rate aims, materials prices, and materials demands).

Furthermore, a binomially distributed variable ϖ is constructed which is 1 for sessions with a hypothetical volatility higher than the actual volatility and 0 in the opposite case. Table 3.8 shows the volatility of actual ($\bar{\delta}^{\text{curr}}$) and hypothetical exchange rates ($\bar{\delta}^{\text{hypo}}$) as well as ϖ for each session.

Table 3.8: Actual vs. hypothetical exchange rate volatility

session	$\bar{\delta}^{\text{curr}}$	$\bar{\delta}^{\text{hypo}}$	ϖ
7	0.0363223	0.0791757	0
8	0.0000350	0.0001090	0
9	0.0010411	0.0008752	1
10	0.0009401	0.0005754	1
11	0.0125613	0.0014151	1
12	0.0023613	0.0048185	0
13	0.0000001	0.0000002	0
14	0.3426598	0.4068589	0
15	0.0709927	0.0664837	1
mean	0.0518794	0.0622569	

The volatility averages suggest that volatility decreases with currency trade volume. In spite of that, a significant difference in the exchange rate volatility in the different cases could neither be substantiated by applying Wilcoxon's signed-rank test (two-tailed $p = 0.7671$) nor the Fisher-Pitman permutation test for paired replicates (two-tailed $p = 0.4258$). The same holds true for different asymmetric volatility measures $\bar{\delta}_e^{\text{asym}} = \sum_{t=1}^{20}\left(\frac{e_t}{e_{t-1}} - 1\right)^2$ and $\bar{\delta}_e^{\text{asym}} = \sum_{t=1}^{20}\left(\frac{e_{t-1}}{e_t} - 1\right)^2$. The mean value for ϖ is 0.44444. Note that a value of 0.5 would indicate no influence of currency trade on exchange rate volatilities. However, the binomial confidence interval at a level of 0.9 for the expected value of ϖ is $[0.2180471; 0.6965233]$. This range cannot be considered tight enough to deduce that currency trade has no influence on the exchange rate volatility. Nevertheless, neither a volatility increasing nor a volatility decreasing effect of currency trade can be found in the experimental data.

Currency crises in the late 1990's have been sparked off by wrong monetary policies and currency trade (e. g. see Köhler 1998, Eichengreen et al. 1995, and Krugman 2001). Similar phenomena could not be observed in the experiments: there seems to be no systematic influence of currency trade on the exchange rate. This is caused mainly by model design: The central banks *implicitly* collude to keep the exchange rate in the interval of their exchange rate aims. Exchange rate variation is still possible, but only within this interval.

The strength of the central banks surely is one reason for the insignificance of the influence of currency trade on the exchange rate volatility in the data. According to Cheung and Chinn (2001), the prevailing opinion among professional currency traders states the opposite: US currency traders think that central bank interventions do not have any substantial effect on exchange rate besides increasing exchange rate volatility. However, the example of China and Japan shows that exchange rates can be kept within narrow limits by central bank interventions.

3.4 Concluding Discussion

The subject matter of this investigation is the currency trade decisions of industrial firms in a laboratory experiment. The experimental design was very rich, that is with subjects in the role of numerous institutions, there was wide scope for endogenous shocks or variations in exchange rates and interest rates. Opportunities to speculate with currency arose, and the firms tried to reap the benefits.

Two determinants of the currency trade behaviour have been identified: There are subjects who base their decision on interest differences or on individual exchange rate estimates. A third fraction acts according to some other heuristics that could not be captured. The firms usually borrow money to place their currency offer from the account with the lower interest rate. The influence of simple technical analysis of the exchange rate on the currency trade behaviour is significantly lower than the influence of the interest difference. This might be due to the fact that subjects fail to estimate the exchange rate correctly. The estimates being stated by the firms confirm this hypothesis, because they were mostly inaccurate.

Although the firms use the given profit calculator tool when they based their currency offer on individual exchange rate estimates, their currency trade profits are on average significantly below the ones of subjects reacting to interest differences. A simple decision rule by the use of which a firm could make positive currency trade profits in most cases has been considered: The decision rule postulates to always offer a fixed amount of home currency if the interest rate in the home country is lower than in the foreign country, offer the same fixed amount in foreign currency at previous period's exchange rate if the home interest rate exceeds the foreign one, and offer no currency at all if the interest rates in both countries are the same. A higher session volatility of the exchange rate leads to a higher exchange rate uncertainty and thus to lower currency offers. Not only the possible losses, also the possible gains are affected by a volatile exchange rate, but subjects fear the uncertainty and trade less often when past exchange rates show major variations. The subjects usually offer home currency to a higher extent and more frequently than foreign currency. This home currency bias can be seen as a way to cope with exchange rate uncertainty by offering home currency in order to settle part of their foreign account debts in the actual rather than in the next period. Another way of meeting exchange rate uncertainty would be to calculate with pessimistic expectations. Significant evidence for the existence of these could be found.

Although the influence of currency trade on the exchange rate cannot be denied, neither a significant increase nor decrease of the volatility can be found in the experimental sessions: central banks are strong enough to curb the influence of currency trade on volatility.

The firms' overconfidence in the criterion of interest rate difference surprises, because the variation of the exchange rate has the larger impact on the resulting payoff. That leads to the assumption that subjects just *like* to base decisions under uncertainty on safe facts rather than on their beliefs about uncertain future events. Room for future research is left not only on this topic. Especially the trade heuristics that could not be explained by the experimental data should be investigated more thoroughly. The central banks have a very strong influence on the exchange rate: they fix the definite range in which the exchange rate is allowed to vary. In the real world, this can only be done to a certain extent and by drawing on the monetary reserve if the policy makers from different countries do not collude. Note that the experimental design chosen limits the currency offers of the firms, but it does not limit the currency offers of the central bank. A currency crisis cannot arise in this model. Because of the strength of the central banks and the only low influence of currency trade on the exchange rate, financial phenomena such as bubbles or crashes cannot be observed.

Furthermore, a model with three countries could give deeper insights on the strength of the determinants of the currency trade behaviour. Our work and the experimental design of Pope et al. should be seen as a starting point for future experimental research.

4 The Tobin Tax

"The volatility of international capital is obviously destabilizing markets today."

– Jeffrey D. Sachs

4.1 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 the Bank for International Settlements, see 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 unstable exchange rates can have dire consequences for whole economies. Exchange rate uncertainty affects international trade, the liquidity of firms which have foreign debts, the behaviour 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. In his eyes, short-run speculators play a price-destabilising role on the market, whereas long-run investors stabilise prices. In his fundamental work *The general theory of employment, interest, and money*[1], he pointed out that imposing a transaction tax on markets could increase the weight of long-term fundamentals of the assets against speculators' guesses of the short-term behaviour of other speculators, thus stabilising the asset's price. Friedman (1953a) is however of a different opinion. He claims that stabilising 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 view of 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 destabilising the price. In general, most post-Keynesian authors assert the opposite of Friedman's theory.

How can one cope with price volatility? This study focuses 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 excess 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% per annum if only the interest earnings were brought back. If the

[1] see Keynes (1936)

horizon was only one month, the asset should yield at least 22.12% annual revenue to remain attractive. The shorter the horizon, the higher the asset yield had to be: A duration of the investment of one week would require a yield of 62.52%, and if it was a one-day investment the yield would have to be no less than 378.68%.

This approach is highly controversial. 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. However, his study deals with stock market data and not with a currency market. 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) criticises 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 recurring 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 favour 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 (and at least the EU, Japan, Singapore, Switzerland, Hong Kong, Australia, and Canada, as Kenen 1996 states in his dissection of evadability by migration).

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 inelastic 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 favour 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 transferred from e. g. the stock market to 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 the price is 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 a recent experimental investigation, Bloomfeld et al. (2005) investigate the behaviour 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 computational simulation and imposes a transaction tax on either none, one, or both of them. In particular, he distinguishes between orders placed by traders motivated by technical and orders placed by traders motivated by fundamental analysis. He concludes that the tax indeed stabilises the prices on the market with the tax, but also destabilises the prices on the respective other market if no tax is imposed on it. Later on, Westerhoff and Dieci (2006) show in a collaborative work with a similar model that both markets stabilise if a tax is imposed on both of them and that other markets are likely to follow if market regulators introduce a tax in only one market.

We want to emphasise 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 impede countries that follow sensible economic policies to advance past countries that 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. That makes it seem plausible to carefully curb volatility.

In this chapter, an experimental market inspired by a discretised double auction is investigated. The market does not follow the traditional double auction design of Smith et al. (1988), because a game-theoretical solution has to be derived as a benchmark for the 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. The height of this tax across markets is varied to assess the volatility elasticity with regard to it. Finally, taxed and untaxed markets are compared and evaluated with respect to trade volume and trade turnover, supply and demand, market prices, volatility, market efficiency, fiscal revenues, and earnings inequality.

4.2 An Asset Market Model

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

4.2.1 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 whether 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 intent of the authors to claim the setting to be an experimental currency market, albeit its features resemble those of standard foreign exchange trading platforms. 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 the setting described here. A simple experimental market design such as this one is cannot capture the complexity of exchange rate formation in the world's economies. Nevertheless, the study at hand should be seen as a market microstructure investigation of the influence of a Tobin tax as a financial stabilising measure on market participants and their trade decisions. For experimental studies of exchange rates and the currency market, confer for example Kaiser and Kube (2009) (a rephrased version of this paper can be found in chapter 3 of this dissertation), Noussair et al. (1997), or Arifovic (1996). Inspired by the approach of Friedman (1984), it draws up a round-based, discrete, and finite-horizon model which is described in the next subsection.

4.2.2 Modelling an Asset Market

In this section, the model for a simple asset market is described. Based on this market model, the impact of a Tobin tax will be analysed later by the means of a laboratory experiment under controlled conditions. In order to obtain a benchmark for what profit motivated, self-centred, risk-neutral, and rational players would do, game-theoretical equilibria will be derived. Therefore, the market design is a compromise of plausibility, playability, and game-theoretical analysability.

On a market, a fixed number of n players has the opportunity to trade units of one asset against units of a numeraire. Each player is initially endowed with m units of the asset and x units of cash (the numeraire).The number m is positive and x is a multiple of 0.01. After a finite and known number T of periods, the market is closed and all players receive their payoffs. Each period t consists of two steps:

step 1 determines market prices and market makers for the period, step 2 allows all players who have not become market makers to place buy or selling orders. More specifically:

Step 1 proceeds as follows: Let $N = (1, ..., n)$ be the set of all players and let N^a be the set of all players with positive holdings of the numeraire and N^b be the set of all players with positive holdings of the asset in the beginning of the period. Every player $i \in N^a$ privately sets a positive ask price p_i^a not greater than his or her numeraire holdings and every player $i \in N^b$ sets a positive bid price p_i^b. Their prices p_i^a and p_i^b must be integer multiples of 0.01 and they must not exceed some (sufficiently high) maximum prices $\bar{p}^a$ and $\bar{p}^b$, respectively. Moreover, $p_i^b \leq p_i^a$ must hold. For $i \in N^a$ the price p_i^a is the number of numeraire units player i is willing to pay for one unit of the asset and for $i \in N^b$ the price p_i^b is the number of numeraire units for which player i is willing to sell one unit of the asset.

After the players have made their decisions on their individual ask and bid prices, the most favourable prices are determined. The market ask price p^a is set to the lowest individual ask price:

$$p^a = \min_{i \in N^a} p_i^a \tag{4.1}$$

Analogously, the market bid price p^b is set to the highest individual bid price:

$$p^b = \max_{i \in N^b} p^b \tag{4.2}$$

As we shall see later, N^a and N^b are always non-empty. Therefore p^a and p^b are always well defined. The players who stated the market bid price are the buying market makers in this period, the players who did so with the market ask price are the selling market makers. After both market ask and bid price as well as market makers are determined, the prices are announced publicly. Information on market makers and individual price decisions remains private. After step 1 a player who becomes a buying market maker is informed about this and the same holds for players who become selling market makers. All other players are informed about the market ask price and the market bid price.

In step 2, all players who became market makers in step 1 do nothing. Every other player has the opportunity to decide on trade orders. A player i may either

- place a buying order for d_i units of the asset, i.e. order to transfer $d_i \cdot p^a$ units of the numeraire to a selling market maker (a player j with $p_j^a = p^a$) for d_i units of the asset in exchange, whereas d_i must be chosen in such a way that $d_i p_i$ is not greater than player i's numeraire holdings,
- place a selling order for s_i units of the asset, i.e. order to transfer s_i units of the asset to the buying market maker (player k with $p_k^b = p^b$) for $s_i \cdot p^b$ units of the numeraire in exchange, whereas the number s_i must be smaller than or equal to the asset holdings of player i,
- or refrain from trade.

Players are not allowed to place buying and selling orders at the same time, neither are they forced to place an order at all. The holdings x_i and m_i of numeraire and asset of player i may not become negative. Consequently, the order size d_i (resp. s_i) may not be chosen in a way that x_i (resp. m_i) is exceeded. Furthermore, orders are limited in size by $\overline{d}$ and $\overline{s}$ and must be positive. The asset is not divisible, that is, only integer amounts of the asset may be ordered. Units of the numeraire are divisible up to the second decimal place. If two or more players are the selling market makers at the same time, all buying orders are distributed among them as near to the equal division as possible, given the available supplies. The same holds true for the buying market makers and selling orders.

One special case can arise: if the selling market makers' total holdings of the asset are lower than the aggregated buying orders, not all orders can be satisfied. Then, the players who placed buying orders are numbered at random. Their buying orders are carried out sequentially and as a whole. If a player's buying order cannot be satisfied completely, the remainder of the market makers' units of the asset is transferred to him and the players not considered so far miss out. The same rule applies if the buying market makers have not enough units of the numeraire to buy all selling orders.

All information remains private: All players only know how their own holdings of the asset and the numeraire change. At the beginning of the next period, all players receive a constant dividend of μ units of the numeraire for each unit of the asset they are holding. μ is a positive multiple of 0.01. There is no such payment at the beginning of the first period, neither is there a dividend payment after the final period. After the final period T, all units of the asset are converted to units of the numeraire at a fixed exchange rate of c. The values of μ, T, and c are known to all players. Consequently, the final payoff of player i is

$$\Pi_i = x_i + cm_i \tag{4.3}$$

where x_i and m_i are the holdings at time T. A variant of the model imposes a transaction tax *à la* Tobin (1978) on the same market institution. Being otherwise identical to the model described before, all players who place orders have to pay a fraction τ of the transferred number of units of the numeraire as a tax. If player i places a buying order over d_i units of the asset and if that order is satisfied completely, the selling market maker will receive $d_i p^a$ units of the numeraire and give d_i units of the asset to player i. Player i has to pay $d_i \cdot (1+\tau)p^a$ units of the numeraire in total for the asset, of which altogether $d_i \tau p^a$ units of the numeraire are transferred to a global tax account. The total transaction cost $\tau d_i p_a$ payable by a buyer i is rounded to the next lower multiple of 0.01. If player i however places a selling order over s_i units of the asset and if that order is satisfied completely, the buying market maker will receive s_i units of the asset and give $s_i p^b$ units of the numeraire to player i. Player i keeps $s_i \cdot (1-\tau)p^b$ units of the numeraire and transfers $s_i \tau p^b$ units of the numeraire to the global tax account. The units of the numeraire paid as tax is not available to the players any more, neither is it included in the payoffs of the players. Pricing and order constraints adjust accordingly.

4.3 On the Game-Theoretic Nature of the Model

This section discusses the model from a game-theoretic point of view. The market model has the structure of an extensive game with an upper bound for the length of play but with a continuum of choices at almost every information set. First, some definitions and notations are introduced for such games. Only pure strategies will be considered here. Therefore, the word "strategy" will always refer to a pure strategy. We think of the players as numbered from 1 to n. A *strategy* of player i is a function which assigns to every information of this player a choice of this information set. For $i = 1, ..., n$ let Λ_i be the set of all strategies of player i. A strategy combination or shortly a combination

$$\lambda = (\lambda_1, ..., \lambda_n) \tag{4.4}$$

is a vector with $\lambda_i \in \Lambda_i$ for $i = 1, ..., n$. The set of all combinations is denoted by Λ. Since we look at games without random choices only, every combination $\lambda \in \Lambda$ determines a unique endpoint and a payoff $H_i(\lambda)$ at this endpoint for every player i with $i = 1, ..., n$. We use the notation $H(\lambda)$ for the vector of these payoffs

$$H(\lambda) = \Big(H_1(\lambda), ..., H_n(\lambda)\Big) \tag{4.5}$$

We refer to $H(\lambda)$ as the payoff vector of λ. The total payoff $K(\lambda)$ for λ is the sum of all $H_i(\lambda)$:

$$K(\lambda) = \sum_{i=1}^{n} H_i(\lambda) \tag{4.6}$$

The maximal total payoff is defined as

$$K = \max_{\lambda \in \Lambda} K(\lambda) \tag{4.7}$$

In games of the kind considered here a maximal total payoff may not exist, but this difficulty does not occur in the case considered here. An i-incomplete combination λ_{-i} results from a combination λ by taking out player i's strategy:

$$\lambda_{-i} = (\lambda_1, ..., \lambda_{i-1}, \lambda_{i+1}, ..., \lambda_n) \tag{4.8}$$

The set of all i-incomplete combinations is denoted by Λ_{-i}. Consider a strategy $\lambda_i \in \Lambda_i$ of player i and an i-incomplete combination $\varepsilon_{-i} \in \Lambda_{-i}$. Let ρ be the combination in which player i uses λ_i and the other players play their strategies in ε_{-i}. We use the notation

$$\rho = \lambda_i \varepsilon_{-i} \tag{4.9}$$

in order to express the relationship between ρ on one side and λ_i and ε_{-i} on the other side. The security level $s_i(\lambda_i)$ of a strategy $\lambda_i \in \Lambda_i$ is defined as follows:

$$s_i(\lambda_i) = \min_{\varepsilon_{-i} \in \Lambda_{-i}} H_i(\lambda_i \varepsilon_{-i}) \qquad \text{for } \lambda_i \in \Lambda_i \text{ and } i = 1, ..., n \tag{4.10}$$

The security level of player i is the maximum of $s_i(\lambda_i)$ over $\lambda_i \in \Lambda_i$:

$$S_i = \max_{\lambda_i \in \Lambda_i} s_i(\lambda_i) \qquad \text{for } i = 1, ..., n \tag{4.11}$$

In general $s_i(\lambda)$ and S_i do not necessarily exist, but this difficulty does not occur for the market model investigated here. An equilibrium is a strategy combination

$$\lambda^* = (\lambda_1^*, ..., \lambda_n^*) \tag{4.12}$$

such that for $i = 1, ..., n$ we have

$$H_i(\lambda^*) \geq H_i(\lambda_i \lambda_{-i}^*) \qquad \text{for every } \lambda_i \in \Lambda_i \tag{4.13}$$

Here λ_{-i}^* is the i-incomplete combination formed by the strategies λ_j^* in λ^* of the other players j with $j \neq i$.

All basic game-theoretic definitions and notations used in this chapter have now been introduced. We continue with some additional definitions and notations relating to the particular market model investigated here. The fundamental value $\phi(t)$ of one unit of the asset at the beginning of period t is defined as follows:

$$\phi(t) = c + (T - t)\mu \tag{4.14}$$

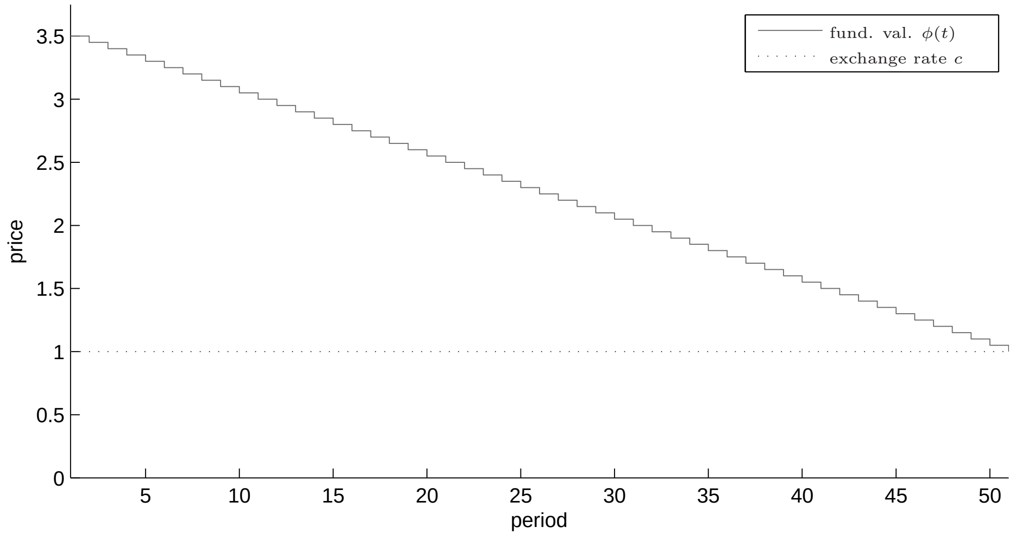


Figure 4.1: The fundamental value $\phi(t)$ as a function of time

Here c is the final money value of the unit at T and μ is the dividend obtained per period. Figure 4.1 displays the fundamental value as a function of time.

Let $m_i(t)$ the money holdings and $x_i(t)$ the asset holdings of player i at the beginning of period T. The sum of all $x_i(t)$ does not change over time and is denoted by x. Trade changes the distribution of asset holdings but not x. The sum of all $m_i(t)$ is denoted by $m(t)$. In view of dividends and possibly transaction costs $m(t)$ is not constant. We refer to

$$\Phi_i(t) = m_i(t) + x_i(t)\phi(t) \tag{4.15}$$

as the fundamental value of player i's holdings at the beginning of period t. The sum of all $\Phi_i(t)$ is denoted by $\Phi(t)$. The maximum prices $\bar{p}_a$ and $\bar{p}_b$ are sufficiently high in the sense that each of them is greater than $m(1)$.

We now describe a type of strategies called "passive". Independently of the prior history of the play, in step 1 of a period t a passive strategy of a player i always selects the same ask price

$$p_i^a(t) > \phi(t) \tag{4.16}$$

and the same bid price

$$(1+\tau)p_i^b(t) < \phi(t) \tag{4.17}$$

If in the second step of a period t a player with a passive strategy is neither a buying market maker nor a selling market maker, she neither buys or sells anything. Of course, different passive strategies may specify different ask and bid prices, but the inequalities for $p_i^a(t)$ and $p_i^b(t)$ must be always satisfied. This completes the description of a passive strategy.

Before the statement of a proposition which summarises the game theoretic properties of the model, we want to show that the set N^a of players with positive numeraire holdings and the set N^b of players with positive asset holdings never can be empty. Let us first look at N^a. The total number x of asset units is positive and therefore at least one player must hold a positive number of asset units. Consequently N^a may change over time but never becomes empty. The total amount of the numeraire also remains constant in the case of a zero transaction tax. If the transaction tax is positive, then part of the total amount of the numeraire flows to the global tax account if transactions take place, but not everything and the total amount of the numeraire at the beginning of the next period will also be positive. It follows that always at least one player must hold a positive amount of the numeraire and N^b never becomes empty.

The game theoretic properties of the model can now be summarised by the following proposition.

Proposition: The extensive game generated by the model has the following properties:

(a) Regardless of the strategy combination used, for $t = 1, ..., T-1$ we have

$$\begin{aligned} m(t+1) &\leq m(t) + \mu x \\ x\phi(t+1) &= x\phi(t) - \mu x \\ \Phi(t+1) &\leq \Phi(t) \end{aligned}$$

(b) The maximal total payoff is

$$K = \Phi(1)$$

(c) If λ_i is a passive strategy of player i, then

$$H_i(\lambda_i \varepsilon_{-i}) \geq \Phi_i(1) \qquad \text{for every } \varepsilon_{-i} \in \Lambda_{-i}$$

(d) The security levels S_i exist and we have

$$S_i = \Phi_i(1) \qquad \text{for } i = 1, ..., n$$

(e) Every equilibrium λ^* has the payoffs

$$H_i(\lambda^*) = S_i \qquad \text{for } i = 1, ..., n$$

Proof: We prove the assertions (a) to (e) in this order.

Proof of (a): At the end of period t all asset owners together receive dividend payment of μx. If there are no transaction costs then $m(t+1)$ is equal to the right hand side of the first inequality. The same is true in the presence of transaction costs, if nothing is bought or sold in period t. If there are transaction costs and assets are traded in period t, then $m(t+1)$ is smaller than the right hand side of the first inequality.

The definition of $\phi(t)$ yields

(4.18) $$\phi(t+1) = \phi(t) - \mu \qquad \text{for } t = 1, ..., T-1$$

This yields the equation for $x\phi(t+1)$. The inequality for $\Phi(t+1)$ then follows by the first two relationships.

Remark: Note that we also have shown that the inequalities in (a) hold with "=" instead of "$\leq$" if in period t no assets are bought or sold or in the case of zero transaction costs.

Proof of (b): A simple induction argument based on the inequality for $\Phi(t+1)$ in (a) shows that we must have $\Phi(T) \leq \Phi(1)$. This means that the maximal total payoff $\Phi(T)$ can be at most $\Phi(1)$. It remains to show that this total payoff is actually attainable. For this purpose it is sufficient to look at a combination in which the strategies of all players are passive. If this is the case, assets are neither bought nor sold during the resulting play. It follows by the remark at the end of the proof of (a) that $\Phi(t+1) = \Phi(t)$ holds for $t = 1, ..., T-1$ during this play and that therefore $\Phi(T) = \Phi(1)$ is the consequence of a simple induction argument. This yields $K = \Phi(1)$.

Proof of (c): Player i does not sell or buy the asset unless she is a buying market maker or a selling market maker. Suppose that in period t with $t = 1, ..., T-1$ player i is a buying market maker. If she sells $y_i(t)$ units of the asset with $y_i(t) > 0$ in period t then her asset holdings at the beginning of period $t+1$ will be

$$x_i(t+1) = x_i(t) - y_i(t) \tag{4.19}$$

The fundamental value of these asset holdings is equal to

$$x_i(t+1)\phi(t+1) = \Big(x_i(t) - y_i(t)\Big)\Big(\phi(t) - \mu\Big) \tag{4.20}$$

or equivalently

$$x_i(t+1)\phi(t+1) = x_i(t)\phi(t) - y_i(t)\phi(t) - \mu\Big(x_i(t) - y_i(t)\Big) \tag{4.21}$$

Her money holdings at the beginning of period t are as follows:

$$m_i(t+1) = m_i(t) + y_i(t)p_i^a(t) + \Big(x_i(t) - y_i(t)\Big)\mu \tag{4.22}$$

The second term is the sales value of $y_i(t)$ and the third one is due to the dividends obtained for what not has been sold at the end of period t. The preceding two equations yield:

$$\Phi_i(t+1) = x_i(t+1)\phi(t+1) + m_i(t+1) \tag{4.23}$$

$$\Phi_i(t+1) = x_i(t+1)\phi(t) + y_i(t)\Big(p_i^a(t) - \phi(t)\Big) + m_i(t) \tag{4.24}$$

In view of $p_i^a(t) > \phi(t)$ and $y_i(t) > 0$ we can conclude

$$\Phi_i(t+1) > m_i(t) + x_i(t)\phi(t) = \Phi_i(t) \tag{4.25}$$

The fundamental value of player i's holdings increases from period t to period $t+1$ if she sells a positive amount of assets in period t. A similar argument can be applied to the case that player i is a selling market maker in a period $t = 1, ..., T-1$ and buys a positive amount $z_i(t)$ of assets at her bid price $p^b(t)$. We obtain:

$$\Phi_i(t+1) = x_i(t)\phi(t) + z_i(t)\Big(\phi(t) - p^b(t)\Big) + m_i(t) \tag{4.26}$$

In view of $(1+\tau)p_i^b(t) < \phi(t)$ and $z_i(t) > 0$ this yields

$$\Phi_i(t+1) > \Phi_i(t) \tag{4.27}$$

Of course, player i may never buy or sell anything in the role of a market maker. However, in any case player i's passive strategy makes sure that the fundamental value of her holdings never decreases. We have

$$\Phi_i(t+1) \geq \Phi_i(t) \qquad \text{for } t = 1, ..., T-1 \tag{4.28}$$

A simple induction argument leads to

$$\Phi_i(T) \geq \Phi_i(1) \tag{4.29}$$

This completes the proof of assertion (c).

Proof of (d): Let λ_i be a passive strategy of player i. In view of (d) player i's payoff is at least $\Phi_i(1)$. Let ε_{-i} be an i-incomplete combination of passive strategies for all players j with $j \neq i$. In $\rho = \lambda_i\varepsilon_{-i}$ all players use passive strategies. Therefore never any assets are bought and sold if ρ is played. In view of the remark after the proof of (a) we can conclude that we have $H_i(\rho) = \Phi_i(1)$. It follows by (d) that a security level exists for a passive strategy λ_i and that it has the value

$$s_i(\lambda_i) = \Phi_i(1) \tag{4.30}$$

In view of (b) no strategy λ_i can yield a higher payoff than $\Phi_i(1)$ against an i-incomplete combination of passive strategies ε_{-i} for all players $j \neq i$ since $H_j(\rho') \geq \Phi_j(1)$ holds for each of them by (d) and this leaves at most $\Phi_i(1)$ for player i. It follows that the security level S_i of a player i exists and that

$$S_i = \Phi_i(1) \tag{4.31}$$

holds as asserted by (d).

Proof of (e): Let λ^* be an equilibrium. Assume that for one player i we have

$$H_i(\lambda^*) < S_i \tag{4.32}$$

It follows by (c) and (d) that this player can obtain a payoff of at least S_i against the equilibrium strategies of the other players. Therefore

$$H_i(\lambda^*) \geq S_i \tag{4.33}$$

must hold for $i = 1, ..., n$. In view of (b) and (d) the sum of all $H_i(\lambda^*)$ is smaller than or equal to the sum of all S_i. Consequently we must have

$$H_i(\lambda^*) = S_i \qquad \text{for } i = 1, ..., n \tag{4.34}$$

as asserted by (e).

Remark: A passive strategy λ_i achieves at least player i's security level S_i, but it is weakly dominated in the sense that player i has another strategy γ_i with

$$\begin{aligned} H_i(\gamma_i\varepsilon_{-i}) &\geq H_i(\lambda_i\varepsilon_{-i}) \qquad \text{for all } \varepsilon_{-i} \in \Lambda_{-i} \text{ and} \\ H_i(\gamma_i\varepsilon_{-i}) &> H_i(\lambda_i\varepsilon_{-i}) \qquad \text{for at least one } \varepsilon_{-i} \in \Lambda_{-i} \end{aligned}$$

The dominating strategy γ_i deviates from λ_i by exploiting mistakes of other players who become market makers. The strategy γ_i spends all the money holdings for buying at $p^a(t) < \phi(t)$ or sells all asset holdings at $p^b(t) > \phi(t)$, if the opportunity arises. However, as we have seen, (e) holds for all equilibria, regardless of whether some or all equilibrium strategies are weakly dominated or not. The equilibrium payoff of a player always is his security level.

4.4 Results of a Behavioural Experiment

The model introduced in section 4.2 was designed to suit the purpose of running experiments based on it and to find a game-theoretic solution as a benchmark. This permits to derive an experimental market to investigate behavioural aspects of the impact of a Tobin tax. In the following, the proceedings for the experiment are described together with the experimental results.

4.4.1 Experimental Setup and Procedures

Experiments have been conducted as computer-based laboratory experiments under controlled conditions. The experiment was programmed and conducted with the software z-Tree[3]. Operational details on the experimental software and the course of the experimental sessions are given in this subsection. Some screenshots of the experimental software can be found in appendix C.3. The model was calibrated with the parameters described in table 4.1.

6 sessions of the untaxed model variant and 6 sessions of the taxed one have been conducted. In the latter case, a constant tax rate was imposed on the market as described in table 4.2. No participant was allowed to take part in the experiment more than once, so statistical independence is given across treatments and across sessions. 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 run at the Laboratory for Experimental Economics in 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 E for an English translation of the German instructions). These instructions were then read aloud to the experimental subjects. After some example calculations and test questions, the session was started. When the session was finished, the subjects 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 $c = 1$). 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

[3]cf. Fischbacher (2007)

[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.

beforehand mentioned amounts. After an experimental session had been conducted, the subjects were asked to fill out an ex-post questionnaire.

Table 4.1: Parameter calibration

$n = 8$	$T = 51$
$x_i(1) = 500 \forall i \in \{1, ..., n\}$	$m_i(1) = 200 \forall i \in \{1, ..., n\}$
$\mu = 0.05$	$\overline{s} = \overline{d} = 25$
$c = 1$	$\overline{p}^a = \overline{p}^b = 10000$

Each round of the experiment was identical. First, every player had to state his individual 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 prices were determined as described in subsection 4.2.2 and shown to the players. Players who neither were a selling nor a buying market maker could then decide whether they wanted to engage in trade. If a player wished to initiate a transaction, he had to choose whether to place a buying or a selling order. The respective price (on taxed markets, also the tax surcharge) appeared on the screen. The player then could enter the amount of units of the asset that he wanted to buy or sell. When all orders had been collected, they were carried out as far as possible. His new holdings, the change in the holdings, and in taxed markets also the height of the paid taxes were shown to him at the end of the period. Then the round was over and the next round started.

In the following subsections, the experimental results are presented. A descriptive overview of the data can be found in table C.5 in the appendix.

Table 4.2: 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

4.4.2 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 is defined as the total transferred money in exchange for the asset on one market. The experimental study of Hanke et al. (2006) comes to the same 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 the experiment described here.

Looking at the aggregate trading volume of each taxed and untaxed market, it is evident that the opposite holds true for the averages which are displayed in table 4.3 for both types of markets. Unfortunately, the discrepancy in averages is not substantiated by non-parametric tests.

Table 4.3: 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 two-tailed significance level of $p = 0.0189$. 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.

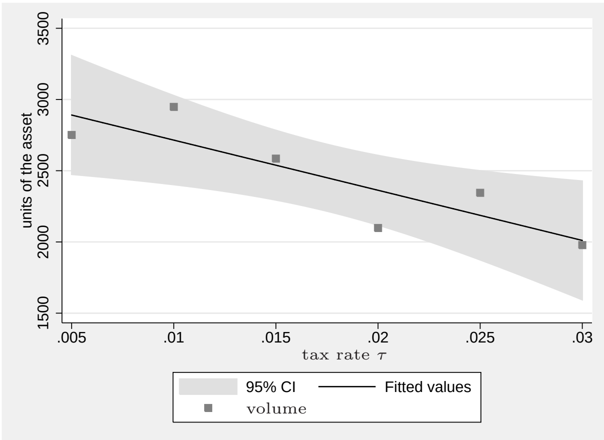


Figure 4.2: Trade volume and tax rate

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

$$v_i = \beta_0 + \beta_1 \tau_i + \varepsilon_i \tag{4.35}$$

where v_i is the session average of 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 $k \in \{0, 1\}$. Only taxed markets are regarded for the sake of comparability. Details of the analysis can be found in table C.3 in the appendix.

The fitted curve and a 95% confidence interval are displayed in figure 4.2. 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. A positive $\beta_0 = 3066.93$ and a negative $\beta_1 = -35205.71$ for the tax rate are estimated by an OLS analysis.

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

Nevertheless, the argumentative power of these coefficients is weak for financial markets in practice. The author shares 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 to markets outside the lab. Thus, it seems inappropriate to compare the regressional coefficients with existing foreign exchange, goods, or asset markets and limit our deductions to the following: A negative relatedness between tax rate and trade volume seems to be likely in the experiments with our model.

Table 4.4: 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

Is there a similar relatedness for the trade turnover, that is, for the units of the numeraire transferred on the markets? Summary statistics on this figure are displayed in table 4.4. 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 statistically significant evidence for a difference between taxed and untaxed markets: A Fisher-Pitman permutation test for independent samples cannot reject the hypothesis of no 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 tie between tax rate and turnover (Spearman's $\rho = -0.3143$, $p = 0.5441$ two-tailed). No significant influence of the tax rate on trade turnover can be found, and neither does the mere existence of a tax influence the trade turnover.

It can be concluded that the tax rate has a significant negative influence on trade volume. There is no significant likewise difference between taxed and untaxed markets in regard to trade volume. Interestingly enough, a similar correlation between trade turnover and the tax rate can not be found – *au contraire*: there is some evidence that neither the height of the tax rate nor a tax as such influences the trade turnover.

4.4.3 Supply and Demand

How does a tax influence the behaviour of the market participants in respect to supply and demand? The number of traders demanding or supplying units of the asset is one measure to investigate this effect. 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: on average, the number of market participants who supply units of the asset is higher in taxed markets. This effect is significant at $p = 0.0886$ (Fisher-Pitman permutation test for independent samples, two-tailed – summary statistics are shown in table 4.5). This does not hold true for the number of traders stating a demand.

Table 4.5: 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, unfortunately only weakly significant ($p = 0.1006$ one-tailed). This does not hold true for the demand. Nevertheless, the total demand for the asset is correlated negatively with the tax rate (Spearman's $\rho = -0.8286$, $p = 0.0414$ two-tailed). A significant correlation can not be observed for tax rate and total supply.

Besides the antagonism between observed and predicted behaviour, it seems 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 boundedly rational behaviour could be that under the prevalence of transaction costs, traders prefer to keep their holdings in the numeraire rather than in the asset. The decline of the total demand for the asset observed with an increasing tax rate gives further circumstantial evidence for this behaviour. In the next paragraphs, further findings are presented in order to substantiate this hypothesis.

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. The opportunity cost factor for one supplied unit sold to the buying market maker is defined as

$$\omega^S = \max\left\{\phi(t) - p^b, 0\right\} \tag{4.36}$$

in the control treatment. This factor has to be corrected for taxes in the Tobin treatment, so the opportunity cost factor for one supplied unit

$$\omega^S = \max\left\{\phi(t) - p^b\left(1 - \tau\right), 0\right\} \tag{4.37}$$

in taxed markets. Analogously, the opportunity cost factors for one demanded unit offered by the selling market maker is defined as

$$\omega^D = \max\left\{p^a - \phi(t), 0\right\} \tag{4.38}$$

in the control treatment and

$$\omega^D = \max\left\{p^a\left(1+\tau\right) - \phi(t), 0\right\} \tag{4.39}$$

in taxed markets. These opportunity cost factors are suited to calculate the total costs all traders in one market accept by supplying units of the asset. The total opportunity costs Ω^S for supplying units of the asset are equal to the sum of every period's ω^S, whereas the total opportunity costs Ω^D for demanding units of the asset are equal to the sum of every period's ω^D. The total opportunity costs per market are displayed in figure 4.3.

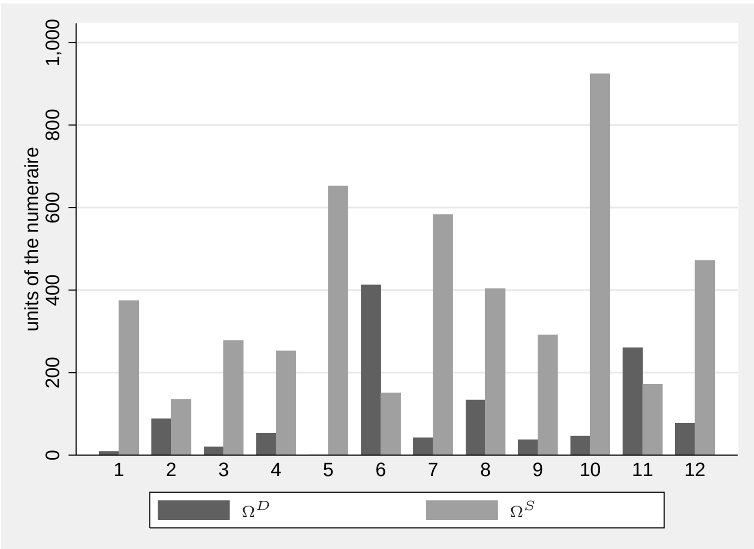


Figure 4.3: Total accepted opportunity costs per market (markets 1-6: untaxed, market 7-12: 0.5 to 3.0 % tax)

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 (Fisher-Pitman permutation test for independent samples, p = 0.12229) is found. Such differences can however not be found for opportunity costs for demanding units of the asset. The accepted opportunity costs for supplying units of the asset under its fundamental value are higher than the respective demand opportunity cost ($p = 0.0092$, two-tailed Fisher-Pitman permutation test for paired replicates).

The behaviour of the experimental subjects in supplying and demanding units of the asset has two seemingly boundedly rational 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 higher in taxed markets. The latter effect cannot be confirmed for the demand opportunity costs. What is observed 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 behavioural 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 propensity of the 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 behavioural 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 behaviour of the experimental subjects 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. This finding must not be exaggerated – the statistical evidence is only weak and a correlation between tax rate and accepted opportunity costs is not significant.

Nevertheless, this effect of a Tobin transactions tax on hyperbolic discounting should be taken into account in ongoing studies.

4.4.4 Market Prices

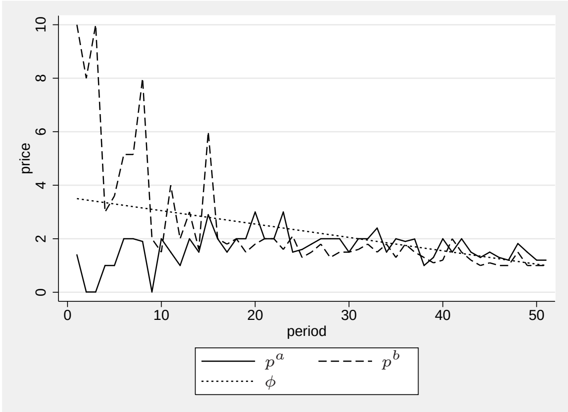
With a significant negative influence of the tax rate on the number of assets traded and no significant influence on the number of numeraires traded, one might suspect that prices might increase significantly with the tax height. As a price measure for one session, we define the average mid point between market bid and market ask price as the average price $\bar{p}$. Furthergoing remarks on prices are based on it. Summary statistics on the average market price are displayed in figure 4.6. Although there is no significant evidence of increasing prices with increasing taxes (Spearman's $\rho = 0.4286$, $p = 0.3968$ two-tailed), it can be found that the average market price is higher in untaxed markets. This effect is weakly significant (Fisher-Pitman permutation test for independent samples, $p = 0.1060$).

Table 4.6: Average market prices and fundamentals in taxed and untaxed markets

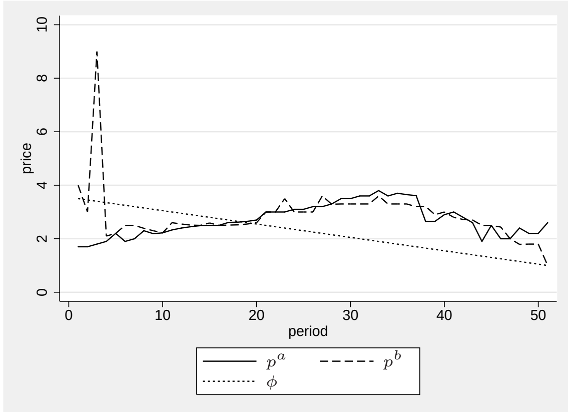
market	mean $\bar{p}$	std. dev.	min.	max.
untaxed	2.827533	1.614946	2.02598	6.10853
taxed	1.994837	.4289407	1.518824	2.77549

Market prices per period of one exemplary taxed and untaxed market each are shown in figure 4.4.

The data 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 behaviour. 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



session 2 (untaxed)



session 11 (taxed)

Figure 4.4: Prices per period in untaxed and taxed markets

for this motivation, this explanation is mere speculation. Nevertheless, some of the market prices were extremely high in taxed markets too, though a situation like the one described previously occurred less often.

Eliminating scattered outlier prices by comparing the medians of the market prices instead of the mean, there is no significant difference between taxed and untaxed markets. This is also predicted by the game-theoretical solution of the model. If one compares the equilibrium median bid and ask prices (both at 2.25), it is significant that both median bid ($p = 0.0053$, Fisher-Pitman permutation test for paired replicates, two-tailed) and median ask prices ($p = 0.0058$) 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 the model, too.

Concluding the findings on market prices, no significant differences in medians across treatments can be found. There are more outliers in untaxed markets. Nevertheless, the median bid-ask spreads are non-negative like on existing financial and asset markets.

4.4.5 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 subsection, the impact of a transaction tax on price volatility on the market model is assessed. Therefore, an adequate volatility measure for the model is needed. One measure which increases monotonically with an increasing variability of bid and ask price is the sum of the standard deviations or variances 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 arbitrary 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:

$$\delta(X_i, X_j) = \left(\frac{X_j}{X_i} - 1\right)^2 \tag{4.40}$$

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 $j = i+1$), a symmetrised measure

$$\delta_{\text{sym}}(X_i, X_j) = \left(\frac{X_i}{X_j} + \frac{X_j}{X_i} - 2\right)^2 \tag{4.41}$$

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

$$\upsilon(X) = \sum_{t=2}^{T} \delta_{\text{sym}}(X_{t-1}, X_t) \tag{4.42}$$

$$= \sum_{t=2}^{T} \left(\frac{X_t}{X_{t-1}} + \frac{X_{t-1}}{X_t} - 2 \right)^2 \tag{4.43}$$

Since both bid and ask price are finite and positive *per definitionem*, it is safe to utilise υ for evaluating volatility of both prices in our experiment. Hence, the sum of $\upsilon(p^a)$ and $\upsilon(p^b)$ is used as a means to quantify the price volatility of an experimental session (note that in the following an index t of all variables denotes its value in period t):

$$\upsilon = \sum_{t=2}^{T} \left[\left(\frac{p^a_{t-1}}{p^a_t} + \frac{p^a_t}{p^a_{t-1}} - 2 \right)^2 + \left(\frac{p^b_{t-1}}{p^b_t} + \frac{p^b_t}{p^b_{t-1}} - 2 \right)^2 \right] \tag{4.44}$$

In equilibrium, volatility in taxed markets should be the same as on untaxed ones. The equilibrium market volatility υ_{eq} can be derived by replacing the market bid and ask prices in (4.44) with the fundamental value $\phi(t)$ from equation (4.14):

$$\upsilon_{\text{eq}} = 2 \sum_{t=2}^{T} \left(\frac{\phi(t-1)}{\phi(t)} + \frac{\phi(t)}{\phi(t-1)} - 2 \right)^2 \tag{4.45}$$

$$= 2 \sum_{t=2}^{T} \left(\frac{c + (T-t+1)\mu}{c + (T-t)\mu} + \frac{c + (T-t)\mu}{c + (T-t+1)\mu} - 2 \right)^2 \tag{4.46}$$

$$= 2\mu^4 \sum_{t=2}^{T} \frac{1}{\phi(t)^2 \phi(t-1)^2} \tag{4.47}$$

Considering the parameter calibration used, the equilibrium market volatility equals $\upsilon_{\text{eq}} = 8.13489 \cdot 10^{-5}$. If this benchmark is compared with the data gathered through the experiments, it can be deducted 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 measured is $2.7784 \cdot 10^{-3}$ 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 the experimental markets? Surprisingly enough, no. The price volatility in untaxed markets is always higher than in taxed ones (significant at $p = 0.0021$, Fisher-Pitman permutation test for independent samples, two-tailed). Besides this strong result, the price volatility is even considerably higher on untaxed markets (see table 4.7).

Table 4.7: Price volatility in untaxed and taxed markets

market	mean υ	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 the experiments. The only explanation for this seemingly erratic behaviour can be the bounded rationality of the market participants. The 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 ($\rho = 0.4286$, $p = 0.3964$, two-tailed). Figure 4.5 shows the price volatility for markets with different tax rates.

Taking a closer look at this figure, something irritating attracts attention: The volatility decreases with an increasing tax, but only for tax rates below 2.5%. A tax rate of 2.5% 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 hint as a starting point for furthergoing investigations.

Summarising the findings concerning the influence of a tax and the tax rate on volatility, one can say that Tobin's approach of a transaction tax in fact does reduce

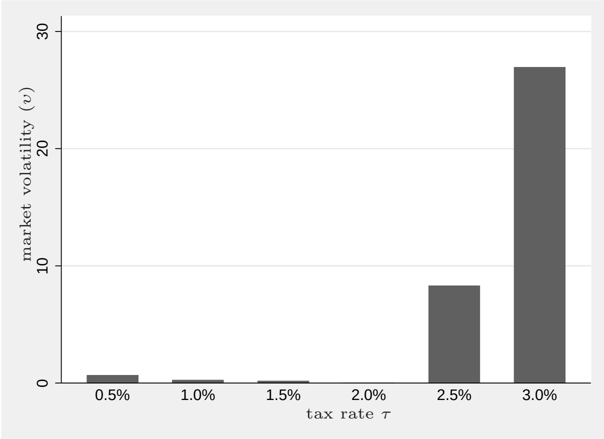


Figure 4.5: Market volatility and tax rate

price volatility in the markets. This effect is highly significant, albeit neither a libertarian nor a taxed market achieves equilibrium volatility or no volatility at all. Some hints are discovered that a higher tax rate reduces volatility only if kept below a certain threshold: if the tax rate exceeds 2%, 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. It is not the aim of this study to calibrate an optimal tax rate for a market setting like the one used, but to find differences in the traders' behaviour on taxed and untaxed markets and to explore reasons for the observed effects.

4.4.6 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 favour 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 this 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 is not 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 in a market. In this subsection, the impact of taxation on market efficiency in the used market model is evaluated.

In this context, market efficiency measures in how far information that is known to all market participants (that is, the rules of the game, which are public information) are reflected in the market's prices (that is, to what extent the prices differ from the fundamental value)[6] The measure for market efficiency is based on the volatility measure defined in subsection 4.4.5. Instead of measuring the symmetrised squared percentage change of the market price between two periods, the symmetrised squared percentage deviation of the market price from the fundamental value in the same period is calculated:

$$\eta = \sum_{t=1}^{n} \left[\left(\frac{\phi(t)}{p_t^a} + \frac{p_t^a}{\phi(t)} - 2 \right)^2 + \left(\frac{\phi(t)}{p_t^b} + \frac{p_t^b}{\phi(t)} - 2 \right)^2 \right] \tag{4.48}$$

A session with a perfectly efficient market would result in $\eta = 0$ – with decreasing efficiency, η increases strictly monotonic; so η literally displays 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 the experiment behave in respect to inefficiency and the equilibrium inefficiency of $\eta_{\mathrm{eq}} = 0$?

In the experiment, the untaxed markets display a higher η and thus a lower efficiency than the taxed ones. This effect is significant at $p = 0.0042$ (Fisher-Pitman permutation test for independent samples, two-tailed). A closer look at the descriptive statistics of the market inefficiency reveals an even more striking result (cf. table 4.8): the mean market inefficiency is higher by more than $7 \cdot 10^4$ in untaxed markets.

[6] In the field of experimental economics, efficiency describes how much lower the total payoff is compared to the maximum possible payoff. Since untaxed markets are constant sum games, this measure would be zero for every untaxed sessions.

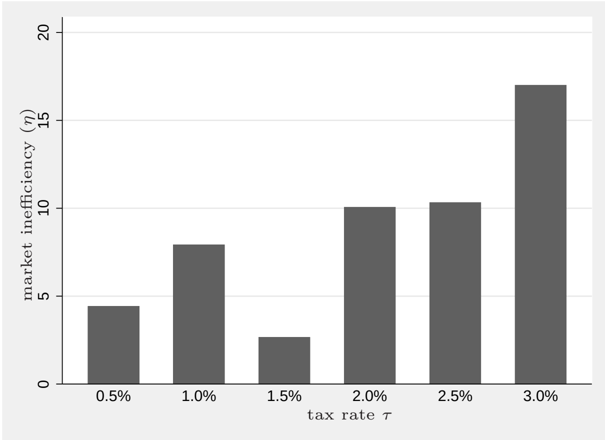


Figure 4.6: Market inefficiency and tax rate

Table 4.8: 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 the 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.

How does the height of the tax rate influence a market's inefficiency? It is evident 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 $\rho = 0.8286$ ($p = 0.0832$, two-tailed). Figure 4.6 displays market inefficiencies for differently taxed markets.

This finding sheds a new light on the influence of transaction costs on the efficiency of the 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 in taxed markets than in untaxed ones if the tax rate exceeds a certain value, because under the highest tax rate evaluated in this experiment (3.0%), η is only 0.6% 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.

4.4.7 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 the market setting chosen 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 with an increasing tax rate. 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 the experiment. Spearman's rank correlation coefficient of a market's fiscal revenues and the tax rate equals $\rho = 0.8857$ (significant at $p = .0376$, two-tailed). This considerably high value suggests that there indeed is a positive relatedness between tax rate and fiscal revenues. Again, an OLS regression of the simple model

$$F_i = \beta_0 + \beta_1 \tau_i + \varepsilon_i \tag{4.49}$$

is conducted where F_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 C.4 in the appendix). Actual values and the fitted curve with a confidence interval are shown in figure 4.7.

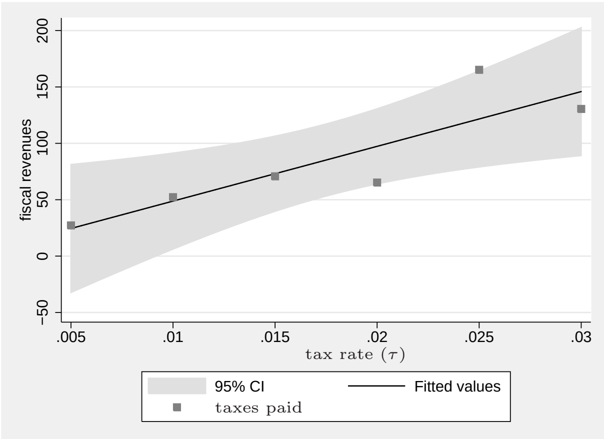


Figure 4.7: Fiscal revenues and tax rate

Although the estimates feature a high goodness-of-fit value, it has to be emphasised 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. The regressional result can be considered 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%.

It is important to stress that this result must not be overinterpreted. As mentioned already before, the setup doesn't allow for traders to evade the tax. If such a possibility was created, it would be likely that the fiscal revenues would decrease.

However, even with no tax escape routes, increasing transaction costs might decrease trade volume to an extent that diminishes the fiscal revenues. It has been shown that one cannot observe a phenomenon as such with relatively low tax rates in the markets, so this seems to be an important finding. Some authors, e. g. Felix and Sau (1996) and Frankel (1996), work with relatively high elasticity parameters of the fiscal revenues to the tax rate to assess the revenue potential of the Tobin tax and come to the results that the tax raising authority might still collect a considerably high amount of taxes even with small tax rates. If the elasticity was in fact smaller, these tax amounts would even be much higher.

4.4.8 Earnings Inequality

The next question this 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, it is important to investigate it for the sake of market microstructure.

In equilibrium, the 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, a variety of inequality measures have been applied: 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 have been calculated. Note that each measure would be zero in equilibrium. Stunningly, earnings inequality is significantly lower in taxed markets (cf. table C.2 in the appendix) – this holds true for all inequality measures but the Piesch index. Figure 4.8 displays the Lorenz curves of all payoffs in equilibrium (bisecting line), taxed treatments (middle curve), and untaxed treatments (lower curve).

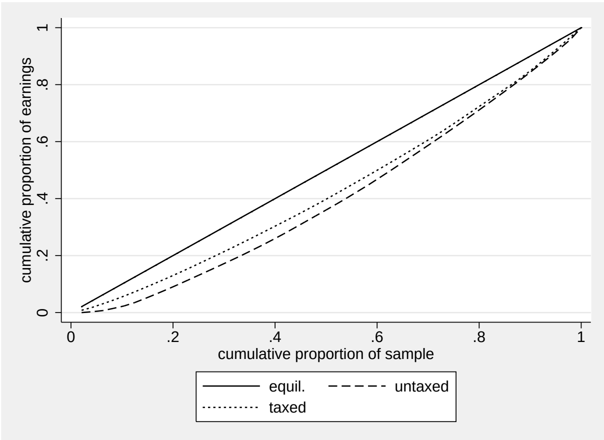


Figure 4.8: Lorenz curves for both treatments

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 (except the relative mean deviation: $\rho = -0.5001$, $p = 0.0978$ for $n = 12$). This is only a weak indicator for a negative influence of the tax rate on earnings inequality.

Summarising our findings on market inequality, it can be said 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.

4.5 Conclusions

This chapter investigates the consequences of a Tobin tax on an asset market. The situation in the beforehand derived game-theoretical equilibrium is compared with the results gained by a series of laboratory experiments. This comparison reveals that players act boundedly rational in regard to several aspects of the market. Firstly, an investigation of the trade turnover and trade volume yields trade turnover stays uninfluenced by a tax, whereas the trade volume decreases 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 boundedly rationial behaviour of hyperbolic discounting is fortified by a Tobin tax. Concerning market prices, it is evident that there are more outliers in untaxed markets. The markets display non-negative median bid-ask spreads in every session.

In the experiments, neither zero nor equilibrium volatility is ever achieved. In equilibrium, a tax should make no difference in volatility. Nevertheless, strong volatility reducing effects of a Tobin tax can be observed: all taxed markets feature a smaller volatility than all untaxed markets. There is no statistically significant correlation between tax rate and volatility, although the results suggest that volatility decreases with an increasing tax, but only to a certain tax height. A growing tax rate above 2% increases the volatility drastically in the experiment, albeit the statistical evidence is not strong enough to generally 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 the experiment. This is not surprising, because the trade turnover does not differ significantly with increasing taxes and only the trade volume decreases. Furthermore, there is evidence that speaks out for a lower earnings inequality on taxed markets.

Concluding the results of this chapter, it has been demonstrated that a Tobin tax in fact improves the situation with regard to volatility and market efficiency, but only if the tax rate is 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 has to be emphasised is that the participants of the experiments have behaved boundedly rational. Our study shows the crucial importance to take bounded rationality 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 various factors like e. g. the interlinks between foreign exchange and other markets and different motives to engage in trade 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 behaviour 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[7] 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 behavioural and experimental studies of stabilisation schemes.

[7] confer Galati et al. (2005, p. 5)

5 Fisher-Pitman Tests

"You gotta have a swine to show you where the truffles are."

– Edward Albee (1962)

Since some of the econometric and statistical methods applied in this thesis are not common ones in the field of experimental economics, they are briefly outlined in this chapter. A slightly modified version of this chapter has been published in the *Stata Journal*[1].

5.1 The Virtues of Non-Parametric Testing

In behavioural sciences, frequently used statistical tools are regression analysis and non-parametric tests like Spearman's rank correlation, the McNemar change test, the Fisher exact test, the Kruskal-Wallis one-way analysis of variance, the Wilcoxon signed ranks test and the Wilcoxon-Mann-Whitney rank sum test. In contrast to parametric statistics, non-parametric approaches do not make assumptions on distributions or parameters of distributions of the samples to be investigated. There are many occasions when normality of the distribution of a sample is implausible. First, it is generally considered to be adventurous to assume normality of a sample when its size is relatively small – often, a sample size of 35 is regarded to be sufficient. Unfortunately, observations can be expensive in

[1] see Kaiser (2007)

experimental economics[2], sample sizes that large are often beyond the boundaries of the budget. Second, decision variables in experimental economics are often discrete and/or censored – two properties that are speaking against the use of normal distributions. The third and probably most important argument against the normality assumption is that the shape of the observed sample does often not even come close to the shape of a normal distribution.

This chapter deals with two tests that can replace the two Wilcoxon tests if the observations are given at least on an interval scale. These tests are known as the Fisher-Pitman test for paired replicates and the Fisher-Pitman permutation test for independent samples (see Fisher 1935 and Pitman 1937), also referred to as randomisation tests. Why are the permutation tests more powerful than the respective Wilcoxon test? Siegel and Castellan (1988) compare both Wilcoxon and permutation tests with the appropriate parametric test. They find that the asymptotic power efficiencies of both Wilcoxon signed-rank and ranksum tests compared with the respective parametric t test are only 95.5%, whereas both permutation tests display power efficiencies of 100.0%. With the exponential decline of costs of computing power, permutation tests – or, resampling methods in general – enjoyed an increasing popularity. For example, Good (2002) derives exact permutation tests for comparing slopes of two different regression lines.

In this chapter, two algorithms for the well-known permutation tests are outlined: one for paired replicates, and one for two independent samples. Both algorithms are complex in regard to sample size. Thus p-values are time-consuming to compute even for moderate sample sizes. After I outline the exact algorithms, I show a Monte Carlo simulation approach to approximate p-values. Monte Carlo methods for permutation tests, firstly mentioned by Dwass (1957), can be useful if the sample size grows to an extent that the time for the computation of exact p-values grows to be too long. This asymptotic approach of determining p-values takes less

[2]For example, an observation of the experiment described in chapters 3 and 2 did cost between 1200 and 1800 Euro.

time, but the p-values determined are less accurate. This accuracy trade-off is examined by the means of a comparative Monte Carlo investigation in this chapter. Later on, examples for the application of both tests are given before concluding the case for the permutation tests.

As an addendum to the article that evolved to be this dissertation chapter, software implementations (for the statistical software packages STATA and MATA) of both tests in questions were developed. The interested reader can find them on the internet.[3]

5.2 Rationale of the Tests

Below, firstly the exact algorithms are outlined. The rationale of the test is described in Siegel and Castellan (1988). I limit the description of the details to the extent necessary for specifying the respective algorithm. The interested reader can find detailed instructions on how to carry out the tests in the book mentioned beforehand. After deriving two algorithms for the exact case, a method to facilitate Monte Carlo simulations is shown.

5.2.1 One Exact Algorithm for Each Permutation Test

The permutation test for paired replicates assumes as the H_0 hypothesis that paired observations of an outcome under two different conditions are randomly assigned to the two conditions for each subject. In the following, a brief summary on the rationale of the test is given before an algorithm to compute the p-values is derived.

[3] see http://www.stata-journal.com/software/sj7-3/st0134/

The Permutation Test for Paired Replicates

Let X_i specify the interval-scaled outcome under a first condition for a subject $i \in \{1, ..., n\}$ and Y_i the outcome for the same subject under a second condition. Let then $d_i = X_i - Y_i$ be the difference of the outcomes under the first and the second condition. If H_0 was true, a positive and a negative sign for d_i would be equally likely. As the size of the regarded sample is n, there are 2^n possibilities for the distribution of a positive or a negative sign among all differences in d_i, which would be all equally likely if H_0 was true.

For each of these possibilities, one can calculate the sum of the differences $\sum d_i$ and compare it with the $\sum d_i$ the actually observed (the critical value). The relation of the number of all theoretically possible sums which are less than or equal to the critical value of all theoretically possible sums, 2^n, is equal to the lower-tailed p-value; the relation of the number of all theoretically possible sums that are greater than or equal to the critical value to 2^n is equal to the upper-tailed p-value. The two-tailed p-value is the minimum of 1 and twice the value of the upper-tailed and the lower-tailed p-values.

The algorithm that facilitates the necessary computations uses binary counting to derive all possible $\sum d_i$. In particular, it performs the following steps:

- Let X_i and Y_i contain the observed values of subject i in a sample of n independent observations.
- Create the differences $d_i = X_i - Y_i$.
- Compute the critical value $c = \sum d_i$.
- Create an n-rows sign vector S with $S^\top = (-1, -1, ..., -1)$.
- Let $l = 0$ and $u = 0$.
- Repeat the following steps:
    1. For every $j \in \{1, ..., n\}$:

   a) If $S_j = -1$, set $S_j = 1$ and end this loop.
   b) Set $S_j = -1$.
2. Compute the test statistic $a = \sum_{i=1}^{n} S_i \times |d_i|$.
3. If $a \leq c$, increase l by one.
4. If $a \geq c$, increase u by one.
5. If $S_i = (1, 1, ..., 1)$, end this loop.

- The upper-tailed p-value equals $p_{\text{upper}} = \frac{u}{2^n}$.
- The lower-tailed p-value equals $p_{\text{lower}} = \frac{l}{2^n}$.
- The two-tailed p-value equals $p_{\text{two}} = \min\{1, 2 \times p_{\text{upper}}, 2 \times p_{\text{lower}}\}$.

Since this test considers not only the signed ranks, but also the actual size of the difference of the observations, it accounts for more of the data than the Wilcoxon signed-ranks test.

The Permutation Test for Independent Samples

The Fisher-Pitman permutation test for independent samples is a powerful alternative to the Wilcoxon Mann-Whitney rank sum test. It tests the difference between the means of two independent samples. Let X_i contain the interval scaled outcome of a subject i among m subjects in the first group and Y_j the outcome of a subject j among n subjects in the second group . The H_0 hypothesis states that there is no difference in the mean of the population from which X_i is drawn to the mean of the population from which Y_i is drawn or, in other words, that all of the $m+n$ observations may be considered to be from the same population. If H_0 were true, it would be equally likely that an observed value occurs in X or in Y. This scenario creates $\binom{m+n}{n}$ equally likely possibilities of distributing all observed values among X and Y.

For each of these possibilities, one can calculate the difference of the sums of both theoretically possible samples $\sum X_i - \sum Y_j$ and compare it with the same measure of the observed values. The latter one is the critical value for the test. The relation of the number of all theoretically possible sums which are less than or equal to the critical value to all theoretically possible sums, $\binom{m+n}{n}$, is equal to the lower-tailed p-value; the relation of the number of all theoretically possible sums which are greater than or equal to the critical value to $\binom{m+n}{n}$ is equal to the upper-tailed p-value. The two-tailed p-value is the minimum of 1 and twice the value of the upper-tailed and the lower-tailed p-value.

The algorithm performs the necessary computations as described here:

- Let X_i contain the observed value of an individual, i, in the first group of m independent observations and Y_j contain the observed value of another individual, j, in the second group of n independent observations.
- Let Z be the concatenation of X and Y. Thus, $X_i = Z_i \forall i \in \{1, ..., m\}$ and $Y_j = Z_{m+j} \forall j \in \{1, ..., n\}$.
- Compute the critical value $c = \sum_{i=1}^{m} Z_i - \sum_{j=m+1}^{m+n} Z_j$.
- Let $l = 0$ and $u = 0$.
- Create a $(m+n) \times \binom{m+n}{n}$ matrix M that contains in its columns all possibilities to distribute m times the number 1 and n times the number -1 in the $m + n$ rows.
- For every $e \in \left\{1, ..., \binom{m+n}{n}\right\}$:
  1. Calculate the test statistic $a = \sum_{i=1}^{m+n} M_{ie} \times Z_i$.
  2. If $a \leq c$, increase l by one.
  3. If $a \geq c$, increase u by one.
- The upper-tailed p-value equals $p_{\text{upper}} = \frac{u}{\binom{m+n}{n}}$.
- The lower-tailed p-value equals $p_{\text{lower}} = \frac{l}{\binom{m+n}{n}}$.
- The two-tailed p-value equals $p_{\text{two}} = \min\{1, 2 \times p_{\text{upper}}, 2 \times p_{\text{lower}}\}$.

Just like the Fisher-Pitman permutation test for paired replicates, this test is superior to respective Wilcoxon test if the observed values are given at least on an interval scale.

As one can see, the realisation of either one of the tests turns out to be very time consuming: for the permutation test for paired replicates, the outer loop has a complexity of $O(2^n)$. The permutation test for independent samples can be even more intensive in terms of computation: the complexity equals $O(\binom{m+n}{n})$. In the following, a method is drawn up to approximate the p-values by using Monte Carlo simulations.

5.2.2 One Monte Carlo-Based Algorithm for each Permutation Test

Monte Carlo simulations are an appropriate device to reduce the number of computing operations and thus the computational costs while setting aside accuracy only to a small extent.

The Permutation Test for Paired Replicates

Instead of computing the test statistic for the complete set of the sign vectors, the it is calculated only for randomly drawn sign vectors (with the possibility of repetition). The p-value equals the ratio of sign vectors for which the test statistic is less than or equal to (or greater than or equal to for a right-tailed test) the critical value to the total number k of sign vectors drawn. Of course, this is less accurate and leads to an error term in the p-values, but with a sufficiently high k the error term influences only their fourth or fifth decimal place.

In detail, the Monte Carlo-based algorithm for the Fisher-Pitman permutation test for paired replicates looks as follows:

- Let X_i and Y_i contain the observed values of subject i in a sample of n independent observations.

- Let k be the number of simulation runs to facilitate.
- Create the differences $d_i = X_i - Y_i$.
- Compute the critical value $c = \sum d_i$.
- Let $l = 0$ and $u = 0$.
- Repeat the following steps:
  1. For every $j \in \{1, ..., k\}$:
  2. Create a sign vector S with $S^\top = (S_1, ..., S_n)$ by setting $S_i = 1 - 2R \forall i \in \{1, ..., n\}$ with $R \sim \text{Bernoulli}(p = 0.5)$.
  3. Compute the test statistic $a = \sum_{i=1}^{n} S_i \times |d_i|$.
  4. If $a \leq c$, increase l by one.
  5. If $a \geq c$, increase u by one.
- The upper-tailed p-value equals $p_{\text{upper}} = \frac{u}{k}$.
- The lower-tailed p-value equals $p_{\text{lower}} = \frac{l}{k}$.
- The two-tailed p-value equals $p_{\text{two}} = \min\{1, 2 \times p_{\text{upper}}, 2 \times p_{\text{lower}}\}$.

By limiting the number of investigated sign vectors to k, the overall computational effort gets reduced drastically. Considering the speed of today's computers, a total of $k = 2 \cdot 10^5$ runs of the simulation should be adequate.

The Permutation Test for Independent Samples

How is the permutation test for independent samples carried out as a Monte Carlo simulation? Basically, the algorithm is conducted as follows:

- Let X_i contain the observed value of an individual, i, in the first group of m independent observations and let Y_j contain the observed value of another individual, j, in the second group of n independent observations.

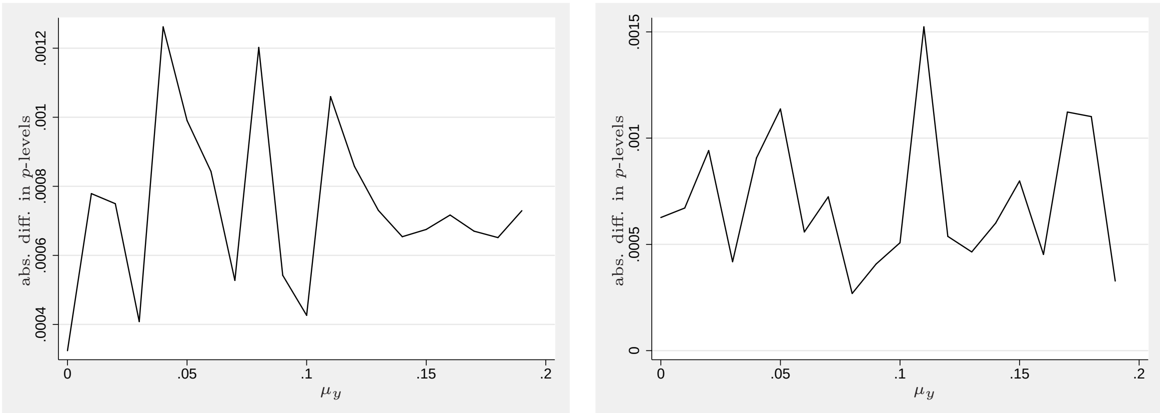
- Let Z be the concatenation of X and Y. For Z holds true: $X_i = Z_i \forall i \in \{1, ..., m\}$ and $Y_j = Z_{m+j} \forall j \in \{1, ..., n\}$.
- Compute the critical value $c = \sum_{i=1}^{m} Z_i - \sum_{j=m+1}^{m+n} Z_j$.
- Let $l = 0$ and $u = 0$.
- Create a sign vector S with $S^\top = (S_1, ..., S_{m+n})$ and $S_i = 1$ if $1 \leq i <= m$ and $S_i = -1$ if $m < i \leq m + n$.
- For every $i \in \{1, ..., k\}$:
  1. Shuffle the sign vector S.
  2. Calculate the test statistic $a = \sum_{i=1}^{m+n} S_i \times Z_i$.
  3. If $a \leq c$, increase l by one.
  4. If $a \geq c$, increase u by one.
- The upper-tailed p-value equals $p_{\text{upper}} = \frac{u}{k}$.
- The lower-tailed p-value equals $p_{\text{lower}} = \frac{l}{k}$.
- The two-tailed p-value equals $p_{\text{two}} = \min \{1, 2 \times p_{\text{upper}}, 2 \times p_{\text{lower}}\}$.

Just like in the case of the permutation test for paired replicates, a total of $k = 2 \cdot 10^5$ runs of the simulation should be sufficient.

5.3 Comparison of Exact and Monte Carlo Results

To get an idea on the size of the difference in the p-values given by the exact and the Monte Carlo versions of the tests, a simulation study is conducted.

In the case of the test for paired replicates, one draws two samples, x and y, with the same sample size, $n = 12$, with specific underlying distributions $X \sim N(\mu_x, 1)$ and $Y \sim N(\mu_y, 1)$. Lower-tailed p-values are calculated for both exact and Monte Carlo versions of the test, and the absolute difference between the p-values is stored. This process is repeated c times for each μ_x and μ_y in question. For the case of two independent samples, one proceeds analogously with a combined sample size of 12. Figure 5.1 displays the average absolute differences in p-values for $c = 5$, $\mu_x = 0$ and $\mu_y = i \times 0.01 \forall i \in \mathbb{Z} \wedge 0 \leq i < 20$.



paired replicates independent samples

Figure 5.1: Mean absolute difference in p-values of exact and Monte Carlo tests for random samples of $N(0, 1)$ against $N(\mu_y, 1)$

It is obvious that the differences in p-values are negligibly small, that is, smaller than 0.001 (paired replicates: significant at $p = 0.0016$, one-tailed Wilcoxon signed-rank test, independent samples: significant at $p = 0.0004$, same test). Additionally, the difference in means of the underlying distributions seems not to be correlated with the simulation error (paired replicates: Bravais-Pearson's product moment correlation coefficient $r = -0.0145$, independent samples: $r = 0.0142$). Thus, the Monte Carlo versions of the tests seem to be accurate enough for the investigated distributions.

5.4 An Example for the Usage of Both Tests

A little notional example will exemplify the usage of both tests. Consider the following (fictional) setting: 6 high school and 6 graduate students are asked independently of each other to collect receipts that show money spent on cinema visits and on music CDs over three months. The receipts are then collected and totaled for each student. The students are classified by the age group they belong to: a student aged 15–18 belongs to the age group 1, a student aged 22–25 belongs to the age group 2. The data set is described in table 5.1.

To determine the statistical significance of a subject's spending more money for movies or music, it is adequate to facilitate the Fisher-Pitman permutation test for paired replicates. The test gives in a two-sided level of $p = .0083$ – that is, the probability of falsely rejecting the null hypothesis that the expenditure for cinema visits is greater than or equal to the expenditure for music is only 0.83%. This probability can be considered highly significant.

The same dataset can be used to demonstrate the permutation test for independent samples. Suppose that one wants to know if the expenditures for music CDs differ significantly between age groups. To investigate this research question, the Fisher-Pitman permutation test for independent samples is an adequate choice. One applies the test for the hypothesis H_0 : *the expenditures for music are identical over age groups.* and finds a two-tailed p-value of $p = 0.0065$.

The permutation test for two independent samples shows that the probability of falsely rejecting the H_0 hypothesis that the expenditure for music CDs in the first age group is lower than or equal to the expenditure for music CDs in the second age group is only .00649. Just like in the first case, this can be regarded highly significant.

Table 5.1: Sample data set

age_group	expd_cinema	expd_music
1	65.22	68.02
1	72.13	83.77
1	58.69	55.96
1	66.72	90.13
1	64.38	70.54
1	81.29	82.43
2	45.08	55.15
2	60.09	61.12
2	33.22	39.75
2	59.67	57.09
2	18.39	26.88
2	22.82	33.64

5.5 Discussion

In this chapter, the rationale of two powerful non-parametric tests is outlined. The Fisher-Pitman permutation test for paired replicates provides p-values for the difference in means of two outcomes of one subject in a sample, whereas the Fisher-Pitman permutation test for independent samples provides p-values for the difference in means of two independent groups. Efficient ways to calculate exact p-values are outlined. The high complexity of the underlying algorithms makes it furthermore necessary to approximate the p-values if the sample size is large, thus a Monte Carlo simulation approach is also drawn up. A comparative simulation study demonstrates that the difference in p-values of exact and Monte Carlo approaches is small enough. Thereafter, the test is exemplified with a fictional dataset.

There is still some room for future work: On one hand, calculating confidence intervals from both tests and Hodges-Lehmann estimators associated with them could be possible. On the other hand, the number of simulation runs to perform has been set to 2×10^5 high-handedly. Although the precision of Monte Carlo tests has been evaluated using comparative simulations, the optimum number of simulation cycles to run could be determined algebraically in order to reduce the error term in p-values to a fixed minimum given the sample size. Nevertheless, the tests in their current design provide the scientist with a serviceable tool to investigate significance levels of differences in means.

6 Final Remarks

"Better is the end of a thing than the beginning thereof."

– The Bible, Ecclesiastes 7:8

This dissertation investigates macroeconomic phenomena by the means of laboratory experiments. Specifically, interlinks between economic policy and the labour market are outlined. Another focus is on the determinants of firms' currency trade behaviour. A further part investigates the impact of a transaction tax as proposed by Tobin (1978) on an asset market. Some of the econometric methods applied in all chapters, namely exact and Monte Carlo versions of the Fisher-Pitman permutation tests for independent samples and for paired replicates, are derived in chapter 5. In this chapter, a more detailed summary of the research chapters of this thesis is given before concluding.

6.1 Summary

Chapter 2 of this dissertation thesis studies how policy decisions of governments and central banks influence the labour market and how they the institutions react to unfulfilled employment goals. This is done by the means of a laboratory experiment: various institutions of two countries are simulated by human players. In the model, the fiscal and monetary policy institutions have several goals to achieve in order to obtain their maximum payoff. Governments can use the fiscal instrument of the expenditures, whereas central banks state a price target for the good that is produced by the country's firms.

The labour market reacts to according to theory on average. Nevertheless, a great share of the labour market reactions cannot be explained by changes in policy. If both instruments are applied in a way that theory predicts changes into the same direction, the effects of policy are stronger. It can even be observed that the effects of uncoordinated policy on wage are opposite to theory.

Governments tend to adjust the expenditures according to theory to reduce over- and underemployment in a significant number of cases. In the currency union treatment, another fraction of decisions is in line with the hypothesis that governments try to influence the actual price with their expenditure decision. In the two currency case, this cannot be observed. Instead, the governments irrationally try to decrease the difference between their own expenditures and the nominal expenditures of the other country. Central banks however fail to apply their target price instrument correctly – instead of doing so, they track the previously observed price in order to keep their penalty for deviations between actual price and target price low. The discovered effects as a whole lead to a new picture of an explanation why observed Phillips curves are not due to a direct causal relationship and how nevertheless a negative correlation between the rate of inflation and the rate of unemployment can arise.

Chapter 3 investigates the determinants of a firm's currency trade behaviour. As a vehicle of the investigation, different aspects of the same model and the same experiments as in chapter 2 are used. Two determinants of the currency trade decisions have been identified, namely the interest rate and individual exchange rate estimates. On average, the firms raised debts in the country with the lower interest rate and transferred the money to the account in the other country. Some decisions are conforming to simple trend extrapolation, although these were significantly less in number. An antagonism can be observed in this behaviour:

It would have been possible to make higher profits by trading on exchange rate changes instead of interest rates, because the variations of currency prices are usually stronger than interest differences. However, it is demonstrated that the subjects are incapable of estimating exchange rate changes correctly. This might be the reason for their reliance on safe facts – namely, interest rates – instead of highly speculative assumptions on future exchange rate changes.

The trade decisions based on exchange rate estimates are significantly less profitable than those based solely on interest rates. In the spirit of Gigerenzer and Todd (1999), a simple decision rule was created on the base of which subjects are likely to make profits. According to this rule, a trader should offer a fixed amount of the currency that is the cheapest in terms of interest rate. It could also be observed that the trade activity declines with an increasing exchange rate volatility. This can be seen as a further indicator for the players' ambiguity aversion affecting their willingness to face the uncertainty of making losses by trading.

It is evident that the players offered their respective home currency more frequently and to a higher extent than the respective foreign currency. This home currency bias is likely to be caused by exchange rate uncertainty, for a positive home currency offer settles the foreign account debts to a certain extent – thus reducing possible losses by exchange rate changes. More evidence for exchange rate uncertainty among players is found in the individual exchange rate estimates entered into the profit calculator: subjects expect the exchange rate rather to increase than to decrease. Since increasing exchange rates lower the production profit of a firm, it is safe to conclude that the subjects deal with exchange rate uncertainty by stating pessimistic expectations. A rather minor finding of this chapter is that the influence of currency trade on exchange rate volatility is quite small.

The currency crises that have been observed for example in the late 1990s in eastern Asia however demonstrate impressively that this is not always the case in practice. James Tobin's idea to cope with excess volatility of exchange rates is to impose a transaction tax on every spot transaction on the currency market. Chapter 4 investigates the influence of a transaction tax as such on an asset market. Laboratory experiments with an experimental asset markets have been conducted with and without a tax imposed. The features of the market model used resemble those of the currency market in practice. A game-theoretical solution is derived as a benchmark for the experimental results.

The observed behaviour suggests that the turnover is not influenced by the tax, but that the trade volume decreases linearly with the tax height. This discrepancy can be explained by the fact that average market prices are higher in untaxed sessions. It is surprising that the average number of suppliers is higher in taxed markets. They are also willing to face higher opportunity costs by selling the asset under its value. One possible explanation for this behaviour is that the mere existence of a transaction tax influences the trader's tendency towards hyperbolic discounting.

Neither zero nor equilibrium volatility was achieved in the experiments conducted, be it on taxed or on untaxed markets. According to the game-theoretical solution, there should be no influence of the tax on price volatility. Contrary to that prediction, taxed markets all display a much lower volatility than taxed ones. Another market feature investigated is market efficiency. Although critics suspect that a Tobin tax might decrease market efficiency, the opposite is however found in the experimental data: market inefficiency is significantly higher in untaxed markets. The tax rate is nevertheless correlated positively with market inefficiency. Fiscal earnings increase with higher tax rates. Additionally, a significantly lower earnings inequality can be observed on taxed markets.

Significance tests are used throughout all chapters of this thesis. In order to test for differences in means, Fisher-Pitman permutation tests are applied. Since these tests can become computationally intensive, efficient ways to compute exact and approximate p-levels are derived in chapter 5. Two different tests are outlined; one for paired replicates and one for independent samples. The H_0 hypothesis of the paired replicates permutation test states that the means of the distributions of two paired samples X and Y are identical. A critical value is computed on the base of the sum of the difference vector. For every possible distribution of -1 and 1 on the difference vector, the test statistic is calculated. With a high n, it is computationally too intensive to compute the test statistics. Hence, a method to facilitate Monte Carlo simulations is derived. It is not necessary to compute the test statistic for *all* possible sign vectors. Instead, one randomly draws a fixed and sufficiently high number of them and calculates the test statistic like in the exact approach.

Contrary to the paired replicates test, the Fisher-Pitman test for two independent samples deals with two samples X and Y that are not paired. Its H_0 hypothesis assumes that the means of both samples in question are identical. As critical value for the test, the difference between the sums of both samples is used. This figure is calculated for all possible redistributions of the observations of the combined sample on both samples. The computational costs increase strongly with higher sample sizes to an extent that calculating the p-values can take excessive time even with modern computers. Hence, an approach similar to the Monte Carlo method applied for the paired replicates test is conducted for a high number of observations: Instead of comparing the test statistic of all possible redistributions of the observations with the critical value, this is only done with a random subset of redistributions. By the means of a Monte Carlo study, it is demonstrated that the p-values approximated by Monte Carlo simulations are sufficiently accurate compared to the exact algorithms. Furthermore, both tests are exemplified with a notional dataset.

6.2 Closing Discussion

This dissertation shows in chapters 2 to 4 that behavioural aspects which make economic agents deviate from strict rationality have to be considered when dissecting macroeconomic phenomena. It has been set forth that the deflexion of the decisions made by experimental subjects from the predicted rational behaviour is not idiosyncratic, but systematic. As already foreshadowed in chapter 1, it seems tenuous to extrapolate the quantitative results from the laboratory to macroeconomies or financial markets in practice or, in other words, to assume external validity. Nevertheless the laboratory evidence makes it possible to explain mechanisms that might be at work when irrational or boundedly rational patterns of behaviour occur.

One such pattern is a significant correlation of employment and the rate of inflation. Not being predicted by theory, it is evident that this relatedness exists and that not the change of the rate of inflation causes the change in employment, but that both of them are caused by a chain of reactions of fiscal policy on firms' production decisions and the other way around.

Another important field that is traditionally investigated with the means of experiments is decision making under uncertainty. In the context discussed in this dissertation, price volatility sparks off uncertainty. This has far reaching consequences for the agents' economic course of action. Theories for behaviour as such are manifold. One of the first and probably most important theories on economic behaviour under risk that took into account cognitive processes of humans is the Nobel Prize winning prospect theory. Developed by Kahneman and Tversky (1979), prospect theory finds psychological explanations for behaviour inconsistent with expected utility theory when subjects face risk at the time they make their decisions. The influence of price volatility on decision making applies on both goods prices and exchange rates, that is, currency prices.

Excess volatility – a property of prices that does not prevail in game-theoretical equilibrium of the model investigated – can be observed in the experiments in question as a product of boundedly rational agents. As has been demonstrated, it can be coped with by the means of transaction costs in form of a Tobin tax. To curb undesirable effects like market inefficiency and reduced trade volume, the tax rate should be kept low.

The advantages of the econometric methods that have been applied in order to arrive at the conclusions of the chapters outweigh the disadvantages, not least because of the efficient realisation of the algorithms. The methods are also superior to rank-based statistical methods because they take into account more of the data if the attributes investigated are measured at least on an interval scale. This is obviously the case for the decision variables and resultant measures elicited by the means of laboratory experiments. Not only are most of these measures censored and too few in number too assume normality; their samples also resemble those obtained by normal distributions only seldomly. This forbids the use of standard econometric methods applied traditionally in macroeconomics.

Many questions remain unanswered so far, many more than could be covered within the scope of a dissertation thesis. The model used in chapters 2 and 3 is adequate to investigate also other effects that occur in macroeconomic settings. For example, the process of wage bargaining can be analysed in a very detailed way with respect to the influence of other decision variables and key measures like unemployment, aggregate profits, or the wage that prevails in the other country. It would also be a interesting to gather evidence on the decision making process of firms with respect to production: Since the firms interact under a quantity-setting Cournot regime with manifold variable parameters (like wages, interest, exchange rate changes, expenditure) that change over time, this experiment is an ideal vehicle for testing the influence of changes in the environment on production decisions in an oligopoly. Although a preliminary analysis yielded no striking results, a detailed inspection of the specific effects of a currency union could be conducted. The model could be extended to three countries. This would open up a whole new horizon for furthergoing investigations: If there was a currency union imposed on only two of the three countries, one could study the effects of currency unions on non-members. With a concept of exchange rates somewhat less easier to capture by the experimental subjects, three countries could also interact without a currency union taking place amongst any two of them. Another viable extension of the model could be the augmentation of a firm's decision variables with a decision on investment into capital. With investment being present in the model, it would be possible to dissect the influence of gross domestic product of one experimental country onto other variables and the other way around. As an extension to chapter 2, Okun's law – the relatedness of the real growth rate and the rate of unemployment – would be an interesting object of study.

The investigation of the impact of transaction costs on markets in chapter 4 was conducted to find whether the levy of a Tobin tax yielded a lower price volatility and what effects on other aspects of the markets could be observed. A tax as proposed by James Tobin is by no means the only imaginable method to reduce price volatility. On asset markets, an authority that intervenes with supply or demand to influence prices in order to keep them stable would be imaginable. Such an authority has been introduced (and abandonned) on the market for tin (confer Bäcker 1998, p. 6). On the currency market, central banks act as watchdogs over exchange rates. Traditionally, central banks intervene with currency supply or demand to cope with excess volatility or to protect exchange rates from devaluation. Besides intervention, they also have the instrument of interest policy. Usually applied under a long term horizon scope, there have been incidents when interest rates have been used to deal with short term fluctuations (e. g. in September 1992, the Swedish central bank raised its overnight interest rate to an annualised interest rate of 500 percent to defend the Krone from a speculative attack, see Eichengreen and Wyplosz 1993, p. 99). An experimental comparison of markets with a Tobin tax, a two-tier transaction taxation scheme as proposed by Spahn (1996), and a market with an intervening authority whose payoff depends solely on volatility would deliver further insights into behavioural aspects of measures that curb excess volatility. If players were endowed with assets and cash asymmetrically, their behaviour could differ significantly. Corsetti et al. (2004) show in the context of currency crises that such asymmetries can have an important influence on behaviour. It would be interesting to explore the effect of endowment asymmetries on asset markets.

The methodology used for calculating the p-levels of the Fisher-Pitman tests in chapter 5 could also be extended. Deriving confidence intervals from both tests in exact and in Monte Carlo versions should be possible, and so should, consequently, be the derivation of a Hodges-Lehmann point estimate – that is, the point that results by shrinking the interval to a confidence level of zero percent asymptotically. The number of Monte Carlo simulation cycles conducted can surely be limited to an upper bound if proof was found on how the number of cycles influences the error term in p-levels.

As has been demonstrated in this work, there are many aspects that influence individual decision making and that are systematically not conforming with the theory that agents behave self-centered, risk neutral, and profit maximising. This emphasises the need for not only further investigation of the models dissected in this thesis, but for the broader establishment of behavioural methods in macroeconomics. This necessity finds more and more advocates in the fields of macroeconomics *and* in the field of experimental economics. As one anonymous referee of a top-ranking economics journal has put it: The field of experimental macroeconomics has a bright future.

A Appendix for Chapter 2: Economic Policy and the Labour Market

A.1 Measuring Association

For testing association of two variables, several methods are utilised. The first one described does so by the use of Yule's Q (Yule 1900), which is a special case of Goodman and Kruskal's Gamma (Goodman and Kruskal 1979). Assume that there are two decision variables x and y. Let $\Delta x = x_t - x_{t-1}$ and $\Delta y = y_t - y_{t-1}$ be the difference of x respective y in two consecutive periods and A, B, C, D the number of changes in one experimental session that satisfy the following conditions:

	$\Delta x > 0$	$\Delta x < 0$
$\Delta y > 0$	A	B
$\Delta y < 0$	C	D

Yule's Q is defined as

$$Q = \frac{AD - BC}{AD + BC} \tag{A.1}$$

and $Q \in [-1; 1]$. If all positive changes of x coincided with positive changes of y and all negative ones of x with negative ones of y, Q would equal 1; if all positive changes of y coincided with negative changes of y and the other way round, Q would equal -1. Q thus gives a measure of association between changes of x and y. Since the values of x and y within one session are no independent observations, Fisher's exact test for 2×2 tables is not applicable here. Instead, Q is used as a descriptor for one session in this context.

This method neglects much of the data, because only the direction of changes is taken into account. A stronger method of showing association would be the use of correlation coefficients like Spearman's rank correlation coefficient ρ and Bravais and Pearson's product moment correlation coefficient r. These measures take also into account the strength of the change – by rank in the first case, absolute in the second. To calculate a measure for one session, one calculates the correlation coefficient with all 20 Δx and Δy in each of the two countries separately. Significance levels of the respective coefficient are meaningless, because the values observed do not satisfy the condition of independence. The average of both countries' correlation coefficients can than be used as a descriptor of association for one session.

Similarly, an OLS regression can be done. Most of the results gained by regressions (like t and F test values) are irrelevant here, since the preconditions for parametric testing cannot be met: It cannot be assumed that Δx and Δy are normal distributed. There are only 20 data points per country and session, and these points are not even independent. Hence, only the coefficients of the fitted model can be interpreted and used as a session descriptor.

The session descriptors obtained by one of the methods mentioned beforehand can now be tested with the standard repertoire of non-parametric tests. In this investigation, treatment effects are investigated either with the Fisher-Pitman permutation test for two independent samples[1] or with the Mann-Whitney U ranksum test. Matched observations are tested for significance either with the Fisher-Pitman permutation test for paired replicates or with the Wilcoxon signed-rank test. The tests have been applied as described by Siegel and Castellan (1988).

[1]For both permutation tests used in this study, only the exact versions have been applied. Details can be found in Kaiser (2007).

Thus, the association tables can be interpreted as follows. The tables are separated in three parts: session values of the corresponding measures are displayed in the first 15 rows. Thereof, the first 6 sessions have been conducted with a currency union imposed, sessions 7 to 15 without. The leftmost column denotes the session number. Column two gives Yule's Q. It has been calculated in the way described above. The deltas of the two variables concerned have been grouped in positive and negative ones – deltas of size 0 have been left out. Column three gives the session average of Spearman's rank correlation coefficient ρ of the deltas of the two variables concerned of both countries. Column four displays the session average of Bravais-Pearson's product-moment correlation coefficient r of the deltas of both countries. In column four, coefficients of a simple regressional model have been calculated. This is done in the following way: Let Δx and Δy be the variables in question. For each country, the coefficients α_1 of the simple regressional model

$$\Delta y_t = \alpha_0 + \alpha_1 \Delta x_t + \epsilon_t \tag{A.2}$$

are calculated. Then, the session averages of α_1 are calculated. These values are displayed in the table's rightmost column.

The next three rows of each table show overall and treatment averages of the respective measures. In the remainder of the table, p-levels for some significance tests are given. The row labeled "U test" shows the p-level of a two-tailed Mann-Whitney U ranksum test for difference in medians of the treatments. Analogously, the p-level of a two-tailed Fisher-Pitman permutation test for two independent samples for differens in means of the treatments is given in the next row. The last six rows show p-levels for two-tailed Wilcoxon signed-rank tests of the hypothesis that the median of the respective session measure is equal to zero. Rows labeled "permtest" give p-levels for two-tailed Fisher-Pitman permutation tests for paired replicates of the hypothesis that the mean of the respective session measure is equal to zero. These two tests are carried out for both samples at a time, for the one-currency treatment only and for the two-currency treatment only. Asterisks aligned to p-levels denote a significance of $p <= 0.1^{*}$, $p <= 0.05^{**}$, $p <= 0.01^{***}$.

Due to the lack of normality of data, the missing independence of the variables, and the number of observations ($n <= 20$), standard panel econometrics are not applicable in this case. Therefore, the statistical approaches described above are applied to gather valid empirical results.

A.2 Tables

Table A.1: Association between changes in D and L

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	.89090908	.53197628	.53698033	3.3303568
2	.86666667	.46782005	.35299572	1.2156571
3	.36842105	.11908777	.07611553	.17857121
4	.55555558	-.00251985	.00065764	-.04580859
5	.53846157	.33457318	.45627755	1.9508604
6	.5714286	.20722342	.17883807	.24171905
7	.57575756	.54344535	.64690089	3.7225645
8	-.41176471	-.05973276	.14957494	.23244147
9	.81176472	.29379556	.33103731	.1751063
10	.70093459	.13254564	.19047837	.69279313
11	.38461539	.04101373	.18007608	.23346035
12	-.16666667	-.19691101	-.12038984	-.40928435
13	.60000002	.53334624	.57978159	.8840574
14	-.07692308	-.12882607	-.14836073	-.37226874
15	.91794872	.48835483	.31350252	1.8677782
mean	.47514061	.22034616	.24829773	.92653361
1 curr.	.63190709	.27636014	.26697748	1.145226
2 curr.	.37062962	.1830035	.23584457	.78073869
U test	.63735189	.63735189	.90618562	.47950012
2-s. permtest	.24055944	.5046953	.81438561	.5966034
Wilcoxon	.00314293***	.0124533**	.00261078***	.0124533**
permtest	.00168***	.00714***	.00153***	.00616***
Wilcoxon (1 curr.)	.02770785**	.04639946**	.02770785**	.04639946**
permtest (1 curr.)	.03125**	.0625*	.03125**	.0625*
Wilcoxon (2 curr.)	.06631603*	.13864063	.02087926**	.10974464*
permtest (2 curr.)	.05859375*	.109375*	.02734375**	.078125*

Table A.2: Association between changes in p and L (sum of both countrys' L in currency union case)

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	.	.02180795	-.00483699	-.00001736
2	-.25	.3381024	.47829017	.00310888
3	-.45454547	-.09086499	-.00699323	-.00002034
4	-.71428573	-.47181401	-.39025187	-.00288319
5	.42857143	.51011044	.61310822	.00492527
6	1	-.04431865	-.05364851	-.00014554
7	-.57894737	-.28180957	-.24491552	-.00272558
8	-.04477612	-.0131925	.00748356	-.00125074
9	.57746476	.25246271	.26515219	.00188907
10	-.15789473	.11524387	.1520485	.00145002
11	-.34693879	-.05468167	-.07480788	-.00033911
12	-.76271188	-.34246856	-.32861868	-.00703706
13	-.83486241	-.39139366	-.38038075	-.00224922
14	.11111111	.06786335	-.02211174	-.00030532
15	-.05882353	.0413316	-.13951713	-.00131199
mean	-.14904562	-.02290809	-.00866664	-.00046082
1 curr.	.00194805	.04383719	.10594463	.00082795
2 curr.	-.232931	-.06740494	-.08507416	-.00131999
U test	.64073838	.72367361	.34577859	.12550647
2-s. permtest	.45254745	.45594406	.22897103	.15264735
Wilcoxon	.22089889	.73327139	.57006088	.36348795
permtest	.31372	.74976	.90644	.5494
Wilcoxon (1 curr.)	.8927384	.91651191	.91651191	.91651191
permtest (1 curr.)	1	.875	.5	.5
Wilcoxon (2 curr.)	.10974464 *	.51466972	.26039294	.17307092
permtest (2 curr.)	.15625	.40625	.26953125	.15625

Table A.3: Association between changes in w and L

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	.71257484	.32984722	.24771473	.00065659
2	-.42857143	-.12325452	.02485628	.00026706
3	-.47169811	-.21301539	-.22725235	-.00145529
4	-.20879121	-.2948477	-.51479226	-.00186467
5	-.5	.01018215	.04027928	.00020162
6	.21348314	-.16453125	-.24525125	-.0009599
7	-.10204082	.16520831	.2976388	.00066269
8	-.55555558	-.54986286	-.50234348	-.00254149
9	-.65605098	-.41557458	-.40107095	-.00239469
10	-.03225806	.04017282	.0258825	-.00178363
11	-.3125	-.04290524	.01794975	-.00024642
12	.18181819	-.05031118	-.00042136	-.00022494
13	-.54929578	-.14973611	.04516982	.000608
14	-.08333334	-.01010194	.04293044	.00050106
15	-.10497238	.32469925	.48303092	.00224936
mean	-.1931461	-.07626873	-.04437861	-.00042164
1 curr.	-.11383379	-.07593658	-.1124076	-.00052576
2 curr.	-.24602097	-.07649017	.00097405	-.00035223
U test	.63735189	.72367361	.40939549	.81366372
2-s. permtest	.51908092	.9978022	.44355644	.81638362
Wilcoxon	.06089266*	.23297911	.95470755	.36348795
permtest	.06243*	.2436	.54986	.24847
Wilcoxon (1 curr.)	.60017949	.46307102	.60017949	.34544753
permtest (1 curr.)	.625	.46875	.5	.28125
Wilcoxon (2 curr.)	.03815171**	.37425932	.51466972	.67840238
permtest (2 curr.)	.03515625**	.40625	.9921875	.55078125

Table A.4: Association between changes in D and w

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	.6793893	.48459259	.57864887	1018.5087
2	-.07284768	.0146476	-.05802431	-21.258877
3	-.17557251	.01508005	.15698358	119.09781
4	.17647059	.0599982	.18128593	58.880119
5	.01408451	.09713202	.22355729	178.51538
6	.375	.04746473	.06938109	42.402367
7	.52380955	.35144183	.50632429	1305.0809
8	.15789473	-.0236753	-.04569466	-13.059792
9	-.85507244	-.39458805	-.56166375	-50.70726
10	.73333335	.51331723	.44191033	167.0609
11	-.65517241	-.03308903	.09227917	5.2726507
12	-.08450704	-.07507601	-.04905227	-1.5794601
13	-.25	-.01846782	-.03429008	-.37407589
14	-.75	-.25765419	-.10227989	-13.083472
15	-.26229507	-.01525696	-.03881077	-290.98178
mean	-.02969901	.05105779	.09070366	166.91827
1 curr.	.16608737	.1198192	.19197208	232.69091
2 curr.	-.16022326	.00521685	.02319138	123.06985
U test	.15729921	.05934644*	.19485065	.15729921
2-s. permtest	.21538462	.38241758	.28091908	.57222777
Wilcoxon	.776425	.60923507	.1914464	.23297911
permtest	.81308	.42847	.23252	.17403
Wilcoxon (1 curr.)	.24886387	.02770785**	.04639946**	.04639946**
permtest (1 curr.)	.28125	.03125**	.0625*	.0625*
Wilcoxon (2 curr.)	.31393809	.44126813	.76709687	.67840238
permtest (2 curr.)	.39453125	.95703125	.953125	.734375

Table A.5: Association between changes in p and w (sum of both countrys' w in currency union case)

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	.	-.33305159	-.25284463	-.54507786
2	.33333334	-.00903955	-.05597125	-.04119897
3	.57894737	.29954642	.49759498	.26627773
4	1	.63155466	.45150989	.89294624
5	.33333334	.1268072	.03056319	.05780348
6	-1	-.30789798	-.15296568	-.15902814
7	.884058	.36071932	.10080601	.19642615
8	.01408451	.09648899	.08198986	.32847983
9	-.90909094	-.41021475	-.49666828	-.57685125
10	.22222222	.10295416	.10760242	.22138473
11	.06666667	.05867929	.21876252	.35573184
12	.13513513	-.02511753	-.11332479	-.1730092
13	.90099013	.32093608	-.03464539	-.01442852
14	.12280702	.13289084	.18402988	.17579302
15	.65517241	.28307295	.00647605	-.37849832
mean	.23840423	.08855523	.03819432	.04045005
1 curr.	.24912281	.06798653	.08631442	.07862041
2 curr.	.23244946	.10226771	.00611425	.01500314
U test	.54806618	.81366372	.90618562	1
2-s. permtest	.96003996	.82157842	.57262737	.75884116
Wilcoxon	.08992365*	.23297911	.57006088	.60923507
permtest	.15686	.24049	.56964	.69011
Wilcoxon (1 curr.)	.41421618	.91651191	.75315236	.75315236
permtest (1 curr.)	.5625	.75	.5	.6875
Wilcoxon (2 curr.)	.10974464*	.13864063	.51466972	.76709687
permtest (2 curr.)	.1953125	.203125	.9609375	.921875

Table A.6: Association between changes in D/p and L

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	.93142855	.57639802	.5454067	.35082471
2	.48571429	.12636699	.02794464	.00684947
3	.125	.07987943	.08791801	.02359653
4	.79591835	.28828776	.29721206	.07577488
5	-.25	-.07664637	-.05843884	-.04298443
6	.43089432	.09705184	.17321727	.02436309
7	.75609756	.60917926	.64462137	.44708923
8	-.11392405	.12974235	.15502077	.03658997
9	-.33333334	-.21628454	-.17405742	-.01990921
10	.56521738	-.10606481	-.07754081	.03323668
11	.35384616	.14661655	.19267555	.03080907
12	.41935483	.1744262	.2101949	.09119759
13	.8101266	.57317352	.65080464	.1051805
14	-.09090909	-.12145458	-.1149544	-.03596649
15	.89830506	.47235805	.33766374	.18998653
mean	.38558244	.18353531	.19317921	.08777587
1 curr.	.41982592	.18188961	.17887664	.07307071
2 curr.	.36275346	.18463244	.20271426	.09757932
U test	.72367361	.90618562	.90618562	.34577859
2-s. permtest	.81118881	.98421578	.87552448	.75724276
Wilcoxon	.00640649***	.02309573**	.01705872**	.01705872**
permtest	.00509***	.02064**	.01198**	.00911***
Wilcoxon (1 curr.)	.0747355**	.04639946**	.0747355*	.17295492
permtest (1 curr.)	.09375*	.0625*	.09375*	.21875
Wilcoxon (2 curr.)	.05061243*	.10974464	.06631603*	.03815171**
permtest (2 curr.)	.0546875*	.125	.0859375*	.03515625**

Table A.7: Association between changes in D/p and w

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	.74100721	.51320571	.57860345	109.66641
2	-.01123596	-.04576236	-.00968262	-.82886106
3	.125	.07438358	-.01597084	1.2281036
4	-.47761193	-.26839751	-.34788638	-26.137983
5	-.04854369	.0412076	.15495096	17.136532
6	.47368422	.15154819	.13259307	9.0600071
7	-.19402985	.14520285	.36507824	124.35532
8	-.01910828	-.16240306	-.13341719	-6.498147
9	.70491803	.33929306	.31997097	5.8814411
10	.18518518	.27714545	.27684125	13.004979
11	-.23076923	-.10798727	-.17827591	-5.8186088
12	-.39784947	-.08311396	.07793891	3.3234096
13	-.72602737	-.25689223	.00976492	.19160923
14	-.3548387	-.24026006	-.25514036	-4.0188293
15	-.05882353	-.07045646	-.08071928	-23.795858
mean	-.01926956	.02044757	.05964328	14.449968
1 curr.	.13371664	.07769754	.08210127	18.354035
2 curr.	-.12126036	-.01771908	.04467128	11.847257
U test	.19485065	.40939549	.81366372	.55568979
2-s. permtest	.25894106	.45234765	.78081918	.80759241
Wilcoxon	.57006088	.90956094	.49552088	.42652825
permtest	.86369	.74011	.37611	.32215
Wilcoxon (1 curr.)	.60017949	.46307102	.60017949	.34544753
permtest (1 curr.)	.5	.59375	.625	.46875
Wilcoxon (2 curr.)	.17307092	.85895492	.59395468	.85895492
permtest (2 curr.)	.38671875	.80859375	.55859375	.6953125

Table A.8: Association between changes in D/p and L if the decision pairs are coordinated

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	.	-.02728797	-.13390854	-.13529666
2	.93548387	.26785713	.22948584	.10098459
3	1	.40194955	.29883602	.08732039
4	1	.28929645	.51181936	.19051759
5	-1	-.25712901	-.29538482	-.13136141
6	.	.43612781	.46366143	.08639194
7	.89473683	.58741629	.44964176	.43708169
8	-.14285715	-.09805222	-.29708052	-.04321771
9	1	.45412415	.55851352	.11068749
10	.60000002	-.19956109	-.12654909	.0855485
11	.71428573	.14285713	.17785874	.04199865
12	.60000002	.16904762	.303271	.08263536
13	1	.81896055	.7951709	.14272234
14	0	-.3564018	-.28044993	-.10644893
15	.80000001	.05000001	.13350612	.06468274
mean	.56935764	.17861364	.18589279	.06761644
1 curr.	.48387097	.18513566	.17908488	.03309274
2 curr.	.60735172	.17426563	.19043139	.09063224
U test	.43336564	.90618562	1	.90618562
2-s. permtest	.73846154	.95024975	.95264735	.49190809
Wilcoxon	.02430906**	.06089266*	.04682647**	.13975587
permtest	.01171875**	.05619*	.05675*	.07931*
Wilcoxon (1 curr.)	.4496918	.1158515	.17295492	.75315236
permtest (1 curr.)	.625	.15625	.21875	.53125
Wilcoxon (2 curr.)	.01741848**	.26039294	.13864063	.08583096
permtest (2 curr.)	.015625**	.21484375	.15625	.07421875

Table A.9: Association between changes in D/p and L if the decision pairs are uncoordinated

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	1	.	.	.
2	-.07692308	-.31360307	-.3891685	-.13617471
3	-.42857143	-.32122993	-.20589526	-.04372591
4	1	-.2	.25681403	.05960754
5	-.66666669	-.3761037	-.47853893	-.08872695
6	1	.5	.11728857	.01558134
7	.81818181	.69166666	.89145756	.54614305
8	1	1	1	.17291805
9	-1	-.58904725	-.65677339	-.04597524
10	.33333334	-.34047621	-.41054296	-.09986776
11	.33333334	.44999999	.22723861	.03197807
12	-.2631579	.16212121	-.14942253	-.03903054
13	.	-.34999999	-.39681503	.00615917
14	-1	.40000001	.47922465	.09277428
15	.81818181	.77142859	.49812344	.37300649
mean	.20483651	.10605402	.05592788	.06033335
1 curr.	.3046398	-.14218734	-.13990002	-.03868774
2 curr.	.12998405	.24396589	.16472115	.11534506
U test	.47127066	.38612467	.38612467	.16151332
2-s. permtest	.6953047	.1958042	.31068931	.11988012
Wilcoxon	.32608698	.36268594	.72989091	.59361824
permtest	.33607	.45508	.69132	.3009
Wilcoxon (1 curr.)	.34008461	.50018426	.34523107	.34523107
permtest (1 curr.)	.4375	.375	.375	.375
Wilcoxon (2 curr.)	.67214397	.17307092	.37425932	.26039294
permtest (2 curr.)	.65625	.21875	.41796875	.17578125

Table A.10: Association between changes in D/p and w if the decision pairs are coordinated

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	1	-.08716691	-.01823908	-371.39996
2	-.42857143	.10778928	.21970341	18.864817
3	-.5	-.53019685	-.54979193	-19.797785
4	-1	-.40592006	-.50417697	-59.712582
5	.	-.187572	-.17381784	-45.858463
6	.	.03702129	.06932826	5.4390054
7	-.71428573	-.29454565	-.21038602	-32.587006
8	.11111111	-.14633854	-.04688209	-3.8038073
9	.	.1240555	.26883948	88.855614
10	.60000002	.64100832	.47857589	29.883244
11	-.71428573	-.1177683	-.09345416	-.32244897
12	0	.12738095	.4040949	30.539755
13	-1	-.1	.14748375	1.3732135
14	-1	-.55135381	-.51880825	-12.536705
15	-.80000001	-.33333334	-.25073233	-18.22263
mean	-.37050265	-.11446267	-.0518842	-25.952383
1 curr.	-.23214286	-.17767421	-.15949903	-78.744162
2 curr.	-.43968254	-.07232165	.01985902	9.2421366
U test	.60722555	.63735189	.40939549	.09896015*
2-s. permtest	.62222222	.55224775	.30769231	.05754246*
Wilcoxon	.09778771*	.12515346	.53212989	.42652825
permtest	.078125*	.16741	.53919	.45416
Wilcoxon (1 curr.)	.58071216	.17295492	.34544753	.1158515
permtest (1 curr.)	.75	.1875	.34375	.15625
Wilcoxon (2 curr.)	.07857855*	.44126813	.85895492	.85895492
permtest (2 curr.)	.0625*	.54296875	.84765625	.5703125

Table A.11: Association between changes in D/p and w if the decision pairs are uncoordinated

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	1	.	.	.
2	.02040816	.17684105	-.07997216	-.15380239
3	0	.59772897	.59360904	31.78647
4	-1	.40000001	.31238237	14.205398
5	1	.09510779	.15821682	-10.747852
6	1	.5	.56376964	45.007366
7	0	.50833333	.50152487	86.563148
8	.	-1	-1	-89.200584
9	1	.70938402	.84509778	11.161258
10	-.2	-.23071645	-.15821312	-3.6615686
11	.33333334	-.55000001	-.88333416	-25.06041
12	-.45454547	-.4848485	-.53441268	-18.15605
13	.	.94999999	.94047678	22.121433
14	-1	-1	-.91404545	-4.7407513
15	1	.88928568	.33797234	187.02032
mean	.20763046	.11150828	.04879086	17.581741
1 curr.	.33673469	.35393556	.30960114	16.019516
2 curr.	.0969697	-.02317355	-.09610374	18.449645
U test	.46118208	.64037086	.38612467	.46335515
2-s. permtest	.58624709	.31368631	.27772228	.98601399
Wilcoxon	.31792699	.55082554	.72989091	.39672623
permtest	.35058594	.53051	.78643	.34476
Wilcoxon (1 curr.)	.23282335	.04311445*	.0796158*	.22491588
permtest (1 curr.)	.375	.0625*	.125	.25
Wilcoxon (2 curr.)	.79771356	.85883234	.59395468	.85895492
permtest (2 curr.)	.8125	.91796875	.69921875	.58984375

Table A.12: Association between ε_G and $D_{t+1} - D_t$

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	.75438595	.38742098	.24595559	.00064395
2	.	.06871861	.05397055	.00003397
3	1	-.13789991	-.24357887	-.00026711
4	.	-.00510327	.07339463	.00051195
5	.	-.26991728	-.2059712	-.00012444
6	.09090909	-.07404934	.04512198	.00033781
7	1	.2242907	.55275005	.00091978
8	-.04761905	.02715698	.12879746	.00044884
9	.	.53477049	.58059114	.006118
10	.	.25354338	.23443931	.00063968
11	.125	.35158992	.38081875	.0010238
12	-1	.06720622	.14590435	.00032316
13	1	.7940805	.82268864	.00353917
14	.	.05448782	.02998783	.00121139
15	.5714286	.24056423	.40387523	.00139475
mean	.38823384	.16779067	.21658303	.00111698
1 curr.	.61509835	-.00513837	-.00518455	.00018935
2 curr.	.27480159	.28307669	.36442809	.0017354
U test	.59942628	.04512695**	.01842213**	.01332833**
2-s. permtest	.5952381	.03396603**	.00919081***	.00559441***
Wilcoxon	.09426431*	.04682647**	.0124533**	.00178538***
permtest	.125	.02834**	.01121**	.00083***
Wilcoxon (1 curr.)	.10880943	.60017949	.75315236	.24886387
permtest (1 curr.)	.25	.90625	1	.28125
Wilcoxon (2 curr.)	.34008461	.00768579***	.00768579***	.00768579***
permtest (2 curr.)	.4375	.00390625***	.00390625***	.00390625***

Yule's Q has been calculated with this matrix:

	$\varepsilon_G < 0$	$\varepsilon_G > 0$
	$a = \#(D_{t+1} - D_t \leq 0)$	$b = \#(D_{t+1} - D_t < 0)$
	$c = \#(D_{t+1} - D_t > 0)$	$d = \#(D_{t+1} - D_t \geq 0)$

Table A.13: Association between ε_C and $p_{t+2} - p_{t+1}$

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	1	0	.1228817	.17999998
2	.	.31701484	.39056888	.13220799
3	1	.49778455	.63880384	.52603078
4	.	-.21663599	-.29540095	-.11356045
5	.	0	-.0650341	-.00921009
6	1	.25457379	-.11903628	-.27254286
7	.53846157	.30576384	.01075415	-.00411319
8	1	.45851845	.35663432	.19388597
9	.	.00081575	-.12973781	-.10493602
10	.	-.10581078	-.23540595	-.16623756
11	.33333334	.26681855	.08908409	-.02731941
12	1	.33999497	.40149528	.26623625
13	1	.79888928	.84194756	1.0796323
14	.	.11881533	.15149602	.0785353
15	1	.23569649	.10072461	.34336954
mean	-.87464388	-.21814927	-.15065169	-.1401319
1 curr.	-1	-.14212287	-.11213052	-.07382089
2 curr.	-.81196582	-.26883354	-.17633247	-.18433924
U test	.28884437	.40897686	.72367361	.55568979
2-s. permtest	.83333333	.38121878	.72927073	.60979021
Wilcoxon	.00500017***	.00577686***	.12515346	.1914464
permtest	.00390625***	.00545***	.0926*	.1174
Wilcoxon (1 curr.)	.08326452*	.19566774	.46307102	.60017949
permtest (1 curr.)	.25	.25	.46875	.5625
Wilcoxon (2 curr.)	.0235441**	.01515597**	.13864063	.21352435
permtest (2 curr.)	.03125**	.01171875**	.1328125	.15625

Yule's Q has been calculated with this matrix:

	$\varepsilon_C < 0$	$\varepsilon_C > 0$
	$a = \#(p_{t+2} - p_{t+1} < 0)$	$b = \#(p_{t+2} - p_{t+1} \leq 0)$
	$c = \#(p_{t+2} - p_{t+1} \geq 0)$	$d = \#(p_{t+2} - p_{t+1} > 0)$

Table A.14: Association between $q_{-} - p$ and changes in D

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	.11111111	-.18556449	-.36925536	-.00173081
2	-.37142858	-.03534833	-.00187327	-.00026552
3	-.33333334	-.17505313	-.17482322	-.00035323
4	1	-.09319478	-.03514126	-.00113276
5	-.7368421	-.31779614	-.4502061	-.00302071
6	-.3548387	-.16261397	-.20196077	-.00074115
7	-.44	-.20414586	-.07946661	-.0003883
8	.64102566	.18944299	.21923411	.00384301
9	1	.21356378	.23768611	.0044742
10	-.5714286	-.19811636	-.25424749	-.00209381
11	-.125	-.02340296	.02134057	.00074243
12	-.21875	-.27271491	-.40580568	-.00299893
13	.81818181	.40921563	.40927172	.00995726
14	.07692308	.04941741	.03951345	.00005057
15	-.17073171	-.1157708	-.42421508	-.00110646
mean	.02165924	-.06147213	-.09799659	.00034905
1 curr.	-.11422193	-.16159514	-.20554333	-.00120736
2 curr.	.11224669	.00527655	-.02629877	.00138666
U test	.44324966	.23859283	.19485065	.15729921
2-s. permtest	.47552448	.10989011	.2041958	.13586414
Wilcoxon	.82024447	.23297911	.17284835	.53212989
permtest	.88303	.25298	.16748	.74056
Wilcoxon (1 curr.)	.46307102	.02770785**	.02770785**	.02770785**
permtest (1 curr.)	.6875	.03125**	.03125**	.03125**
Wilcoxon (2 curr.)	.76709687	.95276502	.76709687	.51466972
permtest (2 curr.)	.56640625	.94921875	.78125	.3671875

Table A.15: Association between relative changes in L_t and q_{t-1}

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	0	.02719297	.03685571	.34049881
2	.11111111	-.16228069	-.24015562	-.77414364
3	.49222797	.50526315	.66575891	1.8775816
4	.2631579	.23245613	.25392616	.4376851
5	.10614525	-.24649122	-.32632536	-.61559677
6	.3114754	.35877192	.62324619	.81490737
7	.21348314	.17192984	.24549127	.24503748
8	.52127659	.36228073	.43824106	.67410618
9	.41935483	.42456138	.36461043	.49668857
10	.28	.1754386	.13670453	.52680421
11	-.11111111	.00964913	.01498001	-.07584679
12	.82456142	.39385965	.21270925	.41525087
13	.65517241	.30263159	.27666157	.74933672
14	.80281693	.3859649	.41261026	.93578738
15	.59183675	.36666667	.39719683	.31314933
mean	.36543391	.22052632	.23416741	.42408309
1 curr.	.21401961	.11915204	.16888433	.34682208
2 curr.	.46637677	.28810917	.27768947	.47559044
U test	.07709987*	.23859283	.63735189	.72367361
2-s. permtest	.08951049*	.16303696	.47712288	.73246753
Wilcoxon	.00146004***	.00451405***	.008985***	.03090801**
permtest	.00055***	.00366***	.0073***	.01754**
Wilcoxon (1 curr.)	.03501498**	.34544753	.34544753	.46307102
permtest (1 curr.)	.0625*	.375	.34375	.4375
Wilcoxon (2 curr.)	.01086222**	.00768579***	.00768579***	.01086222**
permtest (2 curr.)	.0078125***	.00390625***	.00390625***	.0078125***

Table A.16: Association between relative changes in Q_t and q_{t-1}

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	-.16556291	.01745877	.03445025	-.06387582
2	.56626505	.03508771	-.09476508	-.04305368
3	.65517241	.39385965	.5347988	.26988158
4	.10614525	.2377193	.24662793	.21882325
5	-.25	-.28079376	-.359467	-.31427941
6	.10497238	.3763158	.57227266	.61045837
7	-.05660377	.11172405	.12874275	.18491416
8	.80555558	.53684211	.57206821	.54092711
9	.59183675	.27456141	.26487455	.27986589
10	.2	.17017543	.01357642	.00445074
11	.56284153	.18070176	.11304444	.18491192
12	.84210527	.45175439	.27637285	.1961229
13	.68159205	.34473684	.34757188	.23666234
14	.56284153	.18859649	.14326699	.10410465
15	.5714286	.30526316	.16044676	.73056674
mean	.38523931	.22293354	.19692549	.20936538
1 curr.	.16949869	.12994125	.15565293	.11299238
2 curr.	.52906639	.2849284	.22444054	.27361405
U test	.07683591*	.28884437	.63735189	.34577859
2-s. permtest	.05554446*	.16663337	.62457542	.27252747
Wilcoxon	.00537636***	.00377224***	.01059354**	.01459661**
permtest	.00215***	.00142***	.01078**	.0084***
Wilcoxon (1 curr.)	.46307102	.17295492	.34544753	.60017949
permtest (1 curr.)	.375	.25	.34375	.5
Wilcoxon (2 curr.)	.01079278**	.00768579***	.00768579***	.00768579***
permtest (2 curr.)	.0078125***	.00390625***	.00390625***	.00390625***

Table A.17: Association between relative changes in L_{t-1} and D

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	-.51145041	-.37742585	-.19270541	-.63881272
2	.07692308	-.08071688	-.09190267	-.09664156
3	-.1	.00110565	-.12752189	-.09685007
4	-.25	-.00534499	-.02731094	.02278833
5	0	-.05443712	-.0951781	-.24388784
6	-.48148149	-.13424119	-.15986913	-.00350131
7	-.42857143	-.27939501	-.3296048	-1.0169687
8	-.14285715	-.06797422	-.06823093	-.02972793
9	-.69696969	-.2730279	-.07125854	-.02634602
10	-.34146342	-.25434208	-.30852425	-.34114212
11	-.25	-.18425277	-.10915067	-.09351409
12	-.41935483	-.01320881	.00343445	-.01054147
13	-.83333331	-.29482493	-.30125234	-.12250231
14	.11111111	.07002227	.10162596	.05229626
15	-.55223882	-.18975817	-.06505205	-.21397085
mean	-.32131242	-.14252147	-.12283342	-.1906215
1 curr.	-.21100147	-.10851006	-.11574802	-.17615086
2 curr.	-.39485306	-.16519573	-.12755702	-.20026859
U test	.26246383	.34577859	.72367361	1
2-s. permtest	.21898102	.43236763	.86273726	.90629371
Wilcoxon	.00236236***	.00261078***	.00377224***	.00377224***
permtest	.0008***	.00104***	.00144***	.00224***
Wilcoxon (1 curr.)	.09169028*	.04639946**	.02770785**	.0747355*
permtest (1 curr.)	.125	.0625*	.03125**	.09375*
Wilcoxon (2 curr.)	.01086222**	.02087926**	.05061243*	.02840184**
permtest (2 curr.)	.0078125***	.015625**	.0390625**	.02734375**

Table A.18: Association between relative changes in Q and q

session	Yule's Q	Spearman's ρ	Pearson's r	Regression
1	-.26436782	-.08085747	.16499878	.04091367
2	-.68472904	-.45187968	-.28590751	-.50519663
3	-.625	-.3631579	-.39408624	-.77369785
4	-1	-.91954887	-.93182832	-.96754473
5	-.65686274	-.19849765	-.00971703	.00064482
6	-.93939394	-.78345865	-.69365346	-.65698183
7	-.02439024	.12123232	.28352794	.22966769
8	-1	-.95714283	-.94044626	-.94107044
9	-.93877554	-.44511279	-.35830751	-.31843233
10	-.75	-.23533835	-.09632505	-.21823981
11	-.95804197	-.55413532	-.44271874	-.35777915
12	-.88764048	-.54887217	-.46500778	-.57965386
13	-.8425197	-.58947372	-.48925203	-.69597834
14	-.94244605	-.4255639	-.36413604	-.51911336
15	-.48571429	-.43984962	.10173719	.1413276
mean	-.73332545	-.45811044	-.3280748	-.40807564
1 curr.	-.69505892	-.46623337	-.35836563	-.47697709
2 curr.	-.75883647	-.45269515	-.30788092	-.36214133
U test	.51649305	.81366372	1	.47950012
2-s. permtest	.67772228	.94505495	.8023976	.58461538
Wilcoxon	.00065331***	.0009871***	.00640649***	.00538567***
permtest	.00007***	.0002***	.00428***	.00208***
Wilcoxon (1 curr.)	.02770785**	.02770785**	.0747355*	.1158515
permtest (1 curr.)	.03125**	.03125**	.09375*	.125
Wilcoxon (2 curr.)	.00768579***	.01086222**	.03815171**	.02840184**
permtest (2 curr.)	.00390625***	.0078125***	.03515625**	.03125**

A.3 Screenshots

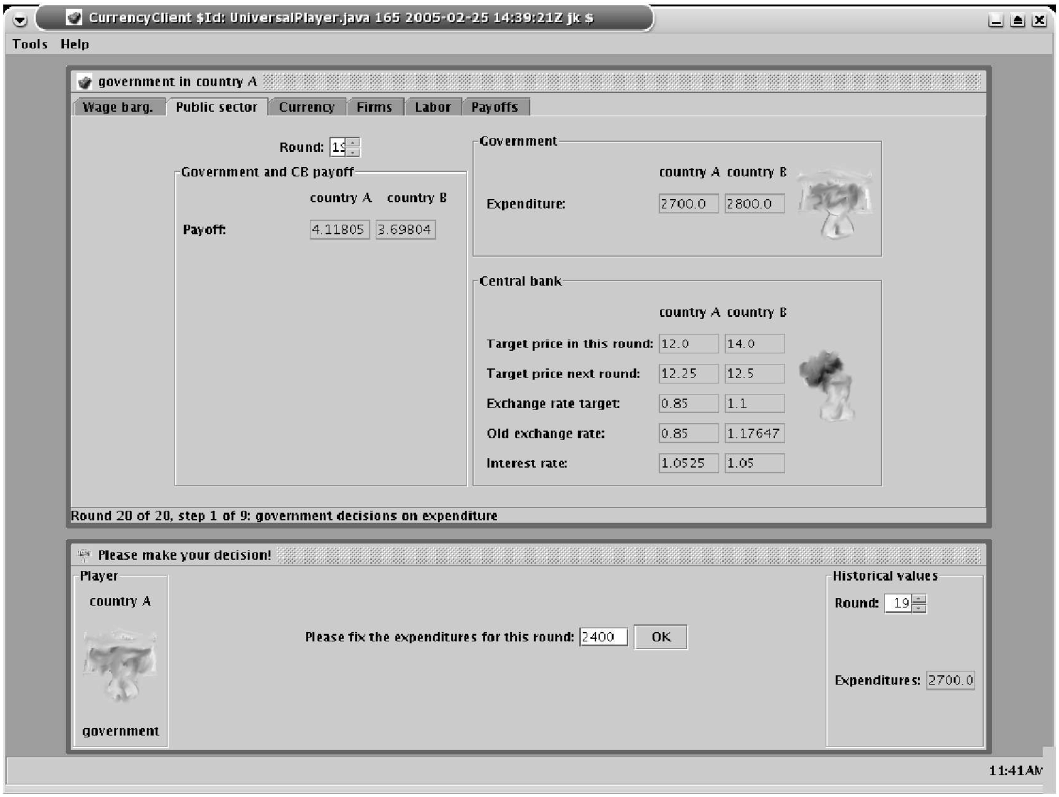


Figure A.1: Screenshot of the government's input frame.

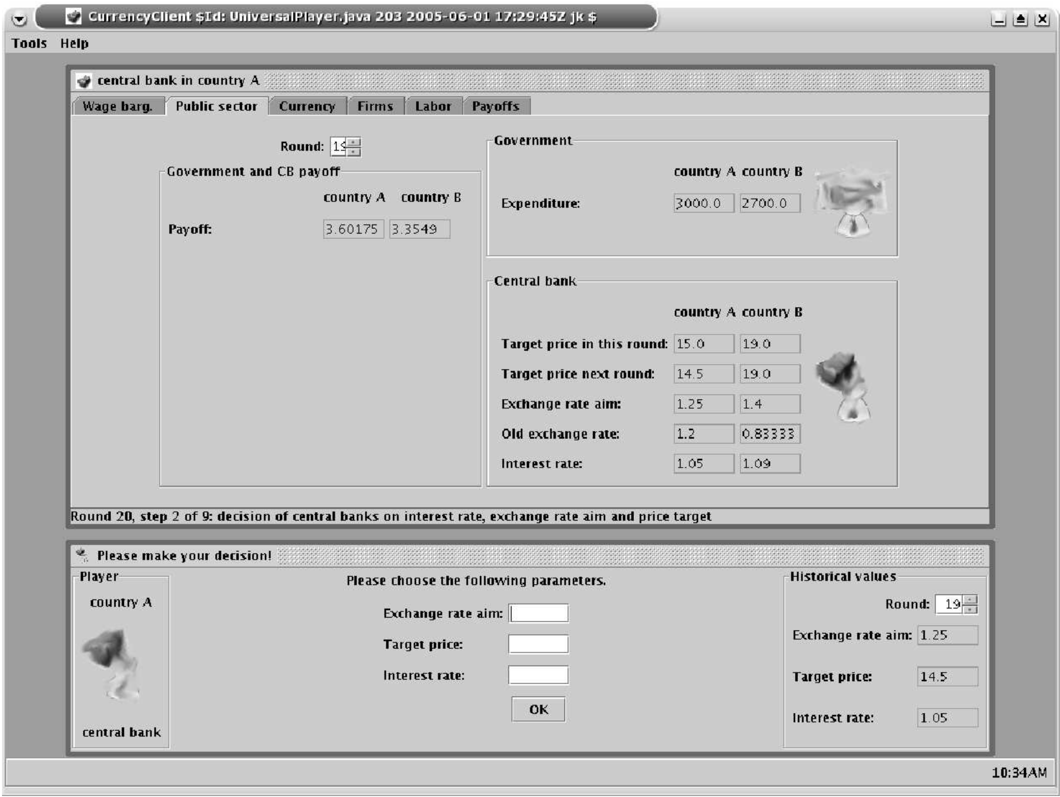


Figure A.2: Screenshot of the central bank's input frame.

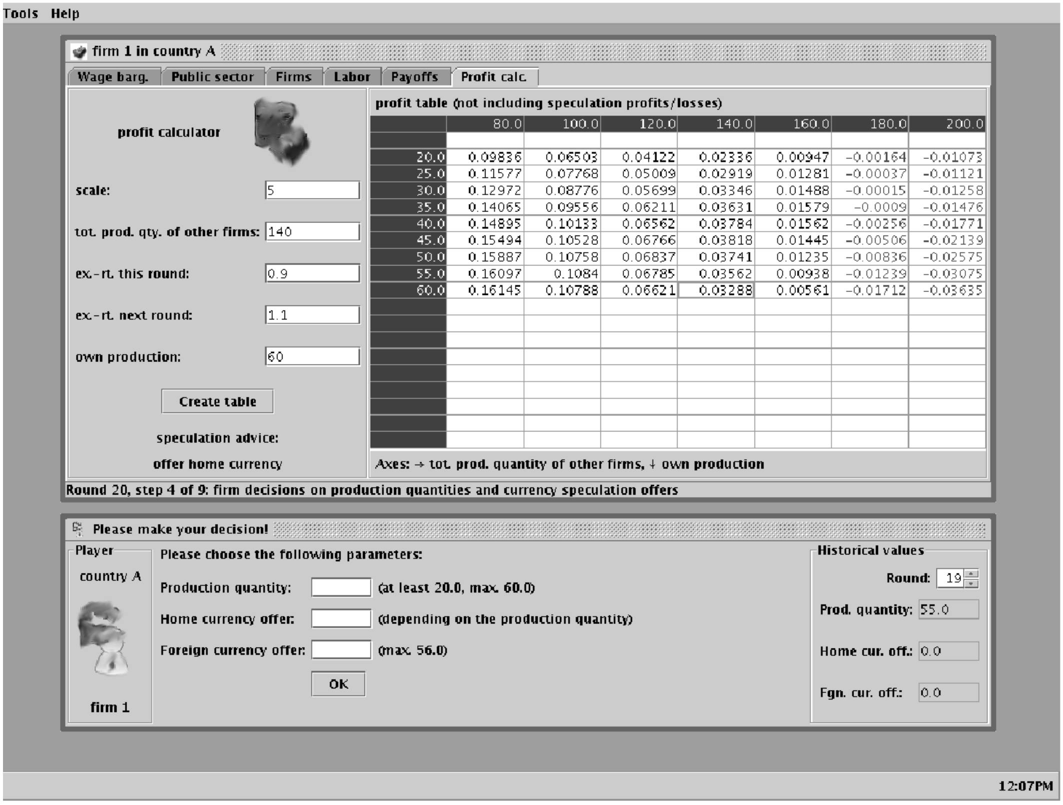


Figure A.3: Screenshot of the firm's input frame.

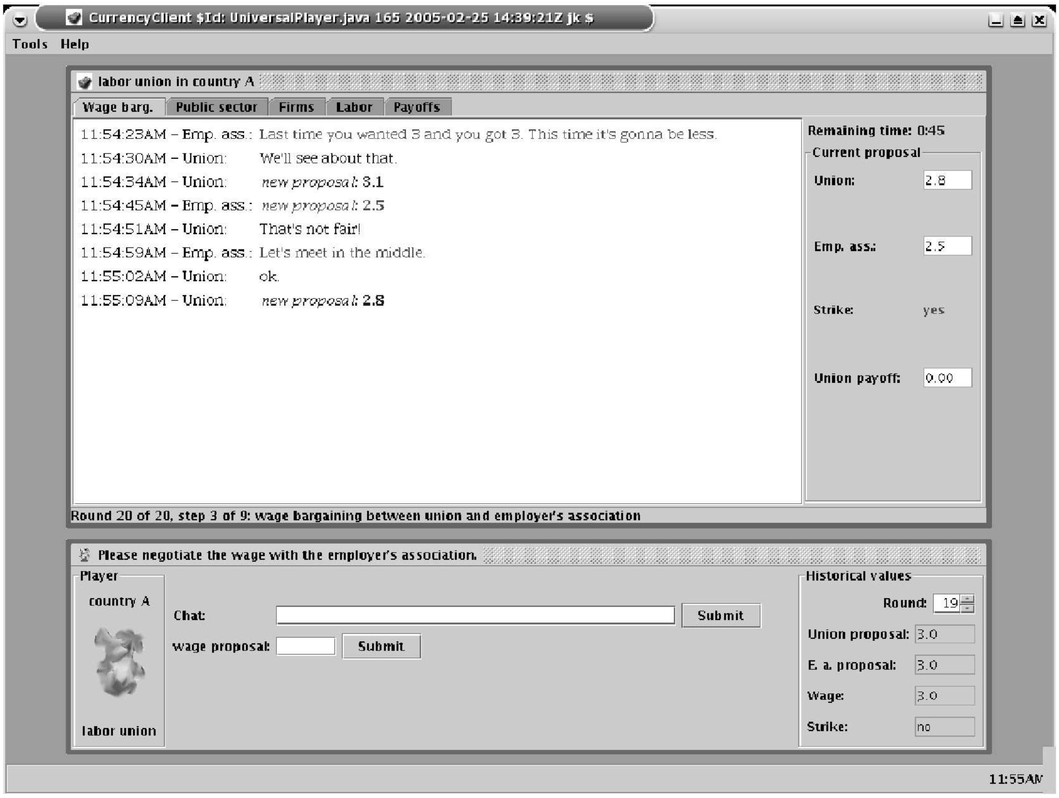


Figure A.4: Screenshot of the labour union's input frame.

B Appendix for Chapter 3: Currency Trade and Exchange Rate Uncertainty

B.1 Tables

Table B.1: Conformance to trading motive (in %)

advice requested	interest difference and speculative advice point in the same direction	decision in this direction	49.06	58.87
		decision in the opposite direction	9.81	
	interest difference and speculative advice point in opposite directions	decision conforming to interest difference	4.91	18.37
		decision conforming to speculative advice	13.46	
advice not requested	decision conforming to interest difference		13.78	22.76
	decision not conf. to interest difference		8.98	

Table B.2: Session averages of the Yule coefficient for home and foreign currency offers and positive and negative interest differences

session	mean of Y
7	0.660509447
8	0.717647059
9	1
10	0.714285714
11	0.685887846
12	1
13	0.364303959
14	0.714285714
15	0.689426144

Table B.3: Correlation between standardised currency offer and exchange rate variation resp. interest difference

session	$\rho^{\psi_i,\Delta e_{t-1}}$	$\rho^{\psi_i,\Delta r_t}$
7	.2455976	.3793693
8	.2247791	.3342151
9	.2307252	.3200829
10	.3652776	.5290438
11	.3357749	.2522709
12	.2256564	.2448294
13	.2222274	.2467859
14	.2878838	.388714
15	.2350855	.1502816

Table B.4: Correlation measures of $\tilde{e}_g$ and $\tilde{e}_r$ per session

session	$\rho^{\tilde{e}_g,\tilde{e}_r}$	R^2
7	.24156232	.00860725
8	-.0553194	.01056194
9	.0622224	.00299655
10	.09360007	.0799354
11	-.19678558	.00004638
12	-.16077205	.00980022
13	.0007471	.00000013
14	-.06672657	.00314537
15	.0533577	.01553479
total	.00174475	.00023264

Table B.5: Percentage of correct and wrong predictions of the sign of the exchange rate change per session

session	% of correct pred.	% of wrong pred.
7	.484472	.515528
8	.2272727	.7727273
9	.3409091	.6590909
10	.287234	.7127659
11	.1060606	.8939394
12	.35	.65
13	.3030303	.6969697
14	.3139535	.6860465
15	.5164835	.4835165
mean	.3254907	.6745093

Table B.6: Profitability of different classes of trade decisions

session	u	Δr_t	h
7	-0.0000129	0.0008271	0.0007644
8	0.0000177	0.0006271	0.000031
9	0.00000952	0.0007683	0.0002806
10	0.00000504	0.0007049	0.0001186
11	-0.0000281	0.000705	0.000736
12	0.000013	0.0007072	0.0000335
13	0.00000841	0.000526	0.0000559
14	0.0000157	0.0006678	0.00044
15	0.00000788	0.0007031	0.000172
mean	0.00000402	0.000692944	0.000292444

Table B.7: Session averages of standardised currency trade profits per trader class

session	$\bar{v}_{\text{curr}}^{\kappa=1}$	$\bar{v}_{\text{curr}}^{\kappa=2}$	$\bar{v}_{\text{curr}}^{\kappa=3}$
7	.00019079	–	.0003877
8	.00002533	.0000529	-.00005867
9	-.00003201	.00018062	.00013901
10	.00003344	–	.00008763
11	.00010462	.00020501	.00023354
12	.00021509	.00026016	–
13	.00000829	.00003267	–
14	-.00002572	–	.00036751
15	.00003503	.00020517	.0001043

Table B.8: Hypothetical (if decision rule was applied) and standardised trade profits

session	$v^{\text{std}}_{\text{curr}}$ (ct. A)	$v^{\text{std}}_{\text{curr}}$ (ct. B)	$v^{\text{std}}_{\text{curr}}$ sess. avg.	$v^{\text{hyp}}_{\text{curr}}$ sess. avg.	$v^{\text{hyp}}_{\text{curr}}$ (ct. A)	$v^{\text{hyp}}_{\text{curr}}$ (ct. B)
7	0.0000179	0.00000499	0.0000115	0.0000111	0.000014	0.00000817
8	0.0000000552	0.000000204	0.00000013	-0.0000000247	-0.000000497	0.000000448
9	0.00000194	0.00000565	0.0000038	0.00000406	0.00000433	0.00000379
10	0.00000334	0.00000127	0.0000023	0.00000269	0.00000353	0.00000185
11	0.00000736	0.00000317	0.00000526	0.00000483	0.0000048	0.00000486
12	0.0000102	0.000011	0.0000106	0.0000122	0.0000129	0.0000114
13	0.000000862	0.000000486	0.000000674	0.0000011	0.00000132	0.000000873
14	0.00000263	-0.00000245	0.0000000872	0.0000161	0.0000222	0.00001
15	0.00000651	-0.00000172	0.0000024	0.0000163	0.0000192	0.0000133

Table B.9: Correlation between cumulative exchange rate volatility and aggregate standardised currency offers

session	$\rho^{\psi,\bar{\delta}_t}$
7	.10857596
8	-.10248707
9	-.35036669
10	-.82100541
11	-.61775789
12	-.04612983
13	.31677962
14	-.77531099
15	-.66592277

Table B.10: Cumulative aggregate standardised home and foreign currency offers

session	ψ_{h}	ψ_{f}
7	61.95385	42.25773
8	67.0229	41.67973
9	61.93498	43.23082
10	31.17691	18.48489
11	49.43409	31.9665
12	71.39223	38.49543
13	53.88873	47.14093
14	52.4529	44.96228
15	57.7877	31.99247
mean	56.33825	37.8012

Table B.11: Shares of growing, falling, and constant exchange rate expectations

session	ϵ^{+}	ϵ^{-}	$\epsilon^{=}$
7	.36024845	.2173913	.42236024
8	.30303031	.25757575	.43939394
9	.30113637	.16477273	.53409094
10	.28723404	.21276596	.5
11	.09090909	.12121212	.78787881
12	.25	.2	.55
13	.42424244	.26262626	.3131313
14	.37790698	.39534885	.22674419
15	.27472529	.22527473	.5

B.2 Calibration

$Q_m =$	20	$\eta =$	0.14
$Q_c =$	60	$\zeta_1 =$	600
$Q_0 =$	45	$\zeta_2 =$	500
$\gamma_1 =$	80	$L_a =$	600
$\gamma_2 =$	20	$L_b =$	720
$\sigma =$	0.6	$r_0 =$	1.05
$F =$	15		

B.3 Symbols

Δe_{t-1}	difference in the height of exchange rate between period t and $t-1$
Δr_t	difference in the height of interest factors of both countries
Ψ	relation of currency offers to foreign account debt
$\bar{\delta}$	exchange rate volatility
ϵ	exchange rate expectation measure
γ_1, γ_2	constants with $\gamma_1 > \gamma_2 > 0$
η	strike wage coefficient
ψ	standardised currency offer
ζ_1, ζ_2	constants with $\zeta_1 \geq \zeta_2 > 0$
C_1	credit constraint on the home account of firms
C_2	credit constraint on the foreign account of firms
D	total expenditures as determined by government
e	exchange rate, price of one unit of foreign money in home currency
$\bar{e}$	tentative exchange rate
e_+	next period's exchange rate
$\hat{e}$	a firm's estimate of this period's exchange rate
$\hat{e}_+$	a firm's estimate of next period's exchange rate
F	fixed labour needed to run the firm
f	exchange rate aim

h	measure for the speculative advice
I	total home central bank currency offer
K	total home account balances of foreign firms transferred to owners
K^*	total foreign account balances of home country firms transferred to owners
K_-	value of K in the previous period
K^*_-	value of K^* in the previous period
L_i	amount of labour needed for producing Q_i
m	price of home materials in home currency
m_-	price of home materials in the previous period
p	target price of the current period
p_+	next period's target price
q	price of the home country consumption good
Q_0	production capacity (in the case of wage conflict) with $Q_0 < Q_c$
Q_c	production capacity (in the case of wage agreement)
Q_i	production of firm i
Q_{-i}	production of all firms except firm i
Q_m	minimum production
$\hat{Q}_i$	estimate on the height of its own production of firm i
$\hat{Q}_{-i}$	estimate of firm i on the height of the total production of all other firms in its home country
r	interest factor
r_0	ideal interest factor
S_i	home account of firm i
S^*_i	foreign account of firm i
$\hat{s}$	scale for the profit calculator of a firm
v	expenditure deflated total profit with $v = \frac{\Pi}{D}$
v_i	expenditure deflated profit of a home country firm i with $v_i = \frac{\Pi_i}{D}$
v_{prod}	production profit
v_{curr}	currency trade profit
w	nominal wage rate

X	total offer of home currency by firms with $X = \sum_{i=1}^{10} X_i$
X^*	total offer of foreign currency by firms with $X^* = \sum_{i=1}^{10} X_i^*$
X_i	amount of home currency offered by firm i
X_i^*	amount of foreign currency offered by firm i
$\bar{X}_i$	maximum foreign currency offer of firm i
$\bar{X}_i^*$	maximum foreign currency offer of firm i
Y	Yule coefficient for a firm player
y	measure for calculating Y

C Appendix for chapter 4: The Tobin Tax

C.1 Symbols

μ - dividend paid for each unit of the asset

η - market efficiency

τ - tax rate

Π_i - payoff of participant i

$\phi(t)$ - fundamental value of one unit of the asset in period t

$\Phi(t)$ - fundamental value of all units of the asset in period t

υ - volatility

c - exchange rate in units of the numeraire for one unit of the asset in the end of the experiment

$\bar{d}$ - statutory demand constraint

d_i - demand of participant i

i - participant number

m - initial endowment of the asset of every participant

m_i - holdings of the asset of participant i

n - number participants

p - average price in period t

p^a - market ask price in period t

p^b - market bid price in period t

p_i^a - individual ask price of participant i in period t

p_i^b - individual bid price of participant i in period t

$\bar{s}$ - statutory supply constraint

s_i - supply of participant i

T - total number of periods

t - current period

x - initial endowment of the numeraire of every participant

x_i - holdings of the numeraire of participant i

C.2 Tables

Table C.2: Different measures of earnings inequality

inequality measure	**untaxed (mean)**	**taxed (mean)**	p
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 C.3: 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 C.4: 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

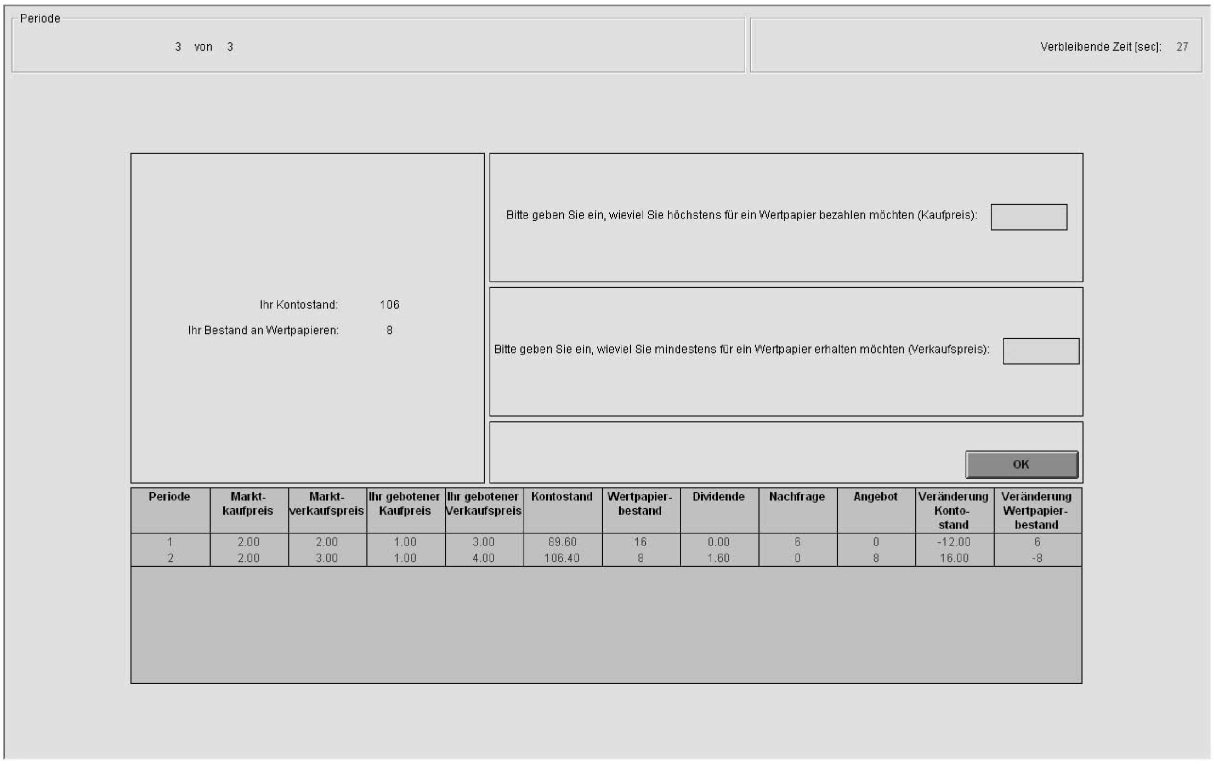
Table C.5: Descriptive statistics per market

	tax rate	fiscal revenues	volatility	market volume	trade turnover	market ineff.	total supply	total demand	#d[1]	#s[1]	Ω^D	Ω^S	median p^a	median p^b	median $p^a - p^b$
1	0	0	27.112	1681	4335.00	51.212	10080	6144	0.92	1.55	9.05	374.55	2	1.8	0.15
2	0	0	103220.8	2024	3873.90	326777.7	7720	10592	1.73	1.69	88.25	135.2	1.8	1.6	0.2
3	0	0	87598.3	1936	4803.46	39877.32	13472	13080	1.41	1.78	20.00	277.96	2	2.05	0.02
4	0	0	65.614	2554	5214.03	17.115	10504	13184	1.63	1.16	53.18	252.65	1.93	1.91	0.09
5	0	0	652.276	2226	3778.99	201.102	9024	10312	1.51	1.43	0.60	652.23	1.6	1.49	0.13
6	0	0	36.018	2759	6075.55	57.488	6920	16448	2.37	1.22	412.57	150.71	2.2	2	0.3
7	0.005	27.21	0.659	2751	5332.06	4.419	13040	10680	1.63	1.94	42.09	583.24	1.94	2	0.15
8	0.01	52.26	0.256	2948	5101.23	7.92	10384	18936	2.1	1.45	133.61	403.71	1.8	1.8	0
9	0.015	70.75	0.176	2585	4631.24	2.656	10368	11016	2.18	1.86	37.22	291.32	1.89	1.85	0.1
10	0.02	65.24	0.003	2098	3175.77	10.06	9112	9752	1.69	1.41	46.18	924.16	1.54	1.47	0.07
11	0.025	165.2	8.293	2345	6309.78	10.327	15584	7648	1	1.78	260.38	171.63	2.61	2.7	0
12	0.03	130.51	26.933	1978	4241.58	17.001	10648	5880	1.47	2.35	77.37	471.92	2	1.68	0.37

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

C.3 Screenshots

Screenshot of Step 1 (Control Treatment)



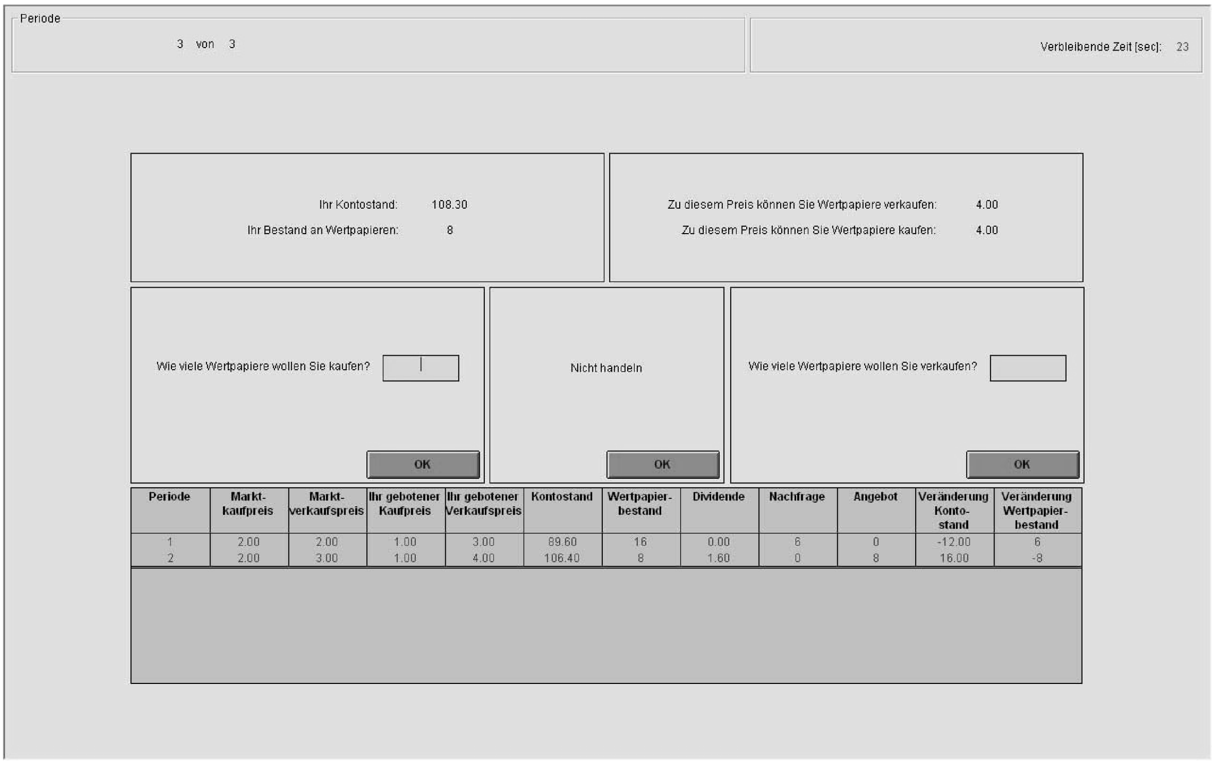
Translation:

- 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 Wertpapier.
asset balance	dividend	demand	supply	change of the account balance	change of the asset balance

Screenshot of Step 2 (Control Treatment)



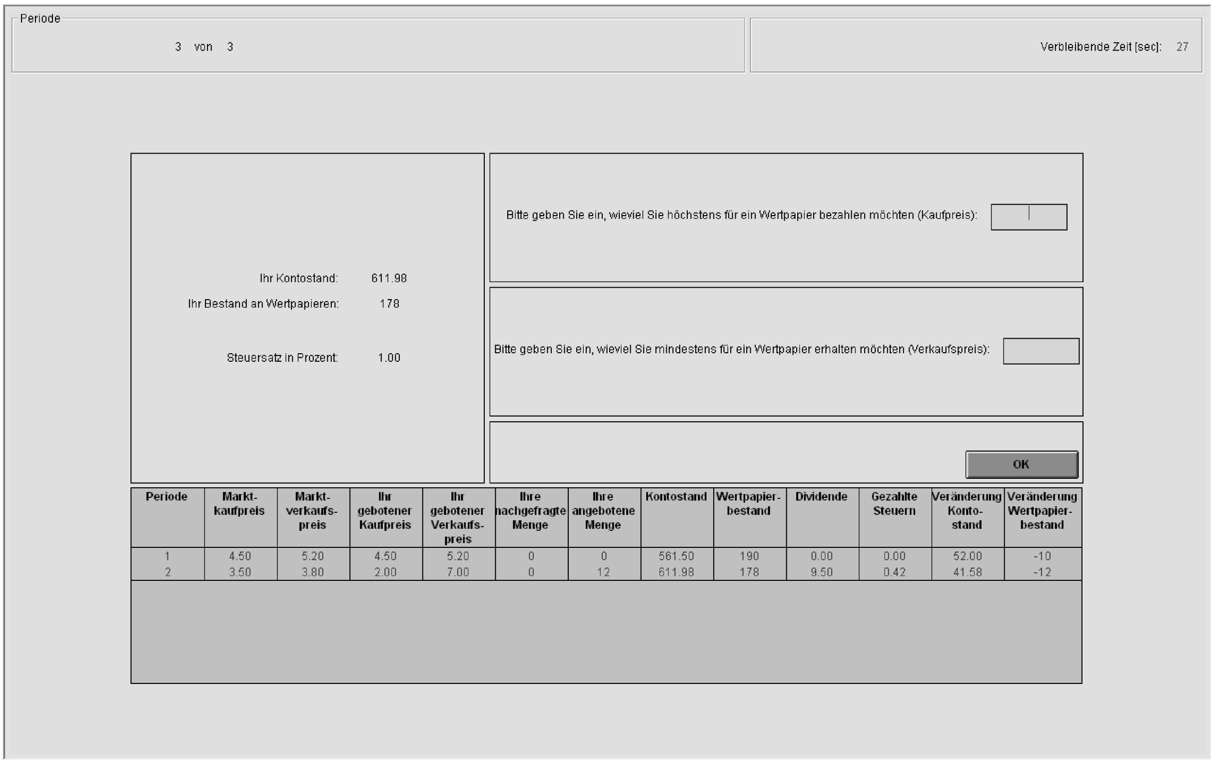
Translation:

- 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 Wertpapier.
asset balance	dividend	demand	supply	change of the account balance	change of the asset balance

Screenshot of Step 1 (Tobin Treatment)



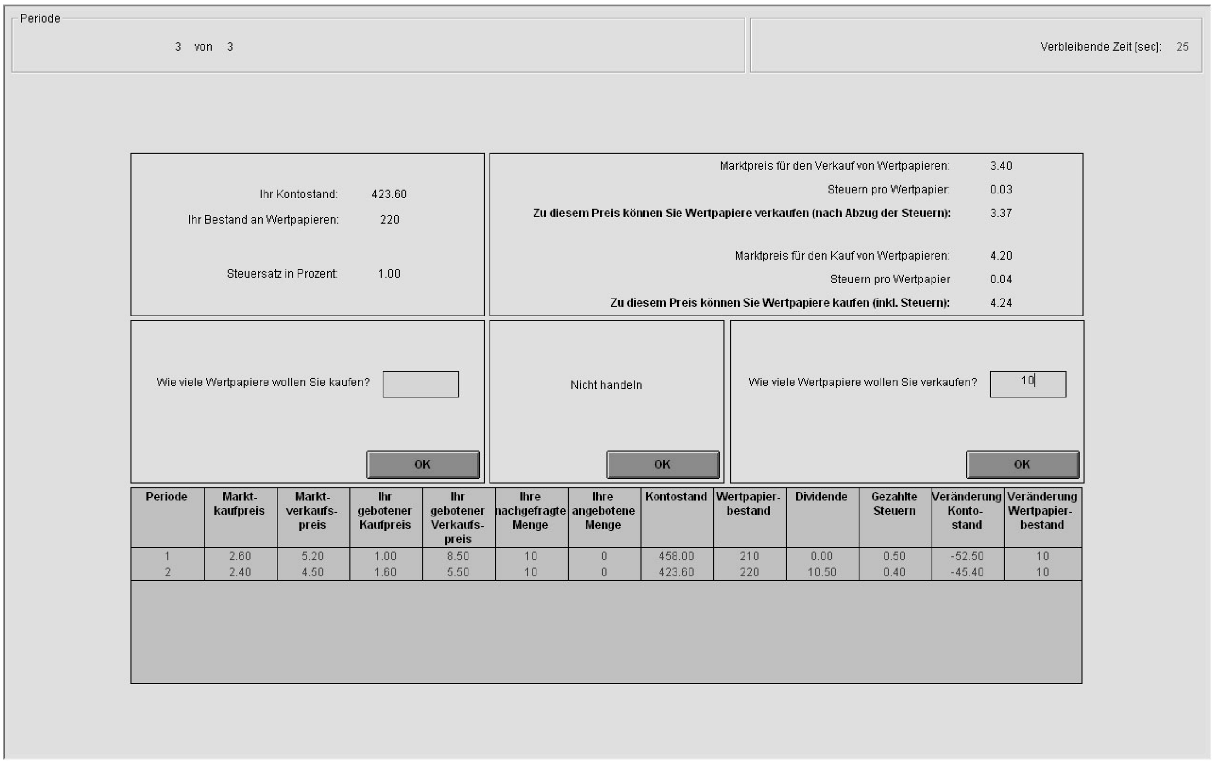
Translation:

- 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 Wertpapier.	
asset balance	dividend	demand	supply	change of the account balance	change of the asset balance	

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 Wertpapier.	
asset balance	dividend	demand	supply	change of the account balance	change of the asset balance	

D Instructions for Experiment 1

D.1 The Two-Currency Case

This is a translation of the original German instructions, taken from the separate paper by Robin Pope, Reinhard Selten, Sebastian Kube, Johannes Kaiser and Jürgen von Hagen (2007): *Exchange rate determination: A model of the decisive role of central bank cooperation and conflict.* Discussion Paper, University of Bonn, Dept. of Economics.

Welcome to This Experiment

This experiment has 18 participants. There are two countries in the experiment

- country A and
- country B

At the beginning of the experiment you will be randomly assigned to one of these countries.

In each of the two countries there are 9 players with 5 different roles:

- government
- central bank
- labour union
- employers' association

- 5 firms.

The firms are numbered from 1 to 5. Each country has its own currency. Your role in this experiment will be randomly assigned to you. The game runs over several rounds. Each round consists of several steps:

- government decision
- central bank decisions
- wage bargaining between union and employers' association
- decisions of firms on production quantities
- decisions of firms on currency transactions

At the above five steps participants playing these roles make their decisions. Three further steps then follow:

- currency market: determination of the exchange rate
- round payments and determination of account balances
- transfer of the firm accounts

In these three steps, players make no decisions. The outcomes of these three steps are calculated by the computer.

The Steps in Detail

In the following everything is described from the point of view of country A. Everything is analogous for Country B. However, the value for country B will be marked by an asterisk, $*$. Decisions are always made for the current round.

Government Decisions

By means of fiscal policy, not modelled in detail, the government in each country determines that country's amount of total expenditure, D and D^*, respectively. This total expenditure is spent entirely on a consumption good produced by firms in that country.

Central Bank Decisions

Each central bank has to fix three decision parameters:

- *the interest rate*
  Note that 1+interest rate = interest factor, r and r^*, respectively. Eg an interest rate of 8% corresponds to the interest factor 1.08. Firms can take short run loans and make short run money investments at this rate.

- *the target price* for the next round, p_+ and p^*_+, respectively. This is the price that the central bank would like to see as the price for the domestic good in the next round. So the current target price p has been set in the prior round, and p_+ is now set for the next round.

- *the exchange rate aim*, f and f^*, respectively. The exchange rate aim states how many units of own currency that the central bank would like to receive for one unit of the foreign currency. What is actually received after the exchange rate market operates, is the actual exchange rate, e and $e^* = 1/e$, something not fixed by each central bank alone but is the result of the currency market's operation. The central banks intervene on the currency market to defend their exchange rate aims. This happens automatically and results in a final exchange rate e between f and $1/f^*$.

Wage Bargaining Between Union and Employers' Association

In this step the union and the employers' association in each country negotiate the wage rate, w and w^*, respectively, for the current round. This is done by exchanging text messages (chatting) and wage offers. These wage offers are not permitted to be lower than the official minimum wage, $w_0 = 0.14p$. Bargainers have 10 minutes for the wage negotiations. If no consensus is reached, there is a strike in that country. In the event of a strike, production capacity and demand are lower than normal in this round, and the wage rate is equal to the minimum wage rate w_0.

Decisions of Firms on Production Quantities

Firms have to make two decisions. The first is to choose a quantity Q_i (here i is the number of the particular firm) of the consumption good to produce and sell. The maximum quantity is 60, but in the case of a strike, the maximum is 45. The minimum quantity is 20. Three inputs are needed for production:

- *Home raw materials*

  For one unit of the consumption good, one needs one unit of home raw materials purchasable on the home material market at a cost of $m = wr$. (This is because each unit of raw materials is produced with a unit of labour that costs w. Then interest paid on prepaid wages increases the total unit cost to wr.)

- *Foreign raw materials*

  For each unit of the consumption good produced a firm uses one unit of foreign raw materials, bought on the foreign material market at a cost of $m^* = w^*r^*$ in foreign currency.

- *Labour*

  Running a firm requires 15 units of labour plus 1 unit of labour for each unit of the consumption good produced. Workers can only be hired on the home labour market where the wage rate is w per unit hired.

If one has decided to produce Q_i units, then one needs:

- $M_i (= Q_i)$ units of home raw materials at a total cost of $M_i m$
- $M_i^* (= Q_i)$ units of foreign raw materials at a total cost of $M_i^* m^*$ in foreign currency
- L_i units of labour with $L_i = 15 + Q_i$ at a total cost of $L_i w$

Decisions of Firms on Currency Transactions

Each firm has a home account and a foreign account. All transactions are entered on the relevant account. Thus the home account is charged with the wage expenses

$L_i w$ and the foreign bank account is charged with the costs $M_i^* m^*$ for foreign raw materials. The existence of two accounts makes currency transactions possible after the production quantity has been fixed. A firm can:

- *either offer home currency* X_i

  Here the firm takes a loan of X_i at an interest inclusive cost of r from its home bank and for this it receives $X_i e^*$ in foreign currency. After earning foreign interest on this foreign currency, the firm has an amount of $X_i e^* r^*$ on its foreign bank account.

- *or offer foreign currency*

  X_i^* Here the firm borrows on its foreign account an amount X_i^* at an interest inclusive cost of r^* . This money is then exchanged on the currency market and the firm receives $X_i^* e$ in home currency, on which it earns interest at the rate r on its home bank account.

- *or offer no currency*

  This means not being active on the currency market.

Take into consideration:

- A firm cannot offer both currencies at the same time

- The amount of currency transactions is limited by how much the firm decided to produce, since a firm must cover its costs for material, labour etc.
  The *maximum amount of home currency* a firm can offer is $(80 - L_i)w$
  The *maximum amount of foreign currency* a firm can offer is $20w^*$

- When a firm offers a currency, it is not yet decided how many units of the other currency it will receive, since it does not get them at the exchange rate for the last round. The currency offers of all firms may have an influence on the exchange rate in the current round. The amount flowing to a firm account in the other currency is calculated at the exchange rate of the current round.

- At the end of the round, the balance on both of a firm's accounts will show what it has earned, however, in different currencies. In the next round the firm's foreign account will be automatically offered at the currency market and will be exchanged to its own currency and this offer may again influence the exchange rate. The value of its foreign account balance in its own currency will be determined by the currency market of the next round. A firm should pay attention to this in connection with its own currency transactions.

- If you are a firm, you can make use of a profit calculator as a decision support. Here you enter your exchange rate expectations for the current round and the next round, how much you want to produce and what you expect the other four firms will produce together. On the basis of these expectations, the computer provides a table with an adjustable scale. In this table you can see your profits obtained if all your expectations come true. At the same time the computer determines which currency you should offer if your exchange rate expectations turn out to be exactly correct.

Currency Market

After all players have made their decisions for the current round, the currency market determines the current exchange rate. The exchange rate is not randomly determined, but depends on the decisions of the firms and the automatic interventions of the central banks. It is determined in such a way that the demand for a currency becomes equal to the supply of this currency.

The *supply* of home currency is composed of:

- The home currency offers of foreign firms (from their point of view the home currency is the foreign currency) and home currency offers of domestic firms ($= X$)

- Money amounts on the foreign accounts of foreign firms at the end of the preceding round, offered in this round, in order to exchange it into their domestic currency ($= K$)

- Possible interventions in home currency of the domestic and the foreign central bank ($= I$)

The *demand* for the home currency is composed of:

- The foreign currency offers of foreign firms (offers of domestic currency from their point of view) and foreign currency offers of home country firms ($= X^*$)
- Money amounts on foreign accounts of home country firms at the end of the preceding period, offered in order to exchange it into home currency ($= K^*$)
- Possible interventions in foreign currency of the domestic and the foreign central bank ($= I^*$)

Therefore the preliminary exchange rate ê is determined by $X + K + I = \hat{e}(X^* + K^* + I^*)$

Central Banks and the Currency Market

The above exchange rate is only preliminary, since the central banks intervene in two ways. At first, each central bank makes precautionary offers in order to defend its own exchange rate aim against that of he other central bank. However, these interventions are limited in the form of a dependence on the preceding round's material price, m and m^* respectively.

There can be two kinds of conflict:

- Each central bank wants a lower value for its own currency than the other bank does, ie $f > 1/f^*$. In this case, the home country central bank offers $I = 600m_{-}$ of its home currency and the foreign central bank offers $I^* = 600m^*_{-}$ of its currency.
- Each central bank wants a higher value for its own currency than the other central bank does, ie $f < 1/f^*$. In this case the home country central bank offers $I^* = 500m^*_{-}$ of the foreign currency and the foreign central bank offers $I = 500m_{-}$ of the home currency (the foreign currency from its point of view).

It is possible that the preliminary exchange rate $\hat{e}$ is outside the interval between the two exchange rate aims. In this case the two central banks cooperate in order to keep the exchange rate in this interval:

- If the preliminary exchange rate $\hat{e}$ is smaller than f and $1/f^*$, then the final exchange rate will be the smaller of the two values, f and $1/f^*$

- If the preliminary exchange rate $\hat{e}$ is greater than f and $1/f^*$, then the final exchange rate e is the greater of these two values.

- If the preliminary exchange rate $\hat{e}$ is between f and $1/f^*$ or at one of these values, then it is also the final exchange rate.

Round Payoffs and Account Balances

In each round you receive a number of points, your round payoff, which depends on your decisions and those of the other participants and on your role. You are credited with these points on your payoff account, an account with a balance in points not usable as a resource in the game.

- Firms
  After each round the account balances of each firm are transferred to its owners. The owners exchange accounts in foreign money to their home currency, but only in the next round. Therefore firms - as also employers' associations - obtain their payoffs for this round only in the next round. Firms and employers' associations receive the value of the domestic account plus that of the foreign account at next round's exchange rate. The domestic component plus the remitted foreign component together comprise the profit of a firm. The round payoff of a firm is profit divided by total domestic expenditure, D or D^*, respectively.

Determination of Firm Account Balances (see Table 2) If You Are a Firm

Home Bank Account

1. Wage payments and offers of home currency are deducted from your home bank account
2. If you have offered foreign currency you are credited on your home bank with the amount into which this converts into your home currency
3. This credit on your home bank account is multiplied up by the domestic interest factor
4. You are credited on your home bank account with the value of your sales (The determination of this value is described below)
5. The costs for domestic materials are deducted from your home bank account

Consequently the final balance on your home bank account is

$$Q_i q + r(X_i^* e - L_i w - X_i) - M_i m$$

Foreign Bank Account

1. If foreign currency is offered, the amount is deducted from your foreign bank account
2. If you have offered home currency, you are credited on your foreign bank account
3. This credit is multiplied up by the foreign interest factor.
4. The costs of foreign materials is deducted

Consequently the final balance on your foreign bank account is

$$r^*(X_i e^* - X_i^*) - M_i^* m^*$$

How Sales are Determined

The total amount produced is always sold. However, the sales price q depends on many factors. Normally the price q is total domestic expenditure divided by total domestic production, ie $q = D/Q$.
In the case of a strike, demand is decreased, and the price is lower, $q = 0.6(D/Q)$.
Once more we want to direct your attention to the profit calculator. It facilitates your decisions by making all these computations for you. It computes the price resulting from your prediction, deducts variable cost per unit for labour and materials, and then computes your gross profits. The fixed labour costs for running firm are deducted from this. Since labour costs arise before interest is paid, the profit calculator also takes account of the opportunity costs arising thereby. In the fields of the table you can see your operating profit. This is not your payoff, but only the part of your profit due to your production decision.

Unions and Employers' Associations

If agreement is not reached in wage bargaining, then there is a strike and you receive no payoff in this round. If, however, you agree on a wage rate, then you receive the following payoffs.

- *Union*
  Your success is measured by the wage rate divided by the current target price. You receive $U = w/p$

- *Employers' association*
  Your success only indirectly depends on the wage rate. You receive the sum Π of profits in your country divided by the total expenditure, $V = \Pi/D$
  Since the sum of profits will only be determined in the next round, you receive the payoff for this round in the next round.

Government and Central Bank

You pursue several goals including price stability and adequate employment. Your payoff function is as follows:

$$\begin{aligned} B &= 5-4\left(\frac{p_+}{p}-1\right)^2-4\left(\frac{q}{p}-1\right)^2-4\,(r-1.05)^2-2\left(\frac{m}{em^*}-1\right)^2 \\ &\quad -2\left(\frac{e}{f}-1\right)^2-0.02\,|600-L|_+-0.01\,|L-720|_+ \end{aligned}$$

Here L denotes total labour demand in your country, ie labour demand of domestic firms for production purposes $(5*15+Q)$ and the labour demand in the domestic materials industry $(M=Q+Q^*)$. The notation $|X-Y|_+$ has the following meaning:

$$|X-Y|_+=\begin{cases} X-Y & \text{for } X>Y \\ 0 & \text{else} \end{cases} \tag{D.1}$$

Your payoff is at its maximum if you attain all of your seven goals.

Final Payoffs

After the end of the experiment you receive the sum of your points (your round payoffs) at a conversion factor depending on your role:

- as a government or central bank, you receive 1 Taler for 1 point
- as a union you receive 19.6875 Taler for 1 point
- as an employers' association you receive 50 Taler for 1 point
- as a firm you receive 250 Taler for 1 point

The number of Talers is then paid in EURO according to the following rule:

Sum in Talers between	*Conversion factor into €*
0 and 60	x
60 and 100	$60+0.5(x-60)$
100 and 200	$80+0.3(x-100)$
200 and 300	$110+0.2(x-200)$
over 300	$110+0.1(x-300)$

You can always look at your decision of the preceding round. You start in an already existing world and therefore you are in round 2 and you can see how the world looked in the preceding round, round 1. This is shown to you in order to help you to get your bearings. You see examples of decisions like those you could take yourself and you can also look at the results obtained (exchange rate, payoffs etc).

Table 1: Example

Explanations:

- / : not relevant here
- values with * eg: if you are in country A, then the D in country B is D^* for you

		country A	country B
values from the preceding round	Materials price in the preceding round m_-	2.666664	3.733338
	actual target price $p=$ that targetted for this round in the preceding round	10	14
government	total expenditure D	2000	2800
central bank	interest rate r	1.05	1.05
	next period's target price p_+	10	14
	exchange rate aim f	0.71429	1.4
wage bargaining	strike	no	no
	wage rate w	2.53968	3.55556
firm 1 as example	production decision Q_1	40	/
	home currency offer X_1	0	/
	foreign currency offer X_1^*	0	/
firm decisions summed for the whole country	total home production	200	200
	total home currency offer	0	0
	total foreign currency offer	0	0
materials industry	demand for materials M	400	400
	materials price m	2.666664	3.733338
markets	final exchange rate e	0.71429	1.4
	consumption goods price q	10	14
payoffs	home bank account of firm 1	146.66692	/
	foreign bank account of firm 1	-149.33352	/
	payoff of firm 1 in this round if $e_+ = e$	0.02	/
	union payoff	0.253968	/
	profit sum	200	/
	payoff of emloyers' association	0.1	/
	payoff of central bank	5	/
	payoff of the government	5	/

Table 2: Development of Account Balances of Firm i

Home Bank Account	Foreign Bank Account
0	0
$-L_i w - X_i$	$-X_i^*$
$X_i^* e - L_i w - X_i$	$X_i e^* - X_i^*$
$r(X_i^* e - L_i w - X_i)$	$r^*(X_i e^* - X_i^*)$
$Q_i q + r(X_i^* e - L_i w - X_i)$	$r^*(X_i e^* - X_i^*)$
$Q_i q + r(X_i^* e - L_i w - X_i) - M_i m$	$r^*(X_i e^* - X_i^*) - M_i^* m^*$
0	0

E Instructions for Experiment 2

This is a translation of the original German instructions for the Tobin tax experiment.

E.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.

E.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.

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