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BACHELOR THESIS

The Impact of the Tobin Tax in a Heterogeneous Agent Model of the Foreign Exchange Market

Author: **Filip Staněk**

Supervisor: **PhDr. Jiří Kukačka**

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Declaration of Authorship

The author hereby declares that he compiled this thesis independently, using only the listed resources and literature.

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Prague, July 21, 2014

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Beside that, my thanks would go to the Institute of Economic Studies and all the people this organisation is composed of. While I might have not used most of what I have learned directly on these pages, it broadened my horizons substantially for which I am incredibly grateful.

Abstract

In this thesis, we assess the impact of the Tobin tax on key statistics of exchange rate returns with use of a heterogeneous agent based model. The answer to the question of how transaction costs affect exchange rate dynamics is not only interesting from a theoretical point of view but also has practical implications as several regulators are contemplating imposition of such a tax nowadays.

Motivated by the recent research showing the great importance of the market micro structure, we choose to explore the impact of the tax in a market cleared by the Walrasian auctioneer. This settings, as we argue, could resemble the two layered structure of the real foreign exchanges more closely than a price impact function which is often adopted in studies regarding the Tobin tax. To assess the impact of the tax, we extend the model of De Grauwe & Grimaldi (2004) by the inclusion of transaction costs. The original model consists of boundedly rational agents who use a blend of fundamental and technical analysis to predict the future exchange rate. An ongoing competition between the forecasting rules creates chaotic price movements not dissimilar to the ones observed in the real foreign exchanges.

We use computational methods to assess the effect of the Tobin tax within the model and find that the Tobin tax is capable of reducing distortions and kurtosis of returns. The effect of the tax on volatility is more intricate. We found that for small values of the tax (0%–0.3%) it negligible increases volatility while for larger values (0.3%–1%) the tax can deliver a decrease of volatility by up to 10% in the case of a 1% tax. Results are robust with respect to the volatility of the fundamental value. In addition, our simulations indicate that the Tobin tax is able to prevent from occurrence of speculative bubbles.

JEL Classification	F12, C63, D84, F31, G18
Keywords	Tobin Tax, Foreign Exchange Market, Agent Based Modelling, Walrasian Auctioneer

Author's e-mail	`Stanek.fi@gmail.com`
Supervisor's e-mail	`Jiri.kukacka@gmail.com`

Abstrakt

Cíl této práce je odhadnout vliv Tobinovy daně na klíčové statistiky časových řad měnových kurzů za pomoci modelu měnového trhu s heterogenními agenty (heterogeneous agent based model). Odpověď na otázku, jak transakční náklady ovlivňují fungovaní měnových trhů, je nejenom zajímavá z teoretického hlediska, ale má také praktické implikace. Hned několik institucí totiž v poslední době zvažuje zavedení určité formy Tobinovy daně.

V naší práci zkoumáme uvalení daně na trh s Walrasovským čištěním (Walrasian clearing). Toto rozhodnutí je motivováno několika studiemi, které demonstrují zásadní vliv tržního uspořádání (market microstructure) při uvalení Tobinovy daně, a nápadnou podobností uspořádání skutečných měnových trhů a teoretického konceptu Walrasovského čištění trhu. Pro samotnou analýzu využíváme model měnového trhu navrhnutý De Grauwe & Grimaldi (2004), který jsme zobecnili zahrnutím transakčních nákladů. Model se skládá z kontinua omezeně racionálních (boundedly rational) agentů, kteří předpovídají budoucí vývoj kurzu pomocí fundamentální a technické analýzy (fundamental/technical analysis). Evoluční souboj těchto dvou strategií pro předpovídání budoucích kurzů dává vznik časovým řadám kurzů s podobnými vlastnostmi, jaké můžeme pozorovat ve skutečných měnových trzích.

Ze simulací, které jsme provedli je patrné, že Tobinova daň skutečně může přispět ke stabilizaci trhů. Uvalení daně snižuje špičatost výnosů (kurtosis) a distorze. Vliv daně na volatilitu je netriviální. Při malých hodnotách (0%–0.3%) Tobinova daň nepatrně (ale statisticky významně) zvýší volatilitu. Naopak při větších hodnotách daň volatilitu snižuje (až o 10% v případě daně 1%). Výsledky jsou robustní vůči volatilitě fundamentální hodnoty. Ze simulací je nadále patrné, že Tobinova daň snižuje pravděpodobnost výskytu spekulativních bublin.

Klasifikace JEL	F12, C63, D84, F31, G18
Klíčová slova	Tobinova daň, měnový trh, agentové modelování, Walrasův proces

E-mail autora	`Stanek.fi@gmail.com`
E-mail vedoucího práce	`Jiri.kukacka@gmail.com`

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Bachelor Thesis Proposal

Author	Filip Staněk
Supervisor	PhDr. Jiří Kukačka
Proposed topic	The Impact of the Tobin Tax in a Heterogeneous Agent Model of the Foreign Exchange Market

Topic characteristics In 1972 economist James Tobin proposed a small tax (less than 0.5%) charged for transactions on foreign exchange markets. The Tax was supposed to discourage speculative investors while not to inhibit the international trade and consequently stabilize foreign exchange markets. The Tobin tax was never actually introduced, however the discussion about its possible effects is alive till now. The aim of this thesis is to design a micro-founded heterogeneous agent model (HAM henceforth) of a bilateral foreign exchange market and using computer simulations examine, whether such model exhibits at least some of stylized facts typical for foreign exchange markets. In the second part of this thesis the Tobin tax will be implemented into the model and its effects on various properties of the exchange rate behaviour such as volatility or market distortions will be analysed.

The research on effects of the Tobin tax is far from conclusive. Recently, two methods have been frequently used to study this policy: HAMs and laboratory experiments. Most of HAMs shows that the Tobin tax can have a positive effect on stability of markets. On the other hand, laboratory experiments suggest otherwise. We believe that a micro-based HAM which relies mostly on behavioural parameters estimated by experimental economists rather than abstract parameters and their tweaking to fit the real data the best (approach adopted by most HAMs studying effects of the Tobin tax) may bring some insights on this issue since it is a combination of previously mentioned methods. Moreover, micro foundations allows implementing factors such as risk non-neutrality and a limited wealth effect of agents — aspects that has not been taken into account in most of HAMs regarding the Tobin tax.

Hypotheses

- HAMs are generally suitable for analysing effects of policies such as the Tobin tax.
- A micro-founded HAM of the foreign exchange market is capable of reproducing stylized facts typical for real exchange markets.
- A micro-founded HAM may help to bridge the gap between results of economic experiments and HAMs.
- Factors such as risk non-neutrality and a limited wealth of agents matter when imposing the Tobin tax and a micro-founded HAM is suitable for incorporating these factors.

Outline

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Author

Supervisor

Chapter 1

Introduction

In 1972, during one of his Janeway Lectures at Princeton economist James Tobin proposed a small, uniform tax on all foreign exchange transactions. J. Tobin argued that the absence of any consensus on fundamentals in foreign exchange markets in combination with low transaction costs and a limited rationality of market participants alters process of price discovery into the *"game of guessing what other traders are going to think"* (Tobin 1978). However if investors form their expectations at least partially based on the perceived expectations of other market participants, it gives rise to a positive feedback which may cause price misalignments and an excessive volatility. Since most of the speculative transactions are made on a very short-term basis, Tobin believed that a small transaction tax imposed on every transaction could dissuade most short-term speculators and consequently stabilize the market. At the same time the tax was intended to be small enough[1] not to severely affect the international trade. As Tobin put it: *"I don't intend to add even a small barrier to trade. But I see offhand no other way to prevent financial transactions disguised as trade."* (Tobin 1978, pp. 14–15)

An idea of taxing financial transactions is not a new one. Tobin was inspired by the work of J. M. Keynes who proposed a tax levied on stock trading for a similar reason. Keynes was concerned with the fact that many investors are trying to gauge market sentiments rather than assess a fundamental value of the asset and act accordingly (Keynes 1936). Likewise in the case of foreign exchange markets, Keynes believed that these "mood" investors trade more frequently than the ones who expect price to eventually converge to some fundamental value and would be therefore penalized by the tax more severely.

[1] Different proposals for the tax are ranging from 0 to 0.5%.

A change of the structure of the population of speculators could make stock markets more predictable and less prone to speculative bubbles.

A more predictable exchange rates is an idea appealing to many participants in a global economy as it allows more precise economic planing for enterprises operating internationally (Round 2000). Ellen Frank summarized the argument for the tax on foreign exchange transactions as follows:

> *"If by globalization we mean the determined efforts of international businesses to build markets and production networks that are truly global in scope, then the current monetary system is in many ways an endless headache whose costs are rapidly outstripping its benefits."* (Frank 2002, para. 4)

It is therefore not surprising that since 1972, a transaction tax levied on foreign exchange markets (henceforth referred to as the Tobin tax) was frequently discussed. Public and political representation seems to be especially inclined to such a proposal in times after a financial crisis when any kind of transaction tax on financial assets is seen as a suitable tool for raising public revenues from whoever originated the crisis.[2] Most recent examples are China which is considering adoption of the Tobin tax to guard Yuan against speculative capital flows (Regan 2014, via Bloomberg) or an initiative of 11 Euro-zone members to introduce a tax on a broad range of financial transactions till 2016. Even thought that the proposed European tax in its current form does not cover currency transactions, it is legally possible for it to be extended in that direction later on (Huw 2014, via Reuters).

Despite the vivid public discussion on the topic, academic scrutiny had remained relatively scant (Westerhoff & Dieci 2006). This is surprising since it is not obvious at all that the Tobin tax could deliver desired results: decrease of volatility. Several researches addressed this intriguing question with use of various methods but the results of these studies seem to be far from conclusive. A need for better understanding of how would the Tobin tax affect market dynamics was among others emphasised by economist Korkut Erturk:

> *"If the Tobin tax is not stabilizing, then much of the rest of the discussion on its feasibility and other related issues are probably moot."* (Erturk 2006, pp. 72)

[2] This "Robin Hood" conception of the tax is in a sharp contrast with Tobin's original view since he considered the tax to be beneficial on its own due to the stabilization of exchange rates and autonomy it provides to national macroeconomic policies. Collected revenues were considered to be a mere side effect.

In this thesis we extend the existing research on the impact of the Tobin tax on price dynamics by exploring how the Tobin tax affects a market populated by boundedly rational agents and cleared by a Walrasian auctioneer. To do so, we generalize a foreign exchange model originally developed by De Grauwe & Grimaldi (2004) by the inclusion of transaction costs and then use computational methods to assess the possible impact of the Tobin tax on the key statistics of exchange rates.

The remainder of this thesis is organized as follows. Chapter 2 reviews existing literature and provides a motivation for the choice of the model. Chapter 3 describes the model we use and the modifications compared to De Grauwe & Grimaldi (2004). Chapter 4 contains details about a calibration of the model and subsequent simulations. Finally in Chapter 5 we summarize our findings.

Chapter 2

Motivation and Literature Survey

The most straightforward way to assess an impact of the Tobin tax is obviously to examine some real word imposition of such a tax. Unfortunately, required time series are not available as the Tobin tax has never been implemented so far (Hanke *et al.* 2010). Aliber *et al.* (2003) nevertheless developed an innovative method for the estimation of transaction costs using foreign exchange futures and found that the transaction cost (such as the Tobin tax) is positively linked with the exchange rate volatility. Even though authors addressed an endogeneity issue, Werner (2003) argued that the causality might still be just as well of the opposite direction—i.e. an exogenous increase of transaction costs might lead to the reduction of the volatility.

Despite the work of Aliber *et al.* (2003) being the *only* empirical evidence regarding the Tobin tax, there exist other empirical studies on the link between transaction costs and volatility conducted on securities markets. To name just a few of them: Umlauf (1993) and Hau (2006) conducted studies on the Swedish and French stock markets respectively. In both ones authors found the transaction tax would cause an increase rather than a decrease of the price volatility. In contrast, Liu & Zhu (2009) examined a deregulation of commissions in the Tokyo stock exchange and found that the increase of the transaction cost is linked with the decrease of the volatility. Interpretation of these conflicting results is even more difficult if we consider that the stock markets differ substantially from foreign exchange markets in terms of a trading volume and their micro-structure. Due to reasons discussed later in this section it is not apparent whether these studies have any bearing on the Tobin tax at all.

Since the empirical evidence is sparse, researchers have to use different theoretical models to address the question how the Tobin tax might alter exchange rate dynamics. Before we examine these models in detail, it is necessary to turn our attention to a key underlying assumption both Keynes and Tobin made in their proposals.

The idea that a transaction tax might stabilize markets by dissuading certain speculators relies crucially on the premise that some speculators are not fully rational (in terms of rational expectations) and cause markets to be more volatile.[1] In our model, just as in the majority of literature presented bellow, we *assume* that market participants are not fully rational and examine the impact of the transaction tax under conditions both Tobin and Keynes had in mind. This is plausible not only due to the body of evidence in favour of the bounded rationality (for a review, see Conlisk 1996) but also due to the fact that models involving boundedly rational agents, unlike these with fully rational ones, are capable to closely mimic statistical properties of real foreign exchange time series (LeBaron 2006). After all, it would be nonsensical to examine the impact of the Tobin tax on a traded volume or an endogenous volatility in a model which is incapable to generate either.

A method of agent based modelling was recently often adopted in studies regarding the Tobin tax since it is suitable for the examination of interactions of various boundedly rational agents in any environment imaginable. This versatility is however not without costs. First, often even relatively simple agent based models are analytically intractable. Even more importantly, the design of an agent based model necessary involves lots of assumptions about the behaviour of agents and the environment they operate in. This is troublesome since every seemingly insignificant assumption may cause conclusions drawn from the model to differ substantially. The aim of this thesis is, among others, to gain a deeper understanding of the influence of one such an assumption which was recently proven to be of great importance when evaluating the impact of the Tobin tax: a way how liquidity is provided to the market and the market is cleared.

There is a wide consensus on the fact that the Tobin tax will reduce market depth which may in turn increase the volatility as the price impact of a single order will be larger (e.g. Doyne Farmer *et al.* 2004). Since the market depth of foreign exchange markets is relatively high, proponents of the Tobin tax argue that the change of the composition of a speculators population (a penalization of short-term speculators) will outweigh this effect and results in the overall decrease of volatility.

[1] Whether this is really possible is disputable, see Friedman (1969).

While most studies explicitly model the structure of a speculators population, only a few take into account the effect of the tax on the volatility through the liquidity of the market. This is due to the fact that most studies explore the impact of the tax in a dealership market where the market price is determined with use of a price impact function (i.e. a function which translates an excess demand into the price change) which is constant in a total trading volume. This danger of a systematic overestimation of the positive effect of the Tobin tax was pointed out by Ehrenstein *et al.* (2005) who demonstrated that under a more realistic price impact function[2] decreasing with respect to the total trading volume (i.e. the price impact of a single order is determined by a relative size of such order compared to the total trading volume—the effect of liquidity is therefore included) the Tobin tax can have either negative or positive effect on the volatility depending on how sensitive the price impact function is with respect to the total trading volume. This fact seriously questions conclusions drawn from previous models.

Pellizzari & Westerhoff (2009) further supports findings of Ehrenstein *et al.* (2005) by exploring the impact of the Tobin tax on an identical population of agents interacting in either a continuous double auction or in a dealership market. In the dealership market where an abundant liquidity is provided by the market maker the Tobin tax indeed reduces the volatility. In the continuous double auction with an endogenous provision of liquidity the otherwise stabilizing effect of the Tobin tax is offset by the reduction of the market depth which in turn increases the price impact of individual market orders. This leads to an increase of the volatility. The results of Pellizzari & Westerhoff (2009) were replicated in a laboratory with human subjects rather than artificial agents by Kirchler *et al.* (2011) which made conclusions especially sound.

A hypothesis induced from the work of Ehrenstein *et al.* (2005) and Pellizzari & Westerhoff (2009) can be stated as follows: the Tobin tax levied on a market with an exogenous provision of liquidity (e.g. dealership market) is capable of stabilizing the market while the Tobin tax levied on a market with an endogenous provision of liquidity (e.g. continuous double auction with an endogenous supply of limit orders) may have little or adverse effect on the stability of the market.

Besides individual studies focusing on the link between market micro-structure and the impact of the Tobin tax, a variety of research papers also indirectly

[2]For an argument why such impact function is more appropriate than the function constant in the total volume see Doyne Farmer *et al.* (2004).

supports our hypothesis as different authors tend to use different agent based models to study the tax. A majority of researchers explored the impact of the Tobin tax in a framework of the dealership market with the price impact function constant in the total trading volume and consistently with our hypothesis found the tax to reduce the volatility. Namely: Ehrenstein (2002), Westerhoff (2003), Westerhoff (2004b), Westerhoff & Dieci (2006), Demary (2006),[3] Westerhoff (2008), Bianconi *et al.* (2009), and Demary (2010) reported that the Tobin tax is capable of stabilizing markets.

While considering only dealership markets, the impact of the Tobin tax seems to be a clear cut, we observe a quite different picture when examining agent based models exploring the impact of the Tobin tax in the framework of the continuous double auction which allows for the endogenous liquidity provision. Mannaro *et al.* (2005) and Mannaro *et al.* (2008) demonstrated that under a double auction like mechanism the Tobin tax actually increases price volatility. Also Lavička *et al.* (2013) in a similar settings reported that the tax increases the volatility but at the same time reduces the kurtosis of returns. Results more in line with expectations of proponents of the Tobin tax were obtained by Hein *et al.* (2006).

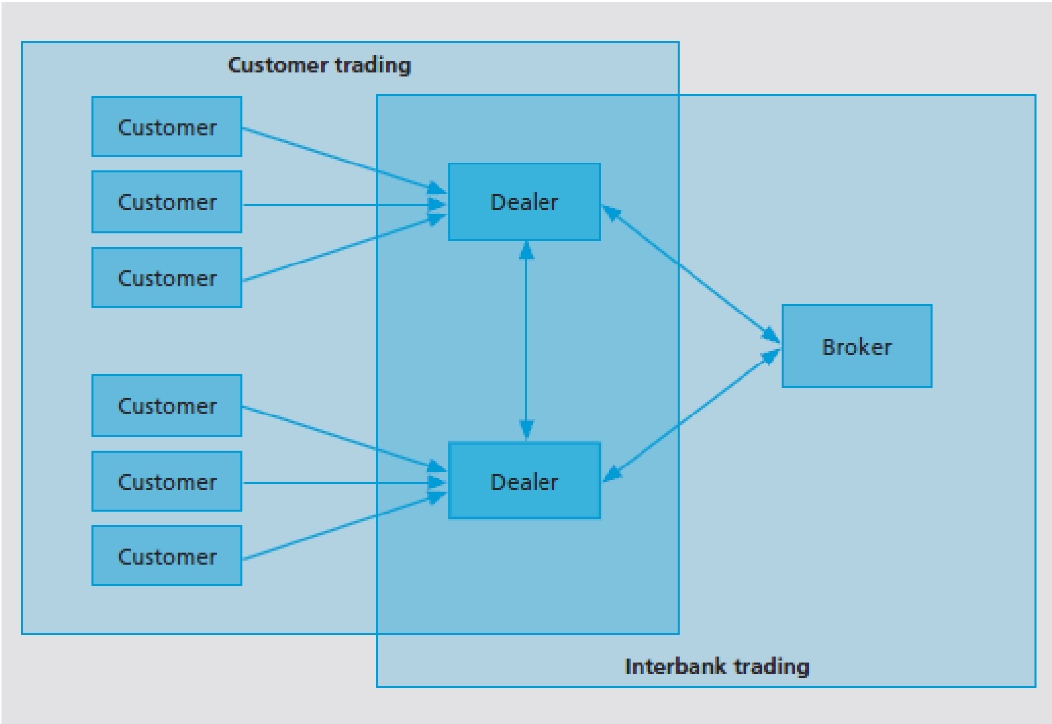
Motivated by the pattern presented above showing the great importance of the market micro-structure, we chose to explore the impact of the tax imposed on a market which is, just like in the studies presented above, populated by several groups of traders with different forecasting rules for the future exchange rate *but* cleared by a Walrasian auctioneer instead of the double auction or the simple price impact function. The reason why we chose to explore the Tobin tax in this particular settings is threefold:

First, the impact of the Tobin tax on the volatility in a market cleared by the Walrasian auctioneer and populated by boudedly rational agents has to the best of our knowledge not been examined in any study so far.[4] Therefore even if real foreign exchange markets differ from the framework presented in our model, our results can be used as a possible building block for reasoning how might the Tobin tax affect much more complex market structures more closely resembling real word foreign exchanges. This is especially important since the real foreign exchange markets are not organized as neither pure continuous double auctions nor dealership markets, as one might expect based on the previous paragraphs.

[3] Authors nevertheless reported an *increase* of the kurtosis of returns.

[4] The walrasian clearing is nonetheless often adopted in a completely different strain of models of rational and noisy traders (e.g. Palley 1999; Damette 2009).

Figure 2.1: Structure of Foreign Exchange Markets



Source: Deutsche Bundesbank (2008).

Simplified structure of a foreign exchange market is depicted in Figure 2.1. Dealers continuously update two way quotes for their customers and thus act as market makers. Beside that dealers also trade with each other either via brokers (in a continuous double auction fashion) or directly using systems such as EBS or Reuters (i.e. dealers are market makers for each other). An obvious question is why to model foreign exchange markets as the continuous double auction, dealership market or Walrasian market if it is none of them. Unfortunately, our understanding of how customers and dealers behave is too limited to construct some full fledged model of a foreign exchange market.[5] But even with a more complete knowledge, such model would be still extremely hard to analyse due to its complexity.[6] We are therefore left to analyse some simplified versions of foreign exchange markets, a market cleared by the Walrasian auctioneer being one of them.

Secondly, we argue that the Walrasian clearing might depict the trading activity at a daily frequency on real foreign exchanges more accurately than

[5]For a review of models of the intra dealer trading see Frankel *et al.* (2009).

[6]An economist Joan Robinson wittily described this trade-off between fidelity and practicability: *"A model which took account of all the variegation of reality would be of no more use than a map at the scale of one to one."* (Robinson 1963, pp. 33)

the price setting via the continuous double auction or the price impact function. The intra dealer trading accounted for roughly 39% of the total trading volume[7] in 2013 (BIS 2013). While this relatively large figure[8] was the basis of the criticism for an extensive speculation on foreign exchange markets, it is not completely true that this trading is primarily of a speculative nature. Instead, it rather represents a tedious task of passing undesired inventories (originated by a single, possibly speculative, customer-dealer trade) along until they happen upon a dealer with the opposite undesired position so they neutralize them-self (Flood 1994). This phenomenon is conveniently called "Hot potato trading" in the literature. In addition, dealers generally change their positions dramatically throughout the trading day but at the end of the day, a majority of them ends with the zero net position just like they started (Cheung *et al.* 2004). Considering these two points, one may easily gain an impression that all the intra day trading among dealers and the adjustment of quotes for customers is some sort of intricate tâtonnement process of searching for the price under which all customers would hold desired positions with respect to their expectations and at the same time none of dealers (which altogether represent "the auctioneer") would be exposed to the exchange rate risk.

A third, more subtle point is that in the Walrasian settings we bypass a decision on the exact form of the price impact function and its relation to the liquidity. This is relieving due to difficulties related to the estimation of the price impact functions (Westerhoff 2004a) and the sensitivity of results on the choice of such a function (Ehrenstein *et al.* 2005).

[7] derivatives included

[8] In past even significantly higher, see BIS (2013).

Chapter 3

Model

To study how the Tobin tax will alter price dynamics in a market cleared by the Walrasian auctioneer we extend an agent based model of a foreign exchange developed by De Grauwe & Grimaldi (2004). The original model is composed of a continuum of boundedly rational risk averse agents who optimize their portfolio based on the anticipated exchange rate development. They form their expectations using two distinct forecasting rules and at the end of a trading round they compare the accuracy of these rules and possibly switch from one to another. An ongoing competition between the forecasting rules creates chaotic price movements not dissimilar to the ones observed in real foreign exchanges which make the model suitable for an examination of how these dynamics will be affected by the Tobin tax.

To assess the impact of the Tobin tax we need to slightly modify the model of De Grauwe & Grimaldi (2004). For obvious reasons we extend the model by the inclusion of transaction costs into the optimization problem agents face. Beside that we also consider the market to be populated by a finite number of agents to facilitate simulations and add a stochastic noise to the system. To enhance comprehensibility, we set the interest rates of both countries to be zero just as in the stimulations runs by De Grauwe & Grimaldi (2004). A slightly more general model allowing for different interest rates can be easily obtained but is not especially insightful.[1] Despite these changes, with a suitable parametrization, both models coincide and our model can be there-

[1] We do not argue that interest rates do not affect the exchange rate, they obviously do. The point is that the constant exogenously determined interest rates just as in De Grauwe & Grimaldi (2004) affect only levels of the exchange rate, not exchange rate dynamics which are our only concern. For details, see De Grauwe & Grimaldi (2004).

fore considered to be a generalization of the model developed by De Grauwe & Grimaldi (2004) allowing for transaction costs.

Although we provide explanations and reasoning behind equations in this section which are sufficient for understanding the model, we strongly recommend reader to also consult the work of De Grauwe & Grimaldi (2004) where the original model is presented altogether with lots of valuable insights about the dynamics produced by the model and its relation to both classical models and other agent based literature. In following paragraphs we focus primarily on modifications compared to the original model.

3.1 Portfolio Optimization

Our model is populated by N boundedly rational risk averse agents. A utility function of the i-th agent is defined as follows:[2]

$$U(W_{t+1}^i) = E_t^i(W_{t+1}^i) - \frac{1}{2}\mu V_t^i(W_{t+1}^i), \tag{3.1}$$

where W_{t+1}^i represents the agent's wealth at time $t+1$. E_t^i and V_t^i are operators of conditional expectations and conditional variance respectively. μ is a positive parameter capturing the degree of the risk aversion.

Agents in our model optimize their portfolio based on the anticipated exchange rate development. Each trading round individual agents can choose to distribute their wealth in either domestic currency or the foreign currency. The wealth of the agent i at time $t+1$ is therefore naturally specified as follows:

$$W_{t+1}^i = W_t^i + d_t^i(s_{t+1} - s_t) - \tau|d_t^i - d_{t-1}^i|s_t, \tag{3.2}$$

where d_t^i are holdings of the foreign currency at time t and s_t is a price of the foreign currency in terms of the domestic currency at time t. The τ is an ad valorem transaction tax. The second term on the right-hand side of Equation 3.2 represents the exposure of the agent to exchange rate movements. The third term is a novelty compared to the original model. It represents an additional cost of changing positions due to the transaction tax τ. The cost is proportional to the change in the position and the price, i.e. the transaction tax

[2]Equation 3.1 can be derived from a widely used utility function $U(W) = -exp(-\mu W)$ under the assumption of normality of the wealth.

is being paid in terms of the domestic currency and by both parties participating in the transaction.

From Equation 3.2 it is immediately apparent that the model is highly asymmetrical. All agents compute their wealth in terms of the domestic currency which is therefore considered to be the safest with respect to exchange rate movements. One may easily question whether such settings is realistic[3] but for the sake of assessing the impact of the Tobin tax alone we will follow the original model as close as possible. Nevertheless, exploring how the exchange rate dynamics change when considering a symmetric version of the model might be an interesting avenue for future research. Please also note that the selling price of the foreign currency is equal to the buying price in Eq. 3.2, i.e. spreads are omitted from the model. While this is certainly unrealistic, a model with non-zero spreads determined endogenously would be extremely hard to design and analyse.

A maximization of the utility with respect to holdings of the foreign currency d_t^i yields individual demands for the foreign currency at time t for given $E_t^i(s_{t+1})$ and $V_t^i(s_{t+1})$:

$$d_t^i(s_t) = \begin{cases} \frac{E_t^i(s_{t+1}) - s_t(1+\tau)}{\mu V_t^i(s_{t+1})} & s_t \in \left(0,\ \frac{E_t^i(s_{t+1}) - \mu V_t^i(s_{t+1}) d_{t-1}^i}{1+\tau}\right) \\ d_{t-1}^i & s_t \in \left[\frac{E_t^i(s_{t+1}) - \mu V_t^i(s_{t+1}) d_{t-1}^i}{1+\tau},\ \frac{E_t^i(s_{t+1}) - \mu V_t^i(s_{t+1}) d_{t-1}^i}{1-\tau}\right] \\ \frac{E_t^i(s_{t+1}) - s_t(1-\tau)}{\mu V_t^i(s_{t+1})} & s_t \in \left(\frac{E_t^i(s_{t+1}) - \mu V_t^i(s_{t+1}) d_{t-1}^i}{1-\tau},\ \infty\right). \end{cases} \tag{3.3}$$

A straightforward interpretation of Eq. 3.3 is that for an exchange rate at time t (suggested by the Walrasian auctioneer) not sufficiently deviating from the expected exchange rate (adjusted for the current position) the agent i chooses to refrain from trading since the expected realized profit from the change of positions would not exceed the cost of transaction $\tau|d_t^i - d_{t-1}^i|s_t$. On the other hand if the price offered in the tâtonnement process is sufficiently smaller (larger) than the i-th agent's expectation of the exchange rate, the agent buys (sells) the foreign currency to realize a profit (minimize lost).

[3]Such model could be a reasonable approximation of reality when considering two currencies, one widely used and the other of only regional importance.

3.2 Clearing Mechanism

Let Z_t be an exogenously determined supply of the foreign currency at time t. Than any $s_t > 0$ such that $\sum_{i=1}^{N} d_t^i(s_t) = Z_t$ is said to be a clearing price. For $\tau = 0$, the model is identical to De Grauwe & Grimaldi (2004) and the unique clearing price can be expressed as:

$$s_t = \frac{1}{\sum_{i=1}^{N} \frac{1}{\mu V_t^i(s_{t+1})}} \left(\sum_{i=1}^{N} \frac{E_t^i(s_{t+1})}{\mu V_t^i(s_{t+1})} - Z_t \right). \quad (3.4)$$

However, for $\tau > 0$ one encounters several difficulties. First, the clearing price s_t may no longer be unique as it is obvious from Eq. 3.3. Secondly, although for all possible clearing prices there exists a close form expression just like Eq. 3.4, such expression is getting exponentially complex with time.[4] The complexity of the clearing price form is fortunately bounded by the number of agents N which is why we choose to populate the model with a finite number of agents rather than by a continuum of agents as in De Grauwe & Grimaldi (2004). In our model, we define the market clearing price at time t as a midpoint between the lowest and the highest possible clearing price.

$$s_t = \frac{\inf\left\{ s_t \in R_0^+ : \sum_{i=1}^{N} d_t^i(s_t) = Z_t \right\} + \sup\left\{ s_t \in R_0^+ : \sum_{i=1}^{N} d_t^i(s_t) = Z_t \right\}}{2}. \quad (3.5)$$

The choice of the market clearing price as a midpoint in a case of ambiguity may seem somehow arbitrary at first glance. These doubts are nevertheless unfounded as multiple clearing prices occurs only for a finite set of values of total market demands compared to the uncountable set of total market demands which corresponds to some unique market clearing price. For practical purposes it is therefore virtually irrelevant how we define the market clearing price in a case of ambiguity as such event occurs with zero probability.

Please also note that the design of the model allows us to examine the effect of the Tobin tax only under the assumption that the Tobin tax does not affect functioning of the dealers as market makers and/or is levied only at trades between costumers and dealers.

[4] This is due to the way how agents switch between different forecasting rules described in Section 3.3 and the fact that individual demands depends also on the past positions.

3.3 Forecasting Rules and Risk Evaluation

Once we chose the agent's utility functions and the clearing mechanism, we need to determine how agents form their opinions about the future exchange rate. In reality, traders lack computational capabilities to solve such demanding problems such as the computation of the expected exchange rate conditioned on an information set available to the agent (Simon 1990).[5] Instead, human behaviour is better described as rule governed—people know several simple heuristics to perform a particular task and choose between them based on their performance (Simon 1990).

Two main strains of heuristics for prediction of the exchange rate were identified in foreign exchange markets: the fundamental and the technical analysis. Traders using the technical analysis (henceforth referred to as chartists) are inferring the future exchange rate based on the past price movements and are to a great extent the target group which Keynes and later Tobin meant to impair due to their supposedly destabilizing behaviour. Traders using the fundamental analysis (henceforth referred to as fundamentalists) are on the other hand betting on the convergence of the market price to some fundamental value[6] and are believed to be stabilizing the market (e.g. Hommes 2006). A questionnaire survey suggests that most traders in foreign exchange markets are familiar with both types of analysis and consider them to be equally important (Oberlechner 2001). In our model, we will follow De Grauwe & Grimaldi (2004) and approximate these two ample families of different forecasting heuristics by two simple forecasting rules. Furthermore we add an autoregressive noise to the original equations to address the variability of forecasting heuristics within the families.

Following De Grauwe & Grimaldi (2004), we define expectations of the i-th trader using the fundamental forecasting rule about the exchange rate at period $t+1$ as:

$$E_t^{i,F}(s_{t+1}) = s_{t-1} - \psi\left(s_{t-1} - s_{t-1}^*\right) + e_t^{i,F} \tag{3.6}$$

$$e_t^{i,F} = \left(1 - \lambda_F\right) e_{t-1}^{i,F} + \lambda_F \varepsilon \quad \varepsilon \backsim N\left(0, \sigma_F^2\right), \tag{3.7}$$

[5] Consider for example the original model of De Grauwe & Grimaldi (2004) where a discontinuity and fractal boarders between different equilibria give a rise to chaotic price movements which are unpredictable unless we posses infinitely precise estimates of parameters of the model. This is striking since this property is observable even within a deterministic version of the model. In a stochastic and less sharply defined market more closely resembling the real foreign exchange this hardship of computing the expected exchange rate would be even more severe.

[6] For example, one may think of the purchasing power parity as the fundamental value in a context of foreign exchange markets but it is certainly not the only possible choice.

where the parameter $\psi \in (0,1)$ denotes the expected speed of an adjustment towards the fundamental value s^*_{t-1}, the term $e^{i,F}_t$ captures different beliefs within the group of fundamentalists and the parameter $\lambda_F \in [0,1]$ is affecting the persistence of different believes amongst the fundamentalists group.

Similarly, expectations of the i-th trader using the chartist forecasting rule about the exchange rate at period $t+1$ can be expressed as follows:

$$E^{i,C}_t(s_{t+1}) = s_{t-1} + \beta \sum_{j=1}^{T_C} \alpha_j \Delta s_{t-j} + e^{i,C}_t \tag{3.8}$$

$$e^{i,C}_t = (1-\lambda_C)\, e^{i,C}_{t-1} + \lambda_C \varepsilon \quad \varepsilon \backsim N\left(0, \sigma^2_C\right). \tag{3.9}$$

An intuitive explanation behind Eq. 3.8 is that chartists are trying to extrapolate from past changes of the exchange rate the future exchange rate. Weight parameters a_j; $j \in \{1,2,3,...,T_C\}$ as well as the overall strength of the extrapolation $\beta \in (0,1)$ are assumed to be positive so if a chartist experienced an increase of the price in the past, he is most likely to expect the exchange rate to rise even further. The term $e^{i,F}_t$ again captures different beliefs within the group of chartists.

Two things are worth further discussion. First, as one can see, when predicting the exchange rate at period $t+1$ agents do not use the information about the exchange rate at period t since it is yet to be determined based on their decision at time t. This accords with Equations 3.3 and 3.5. Secondly, all agents keep track of both their fundamental and chartist expectations regardless of whether they are currently chartists or fundamentalists. Otherwise they would not be able to compare the accuracy of these forecasting rules. Naturally, only the expectations matching the current type of agent are being used to determine the individual demand. This can be expressed with the use of an indicator function I in the following manner:

$$E^i_t(s_{t+1}) = I(i,t)E^{i,F}_t(s_{t+1}) + (1 - I(i,t))\, E^{i,C}_t(s_{t+1}), \tag{3.10}$$

where

$$I(i,t) = \begin{cases} 1 & \text{iff the } i\text{-th trader at time } t \text{ is a fundamentalist} \\ 0 & \text{iff the } i\text{-th trader at time } t \text{ is a chartist} \end{cases}. \tag{3.11}$$

Now we turn to the way how individual agents are evaluating the risk of their portfolios. The conditional exchange rate variance of the fundamentalist $V_t^{i,F}(s_{t+1})$ and chartist $V_t^{i,C}(s_{t+1})$ is determined by the proportion of exchange rate movements which cannot be explained by fundamentalist and chartist expectations respectively, i.e:

$$V_t^{i,F}(s_{t+1}) = (1-\theta)\,V_{t-1}^{i,F} + \theta\left(E_{t-2}^{i,F}(s_{t-1}) - s_{t-1}\right)^2, \tag{3.12}$$

$$V_t^{i,C}(s_{t+1}) = (1-\theta)\,V_{t-1}^{i,C} + \theta\left(E_{t-2}^{i,C}(s_{t-1}) - s_{t-1}\right)^2. \tag{3.13}$$

The parameter $\theta \in (0,1)$ is used so that agents place more weight to forecasting errors made most recently. Combining Equations 3.12 and 3.13 we obtain:

$$V_t^{i}(s_{t+1}) = I(i,t)V_t^{i,F}(s_{t+1}) + (1 - I(i,t))\,V_t^{i,C}(s_{t+1}). \tag{3.14}$$

3.4 Fitness of the Rules

The only thing that is left to complete the model is a specification of the function $I(i,t)$, i.e. how an agent decide whether to be a chartist or a fundamentalist. In line with a capability of the model to generate unpredictable dynamics we will assume that agents are incapable of computing the most profitable rule ex ante and use a method of trial and error instead. To be more precise, agents evaluate the past profitability of forecasting rules and tend to choose the one that performed better. The probability of the agent i being a fundamentalist or a chartist respectively at time t is defined as follows:

$$P\left(I(i,t)=1\right) = \frac{\exp\left(\gamma\pi_{t-1}^{*\,i,F}\right)}{\exp\left(\gamma\pi_{t-1}^{*\,i,F}\right) + \exp\left(\gamma\pi_{t-1}^{*\,i,C}\right)}, \tag{3.15}$$

$$P\left(I(i,t)=0\right) = \frac{\exp\left(\gamma\pi_{t-1}^{*\,i,C}\right)}{\exp\left(\gamma\pi_{t-1}^{*\,i,F}\right) + \exp\left(\gamma\pi_{t-1}^{*\,i,C}\right)}, \tag{3.16}$$

where the $\pi_{t-1}^{*\,i,F}$ and $\pi_{t-1}^{*\,i,C}$ are risk adjusted profits of the agent i being either a fundamentalist or a chartist at time $t-1$. The parameter $\gamma \in [0,\infty)$ is often referred to as the *intensity of choice* in the literature and measures the intensity with which traders revise their forecasting rules. By setting $\gamma = 0$ agents become insensitive to the past profitability and the probability of an agent being either a fundamentalist or a chartist is constant and equal to 0.5. On the other hand as $\gamma \to \infty$, agents choose whatever forecasting rule was proven to be more profitable in the previous trading round. Negative values of γ are not economically meaningful. The parameter γ is expected to be finite due to the body of the literature supporting the so called status quo bias hypothesis (e.g. Samuelson & Zeckhauser 1988).

We define the risk adjusted profit of chartists and fundamentalists on per unit basis just as in De Grauwe & Grimaldi (2004):

$$\pi_t^{*\,i,F} = \pi_t^{i,F} - \mu V_{t+1}^{i,F}(s_{t+2}) \qquad (3.17)^7$$

$$\pi_t^{i,F} = (s_t - s_{t-1})\text{sgn}\left(d_{t-1}^{i,F}\right) - \frac{\tau|d_{t-1}^{i,F} - d_{t-2}^{i}|s_{t-1}}{|d_{t-1}^{i,F}|}, \qquad (3.18)$$

and

$$\pi_t^{*\,i,C} = \pi_t^{i,C} - \mu V_{t+1}^{i,C}(s_{t+2}) \qquad (3.19)^8$$

$$\pi_t^{i,C} = (s_t - s_{t-1})\text{sgn}\left(d_{t-1}^{i,C}\right) - \frac{\tau|d_{t-1}^{i,C} - d_{t-2}^{i}|s_{t-1}}{|d_{t-1}^{i,C}|}, \qquad (3.20)$$

where $d_{t-1}^{i,F}$ and $d_{t-1}^{i,C}$ are demands of the agent i for the foreign currency under the assumption that the agent is a fundamentalist or a chartist respectively, i.e. d_{t-1}^{i} provided that $I(i,t-1) = 1$ or $I(i,t-1) = 0$. The second term on the right-hand side of Equations 3.18 and 3.20 is a novelty compared to the original model. It represents a per unit cost of changing positions from one period to the next. It is defined consistently with Eq. 3.2.

Equations 3.15 and 3.16 complete the model (provided that s_t^* and Z_t are being exogenously determined) and altogether with Eq. 3.1–3.14 form a non-linear system of stochastic difference equations. The system is unfortunately difficult to examine analytically so we use simulations to assess the impact of the parameter τ on statistics of exchange rate realizations. The model itself is a generalization of the model De Grauwe & Grimaldi (2004) since by setting $\tau = 0$, $\sigma_F^2 = \sigma_C^2 = 0$ and letting $N \to \infty$ both models coincide.

[7] A mismatch of time indices of the terms $\pi_t^{i,F}$ and $V_{t+1}^{i,F}(s_{t+2})$ is only seeming as both terms incorporate the most recent information avaliable to the agent at time t. Confusion arising from 3.17 can be easily corected by a mere relabeling but we choose to follow the notations of De Grauwe & Grimaldi (2004) to make models easily comparable.

[8] see footnote 7

Chapter 4

Simulations

4.1 Calibration[1]

The above presented model has at least 12 parameters[2] and the impact of the Tobin tax on statistics generated by the model may heavily differ depending on which exact parameter settings are we considering. Unfortunately, some of the parameters have no apparent real world interpretation which makes it difficult to estimate them individually. We therefore adopt another commonly used approach and calibrate the model so that time series generated by the model mimic selected statistics of real exchange rates. To do so, we will focus on four statistics of returns (i.e. $r_t = \frac{s_t - s_{t-1}}{s_t}$) capturing the key characteristics of financial time series:

- $s = \sqrt{\dfrac{1}{T} \sum\limits_{t=1}^{T} (r_t - \bar{r})^2}$

  representing the annualized volatility. This statistic is essential since it allows to examine the impact of the Tobin tax on volatility in absolute terms.

- $kurt = \dfrac{\frac{1}{T} \sum_{t=1}^{T} (r_t - \bar{r})^4}{\left(\frac{1}{T} \sum_{t=1}^{T} (r_t - \bar{r})^2 \right)^2}$

  measuring fat tails of the distribution of returns (e.g. Kirchler & Huber

[1]Due to the nature of computational methods used in this section we are unable to describe every aspect connected to the calibration and subsequent analysis in detail. Following paragraphs are therefore intended to acquaint the reader with methods we used rather than to provide their exhaustive description. We refer the interested reader to an enclosed DVD which contains datasets, log files, the source code of the model altogether with the random seeds allowing replication of results.

[2]Depending on the length of the window for computation of chartist expectations.

2007). The excess kurtosis is a typical feature of time series of exchange rate returns (e.g. Nekhili *et al.* 2002) and a model incapable of reproducing $kurt > 3$ could therefore hardly capture the true underlying process generating exchange rate dynamics. In addition, it allows us to assess the impact of the Tobin tax on kurtosis in absolute terms.

- $\rho^r = \dfrac{\sum_{t=2}^{T} r_t r_{t-1}}{\sum_{t=2}^{T} r_t^2}$
  as an estimate of the slope coefficient from the equation $r_t = \rho^r r_{t-1} + \varepsilon$, where ε represents a stochastic noise. The parameter ρ^r captures the degree to which a future return can be predicted based on the last return and is usually not significantly different from 0 (e.g. Nekhili *et al.* 2002).
- $\rho^{|r|} = \dfrac{\sum_{t=2}^{T} |r_t r_{t-1}|}{\sum_{t=2}^{T} r_t^2}$
  as an estimate of the slope coefficient from the equation $|r_t| = \rho^{|r|}|r_{t-1}| + \varepsilon$, where ε represents a stochastic noise. The parameter $\rho^{|r|}$ is a simple measure of the autocorrelation of absolute returns which is a typical feature of financial time series (e.g. Nekhili *et al.* 2002).

There are of course many other interesting statistical properties of foreign exchange returns (for an extensive survey, see Sewell 2011) but the above presented four statistics should capture the most fundamental characteristics and can be therefore used as a rough measure for assessing the similarity of time series generated by the model and the real world data. The calibration itself was performed with use of genetic algorithms minimizing the following fitness function with respect to the vector of parameters $\vec{p} = (\mu, \psi, \lambda_F, \sigma_F^2, \beta, \theta, \gamma)$:[3]

$$fitness = \frac{|s - \widehat{s}|}{SE_{\widehat{s}}} + \frac{|kurt - \widehat{kurt}|}{SE_{\widehat{kurt}}} + \frac{|\rho^r - \widehat{\rho^r}|}{SE_{\widehat{\rho^r}}} + \frac{|\rho^{|r|} - \widehat{\rho^{|r|}}|}{SE_{\widehat{\rho^{|r|}}}} \tag{4.1}$$

The estimates $\widehat{s}$, $\widehat{kurt}$, $\widehat{\rho^r}$, $\widehat{\rho^{|r|}}$ and their standard errors denoted by SE were obtained from a dataset published by ČNB (ČNB 2014) which contains daily exchange rates of 34 different currencies vis-à-vis CZK throughout 250 trading

[3] To facilitate the calibration, both types of traders are assumed to be same in terms of the noise in their expectations (i.e. $\lambda_F = \lambda_C, \sigma_F^2 = \sigma_C^2$). In addition, estimates of the parameters β_1 through β_5 are adopted from De Grauwe & Grimaldi (2004). Parameters N, Z_t and s_t^* for $t \in \{1, 2, 3, ..., T\}$ are assumed to be constant and are set to 100, 0, 1 respectively.

days (2. Jan 2013–27. Dec 2013, the day 7. Nov 2013 is omitted due to the intervention of ČNB) and are depicted in Table 4.1.[4]

Table 4.1: Calibration Statistics

Statistic	Estimate	Standard Error	Average under $\vec{p}_0$
$\widehat{s}$	$5.956 \cdot 10^{-3}$	$7.380 \cdot 10^{-5}$	$6.101 \cdot 10^{-3}$
$\widehat{kurt}$	6.257	$4.519 \cdot 10^{-1}$	5.242
$\widehat{\rho^r}$	$-6.590 \cdot 10^{-2}$	$1.098 \cdot 10^{-2}$	$-4.422 \cdot 10^{-2}$
$\widehat{\rho^{\lvert r \rvert}}$	$6.056 \cdot 10^{-1}$	$8.788 \cdot 10^{-3}$	$6.152 \cdot 10^{-1}$

Notes: Standard errors of $\widehat{s}$ and $\widehat{kurt}$ are obtained via the bootstrap method (10 000 re-samplings). The last column captures the capability of the calibrated model to reproduce target statistics. Averages of the statistic under $\vec{p} = \vec{p}_0$ were obtained from 1000 simulations runs lasting 3400 trading rounds. All lie within three standard errors of the estimates, usually much closer.

We perform a search consisting of more than $2 \cdot 10^5$ independent model runs with varying length altogether accounting for more than $8.5 \cdot 10^7$ trading rounds (an equivalent of $2.5 \cdot 10^5$ years).[5] The Parameter settings $\vec{p}_0$, whose individual coordinates are depicted in Table 4.2, performed the best in terms of fitness function 4.1 of all other parameter settings we considered.[6] Table 4.1 illustrates that the model under the parameter settings $\vec{p}_0$ is indeed capable to mimic the target statistic quite closely and is therefore suitable for the analysis. But before we turn to simulations to evaluate the impact of the Tobin tax, it is necessary to stress two possible shortcomings of the calibration we performed.

Table 4.2: Results of Calibration Runs

	μ	ψ	λ_F	σ_F^2	β	θ	γ	$fitness$
$\vec{p}_0$	64.116	0.672	0.953	0.019	0.35	0.932	55.647	8.921

A diversity of results we obtained from multiple searches indicates that the parameter space was to some degree left unexplored. It is therefore more appropriate to think of $\vec{p}_0$ as the best parameter settings given the computational restrictions we face rather than *the* best settings.

[4]Estimations performed via the software Stata 12 (Stata 2011). For details about the dataset see the enclosed DVD.

[5]All computations were made via the software BehaviourSearch (Stonedahl & Wilensky 2010) which is integrated with the programming language NetLogo (Wilensky 1999) that we use to implement the model.

[6]The parameter settings $\vec{p}_0$ also perform the best under a modified fitness function with different weights (see the DVD). This is relieving since the choice of Eq. 4.1 is not the only possible. For a review of different fitness functions see Ciuffo *et al.* (2012).

Apart from the practical problem of a lacking computational power to optimize a stochastic function mapping from a seven-dimensional space, there is another, purely theoretical, issue. That is, that the similarity in terms of the statistics presented above is a necessary, not sufficient condition for capturing the true underlying process generating exchange rate dynamics. This problem is inherently present when examining complex systems and aside from a careful design of the model there is a little we can do about it. Despite these objections, we believe that the model under $\vec{p} = \vec{p}_0$ will yield interesting insights about the possible impact of the Tobin tax in the real markets.

4.2 Qualitative Analysis

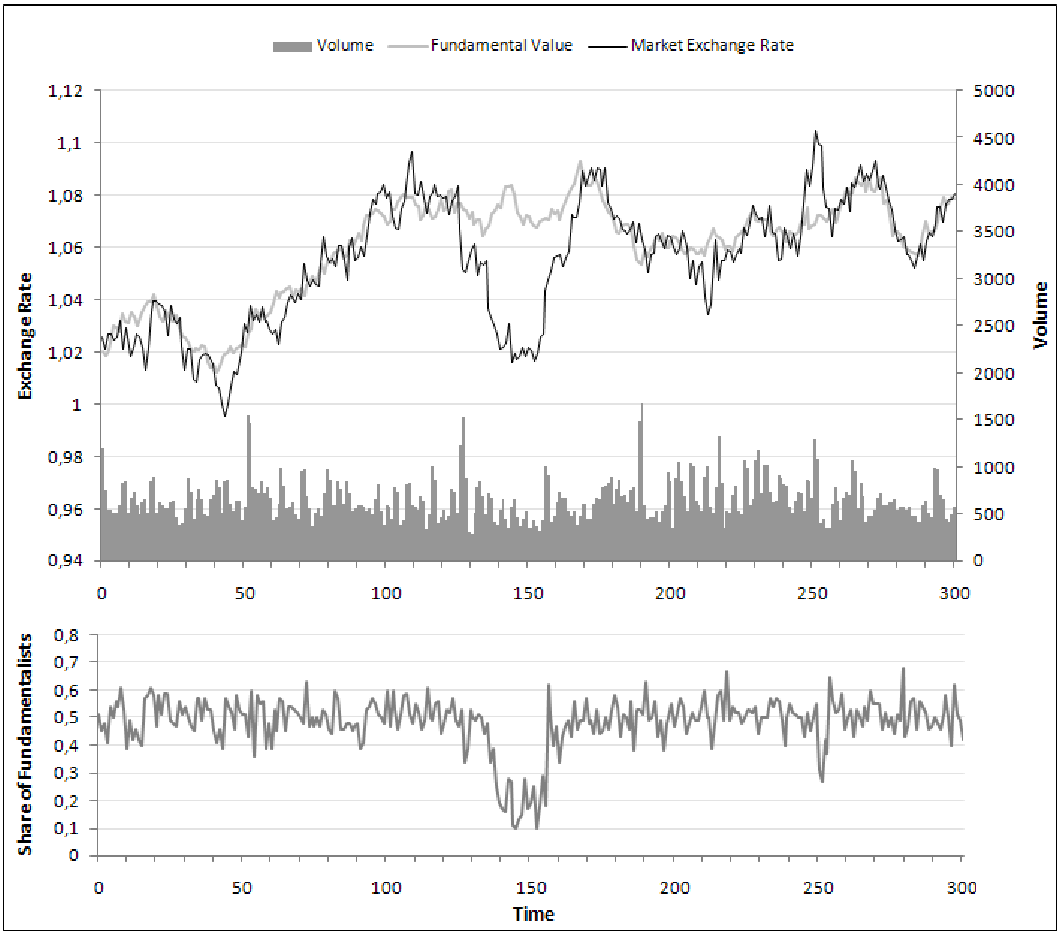
Before we analyse statistics from multiple model runs, let us see whether some insights cannot be also deduced from a single realization of prices. While generalization from a single data point is ill-advised, time series presented in this section may serve well for illustrative purposes and for gaining deeper understanding of dynamics produced by the model.

First we examine a scenario without the Tobin tax. To do so, we assume that the fundamental value follows a Gaussian random walk with zero mean and standard deviation $3 \cdot 10^{-3}$. One particular time series of market exchange rate realizations under the parameter settings $\vec{p} = \vec{p}_0$ and $\tau = 0$ is depicted in Figure 4.1. It is immediately apparent that the market exchange rate is excessively volatile compared to the fundamental value. Beside that, the figure captures a quite intriguing behaviour between the trading day 120 and 170.

Approximately around the day 120 a series of small random shocks (either from the fundamental value or from errors in individual expectations) caused the market exchange rate to decrease bellow its fundamental value. As the market price moved steadily in one direction for a couple of periods, a profitability of the chartist forecasting rule increased and more traders become chartists. This in turn further reinforced the fall of the exchange rate and made the chartist forecasting rule even more profitable compared to the fundamentalist one. Such self reinforcing process continued until the market was populated almost exclusively by chartists, than it slowed down and the market exchange rate settled in an unstable equilibrium around 1.02. Only a small random shock than triggered a similar process over again except in the opposite direction.

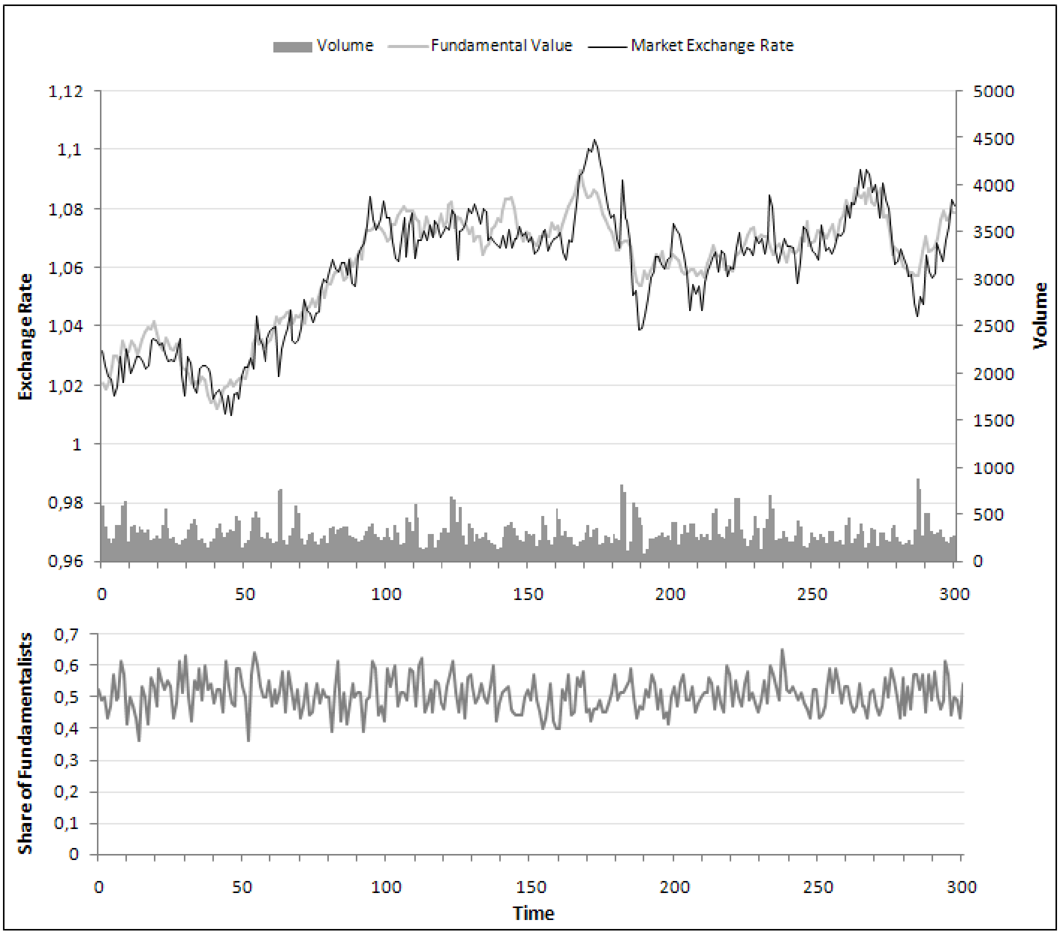
Interestingly, the adjustment of the market exchange rate back towards fundamentals is more rapid than the process which brought the exchange rate

Figure 4.1: Realization of Time Series under $\vec{p} = \vec{p}_0$ and $\tau = 0$



Notes: A realization of exchange rates capturing an excess volatility and the formation of a bubble during the period 120–170. The bubble emerged when a series of small random shocks caused the market exchange rate to move steadily in one direction. This made the chartist forecasting rule more attractive which further reinforced the fall of the exchange rate. The process continued until the market was populated almost exclusively by chartists, than it slowed down and the exchange rate settled in an unstable equilibrium around 1.02. Another random shock than triggered a similar process except in the opposite direction.

Figure 4.2: Realization of Time Series under $\vec{p} = \vec{p}_0$ and $\tau = 0.01$



Notes: A realization of exchange rates seeded by the same random numbers as in Figure 4.1 but with a 1% Tobin tax levied. The excesses volatility is still present but the bubble in the period 120–170 did not occur. Whether this is a direct result of the Tobin tax or a coincidence is hard to judge from a single realization.

away from fundamentals. This is caused by the fact that during the formation of a bubble chartists and fundamentalists drive the exchange rate into opposite directions while in case of the crash of a bubble both groups speculate on the reversion of the exchange rate back to the fundamental value (despite the fact that each from a completely different reason). This asymmetry of bubbles is a well known empirical phenomenon in financial markets (Sornette 2003). Beside the bubble during the period 120–170 one can observe a smaller upward bubble around the trading day 250 and a series of exchange rate movements which did not develop into full bubbles but still amplified changes of the fundamental value.

To examine whether the Tobin tax might be a suitable tool for a stabilization of markets we run exactly the same (seeded by the same random numbers) simulation as in Figure 4.1 except for τ which is set to 1%. Results are depicted in Figure 4.2. The first thing that is apparent from Figure 4.2 is a great drop in volume traded across the whole period. An average volume for the scenario $\tau = 0$ is above 600 units. After imposing a one percent Tobin tax it declines to almost 200 units. Also the behaviour during the period 120–170 changed markedly. The bubble discussed in previous paragraphs did not fully emerge. Whether that is a direct result of the Tobin tax or a mere coincidence caused by the sensitivity of the model to initial conditions is impossible to judge from a single realization. The volatility on the other hand seems to be affected only little but since the visual inspection tends to be unreliable, we postpone this question until Section 4.3 where it is given more rigorous treatment. Also the impact of the Tobin tax on individual types of traders contradicts expectations of proponents of the Tobin tax. An average share of fundamentalists who choose not to trade due to the imposed tax is approximately 30%, same as in case of chartists. Nevertheless, shares of non-trading chartists and fundamentalists fluctuate widely with time (not depicted in the figure) so it is plausible that the Tobin tax affects price movements through dynamics of these shares rather than through their long term averages.

4.3 Quantitative Analysis

Section 4.2 outlined possible results of imposing the Tobin tax. These should be nevertheless interpreted with a caution due to the stochastic nature of the model. To address this issue, we run simulations multiple times under various values of τ and examine how selected statistics of exchange rate realizations change with τ. We choose to analyse four statistic which are frequently discussed in relation to the Tobin tax:

- $s = \sqrt{\frac{1}{T}\sum\limits_{t=1}^{T}(r_t - \bar{r})^2}$

  The impact on volatility is a central question of the debate regarding the Tobin tax. While proponents of the tax argue that it could reduce volatility, the evidence seems to be mixed (see Chapter 2).

- $kurt = \frac{\frac{1}{T}\sum_{t=1}^{T}(r_t - \bar{r})^4}{\left(\frac{1}{T}\sum_{t=1}^{T}(r_t - \bar{r})^2\right)^2}$

  Kurtosis is covered here since several research papers indicates that the impact of the Tobin tax on volatility and kurtosis might be of the opposite direction. Results of Demary (2006) suggests that the Tobin tax might reduce volatility but increase kurtosis of returns. On the other hand Lavička *et al.* (2013) reported that the Tobin tax increases volatility but decreases excess kurtosis.

- $dist = \frac{1}{T}\sum\limits_{t=1}^{T}|s_t - s_t^*|$

  Distortions measure the degree of mispricing in the time series. It also indirectly captures bubbles like the one depicted in Figure 4.1.

- $vol = \frac{1}{2T}\sum\limits_{t=1}^{T}\sum\limits_{i=1}^{N}|d_t^i - d_{t-1}^i|$

  The direction of the impact of the Tobin tax on traded volume is hardly an controversial issue. Nonetheless the degree to which volume would be affected is often discussed as it is crucial for the estimation of possible revenues from the tax.

To assess the impact of the Tobin tax on the aforementioned statistics, we perform 1000 simulation runs lasting 340 trading rounds for each of 51 different values of τ ranging from 0 to 1% (i.e. 0.02% step). The 10^{th} and 90^{th} percentiles of measured statistics for different values of τ are depicted in Figures 4.3, 4.4, 4.5, and 4.6. The charts also contains estimates of the means of statistics altogether with their 95% confidence intervals. To allow for an easy comparison of effects of the tax across different statistics, we chose to capture statistics in their relative terms—the scenario $\tau = 0$ taken as a base.

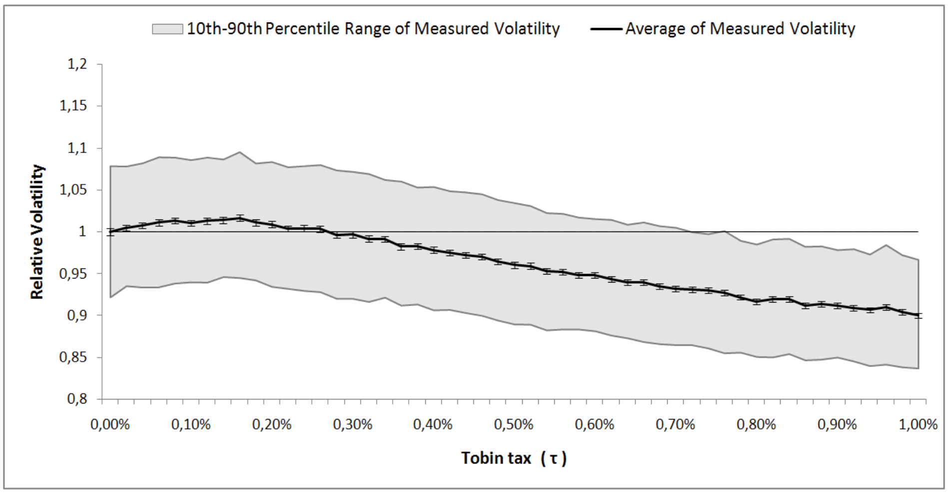
Figure 4.3 shows that the effect of the Tobin tax on volatility is ambivalent. For values ranging from 0 to 0.3% the tax actually negligible (yet statistically significantly) *increases* the average volatility. For values between 0.3% and 1% the tax is capable to deliver a moderate (up to 10%) decrease of volatility. This relation between the magnitude of the tax and its qualitative effect was to the best of our knowledge not reported by any agent based model regarding the Tobin tax. Unfortunately it is hard to judge what exactly might by the cause of this intriguing behaviour.

In line with Lavička *et al.* (2013) we found that the Tobin tax is better at reducing kurtosis of returns rather than their volatility. Only a 0.1 % tax is capable to reduce the average kurtosis by 8%. For larger values of the tax the effect slowly strengthens.

In Section 4.2 we discussed a possibility that the non occurrence of the bubble under $\tau = 0.01$ might be a mere coincidence. This turned out to not be the case as can be seen from Figure 4.5. The Tobin tax reduces distortions (which are composed mostly of persistent bubbles) by up to 30% in case of a 1% tax.

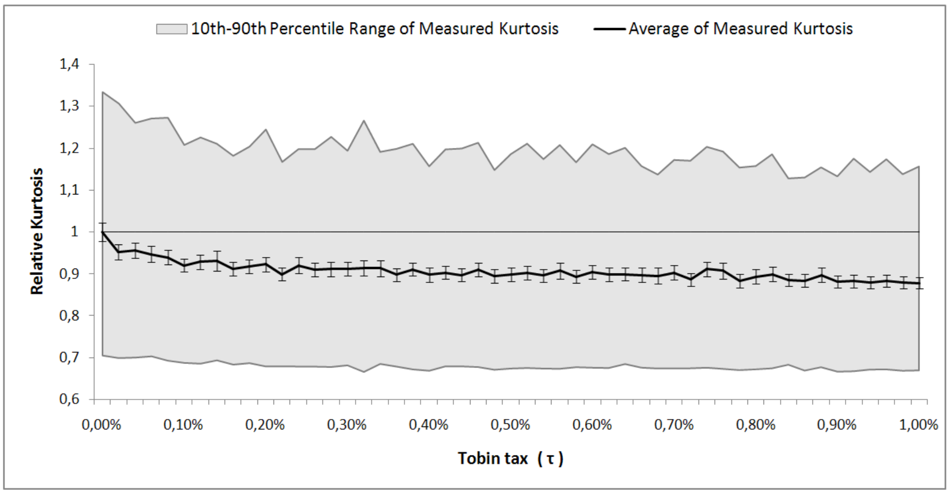
The impact of the Tobin tax on traded volume is as expected negative. A 1% tax reduces the average trading volume by more than 50%.

Figure 4.3: Impact of τ on Volatility



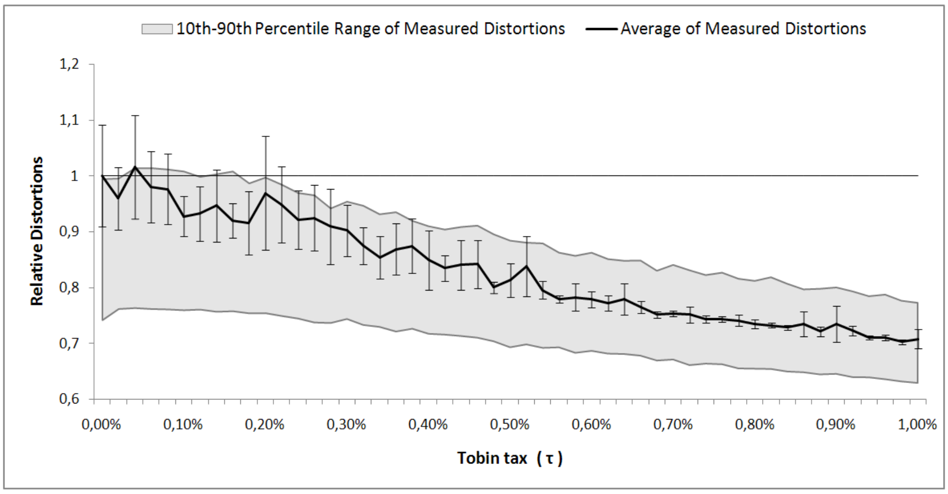
Notes: A statistically significant increase of the average volatility for values of $\tau \in [0.02\%, 0.26\%]$ and a statistically significant decrease for values of $\tau \in [0.32\%, 1\%]$ (up to 10% in the case of a 1% tax). The chart is scaled so that the relative volatility in the scenario $\tau = 0$ is equal to 1. The scale factor (i.e. the average volatility under $\tau = 0$) is $6.06 \cdot 10^{-3}$.

Figure 4.4: Impact of τ on Kurtosis



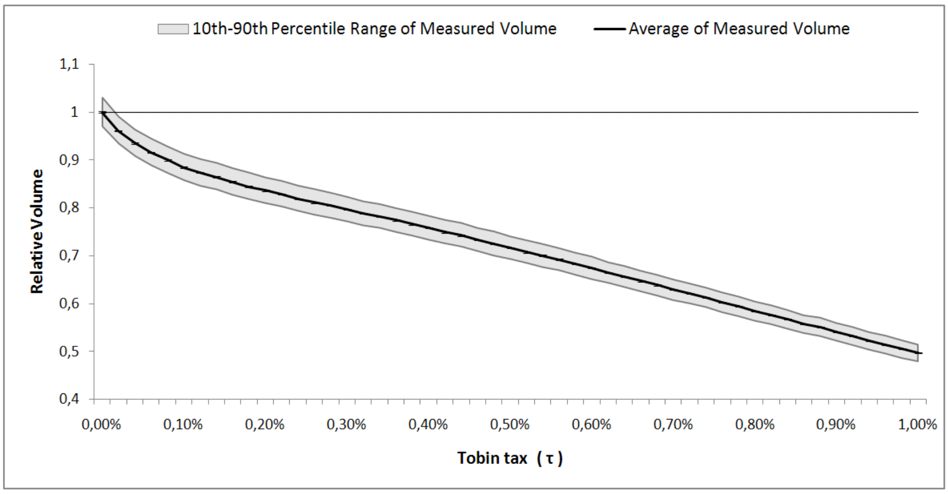
Notes: A statistically significant decrease of the average kurtosis for values of $\tau \in [0.02\%, 1\%]$ (up to 12% in the case of a 1% tax). The chart is scaled so that the relative kurtosis in the scenario $\tau = 0$ is equal to 1. The scale factor (i.e. the average kurtosis under $\tau = 0$) is 5.07.

Figure 4.5: Impact of τ on Distortions



Notes: A statistically significant decrease of the average distortions for values of $\tau \in [0.24\%, 1\%]$ (up to 29% in the case of a 1% tax). This is done mostly by preventing from the occurrence of bubbles. The chart is scaled so that the relative distortions in the scenario $\tau = 0$ are equal to 1. The scale factor (i.e. the average distortions under $\tau = 0$) is $7.81 \cdot 10^{-3}$.

Figure 4.6: Impact of τ on Volume



Notes: A statistically significant decrease of the average traded volume for values of $\tau \in [0.02\%, 1\%]$ (up to 50% in the case of a 1% tax). The chart is scaled so that the relative volume in the scenario $\tau = 0$ is equal to 1. The scale factor (i.e. the average volume under $\tau = 0$) is 659.3.

4.4 Sensitivity Analysis

Up until now, we assumed that the fundamental value is constant. We made this assumption since it is a reasonable starting point for analysing dynamics of the model. But the truth is that the fundamental value need not be constant, especially for longer periods of time. It is therefore necessary to test weather our results also holds when the fundamental value follows some random process. To do so, we replicated simulations we made to construct Figures 4.3, 4.4, 4.5, and 4.6 but we let the fundamental value to follow a Gaussian random walk with zero mean and standard deviation $2 \cdot 10^{-3}$, $4 \cdot 10^{-3}$, and $6 \cdot 10^{-3}$.[7]

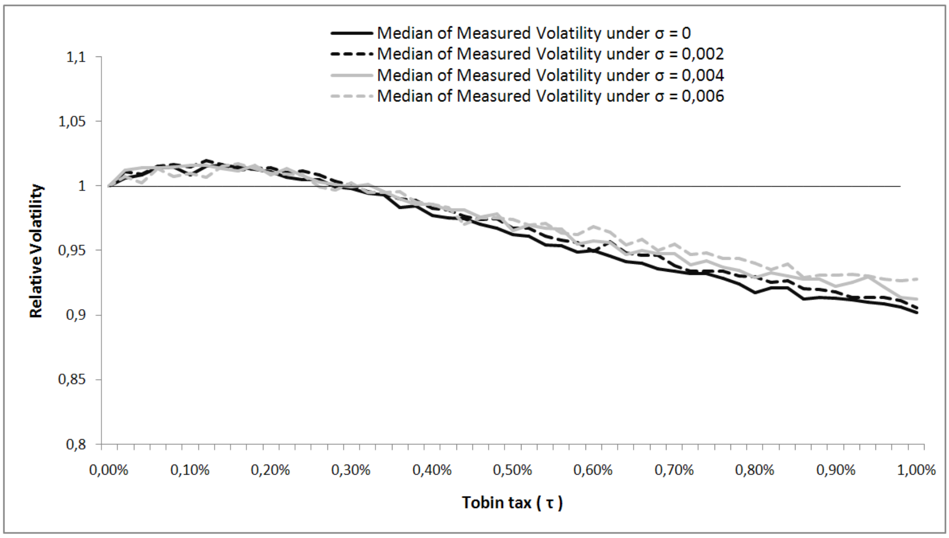
Figures 4.7, 4.8, 4.9, and 4.10 capture how the Tobin tax affect volatility, kurtosis, distortions, and volume under scenarios with the different volatility of the fundamental value. Figures display the sample median[8] rather than the sample average of statistics since it was shown to be less prone to the random noise. The sample average would tell a similar, jet more noised story and might be even misleading since it is impossible to lucidly present additional statistics necessary for its interpretation within one chart.

Directions of effects on all examined statistics are robust with respect to the volatility of the fundamental value. Interestingly, the capability of the Tobin tax to reduce both volatility and especially distortions seems to be inversely related to the volatility of the fundamental value. This is sensible since the tax reduces the ability of the market exchange rate to quickly adjust to new levels. While this subdues erratic oscillations of the market exchange rate, it also reduces the ability of the exchange rate to quickly adjust to new levels when the fundamental value changes. This become considerable for scenarios with high levels of the fundamental volatility (see Figure 4.9). Nonetheless, even in the scenario $6 \cdot 10^{-3}$ the tax can still significantly reduce distortions as the ability of the tax to prevent from occurrence of bubbles remains unaffected (not depicted in the figure). The volatility of the fundamental value has no impact on the ability of the tax to reduce traded volume and a non-trivial impact on the ability of the tax to reduce kurtosis of returns.

[7] For comparison, the estimated standard deviation of real foreign exchange returns is approximately $6 \cdot 10^{-3}$.

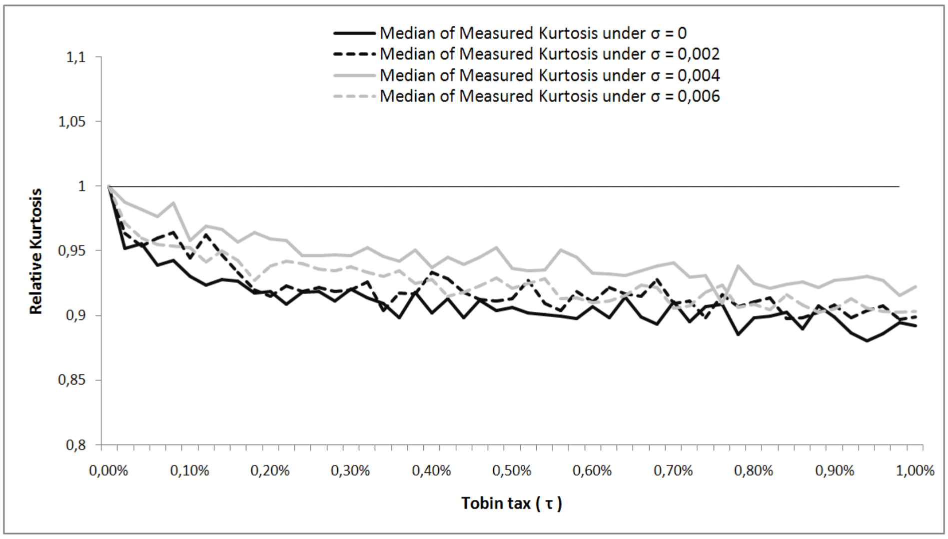
[8] In line with the conventions we define the median as the average of the two middle observations as it is computed from an even number of observations. Insignificant yet hopefully enlightening comment on that note is that Stigler (1977) filled the much needed gap in the literature and named this pair of central observations as "comedians". It remains unclear to which extent he was joking (Stata 2014).

Figure 4.7: Sensitivity of the Effect on Volatility with Respect to σ



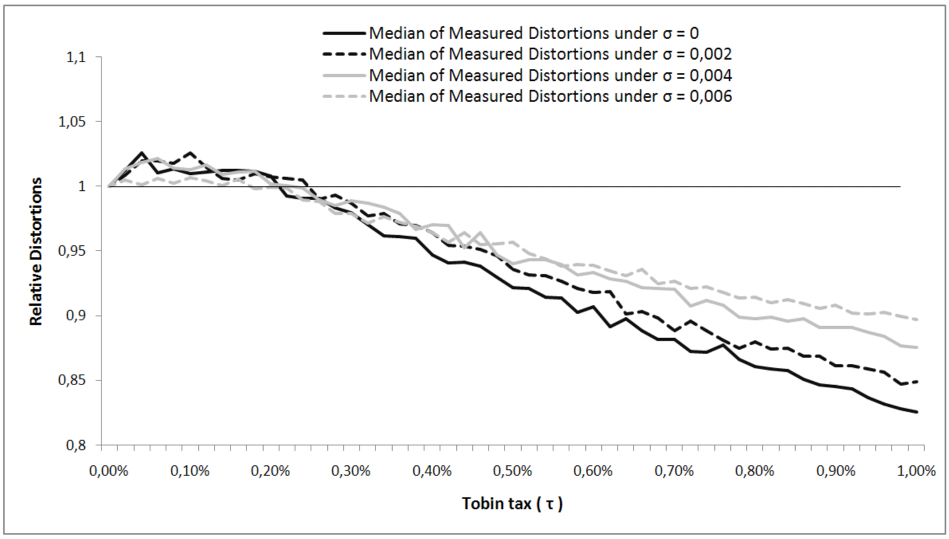
Notes: The ability of the Tobin tax to reduce volatility of returns is mildly inversely related to the volatility of the fundamental value. Plots are again depicted in relative terms in order to facilitate comparison.

Figure 4.8: Sensitivity of the Effect on Kurtosis with Respect to σ



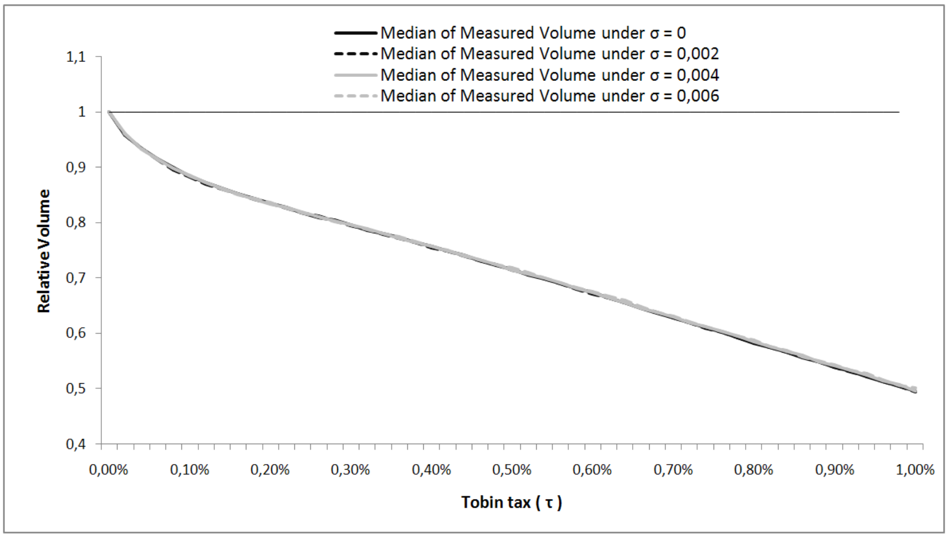
Notes: The ability of the Tobin tax to reduce kurtosis of returns is non-trivially affected by the volatility of the fundamental value. Plots are again depicted in relative terms in order to facilitate comparison.

Figure 4.9: Sensitivity of the Effect on Distortions with Respect to σ



Notes: The ability of the Tobin tax to reduce distortions is inversely related to the volatility of the fundamental value. This is caused by the trade-off between the reduction of volatility and distortions occurring in scenarios with high levels of fundamental volatility. Plots are again depicted in relative terms in order to facilitate comparison.

Figure 4.10: Sensitivity of the Effect on Volume with Respect to σ



Notes: The ability of the Tobin tax to reduce volume is unaffected the volatility of the fundamental value—individual plots almost perfectly coincide. Plots are again depicted in relative terms in order to facilitate comparison.

Chapter 5

Conclusion

The question of how transaction costs affect price dynamics is not only interesting from a theoretical point of view but also of practical importance as some regulators contemplate imposing such tax nowadays. An example might be China which is considering adoption of the Tobin tax to guard Yuan against speculative capital flows (Regan 2014, via Bloomberg).

In this thesis we assess the impact of the Tobin tax on the key statistics of exchange rate returns with use of a heterogeneous agent based model. This approach was proven to be quite fruitful in examining dynamics of various markets as it allows to take into account limited rationality of agents (e.g. Tesfatsion 2002).

Motivated by the recent research showing the great importance of the market micro structure, we choose to explore the impact of the tax in an artificial market cleared by the Walrasian auctioneer. This settings, as we argue, could resemble the two layered structure of the real foreign exchanges more closely than a price impact function which is often adopted in studies regarding the Tobin tax. In addition, by using the Walrasian clearing we bypass a troublesome decision on the exact form of the price impact function which influences results greatly (Ehrenstein *et al.* 2005). The impact of the Tobin tax on exchange rate dynamics in this particular settings was to the best of our knowledge not been examined in any study so far.

To evaluate the impact of the tax we extend the model of De Grauwe & Grimaldi (2004) by the inclusion of transaction costs. The original model consists of boundedly rational agents who use a blend of fundamental and technical analysis to predict the future exchange rate. The ongoing competition between the forecasting rules creates chaotic price movements not dissimilar to the ones observed in the real foreign exchanges.

We calibrate the model so that the time series it generates match the real foreign exchange rates in terms of selected descriptive statistics. The calibrated model exhibits features typical for real foreign exchanges such as speculative bubbles, excess kurtosis, an autocorrelation of absolute returns and no autocorrelation of raw returns.

By performing multiple simulations we found that the tax is capable of reducing distortions (by up to 29% in the case of a 1% tax) and excess kurtosis (by up to 12% in the case of a 1% tax). The effect of the tax on volatility is more intricate. We found that for small values of the tax (0%–0.3%) it negligible increases volatility while for larger values (0.3%–1%) the tax can deliver a decrease of volatility by up to 10% in the case of a 1% tax. As expected, the Tobin tax significantly reduces trading volume (by up to 50% in the case of a 1% tax). The Tobin tax also successfully prevents from occurrence of speculative bubbles.

Results are robust with respect to the volatility of the fundamental value. The sensitivity analysis also indicates that the ability of the Tobin tax to reduce distortions (and to less extent volatility of returns) is inversely related to the volatility of the fundamental value. This is caused by the trade-off between the reduction of volatility and distortions occurring in scenarios with high levels of fundamental volatility.

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Appendix A

Content of Enclosed DVD

- Model - Source Code (3.1 - 3.4)
  - · De Grauwe Grimaldi 2004 + Tobin.nlogo
- Calibration (4.1)
  - Dataset - CNB
    - · dataset.dta
    - · commands.do
    - · log.smcl
  - Searches
    - 5x2000x1700 Trading Rounds - fitness1 (bestcheck on)
      - · bestHistory.csv
      - · finalBests.csv
      - · finalCheckedBests.csv
      - · modelRunHistory.csv
      - · objectiveFunctionHistory.csv
      - · searchConfig.xml
      - · seed.txt
    - 10x10000x340 Trading Rounds - fitness0 (bestcheck off)
      - · bestHistory.csv
      - · finalBests.csv
      - · finalBests-2.csv
      - · modelRunHistory.csv

- objectiveFunctionHistory.csv
- searchConfig.xml
- seed.txt
- settings.bsearch

- 20x5000x340 Trading Rounds - fitness0 (bestcheck on)
  - bestHistory.csv
  - finalBests.csv
  - modelRunHistory.csv
  - objectiveFunctionHistory.csv
  - searchConfig.xml
  - seed.txt
  - settings.bsearch
- Target Statistics under p_0
  - Target Statistics under p_0.xlsx

- Qualitative Analysis (4.2)
  - 0 tau.csv
  - 0.01 tau.csv
  - graphics.xls
  - seed.txt
  - De Grauwe Grimaldi 2004 + Tobin (calibrated and seeded).nlogo
- Quantitative Analysis (4.3)
  - 0 fund.xlsx
- Quantitative Analysis (4.3)
  - 0.002 fund.xlsx
  - 0.004 fund.xlsx
  - 0.006 fund.xlsx
  - summary.xlsx