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PhD Thesis

Patrick Thöni

Essays on Financial Transaction Taxes

Impact on Trading Volume, Market Composition and Liquidity

Supervisor: Peter Norman Sørensen

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Contents

Acknowledgments

As I am completing this dissertation, I recall with joy the arduous, yet immensely rewarding journey that led to this point. These past years spent as a PhD student have taught me many valuable lessons, many of which I will cherish for the rest of my life. Yet, while writing a doctoral thesis can certainly be a lonely task at times, this journey would have undoubtedly been impossible - and at the very least less joyous - if it wasn't for the support and encouragement from family, friends, and fellows. It is therefore only right that I spend the next few paragraphs acknowledging them.

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Summary

Financial Markets have undoubtedly played a crucial role in the economic development and technological growth the world has experienced over the last century. The availability of liquid markets greatly facilitates the opportunities of raising capital and risk sharing, allowing the financing of large-scale real enterprises. Additionally, it enables savers to increase their returns while diversifying their risk. On the other hand, liquid markets also allow for speculative trading, which ultimately can lead to a misallocation of resources. This fundamental trade-off is what lies at the core of the original idea of a financial transaction tax (FTT). While proponents of FTTs highlight their potential to curb speculation driven by short term incentives, opponents argue that it would harm market quality by decreasing overall liquidity, interfering with price discovery and raising the cost of capital. This thesis furthers the existing body of work on this key tension surrounding FTTs from a financial microstructure perspective. By means of both theoretical and empirical analysis, the three self-contained chapters presented in this dissertation investigate the impact of FTTs on trading volume and migration, trader composition and ultimately market quality.

In the first chapter, **"On the Non-Homogeneous Effect of Financial Transaction Taxes"**, I investigate the introduction of a linear tax in the classic setting presented in Kyle (1985, "Continuous Auctions and Insider Trading." Econometrica 53: 1315–1335). Analysis of the benchmark model confirm negative effects of taxation on market liquidity found by most of the previous literature. Importantly, I also find that taxation, through the creation of a no-trade zone, forces the market maker to price the asset non-linearly with respect to traded quantities. This non-linearity, in turn, leads to heterogeneity's in the impact of the FTT across different trading sizes. While for large trades taxation only leads to increased spreads and prices, small trades also experience a decrease in market depth and trading aggressiveness compared to a market without taxation.

The second chapter, **"Financial Transaction Taxes and Trading Migration"**, somewhat departs from the approach and issues generally discussed in the existing theoretical literature. This paper aims at characterizing trading migration induced by taxation, and its effects on trader composition and market quality. I investigate the introduction of taxation in a multi-market setting, where traders are allowed to

trade in stocks and the respective option markets. Equilibrium analysis in this setting provides the following intuitions. First, taxation of equity and derivatives, conditional on the same tax rate and function being applied to both markets, will lead to asymmetric effects due to the leveraged nature of derivatives. Second, taxation can result in positive effects on liquidity if trading migration is allowed. This result arises due to an alleviation of the adverse selection problem, caused by migration of informed traders to the untaxed market. If effects of taxation on market makers are taken into consideration, the impact on liquidity becomes ambiguous. Specifically, increased cost of providing liquidity due to taxation will lead to negative effects on liquidity due to less competition among market makers. Therefore, the combined effect of taxation in this setting depends on the relative magnitude of these two forces.

Finally, in the third and last chapter, **"Multi-Market Effects of Financial Transaction Taxes: Evidence from Italy, France and Spain"** (coauthored with Vincent Wolff), we empirically explore some of the predictions made in the previous chapters. We leverage quasi-random experiments in France, Italy and Spain to investigate the introduction of FTTs across equity, derivative and OTC markets. We find striking differences in the effect of taxation on volume and liquidity across countries, which can largely be attributed to differences in tax design. Italy experienced trading migration across regulated and OTC equity markets as well as significant negative effects on aggregate liquidity. We rationalize the latter through increased informed trading migrated from OTC markets as well as increased costs of providing liquidity due to the specific tax design implemented in Italy. In France and Spain we do not find evidence of trading migration across regulated and non-regulated equity markets. In turn, regulated equity markets experienced significant drops in trading volume, accompanied by very mild effects on aggregate liquidity. Additionally, we do not find evidence of trading migration across equity and regulated derivative market. We therefore reject the idea that payoffs of taxed assets are replicated through standardized derivative products.

Summary in Danish

Finansielle markeder har utvivlsomt spillet en markant rolle i den økonomiske og teknologiske udvikling verden over det sidste århundrede. Likvide markeder gør det muligt for virksomheder at finansiere investeringer, sprede risiko, og vokse sig større. Købere kompenseres i afkast og diversificeret deres portefølje. Alt sammen velfærdsskabende i en økonomisk forstand. På den anden side kan likvide finansielle markeder give incitament til spekulative handler. Dette kan lede til ikke-efficiente allokeringer af ressourcer, og det er netop denne afvejning, som er kerneidéen i en finansiel transaktionsskat (Financial Transaction Tax, FTT). Fortalere af FTTs fremhæver deres potentiale til at hæmme spekulation i finansielle produkter drevet af kort-sigts incitamenter. Opponenter hævder, at FTTs vil dræne likviditet og overordnet sænke kvaliteten af markeder ved at puste prisen på kapital op og hæmme prisfastsættelse. Motiveret af disse modstridende argumenter udvider denne afhandling den eksisterende litteratur på FTTs. Specifikt ligger fokus på effekter af FTTs set fra et finansielt mikrostruktur perspektiv. Ved både teoretisk og empirisk analyse undersøges virkningen af FTTs på handelsvolumen og migration, sammensætningen i typen af agenter i markedet, og ultimativt kvaliteten af markedet.

I det første kapitel, **On the Non-Homogeneous Effect of Financial Transaction Taxes**, undersøger jeg effekten af en lineær skat i det klassiske modelscenarie præsenteret i Kyle (1985, "Continuous Auctions and Insider Trading." Econometrica 53: 1315–1335). Min analyse bekræfter som tidligere fundet i litteraturen at markedslikviditeten falder ved introduktionen af en skat. Udover det, så viser jeg, at beskatningen forårsager en ingen-handels zone, som tvinger prisstillere til ikke-lineær prisfastsættelse i forhold til de handlede mængder. Denne ikke-lineære prisfastsættelse implicerer heterogenitet i effekten af FTT på tværs af handler af forskellig størrelse. Mens beskatning af store handler kun medfører større bid-ask spreads og handelspriser, ses der yderligere for små handler et fald i markedsdybde og i hvor høj grad, der generelt ageres på handelssignaler (hvor aggressiv markedsagenterne er).

Det andet kapitel, **"Financial Transaction Taxes and Trading Migration"**, tager en alternativ vinkel i forhold til den eksisterende litteratur. Målet er her at karakterisere, hvordan introduktionen af beskatning påvirker sammensætningen af markedsagenter og kvaliteten af markedet. Sammensætningen af agenter i markedet

er forstået som andele af grupper af agenter med forskellige initiale forudsætninger og incitamenter. Effekten af en introduktion af beskatning undersøges på flere markeder. Markedsagenterne kan specifikt handle i henholdsvis aktier og de tilhørende optionsmarkeder. Analyse af ligevægten i sådan et marked har en række indsigter. For det første er der en asymmetri i effekten af den samme skatterate og implementering af skatten (skattefunktion) på tværs af de to markeder, netop fordi der - per konstruktion er forskel i, hvordan afkast realiseres for aktier og optioner. Den anden hovedpointe er, at beskatning rent faktisk kan have en positiv effekt på likviditet, hvis ændringer i sammensætning af agenter i markedet tillades. Den positive effekt følger af en mindskning af det ugunstig-udvælgelse problem, som migrationen af informerede markedsagenter til det ikke-beskattede marked forårsager. Der opstår dog en tvetydig effekt af beskatningen, hvis konsekvenserne for prisstillere også tages i betragtning. Konkret vil højere omkostninger ved at stille priser lede til negative effekter på likviditet grundet mindre konkurrence imellem prisstillere. Den samlede effekt af beskatningen afhænger altså af forholdet mellem disse modstridende effekter.

I det tredje og sidste kapitel, **"Multi-Market Effects of Financial Transaction Taxes: Evidence from Italy, France and Spain"** (lavet i samarbejde med Vincent Wolff), undersøger vi empirisk implikationerne dikteret af mekanismerne i det foregående papir. Vi bruger data fra kvasi-tilfældige eksperimenter i Frankrig, Italien, og Spanien til at undersøge introduktionen af FTTs på tværs af aktie-, derivat- og OTC-markeder. Vores resultater viser store forskelle i effekten af beskatning på handelsvolumen og likviditet på tværs af lande, som i høj grad kan forklares af forskelle i skattedesign. I Italien har man set ændringer i markedsagent sammensætningen på tværs af både regulerede- og OTC-aktiemarkeder samtidig med en signifikant negativ effekt på samlet likviditet. Vi forklarer den negative effekt ved, at flere markedsagenter af den informerede type migrerer fra OTC-markeder i kombination med højere omkostninger ved at stille priser grundet det specifikke skattedesign i Italien. I Frankrig og Spanien ses der ikke forskelle i migration af markedsagenter på tværs af regulerede og ikke-regulerede markeder. På de regulerede aktiemarkeder så man dog store fald i handelsvolumen, mens effekten på likviditet var mild. Vi finder ingen indikation af migration af markedsagenter på tværs af aktie- og derivatmarkeder. Af den grund afviser vi, at afkast af beskattede aktiver replikeres gennem almindelige derivater.

Chapter I

On the Non-Homogeneous Effect Of Financial Transaction Taxes

On the Non-Homogeneous Effect of Financial Transaction Taxes[*,†]

Patrick Thöni[‡]

Abstract

This paper investigates the impact of a financial transaction tax (FTT) in a classic financial market setting. The benchmark analysis is based on an extension of the model presented in Kyle (1985). Opposed to the existing literature, I am able to find equilibrium values with a linear tax. Results of the benchmark model confirm standard findings of FTT's, such as an increased bid-ask spread and an overall less deep market. Importantly, I find that the introduction of a tax leads to a non-linear pricing function. In turn, the model predicts a decrease in market depth and trading aggressiveness for small trades, whereas for larger trades the introduction of a FTT only leads to increased spreads and prices.

JEL-Code: D53, G14

Keywords: Financial transaction tax, financial microstructure, rational expectations

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[‡]Department of Economics, University of Copenhagen. (email: pt@econ.ku.dk)

1 Introduction

The introduction of a financial transaction tax has been a focus point of research in the financial field for over 50 years, with Keynes (1936) and Tobin (1978) as its earliest and possibly most notable proponents. Since its first inception, the idea behind a FTT was based on the belief that its introduction would help correcting some market imperfections by reducing the trading of a specific group of traders. Specifically, Keynes proposed a tax as a tool to discourage unproductive speculative trading, whereas Tobin's tax was more focused on its ability to reduce excess volatility in currency exchange rates. Both, though, were different expression of the same idea, namely that markets are populated by too many noise traders, whose trades are not based on information and therefore create excess volatility. Stiglitz (1989) and Summers and Summers (1989) present slightly different arguments in favour of a transaction tax, based on the grounds that it would slow down excessive speculative trading. Naturally, opposing viewpoints have been provided by the literature, most notably by Scholes (1981), who argues rather for the distortionary and self-defeating nature of transaction taxes.

The aim of this study is to help shed further light on the directional effect of a transaction tax while allowing for a more realistic tax design. The benchmark analysis is based on an extension of the market model introduced in Kyle (1985). That is, we have a market populated by three types of traders: a market maker, noise traders and informed traders (insiders) who have perfect knowledge of the securities price before trading. We therefore have a classic microstructure model with asymmetric information. Effectively, this model resembles a rational expectation model of the type introduced in Grossman (1976) and Grossman and Stiglitz (1980), where agents act based on their expectations of the other agents behaviour. Ultimately, these expectations need to be fulfilled in equilibrium.
Analysis of the benchmark model supports most of the previous findings of the effect of transaction taxes on bid ask spreads, market depth and trading aggressiveness of the informed trader. In this market setting, the introduction of a tax forces the market maker to increase the bid ask spread, reduces market depth and therefore reduces also trading aggressiveness of the insider. Importantly, this study also finds an effect that differs from the existing literature. By modelling the transaction taxes in a linear fashion, I find that the market makers pricing function becomes non-linear. This, in turn, leads to a heterogeneous effect of the tax across different order sizes, effectively rendering small trades more costly relative to large trades.

2 Related Literature

My modelling approach most closely resembles the work of Subrahmanyam (1998), which also studies the effects of a transaction tax in a version of the Kyle model. The main difference lies in the way the transaction tax is modelled. Specifically, Subrahmanyam models a tax that, for tractability, is a quadratic function of the order size, whereas in my model the tax increases linearly with order size. Additionally, in Subrahmanyam the amount of informed traders is also modelled, which allows to investigate the heterogeneous impact of the tax in the case of a monopolist trader as opposed to a market with multiple informed traders. My analysis is mainly focused on testing the robustness of the findings in Subrahmanyam, as well as others, to a different and more realistic tax design.

Various other authors have investigated the impact of a transaction tax by the use of a model similar to the one in Glosten and Milgrom (1985), such as Dow and Dow and Rahi (2000), Sørensen (2017), and Dupont and Lee (2007). While the former two focus primarily on the welfare implications of a tax, Dupont and Lee are more interested in the liquidity effects of a tax. Their main result is that the effect of a transaction tax changes substantially with the degree of asymmetric information present in the market.

Finally, the introduction of transaction taxes in both France and Italy as recently as 2012 and 2013 has made it possible to perform rigorous empirical tests on many theories around FTT's. Gomber, Haferkorn, and Zimmermann (2016), Meyer, Wagener, and Weinhardt (2015), Becchetti, Ferrari, and Trenta (2014) and Capelle-Blancard and Havrylchyk (2017) are some of the empirical studies that study the French FTT. They all reach very similar conclusion about the tax' aggregate impact. In general, they do not find any evidence that a tax improves market quality. On the contrary, they find that the reduced market volume reduces liquidity and therefore market quality. Perhaps the most comprehensive empirical study is Colliard and Hoffmann (2017). By using more granular data, they are able to go to beyond the aggregate effects of the tax and find a substantial heterogeneous response by individual agents. Additionally, they also find that the tax has a heterogeneous effect across stocks with different liquidities. That is, stocks with higher liquidities are affected less adversely in terms of various market quality measures by the introduction of a tax.

3 Model

As mentioned above, this model in many ways draws from the setting developed by Kyle (1985) which, together with the Glosten-Milgrom model, represent the benchmark of financial microstructure models in the presence of asymmetric information.

Setting and Notation I assume a classic financial market setting with two assets, a risky security, $v = \mu + \epsilon$ with $\epsilon \sim N(0, \sigma_\epsilon^2)$ and a riskless bond whose interest rate is normalized to zero. The market is populated by three type of agents: a market maker, an informed investor and a liquidity/noise investor. The liquidity traders submit a random aggregate order u, with $u \sim N(0, \sigma_u^2)$. The informed investors on the other hand have advanced knowledge of the risky assets payoff and can make their market orders contingent on its value, $x = X(v)$. The other market participants see the value of the risky asset as a random variable with distribution $v \sim N(\mu, \sigma_\epsilon^2)$. It is further assumed that only market orders are allowed. The market makers observes the net batched order $q = x + u$, from which they try to infer the value of v. Finally, a tax t is introduced as a percentage cost of the value of every transaction.

The model outlined in this setting belongs to the family of rational expectation models, where agents form conjectures about each others behaviour. In equilibrium, these conjectures then need to be satisfied. In this environment, the market makers know that the order flow will reflect information about the fundamental, since some of the agents that trade in the market have advanced knowledge of the true value of v. In order to infer the value of the underlying from the order flow, they need to make a conjecture about the relationship of x and v. I assume that this conjecture takes the following form:

$$x = X(v)) = \begin{cases} \beta(v - \mu(1+t)) & \text{if} \quad v > \mu(1+t) \\ 0 & \text{if} \quad \mu(1+t) > v > \mu(1-t) \\ \beta(v - \mu(1-t)) & \text{if} \quad v < \mu(1-t) \ , \end{cases} \tag{1}$$

where β represents the trading aggressiveness of the informed agent. The introduction of a tax implies that the order flow of the informed agent will follow a piecewise function, that is, there is a range of values of v for which it is neither profitable to buy nor to sell[1]. The full order flow observed by the market maker is then given by:

[1]This is similar to the "no-trade zone" found in Constantinides (1986). Effectively, the introduction of a tax creates a range of values of the underlying for which it is no longer profitable to trade.

$$q = \begin{cases} \beta(v-\mu(1+t))+u & \text{if} \quad v > \mu(1+t) \\ u & \text{if} \quad \mu(1+t) > v > \mu(1-t) \\ \beta(v-\mu(1-t))+u & \text{if} \quad v < \mu(1-t) \ . \end{cases} \tag{2}$$

Market Clearance Market makers are assumed to be competitive and risk-neutral. The clearance of the market is organized as follows. First, both informed and uninformed traders post their market orders, which are then batched together in a single net order, $q = x + u$. This order flow is observed by the market maker, which in turn will post a price at which he is willing to execute that order. Finally, the entire order will be routed to the market maker that offers the best price. This in turn means that the market makers engage in a Bertrand competition, that is, market makers will effectively post a price equal to the marginal cost. The market maker that posts the best price p will get the order flow q routed to him.

Trading Strategy Next I characterize the demand side of the market. The informed traders are assumed to be risk neutral. In this model, both the market maker as well as the informed trader execute strategies that depend on their assumption about each others behaviour. In equilibrium, these assumptions need to be fulfilled. Therefore, the informed traders optimal trading strategy will depend on the market makers pricing policy. Intuitively, the deeper he expects the market to be, the more aggressive he can be in his trading strategy and vice versa. This effectively means that we are looking for a Nash equilibrium, where every agent behaves optimally given the other agents' behaviour.

Given that the conjectured trading behaviour of the informed trader is a piecewise linear function, it is reasonable to assume a similar functional form for the price. Therefore, I assume that the informed trader conjectures the following pricing function

$$p = \begin{cases} \mu_1 + \lambda_1 q & \text{if} \quad q(v) > b \\ \mu_2 + \lambda_2 q & \text{if} \quad a < q(v) < b \\ \mu_3 + \lambda_3 q & \text{if} \quad q(v) < a \quad . \end{cases} \tag{3}$$

where $\lambda_i, \quad i = \{1, 2, 3\}$ can be interpreted as the market depth[2] for different trading sizes.

[2]More precisely, as λ increases, the impact of a trade on the price increases. Therefore, the higher λ, the less deep the market.

Equilibrium notion The notion of equilibrium that is used for the economy above is the standard one for rational expectations. It is defined as a pair x and p, such that the following two conditions hold:

- *Profit Maximization:* The trading strategies of the informed traders need to be such that

$$x(p,v) \quad \in \quad \max_{x(p,v)} \mathbb{E}[(v-p)x]$$

- *Market Efficiency:* The pricing function of the market makers needs to satisfy

$$p(x,v) = \mathbb{E}[v \mid q]$$

In the setting above I only allow for a fixed size of the transaction tax, thus abstracting from a possible differential impact arising due to differences in tax rates. In general, for countries that have implemented ad valorem transaction taxes on equity of the type we consider, the tax rates are usually very low and vary mostly between 20 and 50 basis points (Matheson (2011)). Such low tax rates are also advocated by the literature (Darvas and Weizsäcker (2011), Schaberg, Baker, and Pollin (2002), Schmidt (2008)) mostly due to concerns that a high tax rate would overly impair liquidity and drive activity to different markets. In the context of our model, as will become clear in the next section, a higher tax rate would lead to an increased non-linearity of the pricing function, therefore simply increasing the adverse effect of the tax.

4 Solution to Equilibrium

The introduction of a linear tax, as described in the previous section, creates non-linearities in the trading strategies of the informed traders and therefore in the pricing function of the market maker. Therefore, standard solution techniques for linear rational expectation models do not apply to this setting. In order to solve the model, I use a novel approach, based on a linear approximation. The solution to the model is defined in the following theorem.

Theorem 1 *Under the market structure and equilibrium notion defined in the previous section, the equilibrium price set by the market maker is:*

$$p = \mathbb{E}[v \mid q] = \mu + \int_{\mu t}^{\infty} \epsilon f(\epsilon \mid q^{+}) d\epsilon + \int_{-\infty}^{-\mu t} \epsilon f(\epsilon \mid q^{-}) d\epsilon \tag{4}$$

where

$$f(\epsilon \mid q) = \frac{e^{-\frac{\left(\epsilon - \mu_{\epsilon|q}\right)^2}{2\sigma^2_{\epsilon|q}}}}{\sqrt{2\pi}\sigma_{\epsilon|q}} \qquad \mu_{\epsilon|q} = \frac{\beta\sigma^2_{\epsilon}(q + \beta\mu t)}{\beta^2\sigma^2_{\epsilon} + \sigma^2_u} \qquad \sigma_{\epsilon|q} = \sqrt{(1-\rho^2)\,\sigma^2_{\epsilon}}$$

and

$$q^{+} = \beta(\epsilon - \mu t) \qquad q^{-} = \beta(\epsilon + \mu t)$$

The pricing function can be approximated by the following piecewise linear function:

$$\mathbb{E}[v \mid q] = \mathbb{E}[v \mid q^{*}] + \begin{cases} c & \textit{if} \quad q(v) > b \\ dq & \textit{if} \quad a < q(v) < b \\ (-c) & \textit{if} \quad q(v) < a \quad . \end{cases} \tag{5}$$

where c and d are defined in the appendix. The optimal order placement for the informed trader is given by:

$$X(v) = \begin{cases} \beta_1(v - \mu_1) & \textit{if} \quad q(v) > b \\ \beta_2(v - \mu_2) & \textit{if} \quad a < q(v) < b \\ \beta_3(v - \mu_3) & \textit{if} \quad q(v) < a \quad , \end{cases} \tag{6}$$

where

$$\beta_1 = \frac{1}{2\lambda_1} \qquad \beta_2 = \frac{1}{2\lambda_2} \qquad \beta_3 = \frac{1}{2\lambda_3}$$

The equilibrium can therefore be characterized by the pair β_i, λ_i, $i = \{1, 2, 3\}$, which is given by the solution to the following equations:

$$\beta_{1,3} = \frac{1}{2\lambda_{1,3}} \qquad \lambda_{1,3} = \frac{\beta_{1,3}\sigma^2_{\epsilon}}{\beta^2_{1,3}\sigma^2_{\epsilon} + \sigma^2_u} \tag{7}$$

for $q(v) > b$ and $q(v) < a$, and

$$\beta_2 = \frac{1}{2\lambda_2} \qquad \lambda_2 = \frac{\beta_2\sigma^2_{\epsilon}}{\beta^2_2\sigma^2_{\epsilon} + \sigma^2_u} + \frac{\partial f(q)}{\partial q}\bigg|_{q=0} \tag{8}$$

for $a < q(v) < b$.

For $q(v) > b$ and $q(v) < a$ we can solve the equations and obtain the following equilibrium values

$$\lambda_{1,3} = \frac{\sigma_\epsilon}{2\sigma_u}\ , \quad \beta_{1,3} = \frac{\sigma_u}{\sigma_\epsilon}$$

Note that these values do not depend on t, but only on σ_u and σ_ϵ. In fact, these are the same equilibrium values obtained when $t = 0$. This result is intuitive if one considers the optimal pricing policy of the market makers. In fact, for high enough order flows, the pricing function has the same slope as the pricing function obtained in this model without taxation (see figure 3 and 4 in the Appendix for a visualization of this concept). Therefore, it follows that the equilibrium values for market depth and trading aggressiveness have to be the same as in the case without taxation. The way the tax impacts the market for high positive (negative) values of q, is by increasing (decreasing) the level of the price set by the market maker. Moreover, we have that increasing the variance of the noise trading decreases market depth and increases the informed trader's aggressiveness. The opposite is true for the variance of the asset. These results are intuitive, since increasing the variance of the noise trader effectively means increasing the noise of the order flow and therefore the informational content of the latter, which leads to a higher market depth. On the other hand, a higher variance of the fundamental asset price increases the informational advantage of the informed trader, which in turn increases the informational content of a given order flow and therefore decreases market depth.

The equilibrium β_2 and λ_2 are determined by the intersection of equations (8) in the $\lambda - \beta$ space. In Figure 1 we can see how the equilibrium is affected by the introduction of a tax. In fact, we have that the equilibrium, compared to a no tax environment, moves up and to the left of the original equilibrium, therefore decreasing market depth as well as the aggressiveness of the informed traders order placement. Moreover, as shown in Figure 2, the impact of σ_u and σ_ϵ described above are retained for these equilibrium values.

Discussion Therefore, we have that the introduction of a tax impacts market depth only for small order flows, while for larger trades the tax does not affect the market depth but only the average level of the price. This result is different to Subrahmanyam (1998) and Dow and Rahi (2000), which do not find a heterogeneous effect for different sizes of trades. Subrahmanyam also allows for an arbitrary amount of informed traders, which

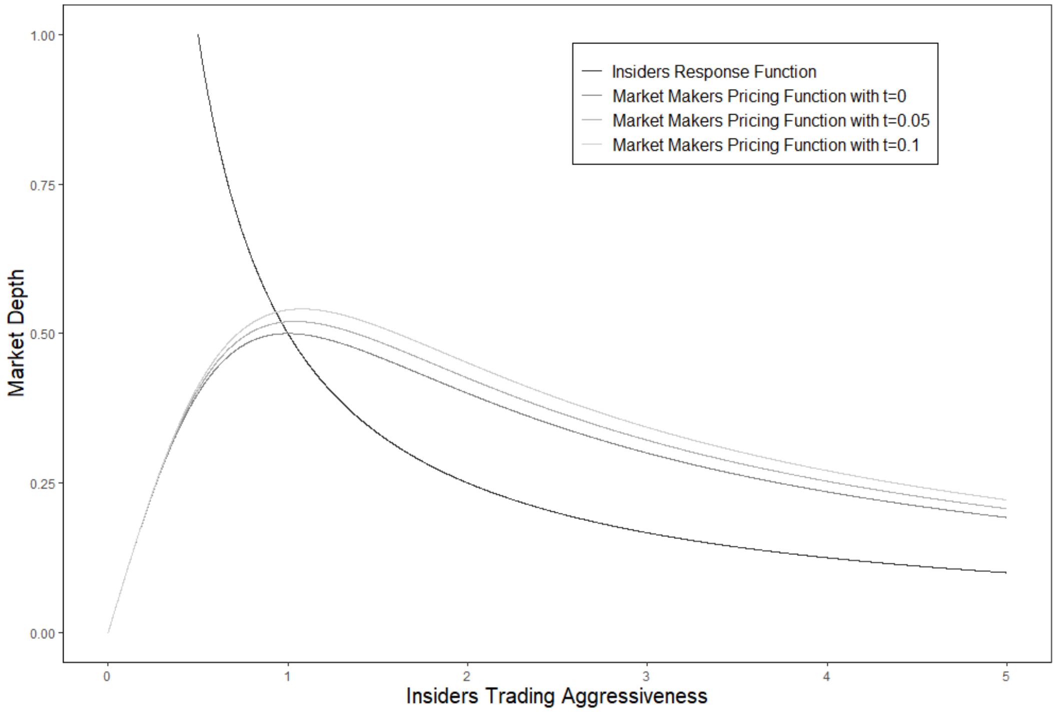

Figure 1: The figure shows the equilibrium λ and β at different tax levels for $\mu = 2$, $\sigma_\epsilon = 1$ and $\sigma_u = 1$.

allows him to distinguish between the case of a monopolist informed trader and the case of multiple informed traders. Surprisingly, he finds that in the case of a monopolist informed trader, market liquidity actually increases with the introduction of a tax. On the other hand, the authors results for the case of multiple informed traders are very similar to the ones presented above, except that his model is not able to capture the non-linearity of the market makers response function. Dow and Rahi (2000) as well as Dupont and Lee (2007) also consider similar issues, but in the context of a Glosten and Milgrom (1985) type of model. While the former are interested in answering the question whether speculators are better or worse off with a tax, in Dupont and Lee (2007) the effects of the tax on spreads and depth are considered. Their main finding is that the effect of a tax depends on the level of information asymmetry in the market. My results are in line with theirs for the case of a high level of asymmetry.

The intuition behind the results found in this paper is that a tax increases the uncertainty about the informational content of the order flow mainly for low levels of the latter. That is, compared to a market without taxation, small order flows have the potential to hide a larger informational advantage from the informed trader if a tax is introduced. For large order flows on the other hand it is easier for the market maker to infer the true value of

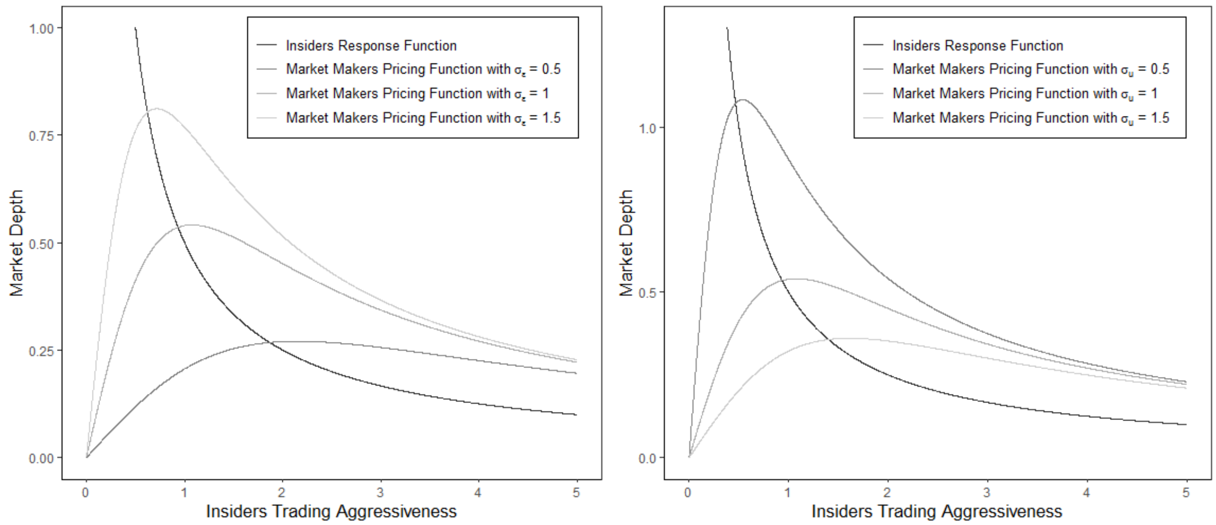

Figure 2: The left graph shows the equilibrium λ and β for different volatilities of the asset and $\mu = 2$, $\sigma_u = 1$. The right figure shows the equilibrium λ and β for different noise trading volatilities and $\mu = 2$, $\sigma_\epsilon = 2$.

the asset, which leads to a deeper market, albeit with higher prices.
The impact of σ_ϵ on the equilibrium, shown in the left graph of figure 2, also lends itself to a different interpretation. Let us assume we have two markets with two different assets, such that

$$v_1 = \mu_1 + \epsilon_1, \qquad v_2 = \mu_2 + \epsilon_2 \qquad \text{with} \qquad \sigma_{\epsilon_1} > \sigma_{\epsilon_2}.$$

Therefore, we have that stock 1 has a higher variance than stock 2. In this model, a higher variance of the asset traded in the market means that the informed trader has a higher informational advantage compared to the other agents in the market. To the extent that a market that allows for a higher informational advantage on average is less liquid (see e.g. Aslan, Easley, Hvidkjaer, and O'Hara (2011)), these two markets can be interpreted as markets with different liquidity levels. Accordingly, the comparative statics shown in the left graph of figure 2 can be interpreted as the effect of taxation on markets or stocks with different liquidities. The model therefore predicts that the higher the liquidity (i.e. the lower σ_ϵ) the less the market/stock is affected by taxation. That is, a market with less liquid stocks, if taxed, will experience a more significant drop in depth and market quality compared to a market with liquid stocks. This result is in line with Colliard and Hoffmann (2017), who study the impact of the introduction of an FTT in the french market. Among other things, they find that more liquid stocks suffered less adverse effects in terms of various liquidity proxies compared to less liquid stocks[3]. In this model, this result arises due to the relationship between informed trading and liquidity. In markets with low liquidity levels, the negative effects of taxation on liquidity are amplified by the increased adverse selection problem present in the market.

The analysis above abstracts from a few features that might be relevant in the broader discussion about the introduction of a transaction tax. Firstly, the paper focuses on the effect of the tax after its introduction, omitting possible effects of the period in between the announcement and the actual implementation of the tax. The modelling of such a period goes beyond the scope of the framework that we use in this paper, but it is worth discussing the possible effects of the announcement of a tax in light of the findings of this paper. If traders correctly anticipate that certain trades will get relatively more expensive after the introduction of a tax, they will try to execute those trades prior to the introduction. Depending on the aggressiveness and amount of such trading prior to the implementation of the tax, the market could experience increased volatility as well as temporary arbitrage opportunities.
Additionally, we only consider the effect of the first implementation of a tax. In fact, one could expect a different behaviour if a tax had already been introduced previously in the market and traders are already familiar with such a regulatory framework. Generally, one would expect the incidence of the introduction of a tax in a market that had already been taxed before, or, alternatively, the incidence of a change of the design of a transaction tax to be lower compared to the effect we find in this paper. A deeper analysis of such issues is left for future research.

5 Conclusion

This study presents a rational expectation model in a classic setting with information asymmetry to study the effects of the introduction of a transaction tax. Different from previous studies, this paper introduces a linear tax to study its effects on the pricing behaviour of the market makers. I am able to confirm most of the results found by previous studies, such as an increased bid-ask spread and a decreased market depth. Importantly, the model shows that the introduction of the tax leads the market makers to post non-linear pricing

[3]In Colliard and Hoffmann (2017) the authors differentiate between liquidity levels of stock by using Euronext's SLP program, which granted rebates on limit orders in exchange for a commitment to provide additional liquidity. This effectively means, that the stocks affected by the program experienced a higher liquidity.

schedules with respect to the size of the order flow. In turn, the equilibrium market depth is lower for small orders, whereas the tax does not affect equilibrium values for large, positive or negative, orders. This analysis therefore suggests that the tax will have a larger effect on agents that post small orders, such as e.g. retail investors.

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6 Appendix

6.1 Proof of Theorem 1

We start by proving equation 4. We have the following:

$$\begin{aligned}\mathbb{E}[v \mid q] =& \mu + \mathbb{E}\big[\epsilon \mid [\beta(v-\mu(1+t)) + u]1_{\{v>\mu(1+t)\}} + [u]1_{\{\mu(1-t)<v<\mu(1+t)\}} \\ &+ [\beta(v-\mu(1-t)) + u]1_{\{v<\mu(1-t)\}}\big].\end{aligned}$$

This allows us to split up the conditional expectation in the following way:

$$\begin{aligned}\mathbb{E}[v \mid q] =& \mu + \mathbb{E}\big[\epsilon \mid \beta(\epsilon-\mu t) + u, \epsilon > \mu t\big] Pr[\epsilon > \mu t \mid q] + \mathbb{E}\big[\epsilon \mid u, -\mu t < \epsilon < \mu t\big] Pr[-\mu t < \epsilon < \mu t \mid q] \\ &+ \mathbb{E}\big[\epsilon \mid \beta(\epsilon+\mu t) + u, \epsilon < -\mu t\big] Pr[\epsilon < -\mu t \mid q],\end{aligned}$$

which can be computed as

$$\mathbb{E}\big[\epsilon \mid \beta(\epsilon-\mu t) + u, \epsilon > \mu t\big] Pr[\epsilon > \mu t \mid q] = \int_{-\infty}^{\infty} \epsilon f(\epsilon \mid q^+, \epsilon > \mu t) d\epsilon \; Pr[\epsilon > \mu t \mid q],$$

$$\mathbb{E}\big[\epsilon \mid u, -\mu t < \epsilon < \mu t\big] Pr[-\mu t < \epsilon < \mu t] = \mathbb{E}\big[\epsilon \mid -\mu t < \epsilon < \mu t] Pr[-\mu t < \epsilon < \mu t\big] = 0,$$

$$\mathbb{E}\big[\epsilon \mid \beta(\epsilon+\mu t) + u, \epsilon > \mu t\big] Pr[\epsilon < -\mu t \mid q] = \int_{-\infty}^{\infty} \epsilon f(\epsilon \mid q^-, \epsilon < -\mu t) d\epsilon \; Pr[\epsilon < -\mu t \mid q],$$

where q^+ and q^- are respectively $\beta(\epsilon-\mu t)+u$ and $\beta(\epsilon+\mu t)+u$ and $f(\cdot)$ and $f(\cdot \mid \cdot)$ are the density and conditional density functions. Moreover the second expectation is 0 since ϵ and u are independent and $\mathbb{E}\big[\epsilon \mid -\mu t < \epsilon < \mu t]$ is the mean of ϵ truncated symmetrically around its mean, 0. After some algebra, the conditional expectation can be rewritten as

$$\begin{aligned}\mathbb{E}[v \mid q] = \mu &+ \frac{f(\beta\epsilon - \beta\mu t + u)}{f(\beta\epsilon - \beta\mu t + u \mid \epsilon > \mu t) f(\epsilon > \mu t)} \int_{\mu t}^{\infty} \epsilon f(\epsilon \mid \beta\epsilon - \beta\mu t + u) d\epsilon \; Pr[\epsilon > \mu t \mid q] \\ &+ \frac{f(\beta\epsilon + \beta\mu t + u)}{f(\beta\epsilon + \beta\mu t + u \mid \epsilon > \mu t) f(\epsilon < -\mu t)} \int_{-\infty}^{-\mu t} \epsilon f(\epsilon \mid \beta\epsilon + \beta\mu t + u) d\epsilon \; Pr[\epsilon < -\mu t \mid q].\end{aligned}$$

Furthermore we have

$$Pr[\epsilon > \mu t \mid q] = \frac{Pr[q \mid \epsilon > \mu t]\ Pr[\epsilon > \mu t]}{Pr[q]} = \frac{Pr[\beta\epsilon - \beta\mu t + u \mid \epsilon > \mu t]\ Pr[\epsilon > \mu t]}{Pr[\beta\epsilon - \beta\mu t + u]}$$
$$= \frac{f(\beta\epsilon - \beta\mu t + u \mid \epsilon > \mu t) f(\epsilon < -\mu t)}{f(\beta\epsilon - \beta\mu t + u)}$$

and

$$Pr[\epsilon < -\mu t \mid q] = \frac{Pr[q \mid \epsilon < -\mu t]\ Pr[\epsilon < -\mu t]}{Pr[q]} = \frac{Pr[\beta\epsilon + \beta\mu t + u \mid \epsilon < -\mu t]\ Pr[\epsilon < -\mu t]}{Pr[\beta\epsilon + \beta\mu t + u]}$$
$$= \frac{f(\beta\epsilon + \beta\mu t + u \mid \epsilon > \mu t) f(\epsilon < -\mu t)}{f(\beta\epsilon + \beta\mu t + u)}.$$

Therefore, $\mathbb{E}[v \mid q]$ becomes

$$\mathbb{E}[v \mid q] = \mu + \int_{\mu t}^{\infty} \epsilon f(\epsilon \mid \beta\epsilon - \beta\mu t + u) d\epsilon + \int_{-\infty}^{-\mu t} \epsilon f(\epsilon \mid \beta\epsilon + \beta\mu t + u) d\epsilon.$$

This conditional expectation can be rewritten as

$$\mathbb{E}[v \mid q] = \mu + \int_{\mu t}^{\infty} \epsilon f(\epsilon \mid \beta\epsilon - \beta\mu t + u) d\epsilon + \int_{-\infty}^{-\mu t} \epsilon f(\epsilon \mid \beta\epsilon + \beta\mu t + u) d\epsilon = \mathbb{E}[v \mid q^*] + f(q),$$

where $q^* = \beta(v - \mu)$, that is, the informed traders trading strategy when $t = 0$ and $f(q)$ is a function with horizontal asymptotes for $q \to \infty$ and $q \to -\infty$. Therefore, the pricing function can be split up in a linear part, $\mathbb{E}[v \mid q^*]$, and a non-linear part, $f(q)$. The linear part is simply the conditional expectation given two jointly normally distributed variables (v, q^*). This effectively means that for values of q above and below a certain threshold, $\mathbb{E}[v \mid q] \approx \mathbb{E}[v \mid q^*] \pm c = (\mu + c) \pm \lambda q$[4]. For values in between those thresholds on the other hand, that is, for values of q around 0, we have $\mathbb{E}[v \mid q] \approx \mathbb{E}[v \mid q^*] + dq$. We can therefore approximate the pricing function by a piecewise linear function in the following way

[4] λ here is the regression coefficient obtained when regressing v on q^*, that is, $\frac{cov(v,q^*)}{var(q^*)}$

$$\mathbb{E}[v \mid q] = \begin{cases} \mathbb{E}[v \mid q^*] + c & \text{if} \quad q(v) > b \\ \mathbb{E}[v \mid q^*] + dq & \text{if} \quad a < q(v) < b \\ \mathbb{E}[v \mid q^*] - c & \text{if} \quad q(v) < a \end{cases} = \mathbb{E}[v \mid q^*] + \begin{cases} c & \text{if} \quad q(v) > b \\ dq & \text{if} \quad a < q(v) < b \\ (-c) & \text{if} \quad q(v) < a \end{cases},$$

where $c = \lim_{q \to \infty} f(q)$, $d = \frac{\partial f(q)}{\partial q}\Big|_{q=0}$ and the thresholds are given by $b = \frac{c}{d}$ and $a = \frac{-c}{d}$, where c and d are obtained in the following way. Since we have that

$$\mathbb{E}[v \mid q] = \mu + \int_{\mu t}^{\infty} \epsilon f(\epsilon \mid \beta\epsilon - \beta\mu t + u) d\epsilon + \int_{-\infty}^{-\mu t} \epsilon f(\epsilon \mid \beta\epsilon + \beta\mu t + u) d\epsilon = \mathbb{E}[v \mid q^*] + f(q),$$

where $f(q)$ is

$$\begin{aligned} f(q) = &-\frac{\beta\sigma_\epsilon^2(q+\beta\delta t)\operatorname{erf}\left(\frac{\mu t - \frac{\beta\sigma_\epsilon^2(q+\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}}{\sqrt{2}\sigma_{\epsilon|q}}\right)}{2\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} + \frac{\beta\sigma_\epsilon^2(q-\beta\mu t)\operatorname{erf}\left(\frac{-\frac{\beta\sigma_\epsilon^2(q-\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}-\mu t}{\sqrt{2}\sigma_{\epsilon|q}}\right)}{2\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} \\ &+ \frac{\sigma\epsilon \mid q \exp\left(-\frac{\left(\mu t - \frac{\beta\sigma_\epsilon^2(q+\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}} - \frac{\sigma_{\epsilon|q} \exp\left(-\frac{\left(-\frac{\beta\sigma_\epsilon^2(q-\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}-\mu t\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}} \end{aligned}$$

and $erf(\cdot)$ is the error function. We thus have

$$\begin{aligned} c = \lim_{q\to\infty} f(q) = \lim_{q\to\infty} &-\frac{\beta\sigma_\epsilon^2(q+\beta\delta t)\operatorname{erf}\left(\frac{\mu t - \frac{\beta\sigma_\epsilon^2(q+\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}}{\sqrt{2}\sigma_{\epsilon|q}}\right)}{2\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} + \frac{\beta\sigma_\epsilon^2(q-\beta\mu t)\operatorname{erf}\left(\frac{-\frac{\beta\sigma_\epsilon^2(q-\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}-\mu t}{\sqrt{2}\sigma_{\epsilon|q}}\right)}{2\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} \\ &+ \frac{\sigma_{\epsilon|q} \exp\left(-\frac{\left(\mu t - \frac{\beta\sigma_\epsilon^2(q+\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}} - \frac{\sigma_{\epsilon|q} \exp\left(-\frac{\left(-\frac{\beta\sigma_\epsilon^2(q-\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}-\mu t\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}} \\ &= \infty + \frac{\beta^2\sigma_\epsilon^2\mu t}{2\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} - \infty + \frac{\beta^2\sigma_\epsilon^2\mu t}{2\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} + 0 + 0 \\ &= \frac{\beta^2\sigma_\epsilon^2\mu t}{\beta^2\sigma_\epsilon^2+\sigma_u^2}. \end{aligned}$$

Therefore, $c = \frac{\beta^2\sigma_\epsilon^2\mu t}{\beta^2\sigma_\epsilon^2+\sigma_u^2}$ is the horizontal asymptote of $f(q)$ as $q \to \infty$. For $q \to -\infty$, we have that the horizontal asymptote is $-c$.
Next, the slope of the middle part of the piecewise linear function is found by evaluating the derivative of $f(q)$ at 0. We have

$$
\begin{aligned}
d = \frac{\partial f(q)}{\partial q} = &-\frac{\beta\sigma_\epsilon^2 \operatorname{erf}\left(\frac{\mu t - \frac{\beta\sigma_\epsilon^2(q+\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}}{\sqrt{2}\sigma_{\epsilon|q}}\right)}{2\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} + \frac{\beta\sigma_\epsilon^2 \operatorname{erf}\left(\frac{-\frac{\beta\sigma_\epsilon^2(q-\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2} - \mu t}{\sqrt{2}\sigma_{\epsilon|q}}\right)}{2\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} \\
&+ \frac{\beta^2\sigma_\epsilon^4(q+\beta\mu t)\exp\left(-\frac{\left(\mu t - \frac{\beta\sigma_\epsilon^2(q+\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}\sigma_{\epsilon|q}\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} - \frac{\beta^2\sigma_\epsilon^4(q-\beta\mu t)\exp\left(-\frac{\left(-\frac{\beta\sigma_\epsilon^2(q-\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2} - \delta t\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}\sigma_{\epsilon|q}\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)^2} \\
&- \frac{\beta\sigma_\epsilon^2\left(-\frac{\beta\sigma_\epsilon^2(q-\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2} - \mu t\right)\exp\left(-\frac{\left(-\frac{\beta\sigma_\epsilon^2(q-\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2} - \mu t\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}\sigma_{\epsilon|q}\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} \\
&+ \frac{\beta\sigma_\epsilon^2\left(\mu \mathrm{t} - \frac{\beta\sigma_\epsilon^2(q+\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}\right)\exp\left(-\frac{\left(\mu \mathrm{t} - \frac{\beta\sigma_\epsilon^2(q+\beta\mu t)}{\beta^2\sigma_\epsilon^2+\sigma_u^2}\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}\sigma_{\epsilon|q}\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)}.
\end{aligned}
$$

If we evaluate it at $q = 0$ we obtain

$$
\begin{aligned}
d = \left.\frac{\partial f(q)}{\partial q}\right|_{q=0} = &-\frac{\beta\sigma_\epsilon^2 \operatorname{erf}\left(\frac{\mu t - \frac{\beta^2\mu t\sigma_\epsilon^2}{\beta^2\sigma_\epsilon^2+\sigma_u^2}}{\sqrt{2}\sigma_{\epsilon|q}}\right)}{2\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} + \frac{\beta\sigma_\epsilon^2 \operatorname{erf}\left(\frac{\frac{\beta^2\mu t\sigma_\epsilon^2}{\beta^2\sigma_\epsilon^2+\sigma_u^2} - \mu t}{\sqrt{2}\sigma_{\epsilon|q}}\right)}{2\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} \\
&+ \frac{\beta\sigma_\epsilon^2\left(\mu \mathrm{t} - \frac{\beta^2\mu t\sigma_\epsilon^2}{\beta^2\sigma_\epsilon^2+\sigma_u^2}\right)\exp\left(-\frac{\left(\mu \mathrm{t} - \frac{\beta^2\mu t\sigma_\epsilon^2}{\beta^2\sigma_\epsilon^2+\sigma_u^2}\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}\sigma_{\epsilon|q}\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} \\
&- \frac{\beta\sigma_\epsilon^2\left(\frac{\beta^2\mu t\sigma_\epsilon^2}{\beta^2\sigma_\epsilon^2+\sigma_u^2} - \mu t\right)\exp\left(-\frac{\left(\frac{\beta^2\mu t\sigma_\epsilon^2}{\beta^2\sigma_\epsilon^2+\sigma_u^2} - \mu t\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}\sigma_{\epsilon|q}\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)} \\
&+ \frac{\beta^3\mu t\sigma_\epsilon^4\exp\left(-\frac{\left(\mu t - \frac{\beta^2\mu t\sigma_\epsilon^2}{\beta^2\sigma_\epsilon^2+\sigma_u^2}\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}\sigma_{\epsilon|q}\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)^2} + \frac{\beta^3\mu t\sigma_\epsilon^4\exp\left(-\frac{\left(\frac{\beta^2\mu t\sigma_\epsilon^2}{\beta^2\sigma_\epsilon^2+\sigma_u^2} - \mu t\right)^2}{2\sigma_{\epsilon|q}^2}\right)}{\sqrt{2\pi}\sigma_{\epsilon|q}\left(\beta^2\sigma_\epsilon^2+\sigma_u^2\right)^2}.
\end{aligned}
$$

Finally, a and b, that is, the thresholds where the functions change, are simply found at the intersection of the three different linear functions. We therefore have $b = \frac{c}{d}$ and $a = \frac{-c}{d}$.

The following two picture visualize the non-linearity of the pricing function as a function of the demanded quantities as well as the linear approximation derived above for different tax levels. From figure 3 it is obvious to see how the pricing function used by the market maker becomes more pronounced as the tax level increases. This is a direct result of an increase in the non-trading zone described above.

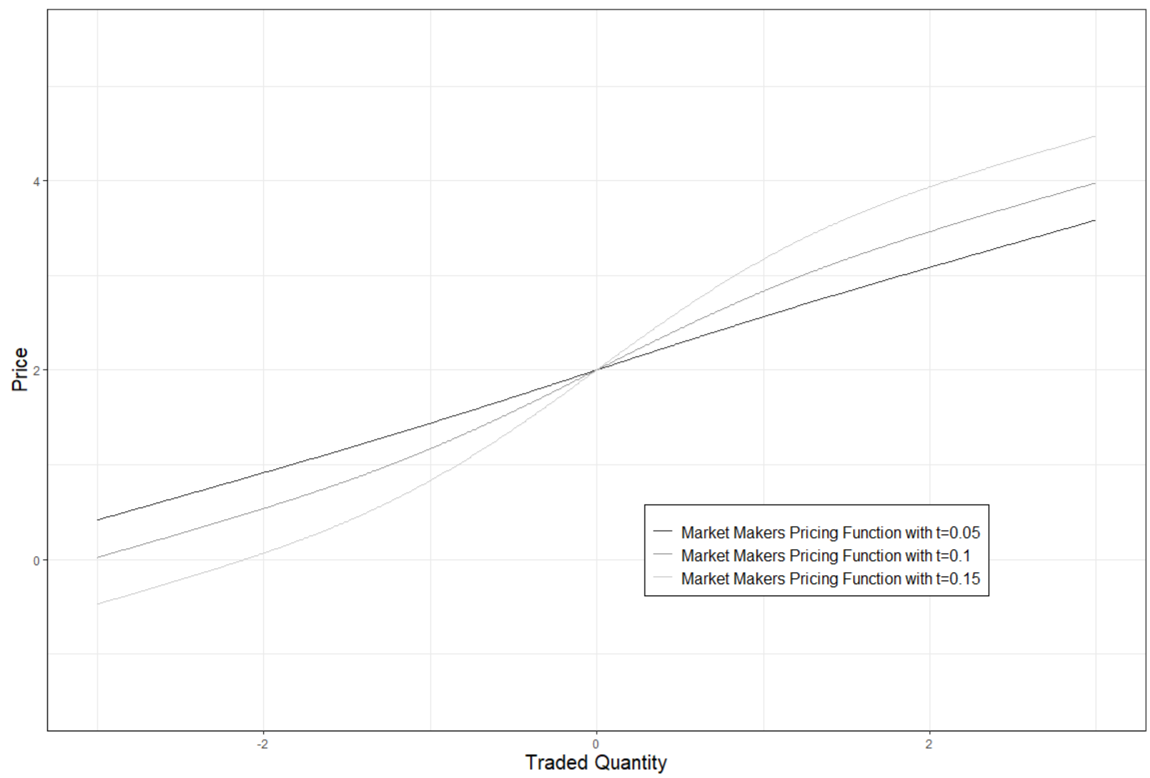

Figure 3: The graph shows the pricing function shown in Theorem 1 and derived in the Appendix for different tax rates.

Figure 3 also visualizes the reason why for $q(v) < a$ and $q(v) > b$ the equilibrium values are the same as for the case without taxation. As $q(v)$ becomes very large (either positive or negative), the pricing function with or without taxation have the same slope (they are parallel for $q(v) \to \infty$ or $q(v) \to -\infty$). This means that for large quantities, the marginal increase in price for a unit increase in quantity is the same (in relative terms).

Figure 4 shows both the pricing function as well as the linear approximation used to derive Theorem 1. The left graph shows these function for $t = 0.01$ and the right one for $t = 0.02$. It is clear that as the tax rate increases, and with it the non-linearity of the pricing function, the approximation becomes less precise. Additionally, it can be seen that the approximation is the least precise at the boundaries a and b, shown by the dashed lines.

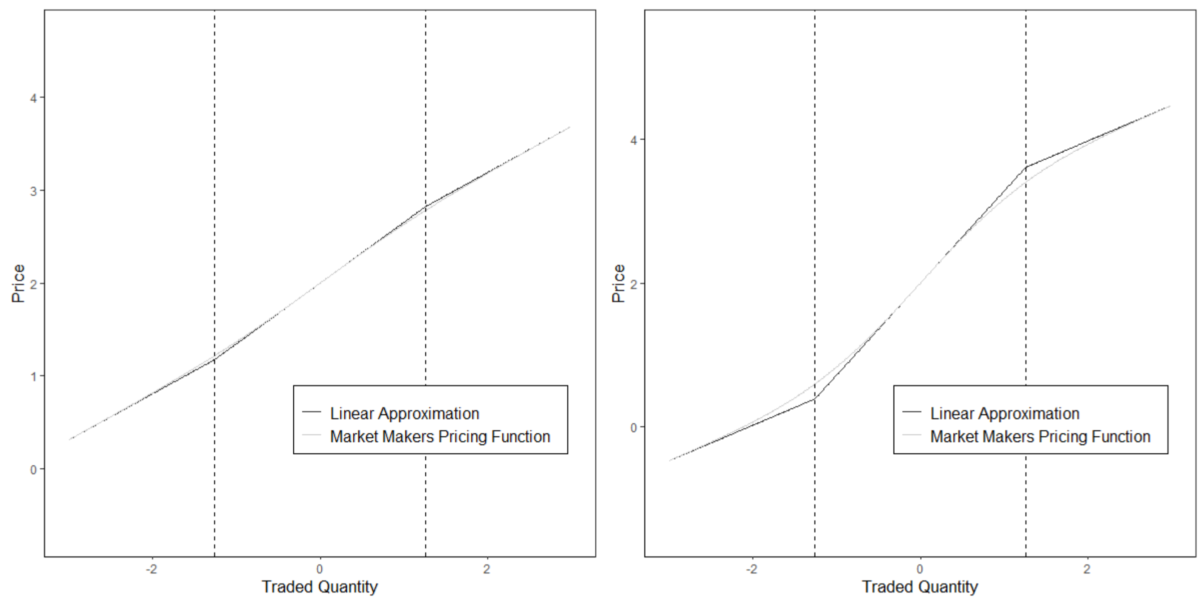

Figure 4: The figure shows the pricing function of the market makers as well as the linear approximation described in Theorem 1. For the left graph $t = 0.01$, for the right one $t = 0.02$. The dashed lines show the cut-off points a and b

Chapter II

Financial Transaction Taxes and Trading Migration

Financial Transaction Taxes and Trading Migration*

Patrick Thöni†

Abstract

Taxation of financial transactions can lead to migration of trading volume across different trading venues. This migration, in turn, can affect market quality in multiple markets. In order to characterize trading migration due to taxation and its effect on market liquidity, I develop a model with adverse selection in which informed and liquidity traders may trade in equity and option markets. I find an asymmetric response to the same tax rate across markets due to the leverage of options. Stock relative to option volume decreases significantly and liquidity in the stock market can improve due to an alleviation of the adverse selection problem. When the effects of taxation on market-making competition are considered, the impact on market liquidity becomes ambiguous.

JEL-Code: D40, D53, D82, F38, G10

Keywords: Financial transaction tax, liquidity, adverse selection, tax avoidance

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† Department of Economics, University of Copenhagen. (pt@econ.ku.dk)

1 Introduction

Taxing financial transactions for the purpose of curbing inefficient or detrimental trades has, over the last century, become a "perennial favorite answer in search of a question"[1]. The idea itself, which is generally attributed to Keynes (1936), has been lingering within academic and political circles and periodically gained relevance in times of economic and financial turmoil. While the original argument of curtailing speculative trading is still cited whenever new tax proposals are made, additional, more "practical" reasons have been added in order to argue in favor of this regulatory tool[2]. These include, among other, exploiting the massive tax base represented by financial transactions as well as creating a level playing field with other sectors from a taxation point of view.
Departing from most of the existing theoretical literature on financial transaction taxes (FTT), this paper is concerned with studying the effect of taxation on trading migration and, in turn, the effect of migration on market liquidity across different markets. It is well known that taxation can lead to substantial migration[3] driven by efforts to avoid paying the tax. It therefore follows that taxation can lead to shifts in trader composition in multiple markets, even when only a single market has been taxed. Characterizing this migration, its effect on trader composition and in turn market liquidity is therefore crucial in order to gauge the effectiveness of taxation and its impact on market quality. In this paper I address these issues and, to the best of my knowledge, provide the first theoretical study of the impact of an FTT across multiple markets.

I consider a sequential market model with three final states, where traders have the opportunity to transact both stocks and options. Risk-neutral market makers provide competitive prices in both equity and derivative markets and serve market orders placed by either liquidity or informed traders. The former are rational utility maximizers that face state contingent liquidity shocks. They trade stocks and options to hedge their risk exposure on their final wealth. Informed traders on the other hand perfectly anticipate the final state of the world. They act strategically to exploit their private information and

[1]Cochrane (2013)

[2]After the global financial crisis, the G-20 leaders made a specific request to the IMF to *"..prepare a report for our next meeting [June 2010] with regard to the range of options countries have adopted or are considering as to how the financial sector could make a fair and substantial contribution toward paying for any burden associated with government interventions to repair the banking system"*. This request was addressed in a report published in 2010, which suggested the introduction of a "Financial Activities Tax". The proposal made by the European Union in 2011 (COM/2011/594) specifically mentioned three objectives for the FTT, one of them being the "fair and substantial" contribution of the financial sector to public finances.

[3]See for example Umlauf (1993) on migration of volume from the Stockholm Stock Exchange to the London Stock Exchange.

earn the highest possible profits, while avoiding excessive information revelation. Similar to Easley, O'Hara, and Srinivas (1998), informed traders are allowed to move around between equity and derivative markets in order to maximize their profits. Within this setting, I study the effect of different tax regimes (tax in the stock market, tax in the option market, tax in both markets) on trading volume and market liquidity. Three main results emerge from this exercise.

First, the model predicts an asymmetric effect of taxes levied on stocks compared to taxes on options. Due to the payoff structure and leverage of options, traders in this model reduce trading quantities less forcefully in the derivative market relative to the equity market when confronted with a tax. Importantly, this result is based on the assumption that both markets are taxed with the same tax rate and function. While intuitive, this result shows the importance of using a different tax base when taxing derivatives. This asymmetric effect in turn also translates into a smaller effect of any tax regime on option markets compared to stock markets. Second, the model predicts a substantial reduction of trading volume in the stock market when a tax on stocks is introduced. This result is a combination of both a decrease in traded quantities as well as lower trading frequencies. It captures the intuitive idea that, if similar payout strategies and profit opportunities are available, and moving between markets is not costly, taxation will lead to a reduction of volume in the taxed market and a respective increase in the non-taxed market. Third, the model predicts increased liquidity in terms of lower spreads for the market affected by taxation. This result is due to alleviation of the adverse selection problem resulting from a shift of informed trading towards the untaxed market. This outcome departs from most results found for single-market settings, whereby taxation adversely affects liquidity, and highlights the importance of considering connected markets and its effect on trader composition.

Additionally, the model is extended to investigate possible effects of decreased competition among market makers due to increased costs of providing liquidity. While in most applications market making is exempted from taxation, the way this exemption works in practice differs substantially across implementations and can effectively lead to significant indirect costs for market makers. In the model, when taxation is allowed to affect market makers, this leads to worse competition in the taxed market and in turn less competitive quotes. Therefore, when taxation increases the cost of providing liquidity, the effects on market liquidity are ambiguous and depend on the relative magnitude of the worsened competition among market makers and the alleviation of adverse selection. Finally, by simulating the sequential model and analyzing the effect of the different tax scenarios on liquidity proxies, I show that these opposing forces are captured by different spread measures, which can therefore be used for empirical tests of their relative magnitudes.

The remainder of this paper is organized as follows. Section 2 discusses related theoretical literature. Section 3 introduces the setting of the benchmark model. Section 4 derives the equilibrium conditions. Section 5 introduces taxation and extends the model to imperfect competition. Section 6 introduces the sequential model and shows the time-series effect of taxation and section 7 concludes.

2 Related Literature

To my knowledge, there exist no theoretical studies that examine the effect of transaction taxes across spot and its derivative markets. Various studies have investigated the effect of transaction taxes on market liquidity in a single-market. In general, these studies do not draw an unambiguous overall conclusion on the directional effect of a tax. Subrahmanyam (1998) finds that a tax can both increase or decrease market liquidity, depending on whether informed traders act competitively or in a monopolistic way. Additionally, he finds that a tax can have positive effects by incentivising agents to acquire more long-term information than short-term information. Similarly, Dupont and Lee (2007) find that the effect of a tax can be both negative or positive, depending on the level of informational asymmetry in the market. Dow and Rahi (2000) study the effect of a tax on the profits of speculators and the risk-sharing opportunities for hedgers. Again, they find that the effect of the tax depends on informational parameters of the model. These models have in common that they rely on a standard noise trading formulation. That is, the non-payoff related trading is modeled as an exogenous random shock to the market. As pointed out by Dávila and Parlatore (2020), this modeling approach is not appropriate to study the effects of trading costs, since in these models it is hard to understand how the behavior of noise traders varies with the level of trading costs. To avoid this problem, they study the effect of trading costs on price informativeness using random heterogeneous priors. This formulation allows for trading motives that are not related to the payoff, therefore rendering prices only partially informative about the asset payoff while at the same time allowing taxes to affect the whole population of traders.

This paper is also related to various theoretical studies that investigate different aspects of the introduction of derivatives into a financial market setting. The theoretical frameworks in this article builds on the setting developed in Biais and Hillion (1994), which study the introduction of an option in an incomplete market. They find that introducing the option can increase the informational efficiency of the market by reducing the probability of market breakdowns. On the other hand, the option also makes it easier for informed traders to disguise their informational advantage, therefore making it harder for market makers to interpret the informational content of trades. Brennan and Cao (1996) and Huang (2016) extend the canonical framework developed in Hellwig (1980) and Grossman (1980) to include a derivatives market. Brennan and Cao (1996) show that introducing an option type contract allows to achieve Pareto efficiency with one round of trading, which, in turn, leads traders to stop trading in both the stock and option after the first trading period. Furthermore, they find that market depth, as defined in Kyle (1985), increases with the introduction of a derivative. Huang (2016), on the other hand, look at the effect of an option market on information acquisition. Compared to Brennan and Cao (1996), they introduce a set of option contracts with different strike prices. They find that the introduction of a continuous set of options increases the incentive of acquiring private information if the information acquisition cost is high. This in turn increases the price informativeness as well as the level of asset prices, while it decreases price volatility and response to earnings announcements. The opposite is found when information acquisition costs are low. Both Brennan and Cao (1996) and Huang (2016) use the classic noise trading formulations in their models. The same is true for Easley, O'Hara, and Srinivas (1998), but differently to Huang (2016) and Brennan and Cao (1996), they develop a model with a binomial payoff structure and risk neutral, competitive market makers. They are able to establish conditions under which informed traders trade options, and consequently, convey information for the stock market. Cao and Ou Yang (2009) develop a framework similar to Brennan and Cao (1996), where agents trade due to differences in opinion rather than asymmetric information. They also show that a Pareto optimal allocation can be achieved with the introduction of an option market. Importantly though, they are able to endogenously generate trading beyond the first trading round in a dynamic model by differential interpretation of public signals, whereas in Brennan and Cao (1996) additional noise trading needs to be assumed for trading volume to be positive after the first trading period. Gao and Wang (2017) investigate the introduction of an option market in a setting similar to Vayanos and Wang (2012), where agents have heterogeneous uncertain endowment and information. In this setting, an option market does not increase the informational efficiency of the market, but, as in Brennan and Cao (1996) and Cao and Ou Yang (2009), it increases the allocational efficiency. Furthermore, in their model the reason for agents trading in options is the disagreement about the payoffs uncertainty, which is similar to the findings in Cao and Ou Yang (2009).

3 Stylized Model

I consider a one-period model with a risk-free asset, one stock, and a set of options on the asset. The return on the risk-free asset is normalized to zero. The market is populated by two different types of traders and risk-neutral market makers that set the prices for the different assets after observing the order flow. The orders are placed by either a strategic, perfectly informed trader (IT, insider) or a competitive, rational, and risk-averse liquidity trader (LT). Furthermore, there exist three states of the world, which determine the final value of the stock at the end of the period. The insiders know the final state and trade to maximize their profits. The liquidity traders are exposed to state-contingent shocks and trade to hedge their risk exposure.

3.1 Market Structure

At the beginning of each trading day, an information event happens with probability η. Conditional on an information event happening, the final value of the asset is either S_0u or S_0d with probabilities μ and $(1-\mu)$ respectively, where S_0 is the value of the stock at the beginning of the trading day. If no information event happens, the final value of the asset is S_0m, with $u \geq m \geq d$. I will refer to the three states of the world as the "u-state" (up-state), "d-state" (down-state) and the "m-state" (middle-state). For the derivative contracts, I restrict my attention to two options, a (European) call and put option with expiration at the end of the period and strike prices K_c and K_p respectively. The orders placed by the traders are market orders. Market makers for both the risky asset and the options set their prices after observing an order that stems either from an insider or from a liquidity trader. Furthermore, it is assumed that the market makers in both the option and stock market have access to the same information set.

3.2 Traders

The market is populated by a unit measure of traders, a fraction δ of which are informed insiders, and the remaining fraction $(1-\delta)$ are liquidity traders. Insiders perfectly anticipate the final state and therefore the stock and option payoff. Additionally, they are risk-neutral and strategic, trade to maximize their profits, and do not face any borrowing or short-selling constraints.

The liquidity traders, on the other hand, are competitive and accordingly do not anticipate the impact of their orders on market prices. They choose their trades to maximize the utility of their terminal wealth, with utility function given by $U(W) = W - \gamma W^2$, where γ determines the risk aversion of the liquidity traders. The liquidity traders have state-contingent shocks and therefore trade in the stock and option market to hedge their risk exposure. Liquidity traders can experience two different type of shocks. LT_1 is exposed to a liquidity shock equal to $-L$ in the u-state, $-l$ in the m-state and 0 in the d-state, whereas LT_2 is exposed to state-contingent shocks equal to 0, $-l$ and $-L$ for states u, m and d respectively. Finally, liquidity traders will trade in the stock market with probability ω or in the option market with probability $(1-\omega)$. Therefore there exist four different type of liquidity traders, depending on the type of shock they experience and the market they use to hedge heir risk $(\{LT_1^S, LT_2^S, LT_1^O, LT_2^O\})$.[4]

Contrary to liquidity traders, informed traders can choose in which market they wish to trade. Therefore, a trader who is informed that the world is currently in an up-state will choose to trade either in the stock or option market based on the profits that he is able to make in either market. Naturally, in order to profit from the up-state, an informed trader will either buy a stock, buy a call or sell a put. Similarly, a trader informed of a down-state will either sell the stock, sell a call or buy a put. The profits available to an informed trader if $S = S_0u$ are therefore

$$\Pi_{up} = \begin{cases} Q_s(S_0u - A_s) & \text{if buy stock} \\ Q_c((S_0u - K_c)\theta - A_c) & \text{if buy call} \\ Q_pB_p & \text{if sell put.} \end{cases} \tag{1}$$

and similarly for the down-state

[4]For simplicity, I further assume that liquidity traders, conditional on trading in the option market, will trade either calls or puts. This is akin to allowing for a unit measure of liquidity traders that trade either in calls or puts with defined probabilities. In general, the assumption that liquidity traders in this model trade either the stock, a call or a put option is innocuous, in that it does not affect the main results of the model.

$$\Pi_{down} = \begin{cases} Q_s(B_s - S_0 d) & \text{if sell stock} \\ Q_c B_c & \text{if sell call} \\ Q_p((K_p - S_0 d)\theta - A_p) & \text{if buy put,} \end{cases} \tag{2}$$

where $\{A_s, B_s, A_c.B_c, A_p, B_p\}$ are respectively the bid and ask prices for stock, call and put, $\{Q_s^*, Q_c^*, Q_p^*\}$ are the trading strategies available to the informed trader and θ is the number of stocks controlled by an option contract. An informed trader will therefore decide in which market to trade based on these profits. The probabilities that an informed trader trades in the stock market conditional on the state, which is denoted by $\{\alpha_u, \alpha_d\}$, as well as the probabilities that informed traders choose calls if they trade in the option market, $\{\beta_u, \beta_d\}$, will therefore be determined in equilibrium.

Before outlining the equilibrium, it is worth briefly summarizing the game-theoretical nature of the model. Figure 1 shows the trading structure and main parameters of the game considered in this model. We can see that the first two moves in the game are nature's decisions regarding the existence and type of information that is going to affect the markets for the stock and options. These events can be thought of as events that happen prior to the opening of the markets (or, similarly, information events that happen overnight if multiple trading days are considered). Given the known probabilities $\{\eta, \mu, \delta, \omega\}$, the market makers will set their initial prices in their respective markets. Finally, a trader is randomly chosen from the population of traders and a trade outcome occurs.

3.3 Equilibrium Notion

The equilibrium in the economy above is a standard rational expectation equilibrium, characterized by a set of prices and trading strategies, such that:

1. The liquidity traders choose market orders to maximize their expected utility.

2. The insiders choose their market orders to maximize their profits.

3. The market makers set prices equal to their conditional expectations.

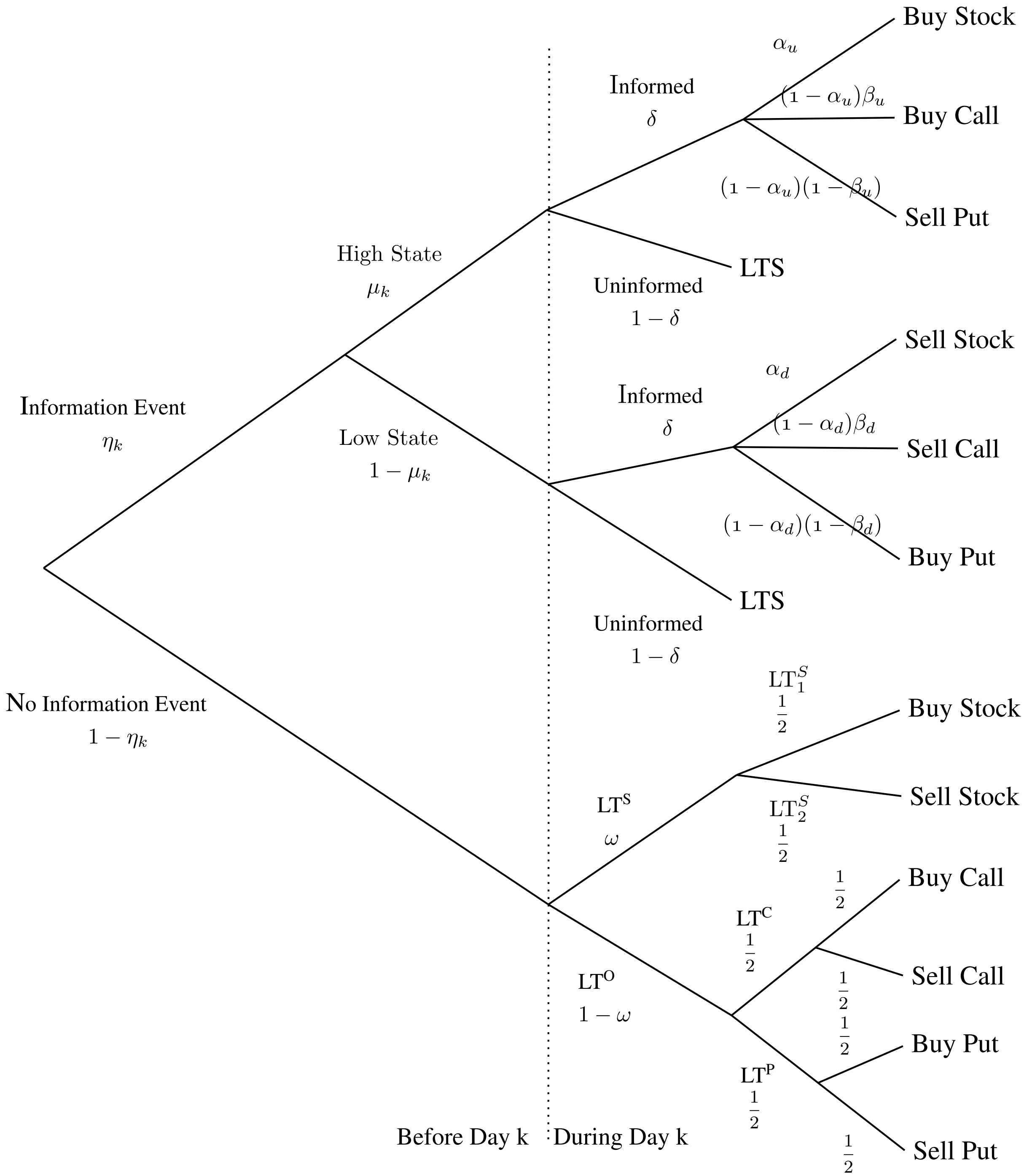

Figure 1: The tree diagram summarizes the probabilistic structure of the model described in this section. At the LTS nodes the game develops as in the case where no information event happens. LT^S, LT^C and LT^P refer to the liquidity traders that trade stocks, call options or put options respectively. LT_1 and LT_2 refer to the type of liquidity shocks experienced by the liquidity traders.

4 Equilibrium Prices and Trades

4.1 Liquidity Traders

As mentioned above, the liquidity traders trade to hedge their liquidity shocks. Since LT_1^S receives negative shocks in the u and m state, it is reasonable to assume that he will therefore buy the stock. In contrast, LT_2^S will sell the stock to hedge against the liquidity shocks he is exposed to. Similarly, the liquidity traders who trade in the option market will either buy a call, sell a put, sell a call or buy a put.

The objective functions for the liquidity traders who trade in the stock market are therefore:

$$\begin{aligned} Q_s^{1*} = \arg\max_{\{Q_s\}} \mathbb{E}[U(Q_s)] = \max_{\{Q_s\}} \Big[&\eta\mu U[-L + (S_0 u - A_s)Q_s] \\ &+ (1-\eta)U[-l + (S_0 m - A_s)Q_s] \\ &+ \eta(1-\mu)U[(S_0 d - A_s)Q_s]\Big], \end{aligned} \tag{3}$$

$$\begin{aligned} Q_s^{2*} = \arg\max_{\{Q_s\}} \mathbb{E}[U(Q_s)] = \max_{\{Q_s\}} \Big[&\eta\mu U[-L + (S_0 u - A_s)Q_s] \\ &+ (1-\eta)U[-l + (S_0 m - A_s)Q_s] \\ &+ \eta(1-\mu)U[(S_0 d - A_s)Q_s]\Big]. \end{aligned} \tag{4}$$

For the liquidity traders who trade in the option market the objective functions are:

$$\begin{aligned} Q_c^{1*} = \arg\max_{\{Q_c\}} \mathbb{E}[U(Q_c)] = \max_{\{Q_s\}} \Big[&\eta\mu U[-L + ((S_0 u - K_c)^+\theta - A_c)Q_c] \\ &+ (1-\eta)U[-l + ((S_0 m - K_c)^+\theta - A_c)Q_c] \\ &+ \eta(1-\mu)U[((S_0 d - K_c)^+\theta - A_c)Q_c]\Big], \end{aligned} \tag{5}$$

$$
\begin{aligned}
Q_p^{1*} = \arg\max_{\{Q_p\}} \mathbb{E}[U(Q_c)] = \max_{\{Q_s\}} \Big[& \eta\mu U[-L(B_p - (Kp - S_0 u)^+\theta)Q_p] \\
& + (1-\eta)U[-l + (B_p - (Kp - S_0 m)^+\theta)Q_p] \\
& + \eta(1-\mu)U[(B_p - (Kp - S_0 d)^+\theta)Q_p] \Big],
\end{aligned} \tag{6}
$$

and similarly for LT_2^C and LT_2^P.

Lemma 1 *The liquidity traders who trade in the stock market buy (sell) Q_s^{1*} (Q_s^{2*}) shares of stock and the liquidity traders who trade in the option market buy (sell) Q_c^{1*} (Q_c^{2*}) call option contracts and Q_p^{1*} (Q_p^{2*}) put option contracts, where*

$$
Q_s^{1*} = Max[0, f_{QS1}] \qquad \textit{and} \qquad Q_s^{2*} = Min[0, f_{QS2}], \tag{7}
$$

$$
Q_c^{1*} = Max[0, f_{QC1}] \qquad \textit{and} \qquad Q_c^{2*} = Min[0, f_{QC2}], \tag{8}
$$

$$
Q_p^{1*} = Max[0, f_{QP1}] \qquad \textit{and} \qquad Q_p^{2*} = Min[0, f_{QP2}], \tag{9}
$$

and the functions $f_{QS1}(\cdot)$, $f_{QS2}(\cdot)$, $f_{QC1}(\cdot)$,$f_{QC1}(\cdot)$, $f_{QP1}(\cdot)$ and $f_{QP2}(\cdot)$ are defined in the Appendix.

4.2 Insiders

The insiders in this model will always mimic one of the trades followed by the liquidity traders. The intuition is the following. Let us assume that we are in state u. Since the insiders are perfectly informed, they will rather choose to buy the stock, buy the call option or sell the put option rather then selling the stock, buying the put or selling a call option. Given that they will buy the stock, buy the call or sell the put, they could choose to trade another amount of stocks, calls or puts compared to the liquidity trader. Since the market maker has rational expectations and perfectly anticipates the strategies of the participants in the market, he will infer that any other amount than Q_s^{1*}, Q_c^{1*} or Q_p^{1*} will necessarily come from the insider. In this case, he will set the price equal to the expected value, which in this case is equal to S_0u, making the trades unprofitable for the insider.

4.3 Prices

As mentioned above, the market makers set the prices equal to the expected value conditional on the available information[5]. Therefore, the ask and bid prices for the first trade of day 1 are given by:

$$\begin{aligned} A_s = \mathbb{E}[\mathrm{S} \mid Qs > 0] &= S_0uPr[u \mid Qs > 0] + S_0mPr[m \mid Qs > 0] + S_0dPr[d \mid Qs > 0] \\ &= \frac{S_0((m - m\eta + d(-1+\delta)\eta(-1+\mu))\omega + u\eta\mu(2\alpha_u\delta + \omega - \delta\omega))}{2\alpha_u\delta\eta\mu + \omega - \delta\eta\omega} \end{aligned} \quad (10)$$

$$\begin{aligned} B_s = \mathbb{E}[\mathrm{S} \mid Qs < 0] &= S_0uPr[u \mid Qs < 0] + S_0mPr[m \mid Qs < 0] + S_0dPr[d \mid Qs < 0] \\ &= \frac{S_0(m(-1+\eta)\omega + u(-1+\delta)\eta\mu\omega + d\eta(-1+\mu)(2\alpha_d\delta + \omega - \delta\omega))}{2\alpha_d\delta\eta(-1+\mu) + (-1+\delta\eta)\omega} \end{aligned} \quad (11)$$

Similarly, the bid price of the call option is given by

$$\begin{aligned} B_c &= \mathbb{E}[\mathrm{Call} \mid Qc > 0] \\ &= (K_p - S_0u)^+\theta Pr[u \mid Qp < 0] + (K_p - S_0m)^+\theta Pr[m \mid Qp < 0] \\ &\quad + (K_p - S_0d)^+\theta Pr[d \mid Qp < 0] \\ &= \frac{\theta(K_c(1 - \eta - (\delta - 1)\eta\mu) - S_0(m - m\eta - u(-1+\delta)\eta\mu))(1 - +\delta)}{1 - \omega + \delta\eta(-1 + 4(-1+\alpha_d)\beta_d(-1+\mu) + \omega)}. \end{aligned} \quad (12)$$

The remaining prices can be computed in the same way. Note that these quantities depend on the probabilities that informed traders either trade in the stock or the option market. Next I therefore determine the conditions for when informed traders will trade in each market and the equilibrium probabilities of informed trading.
For the remainder of this section I will assume $\eta = 1$, $m = 1$, $K_c = S_d$, $K_p = S_u$ and $S_0 = 1$ in order to facilitate the exposition of the results.

[5]The available information for the market maker in this setting includes all the unconditional probabilities that define the probabilistic structure of the model shown in figure 1 as well as the complete history of trades.

4.4 Informed Trading

Intuitively, there exist two types of equilibria: one where informed traders only choose to trade in either the stock market or the option market (e.g. α_u, α_d are at their boundaries) and one where informed traders are indifferent between trading in the two markets (e.g. α_u, α_d are inside their boundaries). As in Easley, O'Hara, and Srinivas (1998), I will call the former a separating equilibrium and the latter a pooling equilibrium. The conditions for a pooling equilibrium are such that, conditional on all insiders trading in the stock market, the profits of trading in the option market are higher than the profits of trading in the stock market. Calculations for the case when the informed trader is informed of an up-state are provided. The conditions for a pooling equilibrium in the down-state are then found in a similar fashion.

In order to profit from an up-state, the informed trader will either buy the stock, buy the call or sell the put. The profit of buying a stock, given that $\alpha_u = 1$, is

$$\Pi(BS) = \frac{(1-\delta)(1-\mu)\omega(\delta - L\gamma\omega + L\gamma\delta\omega)}{\gamma(2\delta\omega(\omega-2\mu) - \omega^2 + \delta^2(4\mu(\omega-1)-\omega^2))}, \tag{13}$$

and the expected profit from buying the call or selling the put is

$$\Pi(BC) = \Pi(SP) = L(1-\mu). \tag{14}$$

The conditions for a pooling equilibrium in the up-state are therefore

$$L(1-\mu) > \quad \frac{(1-\delta)(1-\mu)\omega(\delta - L\gamma\omega + L\gamma\delta\omega)}{\gamma(2\delta\omega(\omega-2\mu) - \omega^2 + \delta^2(4\mu(\omega-1)-\omega^2))}. \tag{15}$$

Whenever this condition holds, at least some of the informed traders will choose to trade in the option market. In that case, the market will be in a pooling equilibrium, as liquidity and informed traders will "pool" together in the option market. Alternatively, whenever this condition does not hold, all informed traders will choose to trade either in the stock market or in the option market, depending on market conditions. That would therefore be a separating equilibrium. The proposition below summarizes the equilibrium of the static benchmark model.

Proposition 1 *For the market structure described above the market is in a pooling equi-*

librium if and only if

$$\frac{\delta(1-\mu)(4L\gamma\mu(\delta(-1+\omega)-\ \omega)+(-1+\delta)\omega)}{\gamma(-\omega^2+2\delta+\omega(-2\mu+\omega)+\delta^2(4\mu\ (-1+\omega)-\omega^2))}>0 \tag{16}$$

and

$$\frac{\mu((1-\delta)\delta\omega-L(-1+\gamma(-1+\delta)^2\omega^2))}{\gamma(\delta^2((-2+\omega)^2+4\mu(-1+\omega))+\omega^2-2\delta\omega(-2+2\mu+\omega))}>0, \tag{17}$$

and the equilibrium $\{\alpha_u, \alpha_d\}$ *and* $\{\beta_u, \beta_d\}$ *are then given by*

$$\alpha_u^* = \alpha_d^* = \omega \qquad and \qquad \beta_u^* = \beta_d^* = \frac{1}{2}. \tag{18}$$

The equilibrium trading strategies are

$$Q_s^{1*} = \frac{L\gamma(-1+\delta)+\delta)(1+\delta(-1+2\mu))}{(d-u)\gamma(1+\delta^2+\delta(-2+4\mu))}, \tag{19}$$

$$Q_c^{1*} = Q_p^{1*} = \frac{L\gamma(-1+\delta)+\delta)(1+\delta(-1+2\mu))}{(d-u)\gamma\theta(1+\delta^2+\delta(-2+4\mu))}, \tag{20}$$

$$Q_s^{2*} = \frac{L\gamma(-1+\delta)+\delta)(-1+\delta(-1+2\mu))}{(u-d)\gamma(1+\delta^2+\delta(2+4\mu))}, \tag{21}$$

$$Q_c^{2*} = Q_p^{2*} = \frac{L\gamma(-1+\delta)+\delta)(-1+\delta(-1+2\mu))}{(u-d)\gamma\theta(1+\delta^2+\delta(2+4\mu))}, \tag{22}$$

and the equilibrium prices are

$$A_s = \frac{d(-1+\delta)(-1+\mu)+u(1+\delta)\mu}{1+\delta(-1+2\mu)}, \qquad B_s = \frac{\delta(1+\delta)(\mu-1)+u(\delta-1)\mu}{\delta(2\mu-1)-1}, \tag{23}$$

$$A_c = \frac{(u-d)(1+\delta)\theta\mu}{1+\delta(2\mu-1}, \qquad B_c = \frac{(u-d)(\delta-1)\theta\mu}{\delta(2\mu-1)-1}, \tag{24}$$

$$A_p = \frac{(u-d)(1+\delta)\theta(\mu-1)}{\delta(2\mu-1)-1}, \qquad B_c = \frac{(u-d)(\delta-1)\theta(\mu-1)}{1+\delta(2\mu-1)}. \tag{25}$$

Note that the conditions for a pooling equilibrium are generally satisfied when stock market liquidity (ω) is low, when the the risk aversion (γ) of the liquidity traders is high, when the liquidity shocks (L, l) are high and when the proportion of informed trading (δ) is low[6]. Furthermore, the equilibrium probabilities of informed trading in the stock market turns out to be equal to the liquidity in these markets. This result, even though surprising at first glance, is rather intuitive: When there is a high liquidity in the stock market, informed trading will be harder to discover for the market maker. This means that informed trades will have a smaller impact on stock prices, which in turn allows them to extract higher profits from these markets. Lastly, the equilibrium quantities for stock and option trades only differ through the leverage effect of the options.

4.5 Comparative Statics

Next, I show how the equilibrium described in Proposition 1 is affected by model parameters. For this purpose I drop the main simplifying assumption made previously, e.g. $\eta = 1$.[7] Figure 2 shows how the pooling equilibrium conditions in the up-state are affected by the main parameters of the model.[8]. It can be seen that increasing μ, η, and δ increases the likelihood of a pooling equilibrium. Intuitively, increasing the probability of an up-state (μ) will increase the probabilities that "up-state trades" (e.g. buying the stock, buying a call or selling a put) will occur. Given that these conditions are derived for $\alpha_u = 1$, this will disproportionally increase the probability that a buy order in the stock market comes from an informed trader, making it necessary for the market makers to increase stock prices

[6]Note that, in this stylized model, the simplifying assumptions make sure that the condition for a pooling equilibrium always hold. This is not the case if the assumptions are relaxed or taxation is introduced in the model.

[7]For the remainder this section, unless stated otherwise, the baseline parameters used for the comparative statics are $\eta = 0.5$, $\mu = 0.5$, $\omega = 0.5$, $\delta = 0.2$, $\theta = 5$, $\gamma = 2$, $L = 0.9$, $l = 0.2$, $u = 1.2$, $d = 0.8$, $m = 1$, $K_c = d$, $K_p = u$.

[8]I only consider the up-state since the results for the down-state are symmetrical.

accordingly. This will in turn make trades in the option market more profitable, making it more likely that a pooling equilibrium exists.

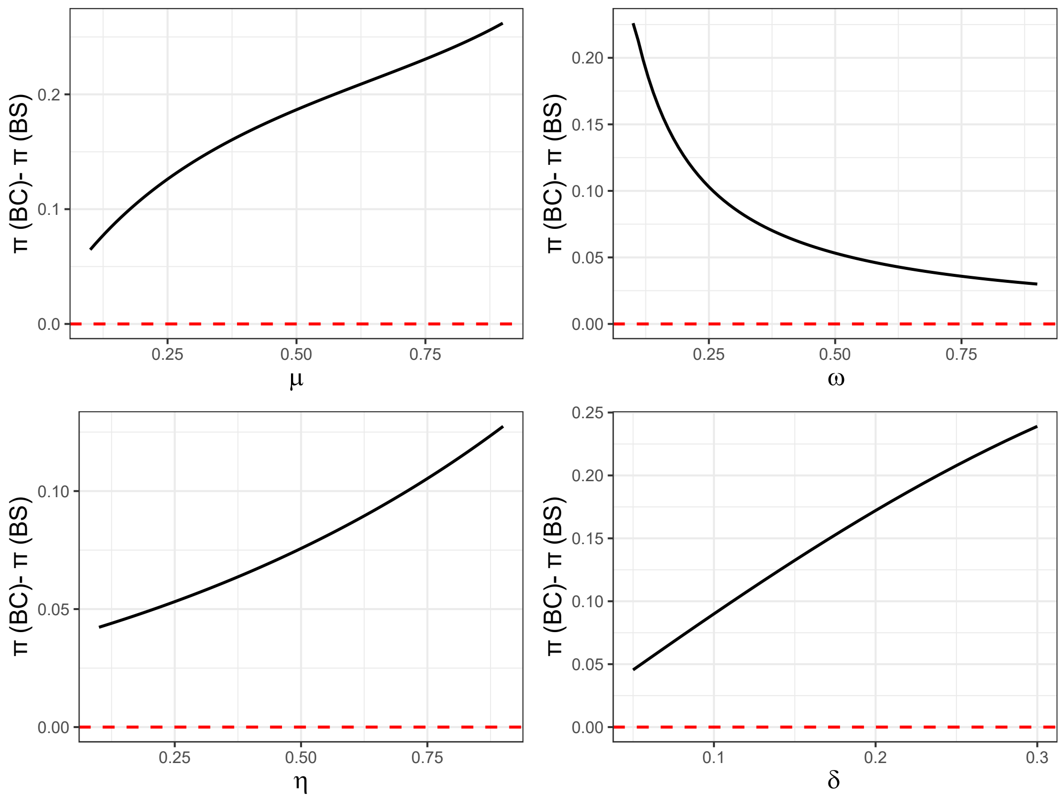

Figure 2: The Figure shows the effect of the probability of an up-state (μ), the proportion of liquidity traders in the stock market (ω), probability of an information event (η) and the proportion of informed trading (δ) on the conditions of a pooling equilibrium, e.g. $\Pi(BC) - \Pi(BS)$ and $\Pi(SP) - \Pi(BS)$

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The intuition is the same for an increase in the probability that an information event happens and the proportion of informed trading in the market. In both cases, the underlying mechanism that leads to an increased likelihood of a pooling equilibrium is that the relative presence of informed trading in the stock market increases, leading to higher prices in the stock market and accordingly to smaller profit margins for informed traders that trade stocks. The opposite is true for an increase in ω. By increasing the proportion of liquidity traders in the stock market, naturally the relative presence of informed trading will be smaller, making it easier for informed traders to extract profits by trading stocks.

Figure 3 shows the equilibrium ask and bid prices as a function of δ, η, μ and θ. For δ, η, the mechanism described above, e.g. an increase in the relative presence of informed trading, naturally also leads to higher spreads in the affected markets. The effect of the leverage of options (θ) has the straight forward effect of increasing the level as well as the spread of option prices, while not affecting the stock prices.

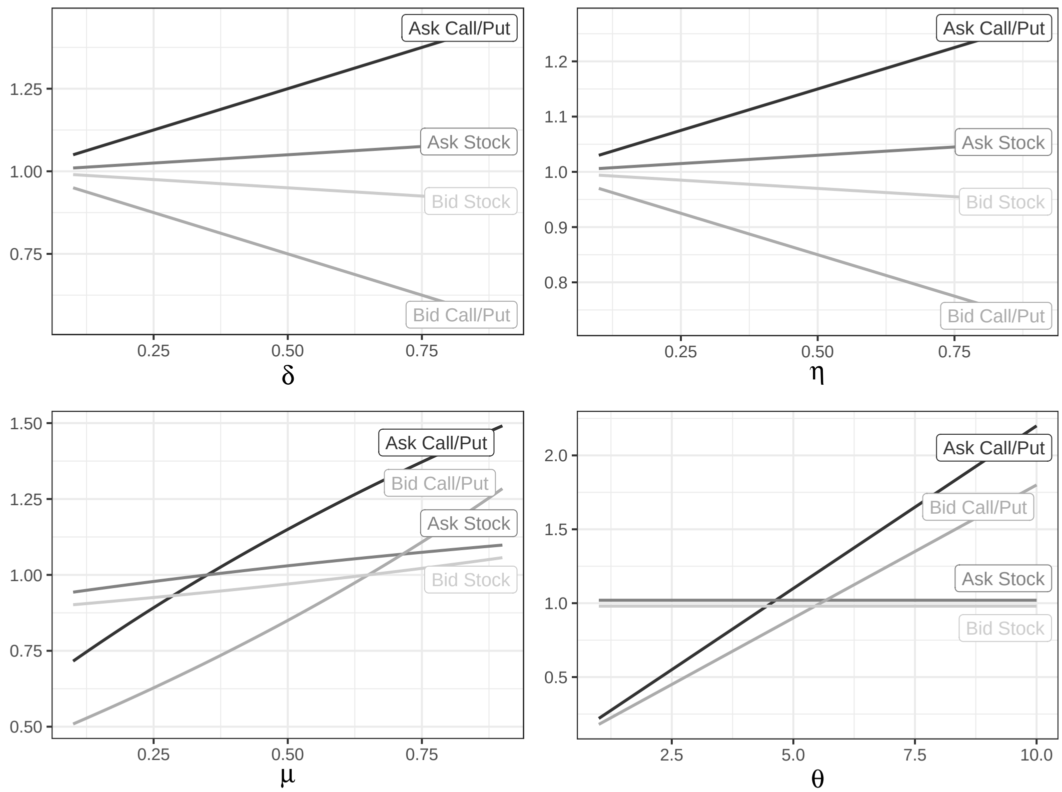

Figure 3: The Figure shows the effect of δ, η, μ and θ on the equilibrium Ask and Bid Prices.

The effect of μ on the equilibrium prices on the other hand is more nuanced. On the one hand, increasing the likelihood of an up-state (down-state) naturally increases (decreases) the level of the prices. In addition to this effect, Figure 3 also shows that the spreads in both market slightly increase as μ moves away from its boundaries. This effect arises due to the higher uncertainty in the market when $\mu = 0.5$, as in this case up and down movements in the markets are equally likely. Finally, it is interesting to note that changing ω does not have any effect on the equilibrium prices. This result could seem counter-intuitive at first glance, but it actually arises due to the equilibrium (Equation 19) shown in Proposition 1. In fact, the decrease in spreads in the stock market that one might expect from an increase in ω is countered by an increase in informed trading. In equilibrium, these effects essentially cancel each other out. As will be seen in the next sections, this result no longer holds once transaction taxes are introduced.

5 Transaction Taxes

Next, I introduce transaction taxes in the markets and analyse how they affect the interaction between the two markets. I consider three different scenarios, one where the tax is only introduced in the stock market, one where it is only introduced in the option market, and one where a tax exists in both markets. The transaction taxes are introduced in the following fashion.

Stock Market
The tax is introduced as a percentage cost on the value of the transaction. Therefore, when buying (selling) a stock, the agent in the market will pay (receive) $A_s(1+t)$ or $(B_s(1-t))$, where t is the transaction tax.

Option Market
Next, I look at how this dual market system is affected by an introduction of a tax in the option market. Again, the tax is introduced as a percentage cost of the value of the transaction, therefore, when trading in the option market the agents will pay (receive) $A_c(1+t)$ or $A_p(1+t)$ and $(B_c(1-t)$ or $B_p(1-t))$.

Both Markets
Finally, in the last scenario a tax is introduced in both markets. Again, the tax is introduced as a percentage cost on the value of the transaction and the traders will therefore pay (receive) $A_s(1+t)$ or $(B_s(1-t))$ when they trade in the stock market as well as pay (receive) $A_c(1+t)$ or $A_p(1+t)$ and $(B_c(1-t)$ or $B_p(1-t))$ if they buy call options (put options).

The objective functions for the liquidity traders given the presence of transaction taxes change in a straightforward way, and the equilibrium results for the three scenarios described above are shown in the next section.

5.1 Equilibrium Investment with Taxes

First, lets explore explore how taxes impact the conditions for a pooling equilibrium.

Figure 4 shows the difference between the profits available to the informed trader in the option and stock market as a function of some of the models parameters.[9] As one would

[9] For the remainder of this section I will focus on the case of an up-state. The results for the down-state are symmetrical.

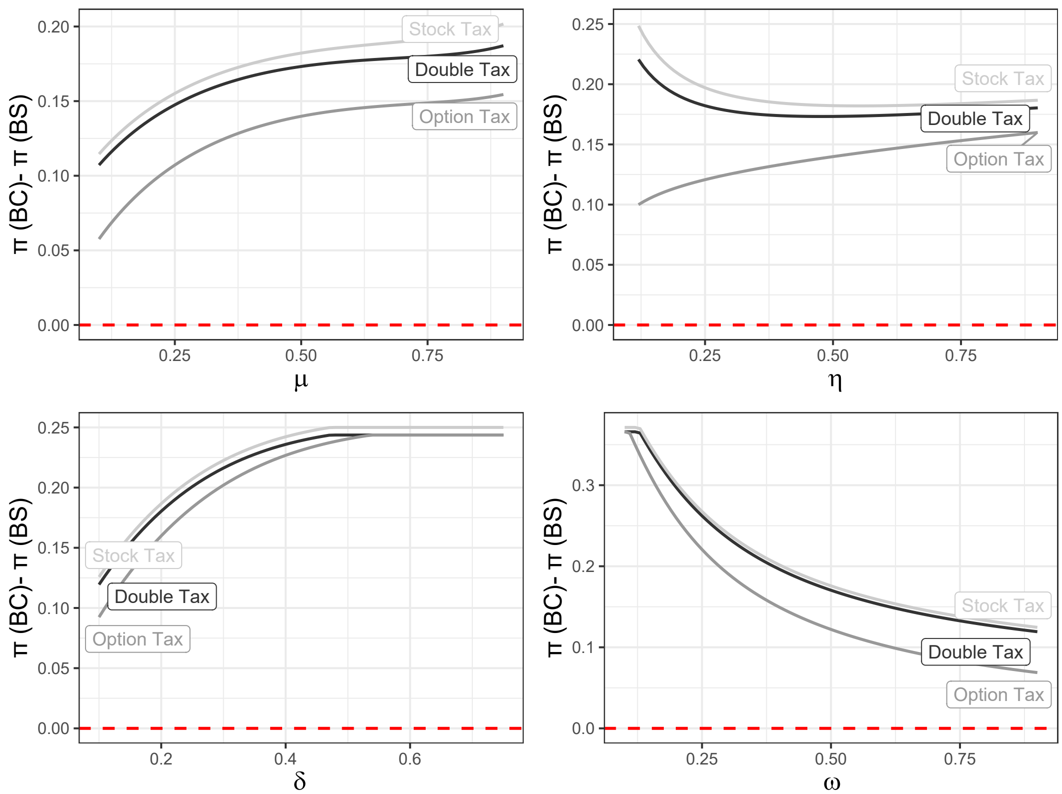

Figure 4: The Figure shows the effect of μ, ω, η and δ on the conditions of a pooling equilibrium, e.g. $\Pi(BC) - \Pi(BS)$ and $\Pi(SP) - \Pi(BS)$

expect, with option taxes in the market it becomes less likely that the conditions for a pooling equilibrium are satisfied, as the profits in the option market are adversely affected by the taxes. Additionally, the difference in profits in the two markets is also slightly lower when taxes are introduced in both markets compared to the scenario when there exists only a tax in the stock market. The directional impact of the parameters on the conditions is the same as shown in Figure 2.

Next I look at the equilibrium probabilities of informed trading in either market. Figure 5 showcases an important result of this model. If the same tax function and rate is introduced for the stock and derivative market, the effect of taxation in the stock market will be larger than the effect in the derivative market. Figure 5 displays this result, which is pervasive throughout the remaining theoretical findings, as an asymmetric deviation of α_u(Option Tax) and α_u(Stock Tax) with respect to the benchmark case of no taxation. This result arises as a consequence of the different payoff structure of stocks compared to derivative products. Intuitively, due to the inherent leverage of derivative products, the price constitutes a smaller proportion of the final payoff compared to stocks. If a standard

tax on the value of the transaction is considered, as described in section 5, and the same tax rate is used for both markets, this will lead to a higher effect of taxation in stock markets compared to derivative market (see Appendix for a more detailed discussion).
In addition, Figure 5 shows that α_u^* and β_u^* are not constant once taxes are considered. The effect of μ, δ and η on α_u^* is the same. For the case of an option tax, as these parameters increase, α_u^* decreases. This is due to the same logic discussed when describing Figure 2, namely that, as μ increases the probability of observing a buy in the stock market increases, leading the market maker to increase prices and informed traders to move to the option market. This holds only in the scenario when only an option tax is present, as in that case the presence of informed traders in the stock market will be naturally higher (due to the asymmetric effect described above) and there are enough profits available in the option market such that informed traders wish to move to the derivatives market. For the other two scenarios, α_u^* will be lower, as the stock market is taxed and returns are therefore decreased. Additionally, as μ is low, expected profits in the option market will be higher as there is a limited downside risk. As μ increases, stocks become more valuable relative to options, leading to a slight increase in $\alpha_u *$. As δ and η increase, the relative presence of informed trading in the market increases which, in turn, leads to a fast increase of α_u^* for low values of the parameters. Naturally, as the presence of informed trading increases, the markets will naturally find an "equilibrium" amount of informed trading. This is clearly shown in the top right graph of Figure 5, where the level of informed trading remains almost constant for $\delta > 0.5$. Depending on the tax regime, this "equilibrium" level will be either above or below the equilibrium α_u^* found in the case of no taxation. The effect of ω on α_u^* is straightforward. As the liquidity in the stock market increases, the proportion of informed trading in the stock market increases as well, no matter the tax regime.

Finally, I look at the equilibrium quantities and prices for the three different tax regimes. Figure 6 shows that in every tax regime the equilibrium quantities traded are lower compared to the case without a tax. This result follows intuitively from the results shown in Figure 5, combined with the effect of taxation on the returns available in the market. For the case of a tax in the option market, we know from Figure 5 that the equilibrium informed trading will be slightly higher than the equilibrium proportion without taxation. This effect alone, without considering the effect of taxation on the return, would lead to higher quantities traded in the option market, resulting from improved liquidity conditions in the option market and simultaneous worse liquidity in the stock market. This effect is countered by decreased returns, which leads to slightly lower quantities traded in the case of an option tax compared to a tax-less scenario, as shown in Figure 13. The same logic

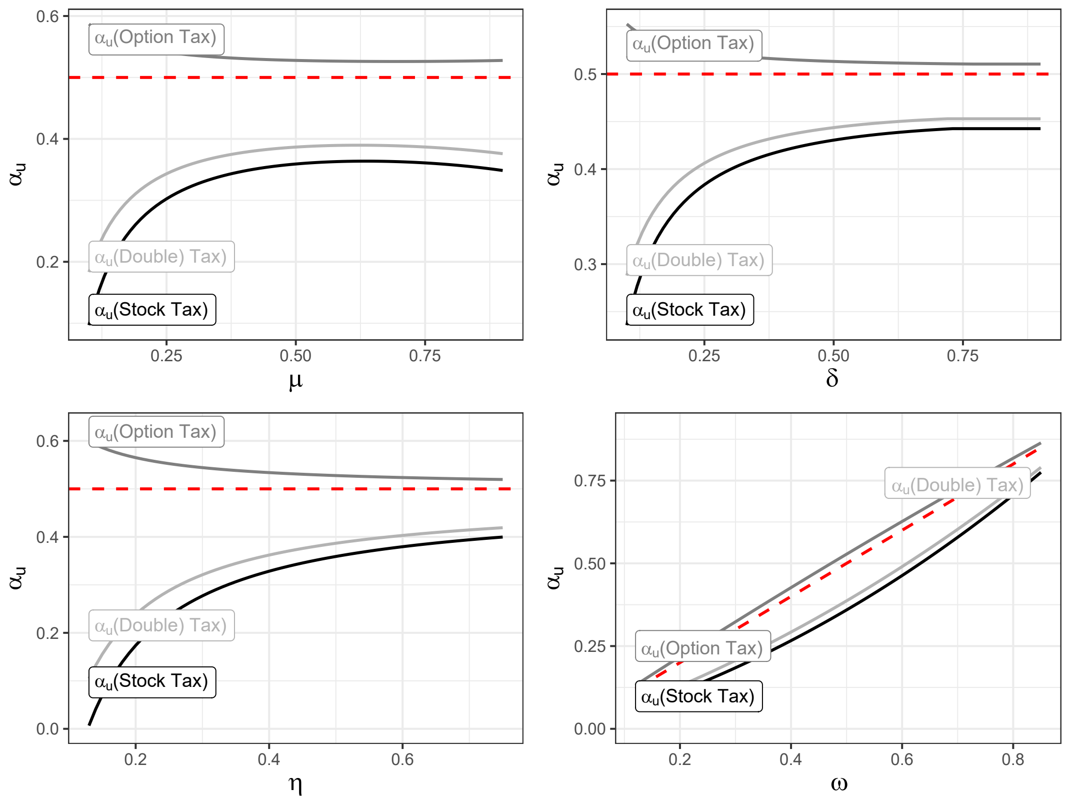

Figure 5: The Figure shows the effect of μ, ω, η and δ on the equilibrium probabilities of informed trading in the stock and option market. The red dashed line shows the equilibrium probabilities of informed trading for the benchmark case without taxation.

applies to the other two tax regimes.

Furthermore, the parameters considered in Figure 6 have different effects on the equilibrium quantities. As shown in the top left quadrant, the latter are an increasing function of μ. As the probability of an up-state increases, these trades become more desirable, leading to increased quantities. The equilibrium quantities also increase as the liquidity shock L increases. This is intuitive, as liquidity traders' optimal way to hedge against liquidity shocks in the up state is to increase the exposure to trades that have positive payoffs in the up state. Increasing the proportion of informed trading in the market leads to an overall decrease in trading. For a certain threshold of informed trading the spreads in the markets will become too large, leading to the well-known result of a market breakdown in the spirit of Glosten and Milgrom (1985). Increasing the leverage of options θ, as expected, does not affect equilibrium quantities in the stock market. Interestingly, increasing the amount of shares controlled by an option contract leads to lower quantities traded in the option market. This is due the adverse effect on option prices of an increased θ, which counters the

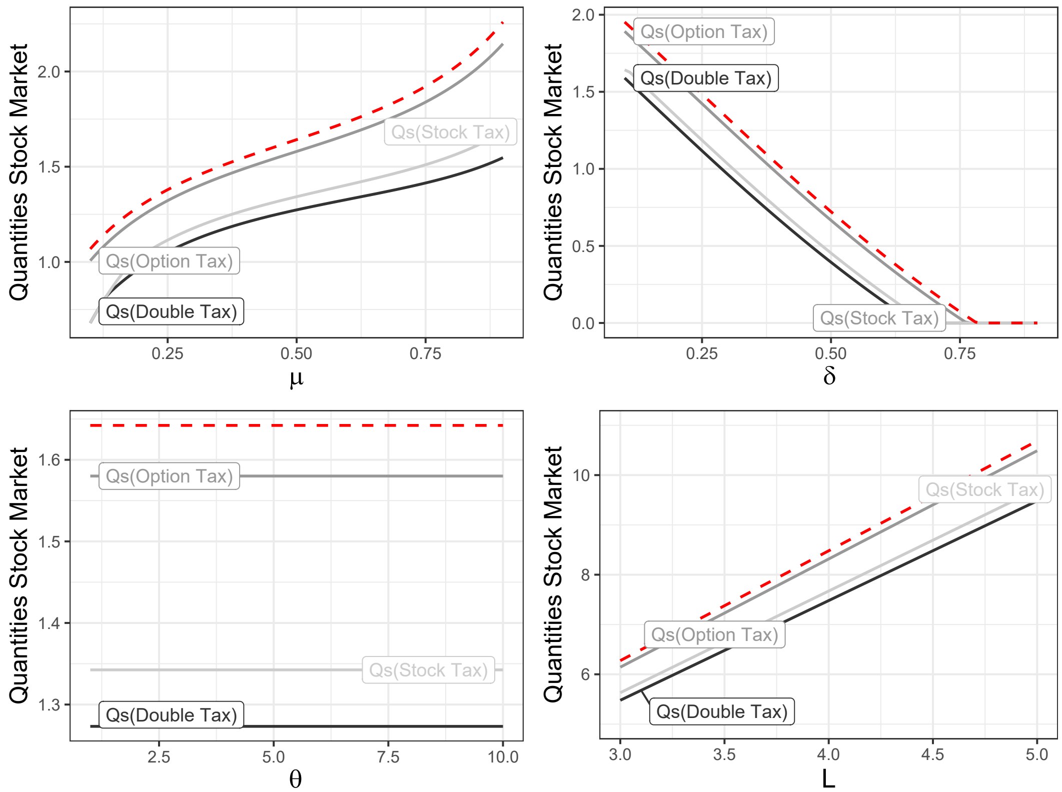

Figure 6: The Figure shows the equilibrium quantities traded in the stock market as functions of μ, δ, θ and L. The red dashed line shows the equilibrium quantities traded in the stock market for the benchmark case without taxation.

effect of increasing the intrinsic value of the option. Figure 7 shows the equilibrium prices for the three tax regimes. In the top left graph we see that increasing the probability of an up-state increases the level of the prices, since the stock becomes more valuable the more likely it becomes that its value will increase. Additionally, the spreads slightly increase as $\mu \to 0.5$, since the uncertainty in the market is the highest when $\mu = 0.5$. Increasing δ and η has the same effect of increasing the spreads in the market, as in both cases the relative presence of informed traders in the stock market increases, which in turn has an adverse effect on the spreads. The effect of increasing the presence of liquidity trading in the stock market has different effects depending on the tax regime. As can be noted from the bottom right graph in Figure 7, for a stock tax and a dual tax regime, increasing the liquidity in the stock market actually increases the spreads. This is due the fact that increasing ω simultaneously increases α_u^*, where the ladder effect dominates the former one. The opposite is true in the case of an option tax, which leads to a slight decrease in spreads.

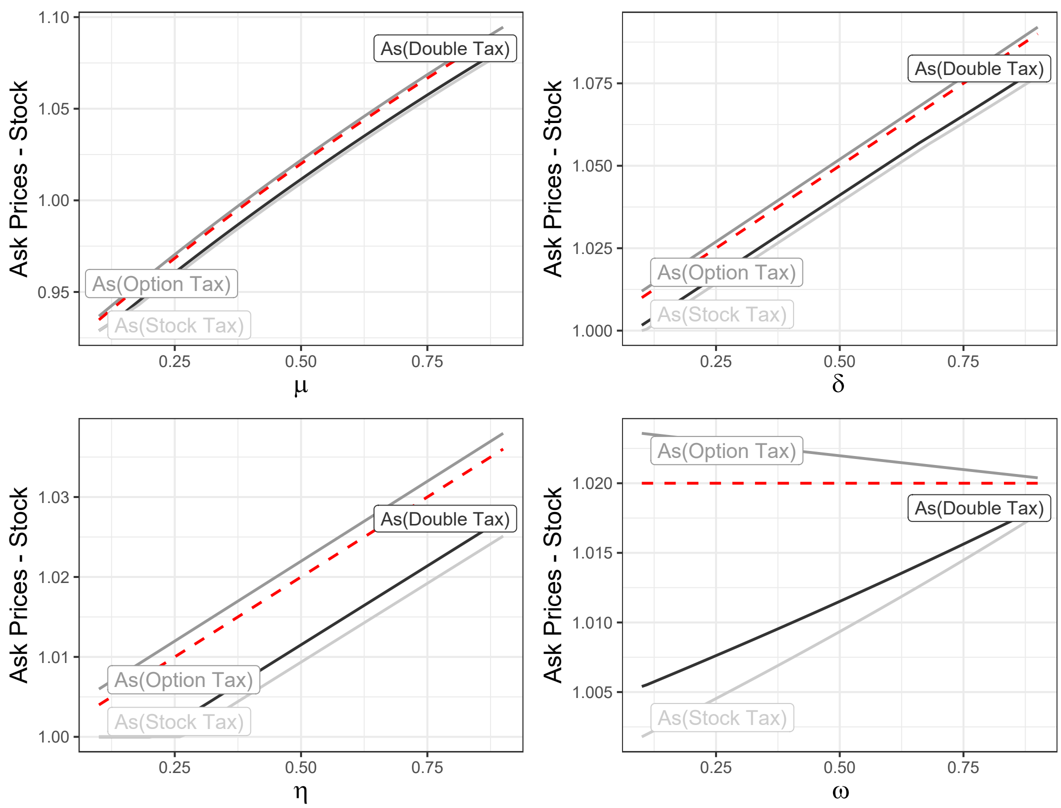

Figure 7: The Figure shows the equilibrium ask prices for the stock as functions of μ, δ, η and ω. The dashed line shows the equilibrium ask prices in the stock market w for the benchmark case without taxation.

5.2 Imperfect Competition

Next, in order to explore the effects of taxation on liquidity provision, I include an additional friction, namely imperfect competition (IC) among market makers. In the benchmark model described so far, I considered a model where market makers, when chosen to trade, are allotted the full order flow. As is well-known, this mechanism leads to market makers slightly undercutting each others quotes until prices eventually reach their conditional expectations and profits are driven down to zero. In this section I consider a different trading mechanism, namely a call auction. Dealers are now assumed to submit a quote schedule, that is, a set of quantities they are willing to trade for at any given price. In every trading round, an auctioneer will then parcel out the full order flow among all the market makers at the market clearing price. More formally, I consider a fixed number of market makers M, a proportion m_s of which provide liquidity in the stock market and $(1-m_s)$

provide liquidity in the option market[10]. I then define $Q_s^m(p_s)$ and $Q_o^m(p_o)$ to be the total number of shares or options that a dealer is willing to sell (or offer to buy if $Q < 0$) at price p. The total market supply for the two markets at price p is then $\sum^M Q_s^m(p_s)m_s$ and $\sum^M Q_o^m(p_o)(1-m_s)$.

Recall that in the model of Section 3, the market makers have rational expectations about the proportion of trades arriving from different traders and their trading strategies, and set prices accordingly. With this trading mechanism, market makers also need to take into consideration the behavior of the other market makers and accordingly how their own strategies impact equilibrium prices. Therefore, in this section we seek a rational expectation equilibrium such that the set of schedules set by market markers $\{Q^m(p)\}_{m=1}^{m=M}$ and the according price mapping $p^*(q)$ is such that (i) it maximizes his profits, (ii) the market makers correctly anticipates the clearing price and forms expectations accordingly, (iii) the markets clear, e.g. $\sum^M m_s Q_s^m(p_s) = Q_s$ and $\sum^M (1-m_s)Q_o^m(p_o) = Q_o$. The following proposition summarizes the equilibrium:

Proposition 2 *For the market mechanism described above, it turns out that market makers in the stock market will post the following quantity and prices schedules:*

$$Q_s^m(p) = \begin{cases} \phi_s p & \text{if} \quad p = A_s \\ \frac{1}{\phi_s} p & \text{if} \quad p = B_s \end{cases} \qquad \textit{with} \qquad \phi_o = \frac{(M-2)}{(M-1)(Mm_s - m_s - M)\alpha_s}, \tag{26}$$

$$p_s(Q_s) = \begin{cases} \lambda_s p & \text{if} \quad Q_s > 0 \\ \frac{1}{\lambda_s} Q_o & \text{if} \quad Q_s < 0 \end{cases} \qquad \textit{with} \qquad \lambda_s = \frac{(M-1)(1-m_s+Mm_s)\alpha_s}{M(M-2)m_s}, \tag{27}$$

and the market makers in the option market will post the following schedules:

$$Q_o^m(p) = \begin{cases} \phi_o p & \text{if} \quad p = A_o \\ \frac{1}{\phi_o} p & \text{if} \quad p = B_o \end{cases} \qquad \textit{with} \qquad \phi_o = \frac{(M-2)}{((M-1)(M(1-m_s)+m_s)\alpha_o}, \tag{28}$$

[10] I decide to not endogenize the choice of m_s, as it does not change the intuitions derived from this section. In order to make m_s endogenous, a similar mechanism to the one used for informed traders could be used, that is, previous to every trading round, market makers would choose the optimal m_s by equalizing the profits available in both the stock and the option markets.

$$p_o(Q_o) = \begin{cases} \lambda_o p & if \quad Q_o > 0 \\ \frac{1}{\lambda_o} Q_o & if \quad Q_o < 0 \end{cases} \qquad with \qquad \lambda_o = \frac{(M-1)(M(1-m_s)+m_s)\alpha_o}{M(M-2)(1-m_s)}. \quad (29)$$

Figure 8 visualizes the proposition above in terms of equilibrium prices. Specifically, Figure 8 shows how imperfect competition affects the equilibrium ask and bid prices - and therefore the spread - in the stock market as a function of μ, δ, η and ω. As is clear from Proposition 2, imperfect competition generally has an adverse effect on the liquidity of the markets. In this case, because I allow market makers to move from the stock to the option market, the liquidity (in terms of spreads) of the stock market will decrease (increase) as m_s decreases (increases).

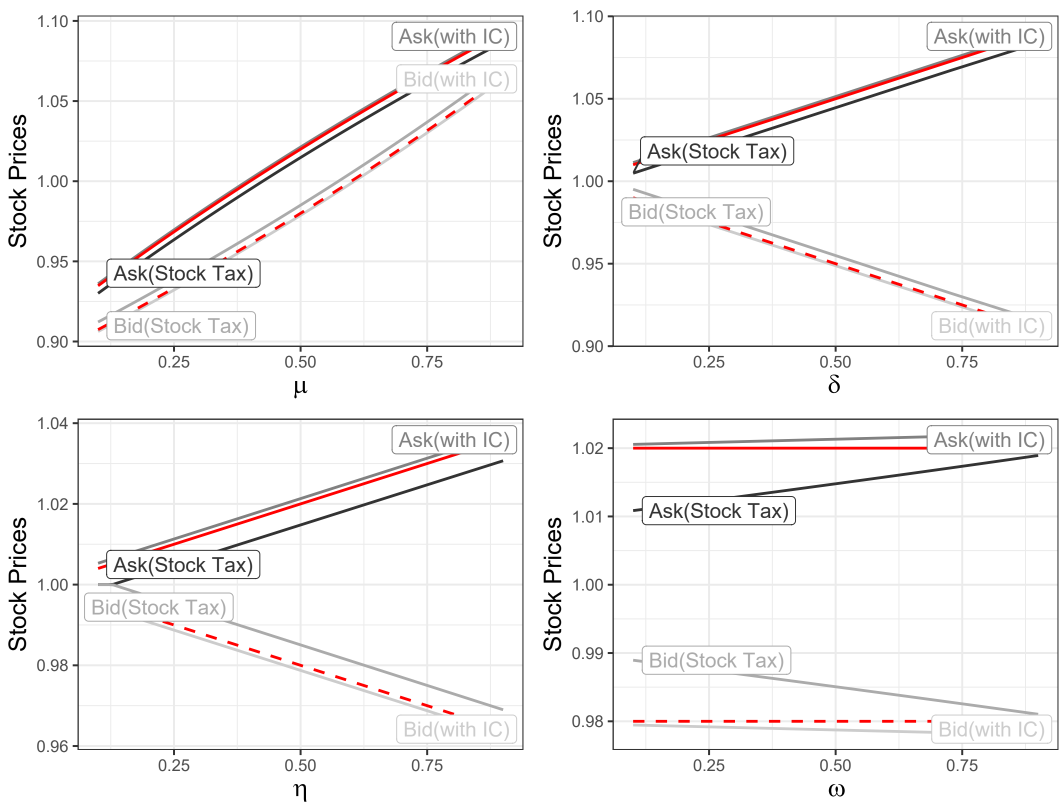

Figure 8: The Figure shows the equilibrium stock prices as functions of μ, δ, η and ω when a tax is levied in the stock market and in the case of imperfect competition among market makers when $M = 1000$ and $m_s = 0.45$. The red solid (dashed) line shows the equilibrium ask (bid) price for the benchmark case of no taxation and perfect competition.

This is clear from Figure 8, where I assume that the proportion of dealers in the stock market has decreased to $m_s = 0.45$, leading to more dealers providing liquidity in the option market than in the stock market. In all four graphs of Figure 8 it is clear that the spread increases compared to the case where just a tax in the stock market is introduced. Recall that introducing a tax in the stock market will lead informed traders to move to the option market, therefore decreasing the level of informed trading in stocks, which in turn has a positive effect on the liquidity. Imperfect competition on the other hand, while also reducing the amount of informed trading, allows market makers to earn rents by posting higher spreads. The net outcome in terms of market quality therefore depends on the relative magnitude of the two effects.

6 Sequential Model

Finally I extend the model to allow the dealer to update his beliefs and post new quotes after every trading round, effectively making the model sequential. Given any first-period trade, the market makers beliefs can be updated in a straight-forward way. As is shown by the probability tree in figure 1, at the beginning of a trading day an information event happens with probability η, and, conditional on the information event happening, we are either in a high or low state of the world. Therefore, during the day, the market maker will update his probabilities that an information event happened at the start of the day and her probability of the state of world based on the incoming trades. For example, a stock purchase will increase the market makers belief that we are currently in an up-state, whereas a stock sale or a the purchase of a put option will increase his belief that we are in a down-state. The sequential model can be represented by the following set of equations:

$$\mu_k(\text{Buy Stock}; \mu_{k-1}, \eta_{k-1}) = \frac{\eta_{k-1}\mu_{k-1}(2\alpha_u\delta + \omega - \delta\omega)}{2\alpha_u\delta\eta_{k-1}\mu_{k-1} + \omega - \delta\omega\eta_{k-1}}, \tag{30}$$

$$\mu_k(\text{Buy Call}; \mu_{k-1}, \eta_{k-1}) = \frac{\mu_{k-1}\eta_{k-1}(\eta_{k-1}\delta - 1 + 4\eta_{k-1}(\alpha_u - 1)\beta_u\delta + \omega - \delta\omega}{\delta - 1 + 4(\alpha_u - 1)\beta_u\delta + \omega - \delta\eta_{k-1}\omega}, \tag{31}$$

$$\mu_k(\text{Sell Put }; \mu_{k-1}, \eta_{k-1}) = \frac{\mu_{k-1}\eta_{k-1}(1 - \omega + \delta(3 + 4\alpha_u(\beta_u - 1) - 4\beta_u + \omega)}{1 - \omega + \delta\eta_{k-1}(4(\alpha_u - 1)(\beta_u - 1)\mu_{k-1} - 1 + \omega)}, \tag{32}$$

$$\eta_k(\text{Buy Stock}; \eta_{k-1}; \mu_{k-1}) = \frac{\eta_{k-1}(2\alpha_u\delta\mu_{k-1} + \omega - \delta\omega)}{2\alpha_u\delta\eta_{k-1}\mu_{k-1} + \omega - \delta\eta_{k-1}\omega}, \tag{33}$$

$$\eta_k(\text{Buy Call}; \eta_{k-1}; \mu_{k-1}) = \frac{\eta_{k-1}(\delta - 1 + 4(\alpha_u - 1)\beta_u\delta\mu_{k-1} + \omega - \delta\omega}{\delta\eta_{k-1}(1 + 4(\alpha_u - 1)\beta_u\mu_{k-1} - \omega) + \omega - 1}, \tag{34}$$

$$\eta_k(\text{Sell Put}; \eta_{k-1}; \mu_{k-1}) = \frac{\eta_{k-1}(1 - \omega + \delta(4(\alpha_u - 1)(\beta_u - 1)\mu_{k-1} + \omega - 1))}{1 - \omega + \delta(4(\alpha_u - 1)(\beta_u - 1)\mu_{k-1} + \omega - 1}, \tag{35}$$

where μ_j and η_j represent the market makers' subjective believes of an up-state or an information event respectively for trading round k, conditional all the information available after trading round $k-1$. The sequential probabilities for the down-state trades are shown in the Appendix. Given this set of probabilities, the model provides a time series of trades, quantities and prices.

6.1 Option Prices

In order to determine the option prices in the sequential model, I exploit the trinomial structure of stock prices implied by the probability tree shown in Figure 1. In fact, the model above implies that the stock prices are determined by the following trinomial tree:

$$S_{t+1} = \begin{cases} S_t u & \text{with probability} \quad p_u = \eta \times \mu \\ S_t m & \text{with probability} \quad p_m = 1 - \eta \\ S_t d & \text{with probability} \quad p_d = \eta \times (1 - \mu). \end{cases}$$

Note that this structure of stock prices can be seen as the discretized version of stock prices derived from a (hypothetical) geometric Brownian motion. In order to determine the risk neutral probabilities $\{p_u^{RN}, p_d^{RN}, p_m^{RN}\}$ and the appropriate jump sizes $\{u, m, d\}$, I construct conditions that match the parameters of the trinomial tree with the first two moments of the distribution of the (hypothetical) geometric Brownian motion, while also imposing that the probabilities are specified so that the growth rate of the stock matches the risk-free rate. This results in the following conditions:

$$\mathbb{E}[S_{t+1} \mid S_t] = e^{r\triangle t} S_t, \tag{36}$$

$$Var[S_{t+1} \mid S_t] = \triangle t S_t^2 \sigma^2. \tag{37}$$

Additionally, I impose the two following constraints on the jumps sizes

$$ud = 1 \qquad \text{and} \qquad m = 1. \tag{38}$$

These constraints imply that the upward jump is the reciprocal of the downward jump, which leads to a recombining tree, where the number of nodes in the tree grow linearly with the number of steps. Then, by additionally imposing $p_m^{RN} = 1 - p_u^{RN} - p_d^{RN}$, we end up with three constraints [36, 37, 38] on four parameters $\{u, d, p_u^{RN}, p_d^{RN}\}$. Therefore there is discretion over the choice of the jump sizes, and, following the literature I set:

$$u = e^{\beta\sigma\sqrt{\triangle t}}, \quad d = e^{-\beta\sigma\sqrt{\triangle t}} \tag{39}$$

where $\beta > 1$ is chosen such that a risk neutral measure exists (and such that $p_u^{RN} + p_d^{RN} < 1$). The risk neutral probabilities are then given by

$$p_u^{RN} = \frac{1 - e^{r\triangle t} - e^{r\triangle t + \sqrt{\triangle t}\beta\sigma} + e^{2r\triangle t + \sqrt{\triangle t}\beta\sigma} + \triangle t e^{\sqrt{\triangle t}\beta\sigma}\sigma^2}{(e^{\sqrt{\triangle t}\beta\sigma} - 1)^2(1 + e^{\sqrt{\triangle t}\beta\sigma})}, \tag{40}$$

$$p_d^{RN} = \frac{e^{2\sqrt{\triangle t}\beta\sigma}(e^{r\triangle t} - e^{2r\triangle t} - e^{\sqrt{\triangle t}\beta\sigma} + e^{r\triangle t + \sqrt{\triangle t}\beta\sigma} - \triangle t\sigma^2}{(e^{\sqrt{\triangle t}\beta\sigma} - 1)^2(1 + e^{\sqrt{\triangle t}\beta\sigma})}, \tag{41}$$

$$p_m^{RN} = 1 - p_u^{RN} - p_d^{RN}. \tag{42}$$

In order to find the option prices, one simply needs to determine the option payoffs at maturity T:

$$C^c(S, T) = max(S - K_c, 0), \tag{43}$$

$$C^p(S, T) = max(K_p - S, 0). \tag{44}$$

The remaining prices can then be determined by the following backward induction formula:

$$C_{n,t}^{c,p} = e^{-r\triangle t}[p_u^{RN} C_{n+1,t+1}^{c,p} + p_m^{RN} C_{n,t+1}^{c,p} + p_u^{RN} C_{n-1,t+1}^{c,p}], \tag{45}$$

where $\{n, t\}$ determine respectively the node and time step of the trinomial tree. In order to make the option pricing coherent with the trading structure shown in Figure 1, I will assume that the step sizes of the trinomial tree (t) represent days. This implies that the option pricing outlined in this section provides daily option prices for every possible path of the probability tree, which in turn is determined by the set of two probabilities $\{\eta, \mu\}$. The intradaily option ask and bid prices can then be determined in the following way:

$$Ask^c_{k,t} = C^c_{n+1,t+1}Pr_{k,t}[u \mid Buy] + C^c_{n,t+1}Pr_{k,t}[m \mid Buy] + C^c_{n-1,t+1}Pr_{k,t}[d \mid Buy], \quad (46)$$
$$Bid^c_{k,t} = C^c_{n+1,t+1}Pr_{k,t}[u \mid Sell] + C^c_{n,t+1}Pr_{k,t}[m \mid Sell] + C^c_{n-1,t+1}Pr_{k,t}[d \mid Sell], \quad (47)$$

where k defines the trading round during trading day t. The ask and bid prices for the put option are found similarly.

6.2 Simulation Results

In this section I show the results of simulating the model described above, that is, the benchmark model without taxation and with perfect competition as well as the model with the inclusion of the different tax regimes and the case of imperfect competition. This exercise allows me to construct time series proxies for volume and liquidity. I simulate a trading year of data, e.g. 252 days, with 30 trading rounds per day. Figures 9 to 11 show the average results of 1000 simulations for volume and liquidity in different scenarios of the model described previously. Furthermore, the options available for trading are European type options with 4 months (80 days) until expiration, which are rolled over every 3 months (e.g. the options are only available up to one month before expiration)[11].

Figure 9 shows the effect of the different tax regimes on the trading volume in both stock and option markets. The top two graphs show the time series of average quantities summed over one trading day, whereas the bottom two graphs show the dollar weighted volume. The figure shows that introducing a tax in the stock market significantly reduces the volume in the stock market for both proxies used. Also, introducing a tax in the option market slightly increases the volume in the stock market, but this effect is smaller compared to the effect of a stock tax. This is in line with the asymmetry of a stock versus an option tax that was already discussed in the static version of the model. Given this result, the effect of taxing both markets is straightforward, e.g. the effect of the stock tax dominates. As shown in the right two graphs in Figure 9, the option market is largely unaffected, which

[11] Additionally, in the baseline simulation I use in-the-money options. Compared to the baseline parameters used in the comparative statics of the static model, for the baseline simulation I use $\delta = 0.2$, $S_0 = 100$, $L = 5$, $l = 2$, $\sigma = 0.15$, $\beta = 1$.

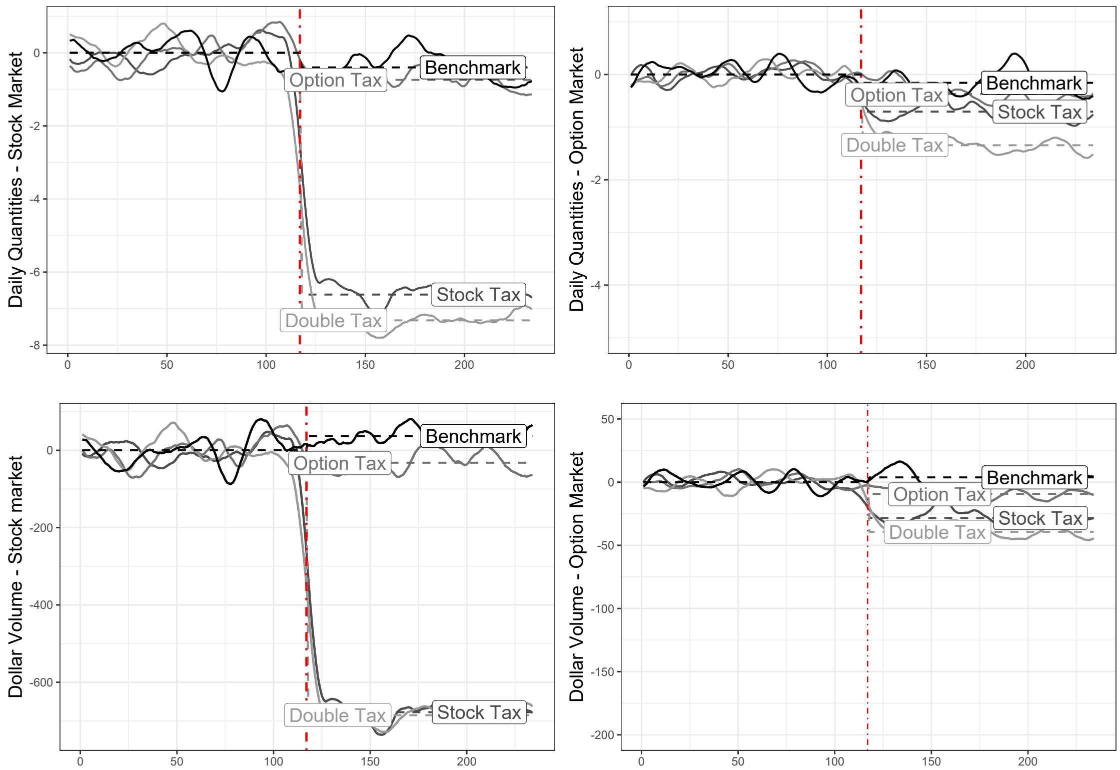

Figure 9: The Figure shows the effect of the different tax regimes on the the daily traded quantities and the dollar volume traded for both stock and options.

is again due to the asymmetric effect of taxation.[12]

Next, I consider the impact of different tax regimes on market liquidity. In order to do so, I construct four different spread measures, namely quoted spread, effective spread, realized spread and price impact, which are formally defined in the following way[13]:

[12]The proxies for volume in the sequential model are a function of both trading quantity and trading frequency. The large effect of taxation of stocks on stock trading volume is due to the fact that both trading quantities and trading frequency experience large decreases due to taxation. The compound effect is therefore a significant decrease in volume. On the other hand, stock taxation has opposite effects on trading frequencies and trading quantities in the option market. While the former increases, the latter decreases, therefore canceling each other out. Figures for trading frequencies and quantities are provided in the Appendix.

[13]In the simulation I substitute $t + 5$ minutes by $t + 5$ trades.

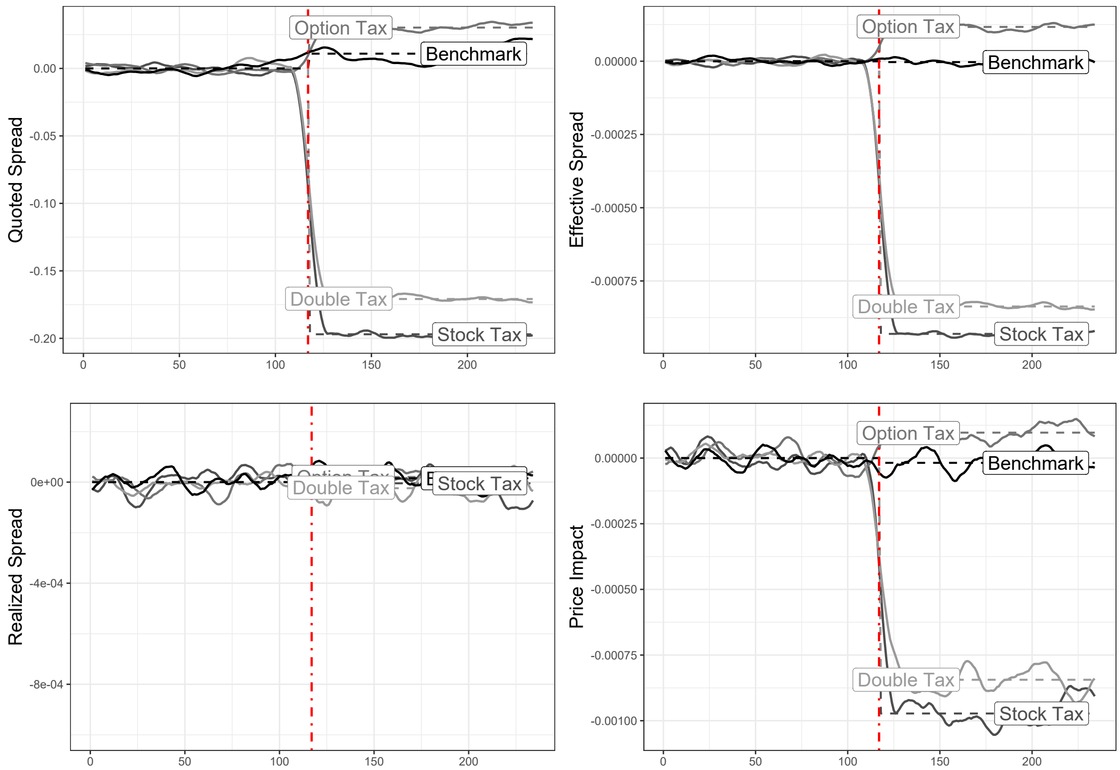

Figure 10: The Figure shows the effect of the different tax regimes on the quoted spread, effective spread, realized spread and price impact in the stock market.

$$\text{Quoted Spread} = \frac{Ask_t - Bid_t}{mid_t}, \qquad \text{Effective Spread} = q_t \frac{p_t - mid_t}{mid_t},$$

$$\text{Realized Spread} = q_t \frac{m_{t+5min} - mid_t}{mid_t}, \qquad \text{Price Impact} = q_t \frac{p_t - mid_{t+5min}}{mid_t}.$$

The quoted spread is perhaps the most obvious and intuitive measure, and it is simply the cost of a hypothetical ”round-trip” transaction, that is, the cost incurred if one would (instantaneously) buy and sell an instrument at the best quotes available. The effective spread on the other hand tries to measure this cost by using the prices actually obtained by investors. It can therefore be seen as the impact of the specific transaction on the prices available in the market. Importantly, the effective spread can be decomposed into the realized spread and the price impact, where, in empirical applications, the former is usually interpreted as a proxy for rents obtained by market makers, and the latter is seen as a proxy for the adverse selection present in the market. Figure 10 shows the effects of the different tax regimes on these spreads for the stock market. The following picture emerges: introducing a stock tax in this setting decreases (increases) the proportion of informed trading in the stock market (option market) which positively affects its liquidity. This can be seen both for quoted and effective spread. Furthermore, it is clear from the two bottom graphs of Figure 10 that this effect is purely driven by the alleviation of the adverse selection problem in the market. Further, introducing a tax in the option market has the opposite effect, even though the magnitudes are again substantially lower compared to the introduction of a stock tax. The results for the spreads in the option market follow the same logic and therefore move in the expected direction, but coherently with the results found so far, are much lower in magnitude.

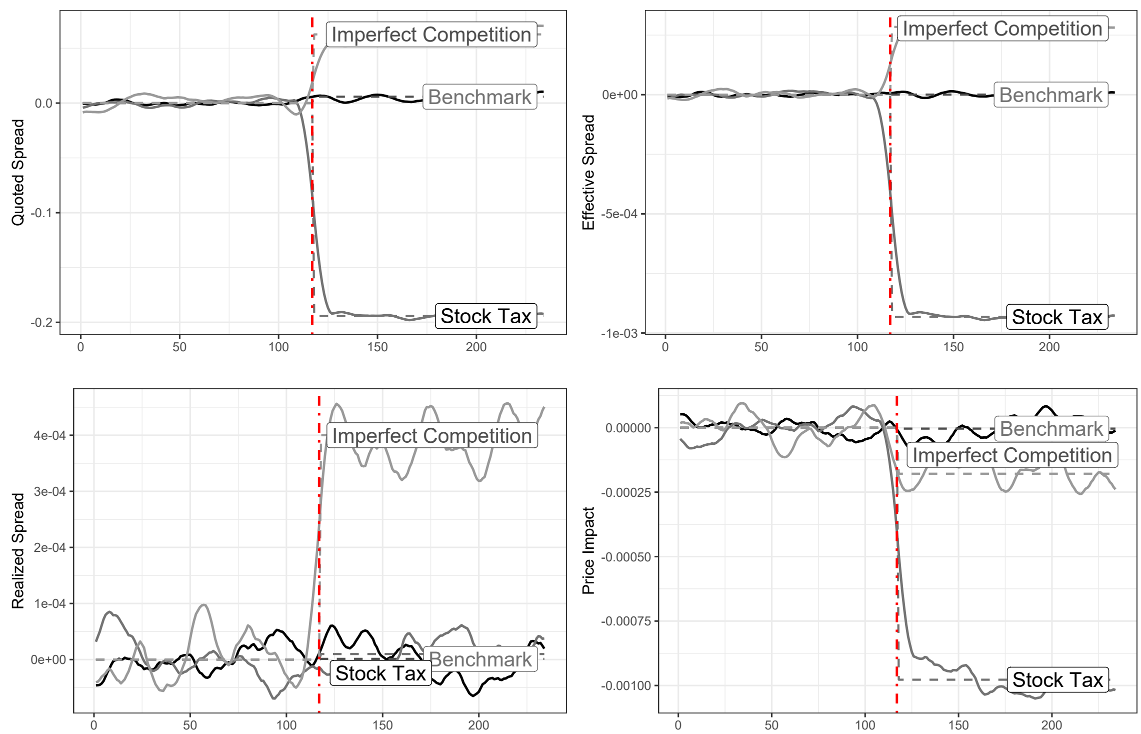

Figure 11: The Figure shows the effect of imperfect competition on the different spreads compared to the benchmark case without taxation and with perfect competition and the case where a stock tax is introduced half way through the trading year. The imperfect competition case assumes M=1000 and m_s drops from 0.5 to 0.45.

Next I simulate the model under imperfect competition. As mentioned earlier, I do not endogenize the choice of m_s, but it is reasonable to assume that the introduction of taxation in a certain market will, if anything, have a negative effect on the competition of market makers in that market.[14] For the simulation with imperfect competition I therefore assume

[14]Most implementations of FTTs include some sort of exemption for market makers. These exemptions

that taxation will also lead to worse competition among market makers by decreasing (or increasing in case of an option tax) the proportion of market makers (m_s) that provide liquidity. Figure 11 shows the result of this exercise on spreads compared to the benchmark case and the scenario in which a stock tax is introduced. Figure 11 clearly shows that decreasing the level of competition adversely affects the spreads in the markets. The bottom two graphs of Figure 11 show that both the quoted spread and the effective spread increase as the proportion of active market markers in the stock market decreases. Opposite to the case where the introduction of a tax does not affect the competition among market makers, this result is mainly driven by an increase in the realized spread. Decreasing competition also positively affects the adverse selection in the market. In fact, as market conditions worsen due to the decreasing competition, informed traders move to the more competitive market.

In summary, this paper provides a new way of approaching the problem of studying the impact of financial transaction taxes on market quality. Much of the previous literature focuses on studying such issues, as well as issues regarding the impact on the welfare of market participants, within a single-market setting. While this has been important to obtain an understanding of FTTs, it does not fully take into account the connectedness of modern financial markets. In order to fully account for the effects of FTTs, it is crucial to be able to foresee how the reaction of different market participants to the tax affects the composition of traders in the taxed market, as well as all the markets that allow for trading in instruments that are directly correlated to the payoffs obtainable in the taxed market. From a policy perspective this would allow for more efficient tax design that is able to minimize the avoidance of taxation, therefore maximizing tax revenue while also being able to control possible adverse effects on market quality. While this study is a step in this direction, many issues within this framework remain to be studied. Some of these certainly include extending the type of traders in the model and allowing for more sophisticated trading motives. A slightly different approach would entail studying the effect of taxation (or trading costs) on the informational relationship between markets, specifically between equity and derivative markets. Additionally, it is only natural that empirical studies on FTTs should also consider effects across connected markets. In the next chapter I provide a first attempt at the latter, whereas the former are left for future research.

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vary across countries and can effectively include significant burdens for market makers in order to provide proof of market making activity. Thus, even though exemptions apply, financial taxes can lead to significant indirect costs for market makers.

7 Conclusion

Taxing financial transactions can notoriously lead to migration of trading, which, besides hampering its ability to effectively raise tax revenue, leads to changes in trader composition across different trading venues. To address these issues, this article studies the effect of taxing financial transaction taxes within a multi-market setting, where traders are allowed to trade both equities and options. Investigating the introduction of taxation in either or both markets gives rise to the following results.

First, using the same tax rate and function for both stocks and options leads to an asymmetric effect, where option trading is less affected due to the different payoff structure of the investment products. This results, which is essentially due to the inherent leverage of derivatives, highlights the importance of using a different tax base when taxing both equities and its derivatives.

Second, taxation can lead to a positive effect on liquidity due to the migration of informed trading. As informed traders seek to avoid paying the tax by exploiting their informational advantage in an untaxed market, the adverse selection problem in the taxed market is mitigated, allowing market makers to post narrower spreads. Naturally, this result should be interpreted with care, as this model focuses on information. While that is certainly important, multiple factors influence trader composition and behaviour. To partly address this, I extend the model to allow market makers to be affected by taxation. As their cost of providing liquidity increases, market makers will choose to move to different trading venues, therefore decreasing the competition among market makers in the taxed market. This, in turn, allows the latter to extract higher rents by posting larger spreads. Therefore, when traders as well as market makers are affected by taxation, the effect of the latter on market liquidity in the context of asymmetric information becomes ambiguous, and depends on the relative magnitude of the two effects.

Overall, this study provides the first step towards recognizing the importance of analyzing the effect of transaction taxes within a multi-market setting. Understanding how taxation affects the migration incentives of market participants, and in turn how trader composition is affected, is crucial for for considerations regarding tax design. While clearly much remains to be learned, substantial benefit can be gained from studying these issues and understanding the effects of FTTs on trading migration.

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8 Appendix

8.1 Derivation of Quantities in Lemma 1

Since $U(x) = x - \gamma x^2$, the objective function for liquidity trader type 1 who trades in the stock market is

$$\begin{aligned}\max_{\{Q_s\}} \mathbb{E}[U(Q_s)] = \max_{\{Q_s\}} \quad & \Big[\eta\mu(-L + (S_0u - A_s)Q_s) - \eta\mu\gamma((-L + (S_0u - A_s)Q_s)^2 \\ & +(1-\eta)(-l + (S_0m - A_s)Q_s) - (1-\eta)\gamma((-l + (S_0m - A_s)Q_s)^2 \\ & +\eta(1-\mu)((S_0d - A_s)Q_s) - \eta(1-\mu)\gamma((S_0d - A_s)Q_s)^2\Big].\end{aligned}$$

Then, taking the FOC with respect to Q_s and setting it equal to 0 gives us the following equation:

$$\begin{aligned}\max_{\{Q_s\}} \mathbb{E}[U(Q_s)] =& (A_s - d)(-1+\mu) + 2(A_s - d)^2 Q_s\gamma(-1+\mu) \\ & + (-A_s + u)\mu - 2(L + Q_s(A_s - u))(A_s - u)\gamma\mu = 0,\end{aligned}$$

which can be solved to obtain f_{QS1}:

$$f_{QS1} = \frac{d - d\mu + u(1 + 2L\gamma)\mu - A_s(1 + 2L\gamma\mu)}{2\gamma(A_s^2 + 2A_sd(-1+\mu) - d^2(-1+\mu) - 2A_su\mu + u^2\mu)},$$

where we already assumed $\eta = 1$, $m = 1$, $K_c = S_d$ and $K_p = S_u$.

Similarly, the objective functions for liquidity traders type 1 who trades call or put options are

$$\begin{aligned}\max_{\{Q_c\}} \mathbb{E}[U(Q_c)] = \max_{\{Q_c\}} & \Big[\eta\mu(-L + ((S_0u - K_c)^+\theta - A_c)Q_c) \\ & - \eta\mu\gamma((-L + ((S_0u - K_c)^+\theta - A_c)Q_c)^2 \\ & + (1-\eta)(-l + ((S_0m - K_c)^+\theta - A_c)Q_c) \\ & - (1-\eta)\gamma(-l + ((S_0m - K_c)^+\theta - A_c)Q_c)^2 \\ & + \eta(1-\mu)((S_0d - K_c)^+\theta - A_c)Q_c \\ & - \eta(1-\mu)\gamma(((S_0d - K_c)^+\theta - A_c)Q_c)^2\Big],\end{aligned}$$

$$\max_{\{Q_p\}} \mathbb{E}[U(Q_p)] = \max_{\{Q_p\}} \Big[\eta\mu(-L + (B_p - (K_p - S_0 u)^+\theta)Q_p)$$
$$- \eta\mu\gamma(-L + (B_p - (K_p - S_0 u)^+\theta)Q_p)^2$$
$$+ (1-\eta)(-l + (B_p - (K_p - S_0 m)^+\theta)Q_p)$$
$$- (1-\eta)\gamma(-l + (B_p - (K_p - S_0 m)^+\theta)Q_p)^2$$
$$+ \eta(1-\mu)(B_p - (K_p - S_0 d)^+\theta)Q_p$$
$$- \eta(1-\mu)\gamma((B_p - (K_p - S_0 d)^+\theta)Q_p)^2 \Big].$$

Again, we can take the FOC with respect to Q_s and Q_p and set it equal to zero, which gives us the following equations:

$$\frac{\partial \mathbb{E}[U(Q_c)]}{\partial Q_c} = A_c(-1+\mu) + 2A_c^2 Q_c \gamma(-1+\mu) - (A_c + (d-u)\theta)\mu$$
$$- 2\gamma(A_c + (d-u)\theta)(L + Q_c(A_c + (d-u)\theta))\mu = 0,$$

$$\frac{\partial \mathbb{E}[U(Q_p)]}{\partial Q_p} = B_p + (d-u)\theta + 2Q_p\gamma(B_p + (d-u)\theta)^2(-1+\mu)$$
$$- 2B_p(-L + B_p Q_p)\gamma\mu + (-d+u)\theta\mu = 0.$$

Solving these equations gives us f_{QC1} and f_{QP1}:

$$f_{QC1} = \frac{A_c + 2_c L\gamma\mu + (d-u)(1+2L\gamma)\theta\mu}{2\gamma(A_c^2(-1+\mu) - (A_c + (d-u)\theta)^2\mu)},$$

$$f_{QP1} = \frac{(d-u)\theta(-1+\mu) - B_p(1+2L\gamma\mu)}{2\gamma((B_p + (d-u)\theta)^2(-1+\mu) - B_p^2\mu)}.$$

The same procedure can be followed for the type 2 liquidity traders that trade in the stock and the option market and obtain f_{QS2},f_{QC2} and f_{QP2}:

$$f_{QS2} = \frac{B_s - 2B_s L\gamma(-1+\mu) + d(1+2L\gamma)(-1+\mu) - u\mu}{2\gamma(B_s^2 + 2B_s d(-1+\mu) - d^2(-1+\mu) - 2B_s u\mu + u^2\mu)},$$

$$f_{QC2} = \frac{B_c - 2B_c L\gamma(-1+\mu) + (d-u)\theta\mu}{2\gamma(B_c^2 + 2B_c(d-u)\theta\mu + (d-u)^2\theta^2\mu)},$$

$$f_{QP2} = \frac{(u-d)(1+2L\gamma)\theta(\mu-1) - A_p(2L\gamma(\mu-1)-1)}{2\gamma((A_p+(d-u)\theta)^2(-1+\mu) - A_p^2\mu)}.$$

8.2 Proof of Proposition 1

We are seeking a pooling equilibrium that satisfies the following equilibrium conditions: (i) liquidity traders trade to maximize their utility (ii) informed traders trade to maximize their profits (iii) market makers are perfectly competitive and set prices equal to the conditional expectations. In the main text I already derived derived the prices set by market makers. Also, we know that the informed traders equilibrium strategy is to mimic the liquidity traders in order to avoid excessive revelation of information. We therefore need to find the strategies that maximize the liquidity traders utility. In the following I will present the result for the up-state, the equilibrium for the down-state is found in the same way (Note that, as stated in text, to simplify the display of the solution, in thew following I assume $\eta = 1$, $m = 1$, $K_c = S_d$, $K_p = S_u$ and $S_0 = 1$.

In order to find the optimal strategies for the liquidity traders we need to solve equations (3), (5) and (6). Equation (3) is given by:

$$\begin{aligned} Q_s^{1*} = \arg\max_{\{Q_s\}} \mathbb{E}[U(Q_s)] = \max_{\{Q_s\}} \Big[&\eta\mu U[-L + (S_0 u - A_s)Q_s] + (1-\eta)U[-l + (S_0 m - A_s)Q_s] \\ &+ \eta(1-\mu)U[(S_0 d - A_s)Q_s] \Big], \end{aligned}$$

where

$$\begin{aligned} A_s = \mathbb{E}[\mathrm{S} \mid Qs > 0] &= S_0 u Pr[u \mid Qs > 0] + S_0 m Pr[m \mid Qs > 0] + S_0 d Pr[d \mid Qs > 0] \quad (48) \\ &= \frac{S_0((m - m\eta + d(-1+\delta)\eta(-1+\mu))\omega + u\eta\mu(2\alpha_u\delta + \omega - \delta\omega))}{2\alpha_u\delta\eta\mu + \omega - \delta\eta\omega}. \end{aligned}$$

If we plug in A_s into the maximization problem above and differentiate with respect to Q_s we obtain

$$\begin{aligned} \frac{\partial \mathbb{E}[U(Q_s)]}{\partial Q_s} = &\frac{2(d-u)(\mu-1)\mu(2\alpha_u^2(2dQ_s\gamma - 2Q_s u\gamma - 1)\delta^2\mu)}{2\alpha_u\delta\mu + \omega - \delta\omega^2} \\ &\frac{(L + Q_s(d-u))\gamma(\delta-1)^2\omega^2 - \alpha_u(\delta-1)\delta(2L\gamma\mu + 4dQ_s\gamma\mu - 4Q_s\gamma\mu - 1)\omega}{2\alpha_u\delta\mu + \omega - \delta\omega^2}. \end{aligned}$$

If we set this equal to 0 we obtain Q_s^{1*}

$$\frac{(2\alpha_u\delta\mu+\omega-\delta\omega)u\mu(-2\alpha_u\delta(\mu-1)-2L\gamma(1+\delta(\mu-1)-\mu)\omega+d(\mu-1)(2\alpha_u\delta\mu+(2L\gamma\delta\mu-2L\gamma\mu)\omega)))}{2\gamma(\mu(u+u\delta(\mu-1)-u\mu+d(\delta+\mu-\delta\mu-1))^2\omega^2+(1-\mu)(d(\delta-1)\mu\omega-2d\alpha_u\delta\mu+u\mu(2\alpha_u\delta+\omega-\delta\omega))^2)}.$$

The same is done in order to find Q_c^{1*} and Q_p^{1*}. Next the profits of the informed traders need to be defined, such that the conditions for a pooling equilibrium can be found. The profits of an informed trader in the up-state are given by:

$$\Pi(BS) = Q_s(Su - A_s),$$
$$\Pi(BC) = Q_c((Su - K_c)\theta - A_c),$$
$$\Pi(SP) = Q_p B_p.$$

Next, the equilibrium strategies Q_s^{1*}, Q_c^{1*} and Q_p^{1*} as well as the prices A_s, A_c and B_p are plugged in, α_u is set to 1 (recall that we want to find conditions such that, when all informed traders are active in the stock market, profits in the option market are higher than profits in the stock market) and we seek the following conditions: $\Pi(BC) > \Pi(BS)$ and $\Pi(Sp) > \Pi(BS)$. After some straight forward algebra these inequalities become equation (16) in Proposition 1. Finally, in order to find the α_u^* and β_u^*, the folowing system of equations

$$\Pi(BC) = \Pi(BS), \qquad \Pi(Sp) = \Pi(BS),$$

needs to be solved subject to $\{\alpha_u^*, \beta_u^*\} \in \mathbb{R}$ and $\{\alpha_u^*, \beta_u^*\} \in (0,1)$. Solving this system of equations for solutions on the real interval between 0 and 1 results in the equilibrium equations (18) shown in proposition 1.

8.3 Proof of Proposition 2

We are seeking a linear rational expectation equilibrium, where we assume that the quantities provided and the price schedule are linear functions of the price and quantities respectively:

$$Q_s^m(p) = \phi_s p_s, \qquad \text{and} \qquad p_s^*(q) = \lambda_s Q_s.$$

Given these strategies, we can compute the residual supply function for a single market maker in the stock market:

$$Q_s = q_s^m m_s + (M-1)\phi_s p_s ms \qquad \Longrightarrow \qquad p_s = \frac{Q_s - q_s^m ms}{(M-1)\phi_s ms}.$$

Now we assume that the market maker knows the market order q (or alternatively that he infers the total market order q from the market price), and therefore that he valuates the asset as $\mathbb{E}[S \mid Qs] = \alpha_s Q_s$, where (for $Q_s > 0$)

$$\alpha = \frac{(m - m\eta + d(-1+\delta)\eta(-1+\mu))\omega + u\eta\mu(2\alpha_u\delta + \omega - \delta\omega)}{2\alpha_u\delta\eta\mu + \omega - \delta\eta\omega}.$$

The market maker will therefore choose his quantity schedule to maximize:

$$\max_{\{q_s^m\}} q_s^m[p_s - \alpha_s Q_s] \qquad \Longrightarrow \qquad \max_{\{q_s^m\}} q_s^m\Big[\frac{Q_s - q_s^m ms}{(M-1)\phi_s m_s} - \alpha_s Q_s\Big].$$

The first-order condition is then

$$\frac{Q_s - 2q_s^m}{(M-1)\phi_s m_s} - \alpha_s Q_s = 0,$$

and therefore

$$q_s^m = \frac{Q_s}{2m_s}\Big[1 - \alpha_s(M-1)\phi_s m_s\Big]$$

and

$$p_s = \frac{Q_s}{2m_s}\Big[\frac{1}{(M-1)\phi_s} + \alpha_s\Big],$$

and finally we can eliminate Q_s from these two equations:

$$Q_s^m(p) = \frac{(M-1)\phi_s[1 + \alpha_s(M-1)m_s\phi_s]}{1 + \alpha_s(M-1)\phi_s} p_s.$$

Then, if we assume a symmetric equilibrium where all market makers use the same supply function, we have

$$\phi = \frac{(M-1)\phi_s[1 + \alpha_s(M-1)m_s\phi_s]}{1 + \alpha_s(M-1)\phi_s} \qquad \Longrightarrow \qquad \phi = \frac{(M-2)}{(M-1)(1 - m_s + Mm_s)\alpha_s}.$$

Due to the market clearing condition we then have

$$\sum^{M} \phi_s p_s m_s = Q_s \qquad \Longrightarrow \qquad p^* = \frac{(M-1)(1-m_s+Mm_s)\alpha_s}{M(M-2)m_s} Q_s.$$

And therefore we have that, in equilibrium, market makers in the stock markets will post a pricing schedule equal to

$$Q_s^m(p) = \phi_s p \qquad \text{with} \qquad \phi_s = \frac{(M-2)}{(M-1)(1-m_s+Mm_s)\alpha_s},$$

and the equilibrium price is given by

$$p_s(p) = \lambda_s Q_s \qquad \text{with} \qquad \lambda_s = \frac{(M-1)(1-m_s+Mm_s)\alpha_s}{M(M-2)m_s}.$$

Note that, as $M \to \infty$, we obtain the same results as in the benchmark case. For the option market the same logic can be applied, and we obtain the following result:

$$Q_o^m(p) = \phi_o p \qquad \text{with} \qquad \phi_o = \frac{(M-2)}{(M-1)(Mm_s-m_s-M)\alpha_o},$$

$$p_o(p) = \lambda_o Q_o \qquad \text{with} \qquad \lambda_o = \frac{(M-1)(Mm_s-m_s-M)\alpha_o}{M(M-2)(1-m_s)}.$$

8.4 Sequential Model - Updated Probabilities

In this section I derive the the sequential probabilities conditional on the previous-round trades being (i) selling a stock, (ii) selling a call or (iii) buying a put. The sequential probabilities are simply the updated probabilities by a Bayesian agent, using the information contained in the trade executed in the previous round. The probability of an up-state conditional on the previous trade being the sale of a stock is

$$\mu_k(\text{Sell Stock}; \mu_{k-1}, \eta_{k-1}) = Pr[\text{up-state} \mid SS] = \frac{Pr[SS \mid \text{up-state}]Pr[up-state]}{Pr[SS]},$$

where

$$Pr[\text{up-state}] = \mu,$$
$$Pr[SS \mid \text{up-state}] = \frac{1}{2}(1-\delta)\eta\omega,$$
$$Pr[SS] = \alpha_d\delta\eta(1-\mu) + \frac{1}{2}(1-\eta)\omega + \frac{1}{2}(1-\delta)\eta(1-\mu)\omega + \frac{1}{2}(1-\delta)\eta\mu\omega.$$

Therefore we have

$$\begin{aligned}
\mu_k(\text{Sell Stock}; \cdot) &= \frac{\frac{1}{2}(1-\delta)\eta_{k-1}\omega\mu_{k-1}}{\alpha_d\delta\eta_{k-1}(1-\mu_{k-1}) + \frac{1}{2}(1-\eta_{k-1})\omega + \frac{1}{2}(1-\delta)\eta_{k-1}(1-\mu_{k-1})\omega + \frac{1}{2}(1-\delta)\eta_{k-1}\mu_{k-1}\omega} \\
&= \frac{(\delta-1)\mu_{k-1}\omega\eta_{k-1}}{2\alpha_d\delta\eta_{k-1}(\mu_{k-1}-1) + (\delta\eta_{k-1}-1)\omega}.
\end{aligned}$$

The remaining probabilities are found in the same way

$$\mu_k(\text{Sell Call}; \mu_{k-1}, \eta_{k-1}) = \frac{\mu_{k-1}\eta_{k-1}(\delta-1)(\omega-1)}{1-\omega+\delta\eta_{k-1}(-1+4(\alpha_d-1)\beta_d(\mu_{k-1}-1)+\omega)},$$

$$\mu_k(\text{Buy Put}; \mu_{k-1}, \eta_{k-1}) = \frac{\mu_{k-1}\eta_{k-1}(\delta-1)(\omega-1)}{\omega-1+\delta\eta_{k-1}(4\beta_d-3+4\alpha_d(\beta_d-1)(\mu_{k-1}-1)+4\mu_{k-1}-4\beta_d\mu_{k-1}-\omega)},$$

$$\eta_k(\text{Sell Stock}; \mu_{k-1}, \eta_{k-1}) = \frac{\eta_{k-1}(2\alpha_d\delta(\mu_{k-1}-1)+(\delta-1)\omega)}{2\alpha_d\delta\eta_{k-1}(\mu_{k-1}-1)+(\delta\eta_{k-1}-1)\omega},$$

$$\eta_k(\text{Sell Call}; \mu_{k-1}, \eta_{k-1}) = \frac{\eta_{k-1}(1-\omega+\delta(\omega-1+4(\alpha_d-1)\beta_d(\mu_{k-1}-1))}{(1-\omega+\delta\eta_{k-1}(\omega-1+4(\alpha_d-1)\beta_d(\mu_{k-1}-1)},$$

$$\eta_k(\text{Buy Put}; \mu_{k-1}, \eta_{k-1}) = \frac{\eta_{k-1}(\omega-1+\delta(4\beta_d-3+4\alpha_d(\beta_d-1)(\mu_{k-1}-1)+4\mu_{k-1}-4\beta_d\mu_{k-1}-\omega))}{\omega-1+\delta\eta_{k-1}(4\beta_d-3+4\alpha_d(\beta_d-1)(\mu_{k-1}-1)+4\mu_{k-1}-4\beta_d\mu_{k-1}-\omega)}.$$

8.5 Asymmetric Effect of tax in stock vs. option market

The asymmetric effect of taxation across stock and derivative markets, that is, the effect shown for example in figure 5, where we can see that the equilibrium α's are much more effected by a taxation on stocks compared to a taxation on options, arises in the following way in our model. Firstly, equilibrium α's are found by equalizing profits across stock and option markets, and profits are a function of both quantities and prices. Since Prices are not directly affected by taxation (in equilibrium they are indirectly affected by taxation trough the asymmetric effect needs to come from the effect of taxation on quantities. Quantities are found by maximization the Utility of terminal wealth of liquidity traders, which is a function of their payoffs in the the different states, as shown in equations [3-6].The utility of LT's in the stock market is affected (shifted downwards) way more by a tax compared to the utility of a LT that trades in the option market when affected by a tax on options. This means that LT's in the stock market adjust their strategies more when faced by a tax compared to LT's that trade in the option market. The reason for this effect is that, when the same tax function and rate is introduced in both markets, the taxed proportion of the payoff of investing in either market will be much smaller for trades in the option market. This can clearly be seen in figure 12 This differential impact of taxation on quantities ultimately means that profits (for informed traders) in the stock market will be more affected by taxation on stocks compared to profits in the option market, which then leads to the effect on α^*'s shown in figure 5 when the profits in both market are equalized in the presence of taxation.

The intuition behind the differential effect of taxation on quantities is that options provide inherently larger payoffs relative to the amount invested compared to stocks. To the extent that standard taxation affects the amount invested, and since the amount invested relative to the potential payoff for derivatives is "small" compared to the stock market, the option trader will adjust his strategy less compared to the stock trader when affected by the same tax.

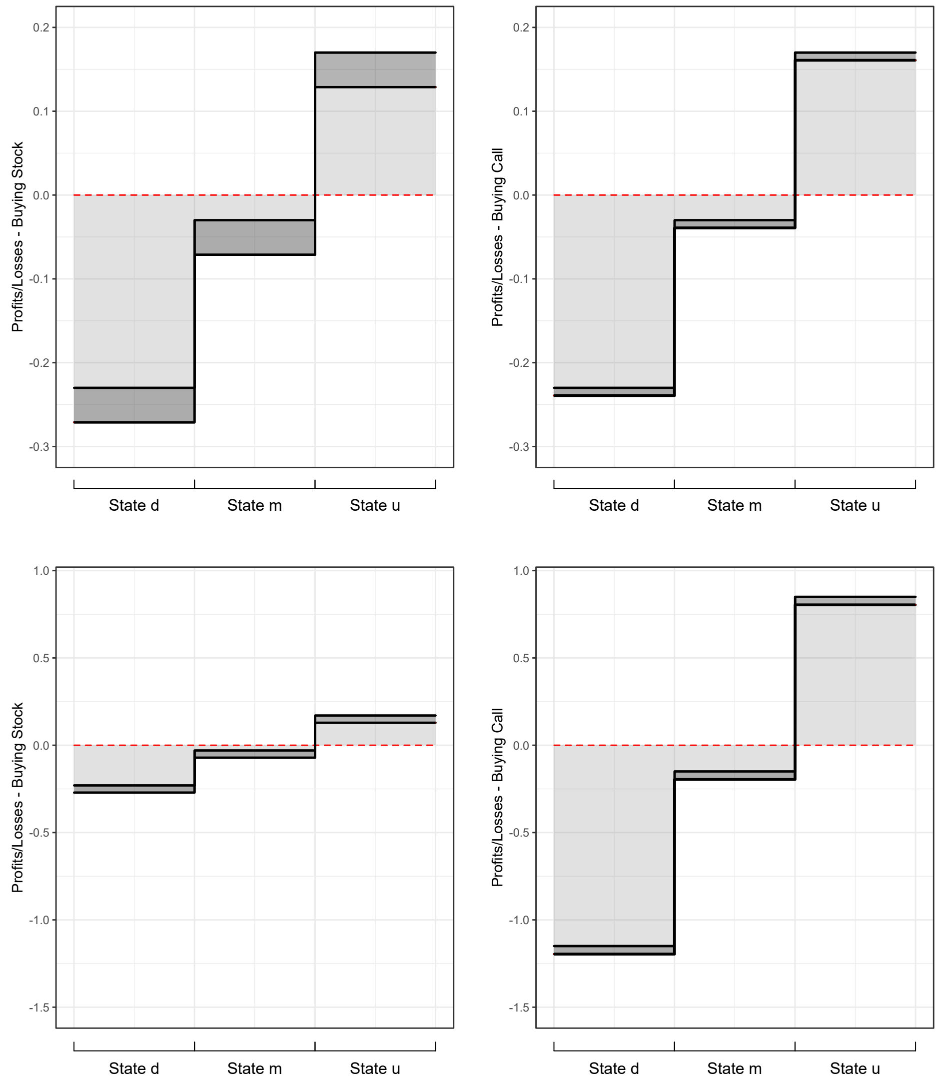

Figure 12: The figure shows the (net of the transaction price) profit of buying a stock (dark and light grey area) versus buying a call. The dark grey area represents the taxed part of the payoff. We use a tax of $t_s = t_o = 0.04$. The upper two graphs show the payoffs for $\theta = 1$, lower two graphs show the payoff for $\theta = 5$

8.6 Additional Figures - Static Model

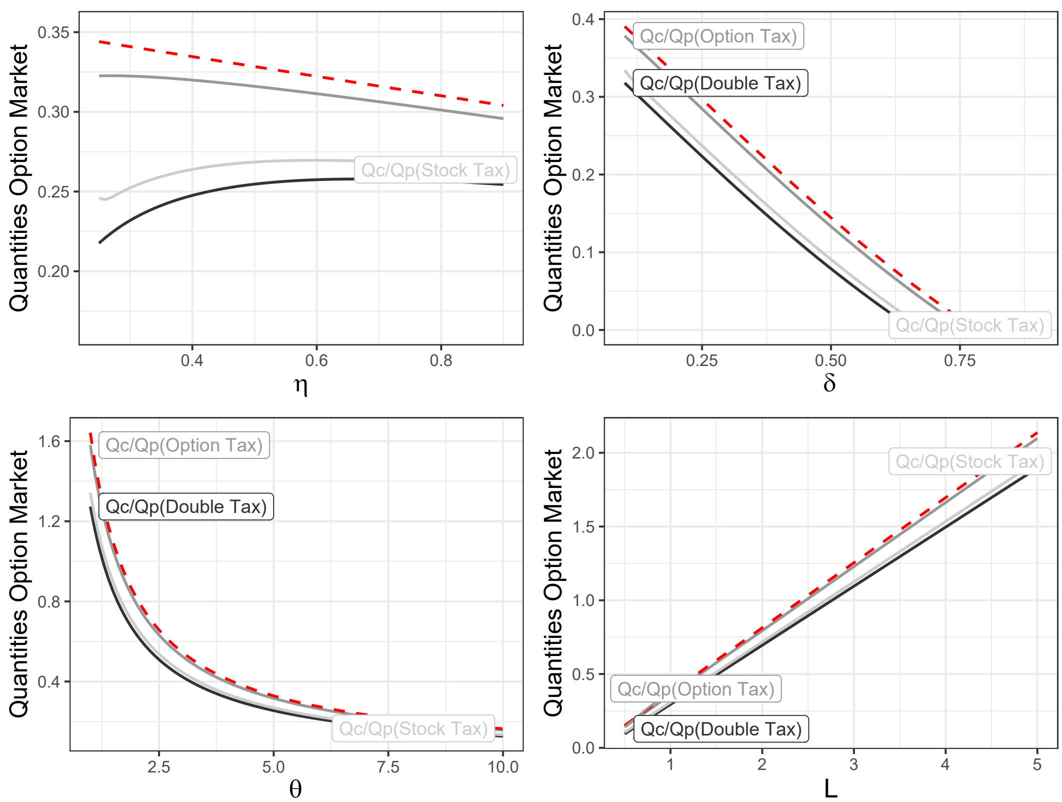

Figure 13: The Figure shows the equilibrium quantities traded in the option market as functions of η, δ, θ and L. The red dashed line shows the equilibrium quantities traded in the stock (option) market when there is no tax.

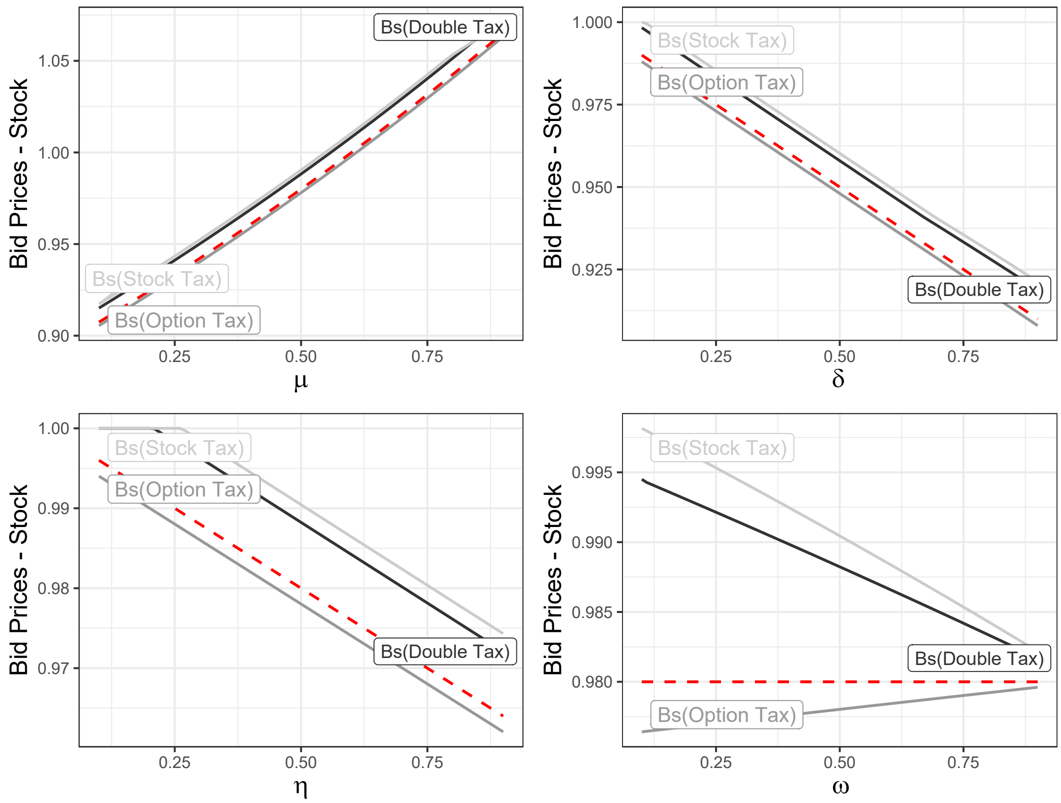

Figure 14: The Figure shows the equilibrium bid prices for the stock as functions of μ, δ, η and ω. The dashed line shows the equilibrium bid prices in the stock market when there is no tax.

8.7 Additional Figures - Sequential Model

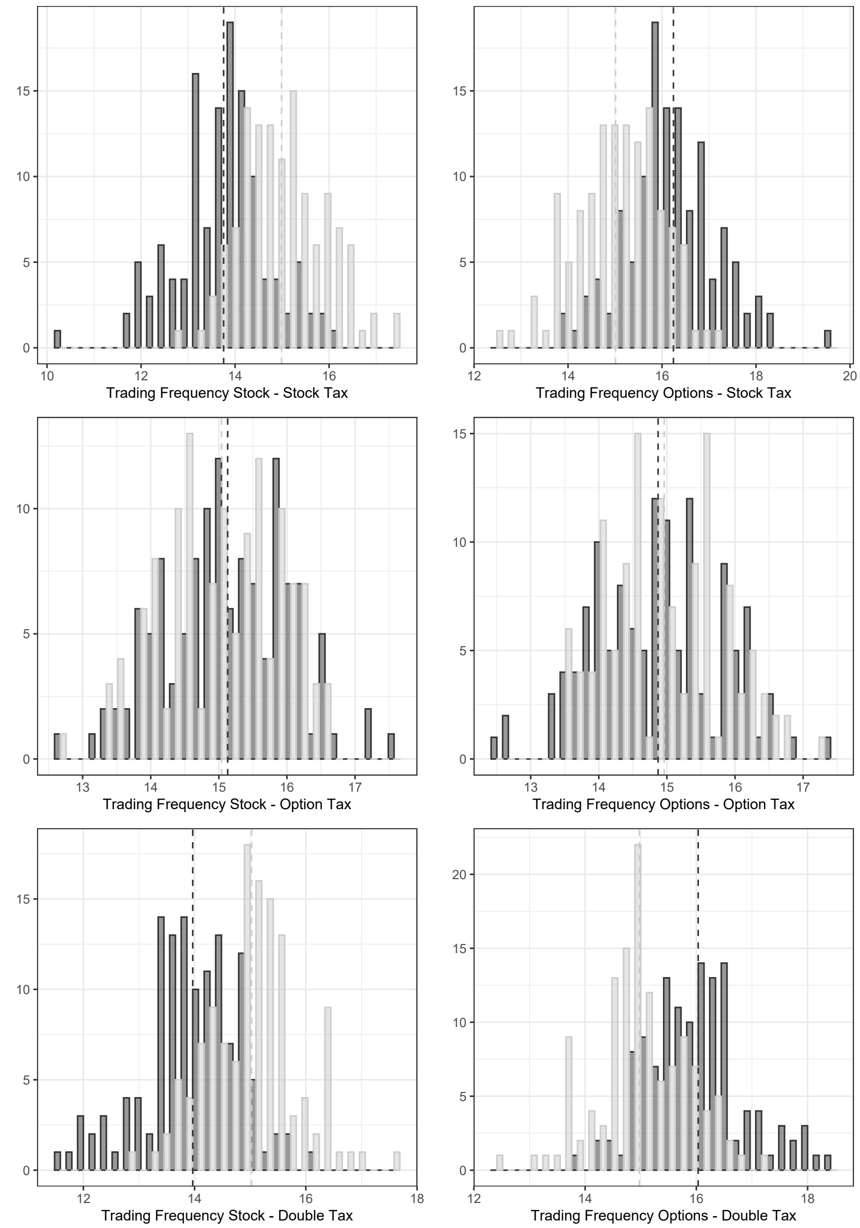

Figure 15: The Figure shows the histogram of daily frequencies for the different tax regimes. The dark bins show the frequency for when the tax is in place, the light bins show the frequency without taxation.

Chapter III

Multi-Market Effects of Financial Transaction Taxes: Evidence from France, Italy and Spain

Multi-Market Effects of Financial Transaction Taxes: Evidence from Italy, France and Spain*

Patrick Thöni† Vincent Wolff ‡

Abstract

This paper empirically investigates the effect of transaction taxes across equity, derivative and OTC markets. We leverage quasi-random experiments in France, Italy and Spain to test the effect of taxation on trading volume and market liquidity. We document trading migration across regulated and OTC markets but do not find evidence of migration across equity and derivative markets. Equity markets in all three countries experience some significant reduction in trading volume, while only Italy experienced a negative effect on aggregate liquidity. We are able to rationalize these results trough previous theoretical findings as well as features of the different tax policies, thus highlighting the importance of multi-market considerations for the optimal design of financial transaction taxes.

JEL-Code: D40, D53, F38, G10, H26

Keywords: Financial transaction tax, liquidity, adverse selection, tax avoidance

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†(Corresponding author) Department of Economics, University of Copenhagen. (pt@econ.ku.dk)

‡ Department of Banking and Finance, University of Zurich. (vincent.wolff@bf.uzh.ch)

1 Introduction

The introduction of a European financial transaction tax (FTT) has been under discussion since 2011, when the EU Commission issued its first proposal. While a pan-European FTT failed to obtain unanimous support by all EU member states, the tax has since then been implemented unilaterally by France, Italy, and Spain. More recently, the ex finance minister and now newly elected chancellor of Germany, together with its French counterpart, renewed the FTT proposal supported by the recent presidency of the EU council.[1] With the FTT already in place in some major European countries and a strong support in favor of the tax coming from Germany[2], the introduction of a pan-European FTT is therefore still highly probably.

While this recent development is restricted to the EU, forms of FTTs have been proposed and introduced many times and in numerous countries.[3] But regardless of its various implementations and the prolific literature it sparked, views regarding different aspects of the impact of FTTs have yet to reach a consensus, making further research within this area crucial to inform and guide future implementations. In this paper we focus specifically on an aspect of FTTs that has largely been neglected by the literature, namely the effects of taxation across connected markets. To the best of our knowledge, Thöni (2022) is the first attempt at addressing the question of how tax-induced trading migration can affect market quality across different markets. In his theoretical study he finds that trading migration can lead to positive effects on liquidity due to an alleviation of the adverse selection in the market. On the other hand, if market makers are affected by taxation, resulting in a less competitive market for liquidity provision, this result is reversed. We extend this study and contribute to the literature by studying these issues empirically, using the introduction of transaction taxes in France, Italy and Spain. Specifically, our paper is the first to empirically investigate the effects of these taxations across equity, derivative and OTC markets. Additionally, we are also the first to study the recent introduction of an FTT in Spain.

[1] Germany and France outlined a joint proposal for a financial transaction tax for the European Union that is based on the French model in December 2018. In December 2019, the then Finance Minister of Germany issued an amended financial transaction tax proposal. In February 2021, the Portuguese presidency of the EU Council proposed an inclusive discussion among all EU Member States regarding tax design issues of the European FTT.

[2] The former finance minister and now chancellor Olaf Scholz is notoriously a strong supporter of the EU FTT.

[3] As is well known, the first notable proponent of an FTT was Keynes (1936). Since then, important contribution have been made, such as e.g. Tobin (1978), Summers and Summers (1989), Stiglitz (1989), Krugman (2009). As of 2021, the following countries have some form of FTT in place: Belgium, China, Colombia, Finland, France, India, Italy, Spain, Peru, Poland, Singapore, Switzerland, Taiwan, United Kingdom, United States.

Our findings of the effects of taxation on regulated equity markets are largely in line with previous studies. We document a significant decrease of trading volume in France, accompanied by a very mild effect on aggregate liquidity (see e.g. Colliard and Hoffmann (2017) and Capelle-Blancard and Havrylchyk (2017). On the other hand, the introduction of an FTT in Italy did not affect trading volume, but resulted in significant increases in different spread measures (see e.g. Hvozdyk and Rustanov (2016) and Coelho (2016)). For the recent introduction of an FTT in Spain, we find very similar results to the French case, namely large reductions in volume and no effects on aggregate market quality. These similarities as well as differences in effects across countries can largely be attributed to differences in tax designs. In fact, while the FTTs introduced in France and Spain are almost identical, they differ significantly compared to the Italian FTT across some dimensions. These include among other the tax rates applied across regulated and OTC equity markets, the inclusion of derivative markets, and the tax exemptions designed for market makers. We specifically find that stricter regulations and higher burdens of proof for market makers in Italy likely contributed to worse outcomes in terms of liquidity.

Additionally, we find evidence that the differential tax rate applied across regulated and OTC equity markets in Italy (0.1% for regulated markets, 0.2% in OTC markets) led to significant trading migration between these markets. In line with Thöni (2022), the potential migration of informed traders to regulated markets, combined with increased costs of liquidity provision, are likely contributing factors that led to an overall negative effect of taxation on liquidity observed in Italian markets.

Importantly, we do not find any evidence of trading migration across equity and regulated derivative markets. Our analysis therefore does not support the idea that investors replicate payoffs in taxed markets by trading standardized derivative products in untaxed markets. Overall, we do not find significant effects of taxation on derivative markets across all three countries. While these results should be further expanded by the inclusion of OTC derivative markets in the future, they seem to suggest that the inclusion of derivative markets in the scope of FTTs is desirable[4].

Altogether, our study highlights the importance of considering the effects of taxation across multiple markets in order to allow for an appropriate assessment of the specific tax design on market quality. Additionally, by unifying the analysis of unilateral taxations introduced in European countries over the last decade, we facilitate direct comparison of tax designs on market outcomes. These combined results emphasize how coordination and

[4]To the extent that regulated derivative markets do not react adversely to taxation, these markets should certainly be included in the design of an FTT to harmonize taxation across different asset classes and broaden the tax base.

harmonisation of FTTs can allow policy makers to more directly target the effect of taxation on trading volume, and, in turn, market quality. A European-wide FTT, opposed to unilateral taxations, seems therefore to be a more desirable solution.

The remainder of this paper is organized as follows. Section 2 provides an overview of the empirical literature. Section 3 introduces the different tax designs. Section 4 describes the data and the empirical strategy. Section 5 presents the results and section 6 concludes.

2 Related Literature

The empirical literature on the effects of FTTs is almost entirely focused on the taxation of stocks.[5] Additionally, a large part of this literature has focused on studying the effects of taxation on market volatility. One of the earliest works that examine this relationship is Roll (1989), who does not find a significant impact of taxation on volatility in a study that includes 23 countries. A similar result is found in Saporta and Kan (1997), Chou and Wang (2006) and Pomeranets and Weaver (2018), which study respectively the effect of the stamp duty in the UK, the tax in the Taiwanese future market and New York State Security Transaction Taxes. Foucault, Sraer, and Thesmar (2011), while not specifically studying the introduction of an FTT, find that increasing the cost of speculative trading for retail investors can reduce the volatility of stock markets. Overall, the results of FTTs on volatility are not conclusive, including positive, negative as well as not significant results.

In terms of market liquidity, the results found by the empirical literature are more one-sided. Hu (1998) examines the introduction of transaction taxes in a range of Asian markets, finding no evidence of negative effects on market quality. On the other hand, various studies (see among other Baltagi, Li, and Li (2006), Liu (2007), Chou and Wang (2006)) find evidence of negative effects of transaction costs on different proxies for market liquidity. While these earlier studies were important to shed light on the effects of FTTs on volatility, liquidity and asset prices, the introduction of the French FTT - due to its unique design - allowed for a much cleaner empirical analysis. By defining a strict threshold for the introduction of the tax[6], the policy provided the possibility to use control groups of firms traded in very similar institutional environments[7]. It is therefore not surprising that the

[5]See Matheson (2011) for a detailed discussion of FTTs.

[6]The French FTT is the first one to apply the tax only on large firms above a certain threshold. The same is true for the Italian FTT and the Spanish FTT.

[7]While earlier studies used similar empirical strategies, often the specific event studied would not only allow for control groups of stocks traded in significantly different environments.

introduction of the transaction tax in France and Italy sparked a new surge of empirical research on FTTs. The most comprehensive analysis for the French case is provided by Colliard and Hoffmann (2017). Using a diff-in-diff framework, they find a strong reduction in trading volume and mild to no effects on aggregate market quality. By using more granular data, they also find evidence of shifts in portfolio holdings (from short-term to long-term) as well as heterogeneous effects of the tax across stocks with different liquidities. Overall, they find no evidence that the FTT improves market quality by affecting the composition of trading volume, as proposed by Stiglitz (1989), but rather that lower trading volume negatively affects market quality. Further studies of the French FTT, while also studying different dimensions of the impact of taxation, are in line with these findings (see Capelle-Blancard and Havrylchyk (2017), Gomber, Haferkorn, and Zimmermann (2016), Meyer, Wagener, and Weinhardt (2015), Becchetti, Ferrari, and Trenta (2014)).

Cappelletti, Guazzarotti, and Tommasino (2017) and Hvozdyk and Rustanov (2016) study the introduction of the transaction tax in Italy. By using different approaches[8], they both document a significant decrease in aggregate liquidity and no effect on trading volume. Additionally, both find insignificant results for market volatility. Coelho (2016) additionally focuses on the behavioral response elasticities to the tax, and finds large turnover and price elasticities with respect to marginal tax changes, especially for the portion of high-frequency traders.

Finally, the empirical work relating transaction taxes to derivatives markets is very sparse. Chou and Wang (2006) studies the effect of of a reduction in transaction taxes levied on futures transactions on the Taiwan Futures Exchange, and find both negative effects of taxation on volume and bid-ask spreads. More recently, Mixon (2021) studied the effect of the US transaction tax on futures during the 1920s and 1930s. He documents a substantial reduction in intra-day trading as well as an increase in spreads through avoidance of trades at the minimum price increments. To the best of our knowledge, there exist no empirical studies that investigate how the introduction of transaction costs or FTTs in the stock market affect their respective derivatives markets.

3 Natural Experiments

Before looking at the specific institutional settings of the financial transaction taxes introduced in Italy, France and Spain, it is worthwhile briefly summarizing the efforts that have

[8]While Capelle-Blancard and Havrylchyk (2017) use a diff-in-diff framework, Hvozdyk and Rustanov (2016) use a combination of Mann-Whiteny U-tests for the equality of means as well as the Levene test to assess changes in volatility.

been made on a European level over the most recent history in terms of FTT's.
In the aftermath of the great financial crisis of 2007/08, many countries shared the same common sentiment of holding the financial sector accountable for the costs it had imposed on governments and tax payers. This common sentiment was then formally stated in a request by the G-20 leaders towards the IMF to "*prepare a report with regard to the range of options countries have adopted or are considering as to how the financial sector could make a fair and substantial contribution toward paying for any burden associated with government interventions to repair the banking system*".[9] This report, among others things, also considered the use of a "Financial Activities Tax" as a form of contribution from the financial sector. Despite these recommendations, efforts to work on the implementation of a form of transaction tax on a G-20 level failed, which prompted the European Union's executive to work unilaterally on a European wide "Tobin-style" tax. This led to a first proposal, issued in September 2011[10], in which the European Commission discussed the possibility of a financial transaction tax applied to the 27 Member States of the Union. The reasons for the introduction of such a tax, as stated in the proposal, can be summarized in three main points: (i) Ensure the fair contribution of the financial sector to covering the costs of the financial sector as well as leveling the field in terms of financial burden compared to other sectors (ii) Avoiding a possible fragmentation of markets due to numerous uncoordinated national approaches (iii) Discourage risky trading activities that could create competitive distortions and complement regulatory measures aimed at stabilizing the financial system. While this proposal did not garner the required unanimous vote from all the member states, a number of Member States expressed a strong willingness to continue working on a European FTT. This effort translated into a final authorization by the European Parliament to allow 11 member States to engage in the procedure of "enhanced cooperation" on a common FTT harmonised amongst themselves. Since then, two new proposals have been put forward, one by the European Commission in 2013 and a more recent one, in December 2019, by the German Finance Minister. Finally, in February 2021, the Portuguese Presidency of the Council of the EU proposed an inclusive discussion among all Member States on tax design issues of the European FTT. To the best of our knowledge, these efforts have been the last updates on the discussion of this topic, and no further announcements have been made on the future of this initiative.

Besides the efforts made on a European level, various countries have unilaterally intro-

[9]see "Financial Sector Taxation: The IMF's Report to the G-20 and Background Material".
[10]see the Proposal for a Council Directive 2011/0261 (CNS) .

duced FTTs during this period, namely France, Italy an Spain. In the next section we will discuss the specific tax design implemented in these countries.

3.1 Italian FTT

The Italian FTT was introduced by the Law n. 228/2012, which was officially published in the Gazzetta Ufficiale on the 29. December 2012. The Law formalized the introduction of a tax on stocks and derivative contracts written on these stocks, which was respectively introduced on March 1st and September 1st 2013. More specifically, starting on March 1st, transactions - executed on a regulated markets or MTFs - of shares issued by companies having their registered office in Italy with a market capitalization above €500 million were taxed at a tax rate of 0.1%[11]. Additionally, a tax rate of 0.2% was applied to all transactions of Italian shares, irrespective of their market capitalization, for trades executed on OTC markets. The tax applies irrespective of the place where the transactions are executed and the state of residence of the counterparties. The tax was also extended to include high frequency trading in Italian equities. The tax rate applied to derivative products is computed based on a fixed sliding scale applied to the notional value of the contract, and ranges from €0.01875 to a maximum of €200. Additionally, the rate is reduced to 20 percent of the amount due for the case of transactions executed on regulated markets or MTFs. The taxable basis for transactions of shares is constituted by the net daily balance of taxable transactions and the the tax is due buy the buy side of the transaction[12]. For derivatives, the tax is due by both counterparties and the tax is applied to the notional value of the contract. The laws also includes a number of exclusions and exemptions, listing all of which goes beyond the scope of this paper. Importantly though, even though transactions executed in the course of "market-making activities" are exempted, this exemption is very narrow compared to the French and Spanish legislation (see Appendix for a more detailed discussion).

3.2 French FTT

The financial transaction tax in France was first announced on February 29th 2012 and came in effect on 1st August of the same year. Compared to the Italian case, the tax in France had a narrower scope, as it was only applied to transactions of equity shares issued by companies headquartered in France with a market capitalization above € 1bn. Furthermore, as for

[11] This also includes securities representing italian shares, such as ADRs, GDRs and EDRs.

[12] This effectively means that intraday transactions are exempted, as long as they net out to 0 at the end of the day.

Italy, the legislation also included transactions executed over-the-counter in the scope of the tax. Differently from the Italian application of the tax, the same marginal tax rate was applied to both regulated and non regulated markets and transactions of derivative products with french stocks as the underlying were effectively exempted from taxation. The taxable basis, on which a marginal tax rate of 0.2% was applied[13], consists of the acquisition value of equities. That is, as is the case in Italy, the tax is borne by the buyer side of the transaction. Additionally, if multiple trades on the same equity are executed during the same day, the net position is considered as the taxable basis. The French tax policy also included various exemptions, most notably one that excludes market makers from the application of the tax[14].

3.3 Spanish FTT

Finally we look at the most recent introduction of a FTT in a European country, namely the Spanish financial transaction tax, formalized by Law 5/2020 and put into force on January 16, 2021. Similarly to Italy and France, the Spanish tax is levied on acquisitions of shares of Spanish companies listed on a regulated market and with market capitalization greater than €1bn. As in the two previous cases, the tax is applied on a "principle of issue", meaning that the tax is applied irrespective of the tax residence of the parties involved or the location of the transaction. Then, as in France, the tax rate is 0.2%, which is applied to the amount of the consideration for the acquisition, net of any transaction fees[15]. The law furthermore also provides numerous exemptions, where again the most important one for our analysis is the one applied to acquisitions performed during market-making activities.

Therefore, in summary, while the Spanish and French tax design are almost identical, they differ significantly compared to the Italian tax in terms of (i) the tax rates implemented across regulated and non-regulated equity markets (ii) the taxation of derivative markets (iii) the type of exemption used for market makers.

[13]The original tax rate announced by the french government was 0.1%, which was then increased to 0.2% on July 4th 2012. The tax rate was then further increased to 0.3% on 1st January 2017.

[14]The law that introduced the FTT contains its own definition of market making. As noted before, this definition is much more generous compared to the Italian case.

[15]Again, as in the other cases considered, if multiple trades are executed during one day, the net positive amount is used as the tax base.

4 Identification Strategy and Data

We leverage the quasi-natural experiment financial transaction tax introductions for stocks and derivatives to test the derived model implications. We adopt a flexible difference-in-differences (diff-in-diff) estimation to identify the different tax impacts on trading activity and market liquidity for three different countries – France, Italy, and Spain. For this purpose, we compare the treated group, stocks whose trading is now taxed, to an untreated group, stocks that are not taxed but that are otherwise as similar as possible.

As control groups we use the Netherlands for France, Spain for Italy and viceversa. Both, treated and control stocks are characterized by a market capitalization above the respective threshold as described in sections 3.1, 3.2 and 3.3. For both country pairs, namely France/Netherlands and Italy/Spain, the control group is chosen to reflect similar macroeconomic environments and strong similarities with respect to pre-event stock market size, design, and liquidity.[16] For the analysis of the derivatives market, we use stock options and futures with the treated and control stocks as the underlying. In order to capture the large majority of trading volume for derivatives on taxed underlying stocks and traded on regulated exchanges we use data from both national exchanges and Eurex.

The stock samples consist of all stocks above the country specific threshold and for which consistent data is available. Table 1 shows the number of treated and control stocks, options and futures in detail and table 5 and 6 (see Appendix) shows the mean and the standard deviation of the financial market variables. In the case of France, all Euronext stock exchanges are natural candidates. Belgium - during the same period of the introduction of the French FTT - experienced an increase of a pre-existing financial transaction tax that could affect the impact evaluation of the French FTT. Portugal has been heavily affected by the European sovereign Debt crisis. Therefore we limit the control group to Dutch stocks. In the case of Italy, we chose Spain as control group for its comparable financial market size and exposure to the European debt crisis. Table 5 shows the pre-event stock market summary statistic for trading activity and market liquidity and validates the assumptions. For analysis on equity OTC markets we rely on data obtained from US OTC markets, due to the lack of transparency and consequent availability of European OTC

[16] In the case of France and the Netherlands, Euronext is the main trading venue and therefore trading in French and Dutch stocks follow the same trading protocol, tick size regime, and fee structure. Spain and Italy, while their exchanges do not share the same trading platform/venues as is the case with France and Netherlands, they share similar macroeconomic shocks and are comparable in terms of sectoral and firm size distribution Coelho (2016). In the Appendix we provide robustness exercises to show the appropriateness of our control groups.

market data[17]. For consistency with the analysis on regulated market, we use the same stock samples for both treatment of control in our analysis of OTC markets[18].

Table 1: Number of treated and control stocks and derivatives

Treated group	Control group
French tax introduction in 2012	
84 French stocks above 1 billion EUR	25 Dutch stocks above 1 billion EUR
2435 stock options on 42 French stocks	3119 stock options on 19 Dutch stocks
303 futures on 38 French stocks	131 futures on 16 Dutch stocks
Italian tax introduction 2013	
51 Italian stocks above 500 million EUR	52 Spanish stocks above 500 million EUR
7764 stock options on 20 Italian stocks	9692 stock options on 18 Spanish stocks
688 futures on 39 Italian stocks	349 futures on 33 Spanish stocks
Spanish tax introduction 2021	
53 Spanish stocks above 1 billion EUR	70 Italian stocks above 1 billion EUR
9642 stock options on 25 Spanish stocks	16374 stock options on 24 Italian stocks
205 futures on 29 Spanish stocks	1208 futures on 53 Italian stocks

The option samples are constructed as follows. We start defining and event window of 6 months before and after the event. We collect all options which are live during the event window with a stock in the treated or control group as the underlying. For example, in the case of France, this gives us 2435 stock options on 42 stocks with a market capitalization above one billion Euros. We drop options with moneyness outside of the range $0.9 - 1.1$ and with maturity longer than five trading weeks or lower than one trading week. Table (6) shows the pre-event stock market summary statistic for trading activity and market liquidity.

The future samples are constructed in a similar manner. We compile all futures which are live during the event window with a stock in the treated or control group as the underlying. For the futures, we drop by the same maturity measures as for the options.

In our identification strategy in equation (R.1), we compare all trading activity and market quality measures of stocks and derivatives with a market capitalization above the

[17]European OTC market data for the most part is only available for central authorities and policy makers. Public availability of such data is limited to highly aggregated measures, see table 7 in the Appendix for the Italian case.

[18]More Specifically, we obtain trade and quote data, as for regulated markets, from the OTCQX, OTCQB and Pink markets.

country specific threshold and thus affected by the tax to the untreated stocks above the same threshold in the control country. Equation (R.1) shows the formal definition.[19]

Formally, the model described satisfies for each stock/derivative i and date t the equation

$$\mathbb{E}(y_{i,t}) = \alpha_i + \gamma_t + \beta D_{i,t}, \tag{R.1}$$

where $D_{i,t}$ is the dummy variables that takes the value of one for treated stocks in the months after the tax introduction and is zero otherwise.[20] The terms α_i captures the security's time-invariant fixed effects and γ_t its time fixed effects. Standard errors are clustered by security and time following Thompson (2011). The regression model specification (R.1), like all diff-in-diffs, relies on the untestable but crucial common trend assumption. This assumption states that, in the absence of treatment, treated and control group would have co-moved closely. It became customary in the diff-in-diff literature to use visual inspection to check for the validity of the control group (see figure 1) and run placebo diff-in-diff estimations. Placebo diff-in-diff is a replication of equation (R.1) on random event days. In absence of the treatment, regression results should be statistically not different from zero.[21] The tests confirm the validity of our control groups (see Appendix).

All empirical tests and results are based on security-day level. We use nanosecond-stamped intraday trade and quote data from Thomson Reuters Tick History.

4.1 Measures of trading activity and market liquidity

In this section we describe the variables used to assess the effect of transaction taxes on volume and liquidity. We use similar variables as used by Colliard and Hoffmann (2017) in their diff-in-diff analysis and Thöni (2022) in the simulation study of his theoretical model.

[19]The case of the tax introduction in France on the 1^{st} of August 2012 is particular due to seasonality. We follow Colliard and Hoffmann (2017) and leverage the abundance of financial market data. We adopt a flexible diff-in-diff to account for this strong seasonality that otherwise significantly biases the the impact evaluation of the tax introduction. The flexible diff-in-diff allows the treatment in the first month after the tax introduction to be potentially different from the other months after the event. The seasonality stems from country-wide summer holidays and based on anecdotal evidence, from legal uncertainty among market participants on whether they are taxed.

[20]For france, the model is more flexibel and is described by the following equation:

$$\mathbb{E}(y_{i,t}) = \alpha_i + \gamma_t + \beta^{first} D_{i,t}^{first} + \beta^{permanent} D_{i,t}^{permanent}$$

where $D_{i,t}^{first}$ and $D_{i,t}^{permanent}$ are dummy variables that take the value of one for treated stocks in the first month and the following months, respectively, and are zero otherwise.

[21]The results are presented as robustness in the online appendix.

Firstly, we assess trading activity of stocks and its derivatives by estimating changes in trading volume and frequency of taxed securities. Secondly, we explain market depth and decompose the standard bid-ask spread into liquidity supplying and demanding trading costs. All our variables are first constructed on a frequency of 5 minutes, and are then aggregated to a stock-day level. In the construction of these variables we further disregard trades that are executed during opening and closing auctions. The variables are listed in the following.

Log volume is a measure of trading activity and calculated as the natural logarithm of the sum of EUR values traded on day t and for stock/derivative i.

Log depth is the natural logarithm of the mean of the available liquidity at the inside spread of bid and ask sides.

As is well known, adverse selection affects spreads and the overall liquidity in the market. The standard measure of the cost of a small round-trip transaction is the difference between the best ask and bid quote normalized by the mid-price. It can be read in percentage points or basis points (BPS), depending on the size. It is often understood as the spread. The richness and abundance of Reuters nanoseconds financial market data allows us to unbundle this spread into four more precise spread measures and its quoted depth. Following Foucault, Pagano, and Röell (2013) we decompose the bid-ask spread into *the quoted spread, the effective spread, the price impact and the realized spread.*

The quoted spread is the weighted average bid-ask spread from the quotes posted on day t for security i. The standard bid-ask spread is only a good measure of trading costs for orders that are small enough to be entirely filled at the best quotes. But if the trade size increases, the available liquidity at the inside spread matters for the price impact. The quoted spread is defined as

$$\textit{quoted spread} = \frac{(a_\tau - b_\tau)(q_\tau/q_{i,t})}{m},$$

where $(a_\tau - b_\tau)(q_\tau/q_{i,t})$ is the weighted average bid-ask spread divided by the mid-price (m).

The effective spread calculates trading costs using the prices actually obtained by investors and measures the slippage. It is defined as the difference between the price at which a market order executes (p_τ) and the mid-quote (mid_τ) on the market the instant right before the trade happens. The effective spread is likely to increase with the size of transactions. The effective spread for trade τ for a given security is then given as

$$\textit{effective spread} = q_\tau \frac{p_\tau - mid_\tau}{mid_\tau},$$

where q_τ is a buy-sell indicator taking the value of 1 (-1) for buys (sells).

Trades are signed using the algorithm proposed by Lee and Ready (1991). The effective spread is comprised of the realized spread and the price impact. The latter two add up approximately to the effective spread. The realized spread can be interpreted as compensation liquidity providers require for the adverse price movement following a trade. Therefore, it is a proxy for revenues of liquidity provision. The price impact can be interpreted as a measure of adverse selection.

The realized spread implicitly adopts the viewpoint of liquidity suppliers and is calculated as the difference between the transaction price and the mid-price five minutes after the transaction. The underlying assumption is that the interval should be long enough to ensure that market quotes have adjusted to reflect the price impact of the transaction.

$$realized\ spread = q_\tau \frac{p_\tau - mid_{\tau+5min}}{mid_\tau},$$

where $mid_{\tau+5min}$ is the mid-quote five minutes after the transaction.

The price impact is defined as follows and measures transaction costs that are based on the extent to which an order generates an adverse reaction in the market price.

$$price\ impact = q_\tau \frac{mid_{\tau+5min} - mid_\tau}{mid_\tau}.$$

5 Results

We start by presenting the results for the introduction of the tax on stocks in Italy, which are shown in table 2 and figure 1. Column (1) shows the effect on volume and market liquidity for stocks traded on regulated markets[22]. We can see that the Italian FTT led to a significant decrease in market liquidity, both in terms of quoted and effective spread.

[22]For all our results on stocks traded on regulated markets we use data for the national exchanges, e.g. Borsa Italian (Italy), Euronext Paris (France), Bolsa de Madrid (Spain). Our choice is based on the fact that the national markets account for the vast majority of the liquidity for stocks issued in the respective countries.

Figure 1: Graphical illustration of the impact of different FTT introductions on trading volume

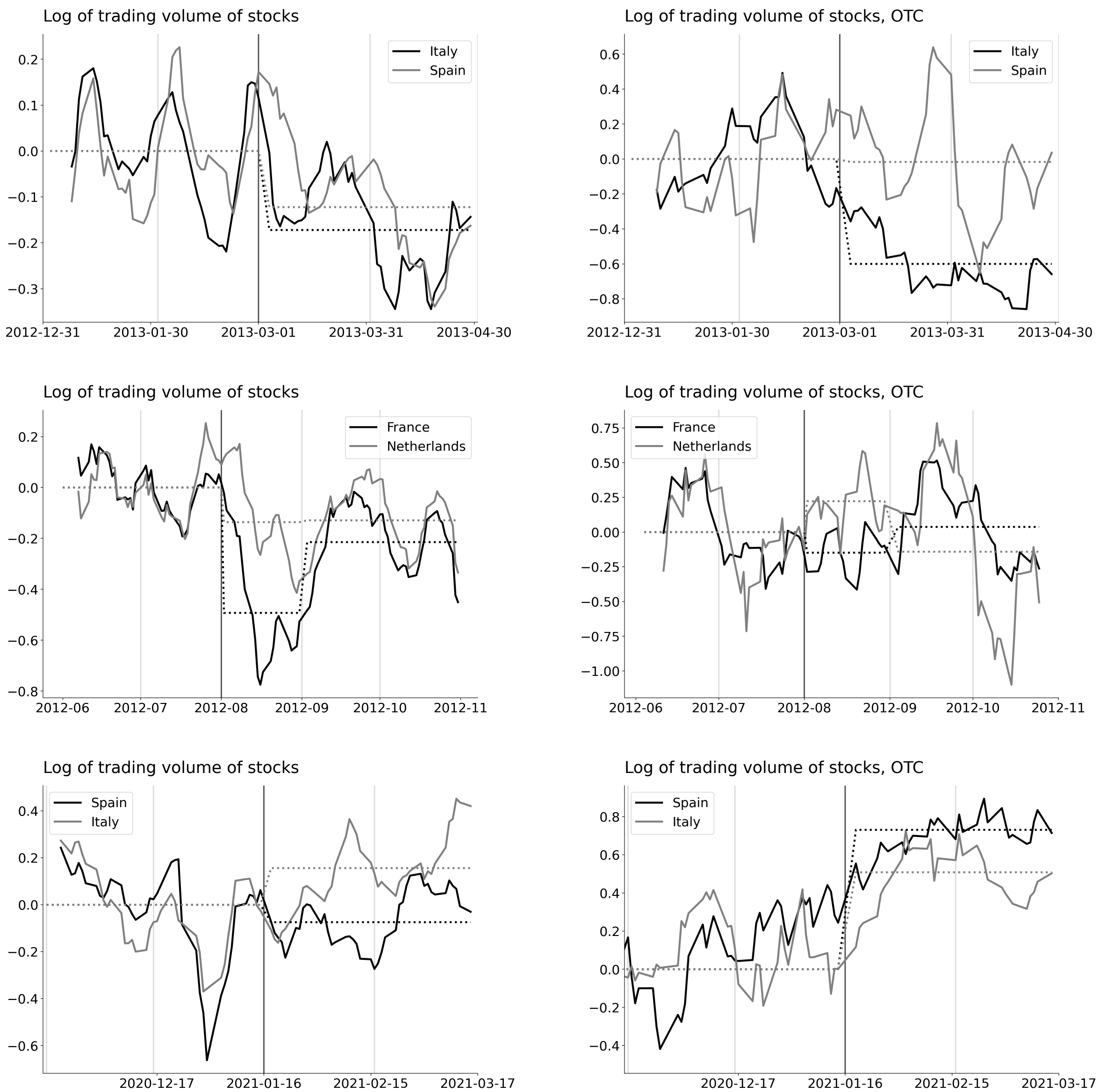

Figure 1 visually illustrates the difference-in-difference estimates for the causal impact of the FTT on trading volume on-exchange and OTC. The plots show the cross-sectional average for treated (black) and control (light gray) stocks, minus the respective pre-event averages. The time series are smoothed with a five-day moving average. The dashed lines indicate the averages for the treated and the control group. By construction they are zero and the same before the event. After the event, the difference reflects the diff-in-diff estimate for volume of the regression result in tables 2, 3 and 4.

The increase in the latter seems to be driven both by an increase of the realized spread as well as price impact. In terms of volume, even though the estimate is negative, therefore suggesting a decrease in trading activity compared to the control group, the effect is not statistically significant. On the other hand, we find a significant drop in trading volume for Italian stocks traded in OTC markets (column (4)). This result is further supported by the quarterly aggregated year-to-year changes of OTC volume in Italian markets reported by the Italian Companies and Exchange Commission (CONSOB) (table 7, see Appendix). Columns (2) and (3) report the results for Options and Futures written on Italian Stocks traded on regulated markets. Specifically, we report measures for the aggregation of derivatives traded on the Borsa Italiana and EUREX, which combined account for the vast majority of on-exchange derivatives trading for the products considered. As is evident, we do not find any significant effects on volume or liquidity for both type of derivative products.

Table 8 (see Appendix) shows the results for the introduction of the tax on derivatives, which was introduced 6 months later, on September 1st 2013. We do not find any significant changes neither in volume nor liquidity, suggesting that the tax on derivatives either had a very mild effect on the markets considered or that the effect had already been anticipated by markets in the introduction of the tax on stocks.

Table 3 and 4 show the results for the introduction of the tax on respectively French and Spanish stocks with market capitalization above 1 billion EUR. As described previously, the tax design in France and Spain, as opposed to the one in Italy, are very similar, which is mirrored in our findings. For both tables column (1) reports the result for stocks traded on exchange, and for both countries we find a significant drop in volume. For Spain we see that the volume decreased by 28% compared to the control group, which is three times as much as the reduction of volume we find for France. Compared to the Italian FTT, we do not find any significant drop in OTC volume and market liquidity seems to be largely unaffected. Similar to Italy on the other hand, trading in the derivative products of the taxed stocks, at least for on exchange trading, is no affected by the introduction of a transaction tax on the underlying.

Before moving on to discussing these results in the context of the literature, we perform an additional analysis of the impact of the FTT on stocks based on their market capitalization. As shown by Colliard and Hoffmann (2017) for the French case, aggregate results on market quality can hide significant heterogeneity's across certain dimensions. To further investigate this result, we split our stock samples based on market capitalization and

Table 2: Causal Impact of the Italian FTT - Stock tax

This table presents the estimates for the coefficient β from specification (R.1), where the dependent variable corresponds to proxies for volume and liquidity described in section 4.1. The regression is applied to the introduction of the tax on Italian stocks with a market capitalization above €500 million and the event date is therefore 01.03.2013. Standard errors (in parenthesis) are clustered by stock and time and as usual ***, **, * denote statistical significance at the 1%, 5% and 10% level.

		Stocks	Options	Futures	OTC
Trading activity					
	log volume	-0.057	-0.121	0.094	-0.600***
		(0.082)	(0.182)	(0.289)	(0.219)
Liquidity					
	log depth	-0.040	-0.188	0.354	
		(0.039)	(0.137)	(0.243)	
	quoted spread	0.484**	-0.001	-0.003*	
		(0.199)	(0.008)	(0.002)	
	effective spread	0.214***			
		(0.081)			
	realized spread	0.153**			
		(0.061)			
	price impact	0.034*			
		(0.020)			
# treated		51	6840	223	65
# control		50	6407	125	37
# observations		8200	108820	5205	5305

perform the same analysis as above separately for small cap versus large cap firms[23]. The results are shown in table 9-11 in the Appendix. What is immediately apparent from the results is that (i) the aggregate results discussed above differ significantly across small and large cap firms and (ii) the differential results between the Italian case versus the French and Spanish case persist also in this exercise. We find that for the introduction of the stock tax in Italy, the negative effect on market liquidity is mainly driven by small cap stocks, whereas large cap stocks were largely unaffected. The opposite is true for France and Spain, where small cap firms do not seem to have been affected by the taxation, while large cap firms experienced significant decreases in liquidity. These results are striking in their consistency, as in all cases the aggregate effects are either captured by small cap or large cap firms. While these results certainly support the notion that the effect of FTTs can be highly heterogeneous across certain stock characteristics, the theoretical underpinning of these results is unclear.

[23]More specifically, we split our stock sample based on market capitalization quantiles and perform the diff-in-diff analysis for stocks that fall below the 25. quantile and above the 75. quantile

Table 3: Causal Impact of the French FTT

This table presents the estimates for the coefficient $\beta^{permanent}$ from specification (R.1) (Note that for France we use the flexible model described in footnote ??) where the dependent variable corresponds to proxies for volume and liquidity described in section 4.1. The regression is applied to the introduction of the tax on French stocks with a market capitalization above €1 billion and the event date is therefore 01.08.2012. Standard errors (in parenthesis) are clustered by stock and time and as usual ***, **, * denote statistical significance at the 1%, 5% and 10% level.

		Stocks	Options	Futures	OTC
Trading activity					
	log volume	-0.093**	-0.473	-0.259	-0.019
		(0.057)	(0.321)	(0.328)	(0.278)
Liquidity					
	log depth	-0.007	-0.167	4.618***	
		(0.037)	(0.194)	(0.872)	
	quoted spread	-0.091	-0.001	-0.019*	
		(0.585)	(0.216)	(0.016)	
	effective spread	0.221			
		(0.156)			
	realized spread	0.002			
		(0.085)			
	price impact	0.124			
		(0.098)			
# treated		81	1036	112	120
# control		25	1260	43	37
# observations		11818	34113	4257	12127

5.1 Discussion

The results described in the previous section have various implications in terms of the (i) the specific tax designs of each country, (ii) previous findings by the literature and (iii) the theoretical predictions of taxation effects across markets found in Thöni (2022).

As we mentioned previously, the tax design in Italy differs significantly from the design implemented in France and Spain across various dimensions. Firstly, a differential tax rate was introduced for stocks traded on exchange and on unregulated markets. As we saw, this led to a significant reduction in trading volume in the OTC market, whereas trading volume executed on exchange was statistically unaffected. From the perspective of the model in Thöni (2022), this differential tax rate for two different markets with (virtually) the same products (e.g. stocks of Italian companies) is akin to trading stocks in two separate markets (as opposed to a stock and an option market). Intuitively, if a differential tax rate is introduced - and given that the same product is traded in both markets - this would move trading from the market with the higher tax rate to the market with the lower tax rate,

Table 4: Causal Impact of the Spanish FTT

This table presents the estimates for the coefficient β from specification (R.1) where the dependent variable corresponds to proxies for volume and liquidity described in section 4.1. The regression is applied to the introduction of the tax on Spanish stocks with a market capitalization above €1 billion and the event date is therefore 16.01.2021. Standard errors (in parenthesis) are clustered by stock and time and as usual ***, **, * denote statistical significance at the 1%, 5% and 10% level.

		Stocks	Options	Futures	OTC
Trading activity					
	log volume	-0.284***	-0.089	0.025	0.219
		(0.059)	(0.101)	(0.060)	(0.198)
Liquidity					
	log depth	0.007	-0.624***	-0.698*	
		(0.037)	(0.128)	(0.357)	
	quoted spread	0.034	-0.010*	0.001**	
		(0.070)	(0.019)	(0.001)	
	effective spread	0.004			
		(0.030)			
	realized spread	0.011			
		(0.019)			
	price impact	0.001			
		(0.011)			
# treated		52	2843	412	74
# control		81	3132	92	86
# observations		11009	116952	8806	14247

therefore decreasing volume in the former and increasing it in the latter. Empirically, the former result holds, whereas the volume in the market with the lower tax rate (regulated markets) is not affected. This could be due to a few different mechanisms. For once, there could be alternative products, for which data is not available, that are used at least by some traders as substitutes for stocks. One type of products that intuitively would lend themselves as possible substitutes are derivatives traded in OTC markets. Such products, opposed to derivatives traded on exchange, are typically non-standardized and are generally able to replicate a much larger set of payoff structures compared to standardized derivatives traded on exchange. On the other hand, the reason we do not see an increase in trading volume for on-exchange trades could be due to an overall drop in volume for Italian stocks.

The results found for the effect on the liquidity of stock markets are also in line with the findings by other articles that analyzed the Italian FTT, such as Cappelletti, Guazzarotti, and Tommasino (2017) and Hvozdyk and Rustanov (2016). As shown in table 2, using high frequency data we find significant increases in both quoted spreads and effective spreads, suggesting that the Italian FTT did indeed worsen the liquidity of stock markets. In terms of the theoretical predictions of Thöni (2022), this suggests that Italy experienced a decrease in competition among market makers, leading to higher spreads on average. This is supported by the fact that the driving component of the increase in effective spread is the realized spread, which is connected to increased costs of liquidity provision. Additionally, this result is also consistent with the narrow market making exemption used in Italy. As obtaining these exemptions is laborious, the cost of liquidity provision was indirectly affected by taxation. Our results suggest that this led to a proportion of market maker exiting the market, therefore reducing competition among liquidity providers. Also, we do not find a decrease in price impact due to less informed trading, as predicted by Thöni (2022), when a stock and option market is considered. Given the (additional) differential tax for regulated and non-regulated market and the consequent reduction in OTC volume we discussed, it is reasonable to assume that potential informed trading previously active in OTC markets moved to regulated markets, therefore counteracting any movement of informed traders active on regulated markets towards other type of products. This result would also be consistent with the results in Thöni (2022), if instead of an option market, two equity markets with different tax rates are considered. In this scenario, the market with the lower tax rate would experience a decrease in liquidity (driven by the price impact), through a migration of informed trading. This is consistent with the results found in Italy.

The results for the regulated equity market we find for France are consistent with the aggregate results found by Colliard and Hoffmann (2017) as well as other articles studying the French transaction tax. Again, consistent with the theoretical predictions in Thöni (2022), we find a significant decrease in volume. On the other hand, we do not find any evidence of decreased OTC volume, suggesting that an equal tax rate in regulated and unregulated markets will disproportionately affect the former (e.g. the more liquid market). The same holds for the newly introduced tax in Spain, which as we described previously, shares very similar features to the French FTT. Additionally we do not find any aggregate effects on market liquidity for both France and Spain. In light of the existing theory, no aggregate results on liquidity can potentially mask opposite market effects canceling each other out. This is also consistent with our results for small and large cap stocks. Therefore, based on our results and the results found in Colliard and Hoffmann (2017), it is more likely that these opposite effects arise within markets than across markets.

Finally, as was the case in Italy, trading in option and future contracts on regulated markets was largely unaffected, which is in line with the asymmetric effect of taxation on stock and option markets predicted by Thöni (2022). This suggests two possible effects that are in line with the observed drop in volume. Firstly, the introduction of the tax could have simply led to an overall decrease in volume, without any volume substitution towards products with similar payout structures. This would be coherent with the heterogeneous effect on liquidity within stocks traded on the same market, leaving aggregated liquidity largely unaffected. On the other hand, as mentioned earlier, our results could also point towards a potential substitution in derivative products traded in OTC markets, for which we are unfortunately not able to obtain data[24]. It is left for future research to discern the magnitude of these two effects.

5.2 Policy Implications

The most recent impact of COVID-19 on public finances is unprecedented. In many countries, the ratios of government debt to GDP have reached all-time highs.[25] Moreover, the commitment to the Paris Agreement implies shifting public expenditures to the green transition in the near future. Governments are in dire need of additional avenues to increase tax revenue. Periodically after economic crises,[26] taxation of financial transactions to support public finances gains broad relevance on the political stage. In this section we will outline the advantages and disadvantages of a financial transaction tax based on the theoretical and empirical findings of our paper.

The contribution of the FTTs in its current designs for public finances is modest at best. The French FTT collected in 2020 1.8 billion Euros (0.1% of GDP), the UK stamp duty 4.4 billion (0.2%) and the Italian FTT 400 million (0.2%). Our findings suggest, that this is due to various reasons. First, the broad list of exemptions reduces the taxable base drastically in all jurisdictions. Casually speaking, after exempting purchases by market makers, financial intermediaries as liquidity suppliers or responsible for price stabilization, CCPs and CSD, there is almost nothing left to tax. Additionally, there is the behavioral response to the tax introduction. For France, a tax of 10 bps reduces trading volume by 10-20% and for Spain a tax of 20 bps reduces the volume by 20-30%.

[24]Over the last decades efforts have been made to make European OTC derivative markets more transparent. As of 2012, EU entities that engage in derivatives transactions are required to report their trades to trade repositories. To the best of our knowledge, these data is only available to regulators.

[25]Total public debt as percent of gross domestic product for the US amounted to 120% (see "FRED, Economic Data, 2021, Federal debt: Total public debt as percentage of gross do- mestic product"), 101% for the European union, 150% for Italy, 125% for Spain and 120% for France (see "Eurostat, 2021, First quarter of 2021, government debt up to 100.5% of gdp in euro are, euroindicators").

[26]As pointed out by Dávila (2021), the collapse of the Bretton Woods system motivated James Tobin's well-known 1972 proposal to throw sand in the wheels of financial markets, the Black Monday (1987) motivated Stiglitz (1989) and Summers and Summers (1989) to argue for a transaction tax and most recently the great financial crisis brought a tax proposal by the European Commission and tax introductions in France and Italy.

Second, as the findings of the Italian case allows to deduce, there are strong incentives to migrate trading to cheaper venues if possible. The theoretical model in Thöni (2022) predicts a weaker reaction of derivatives to a FTT introduction relative to stock markets. Our empirical results confirm the prediction. We do not find a synthetic reproduction of stocks on its on-exchange derivative markets. Through talks with sell-side equity-trading specialists, we gather anecdotal evidence that in the case of France, the preferred avoidance strategy of the FTT has became contract-for-differences (CFDs).[27] The French financial markets regulator (AMF) is closing this loophole through restriction of the marketing, distribution or sale of CFDs to retail investors. This suggest that an optimal financial transaction tax rate should target on-exchange stock trading, its OTC market and its derivative market on-exchange and OTC.[28] As the theoretical literature suggest, the derivative tax might not have a fundamental impact but it discourages efforts to find loopholes in the alternative markets and therefore reduces incentives to migrate.

Thus, our analysis suggests that in order to maximize tax revenue while minimizing liquidity impacts, a pan-European tax should be preferred over unilateral, national taxes. The widespread coverage of such a tax would allow for less exemptions, as the incentives of avoidance for liquidity providers are reduced. Additionally, derivative markets should be included in the scope of the tax and taxed a tax rate that takes into account the specific payoff structure of the instrument.

6 Conclusion

In this paper we empirically investigate the effect of taxing financial transactions on volume and liquidity across equity, derivative and OTC markets. We leverage quasi-random experiments in France, Italy and Spain in a difference-in-difference setting to test effects of trading migration on market liquidity. Our results show striking differences between countries that we are able to rationalize through previous theoretical findings as well as differences in tax designs. In Italy we document evidence of trading migration from OTC markets to regulated markets for equities. Further, we find negative effects on aggregate liquidity. We rationalize these results by (i) a migration of informed traders to regulated

[27]CFDs are equity derivative contracts that mimic the underlying stock. The main difference between a CFD and stocks is that with CFDs one never owns the stock because it is never bought or sold. CFDs provide on-to-one the up- and down-side potential of the underlying. CFDs are leveraged products and are able to reveal therefore a different risk profile than stocks. CFDs are exempt from the stamp duty in the UK.

[28]At the moment, only Italy covers on-exchange stock trading, its OTC market and its on-exchange derivative market. It currently does not include OTC derivatives.

markets and (ii) decreased presence of market making due to increased costs of providing liquidity. In France and Spain, which share very similar tax designs, we find significant decreases in volume, but mild to no effects on aggregate liquidity. When splitting our stock sample by market capitalization, we also find that aggregate results can hide large heterogeneity's across different subgroups of stocks, as was already suggested by Colliard and Hoffmann (2017). Finally, we do not find evidence of migration across equity and derivative markets. In general, regulated derivative markets seem not to be significantly affected by taxation, both when only the underlying is taxed as well as when actual derivative trading is taxed.

While additional research is certainly needed, our results combined with previous findings by the literature suggest that unilateral taxation of financial transaction is not optimal. Through harmonization and coordination, policy makers would increase their ability to control trading volume and migration, allowing them to also better control the impact of taxation on market quality while at the same time maximize tax revenue.

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7 Appendix

7.1 Summary Statistics

Table 5: Summary statistics of stock market variables

	France	Netherlands	Italy	Spain	Spain	Italy
Stock trading activity						
log volume	16.32	16.68	15.53	15.48	15.51	15.61
	1.45	1.16	2.02	2.31	1.84	1.71
Stock liquidity						
log depth	3.68	4.13	3.81	3.47	3.26	3.5
	0.90	0.74	1.23	0.86	0.66	0.61
quoted spread	12.67	9.37	25.12	29.14	23.47	18.35
	9.30	5.48	20.09	27.26	35.86	15.56
effective spread	4.27	3.60	9.03	11.07	9.63	5.17
	2.60	1.61	7.42	11.28	14.12	5.38
realized spread	1.83	0.72	4.26	6.11	4.86	3.86
	1.42	0.92	5.23	7.94	10.01	4.63
price impact	2.00	1.58	2.85	2.83	1.64	1.01
	1.47	1.14	2.47	2.94	3.13	2
# stocks / derivatives	81	25	50	51	81	80
# observations	3321	1025	2050	2550	4212	3280
OTC Stock trading activity						
log volume	11.15	10.77	10.87	9.16	10.47	9.61
	2.25	2.14	2.17	1.84	3.12	2.75
# stocks / derivatives	117	37	59	28	62	76
# observations	6682	2125	2301	1092	3936	4669

Table 6: Summary statistics of equity derivative market variables

	France	Netherlands	Italy	Spain	Spain	Italy
Option trading activity						
log volume	3.88	3.12	3.20	3.45	2.78	2.27
	(1.73)	(2.17)	(2.65)	(1.96)	(1.99)	(1.81)
Stock liquidity						
log depth	9.83	10.58	9.54	9.54	9.60	9.29
	(1.80)	(2.36)	(2.13)	(2.13)	(2.84)	(2.78)
quoted spread	1.90	1.43	2.48	3.57	3.17	4.49
	(1.52)	(1.49)	(2.79)	(3.62)	(3.11)	(4.68)
# options	661	844	2190	3106	4198	2899
# observations	8083	11865	34658	50995	74229	60796
Futures trading activity						
log volume	1.27	0.29	3.68	5.84	5.17	7.56
	(2.97)	(1.47)	(2.26)	(2.17)	(2.34)	(3.55)
Stock liquidity						
log depth	12.43	12.94	10.92	12.43	10.91	12.37
	(2.91)	(4.33)	(2.66)	(4.27)	(4.17)	(3.08)
quoted spread	1.21	1.07	1.91	1.31	1.27	1.40
	(1.41)	(1.26)	(2.68)	(1.64)	(1.63)	(1.10)
# futures	112	43	154	70	76	271
# observations	2111	928	2780	1143	924	3448

7.2 Aggregate OTC data for Italy

Table 7: Quarterly OTC volume change w.r.t to previous year

Quarter	Q1	Q2	Q3	Q4
yty Change	44%	-60%	-40%	- 23%

7.3 Additional Tables and Figure of Diff-in-Diff analysis

Table 8: Causal Impact of the Italian FTT - Derivatives

This table presents the estimates for the coefficient β from specification (R.1), where the dependent variable corresponds to proxies for volume and liquidity described in section 4.1. The regression is applied to the introduction of the tax on derivatives written on italian stocks and the event date is therefore 01.09.2013. Standard errors (in parenthesis) are clustered by stock and time and as usual ***, **, * denote statistical significance at the 1%, 5% and 10% level.

		Stocks	Options	Futures	OTC
Trading activity					
	log volume	-0.005	-0.211	-0.272	-0.0157
		(0.007)	(0.297)	(0.434)	(0.216)
Liquidity					
	log depth	0.040***	-0.075	0.246	
		(0.013)	0.183	(0.129)	
	quoted spread	0.0361*	0.001	-0.003**	
		(0.203)	0.0074	(0.001)	
	effective spread	0.155			
		(0.096)			
	realized spread	0.123			
		(0.079)			
	price impact	0.019			
		(0.079)			
# treated		51	6840	223	65
# control		52	6407	125	37
# observations		8858	158452	8683	5854

Figure 2: Graphical illustration of the FTT impact on French stock market measures

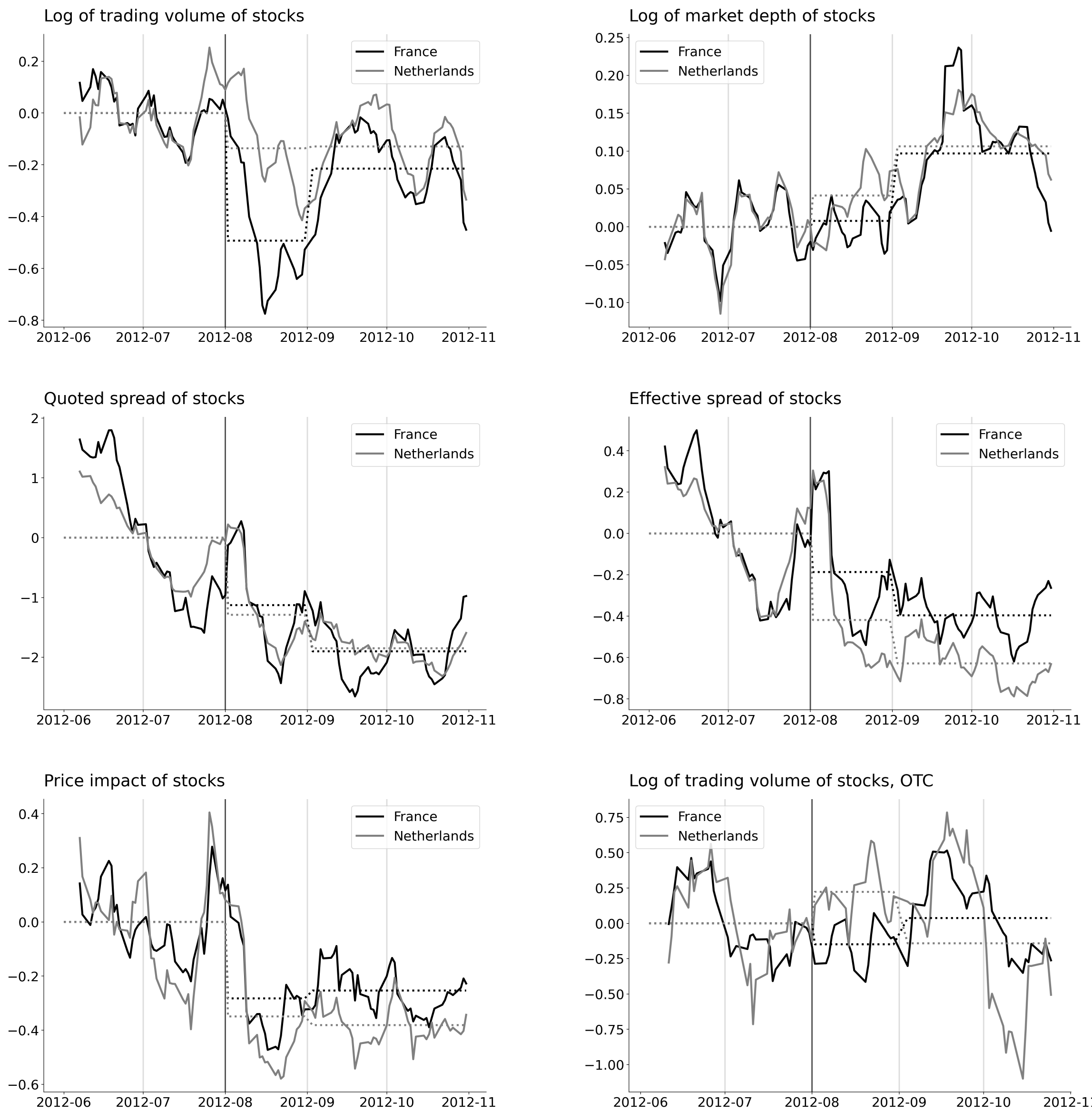


Figure 3: Graphical illustration of the FTT impact on French option market measures

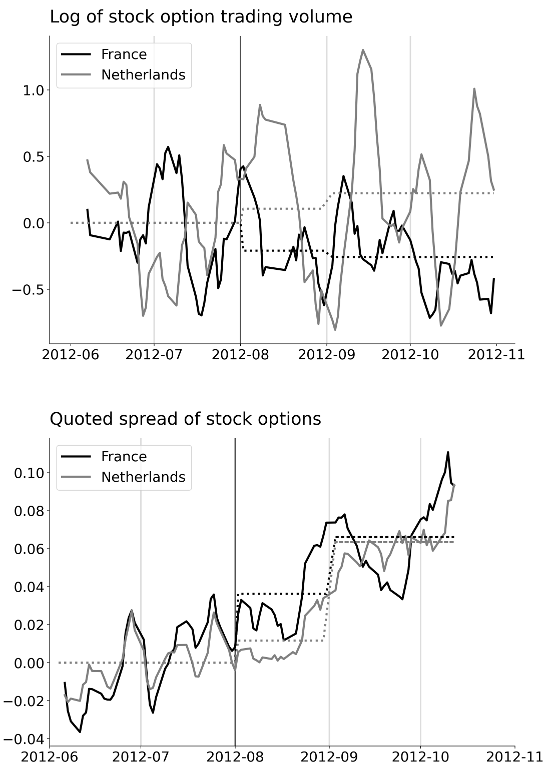
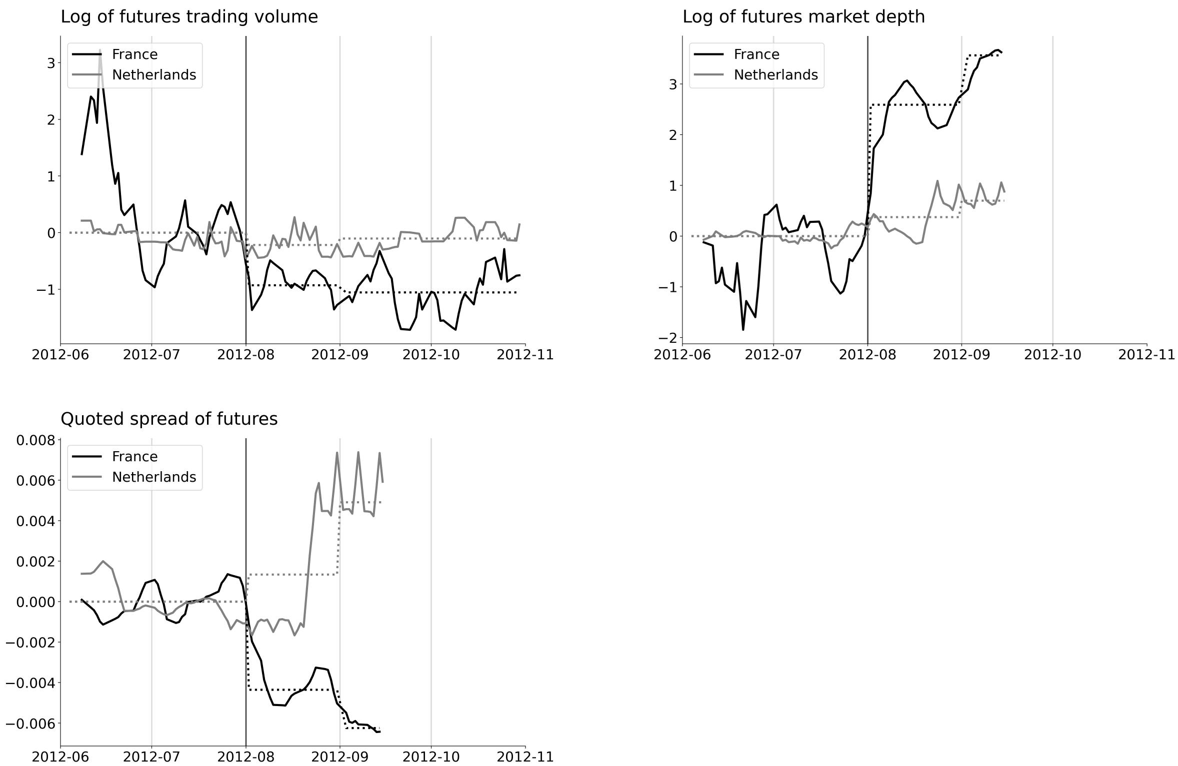


Figure 4: Graphical illustration of the FTT impact on French futures market measures



7.4 Diff-in-Diff Results by Market Capitalization

Table 9: Causal Impact of the Italian FTT - Stock tax

This table presents the estimates for the coefficient β from specification (R.1) of small and large firms for stocks. The respective proxy is sampled for the 25% smallest and the 25% largest firms, measured by market capitalization. The dependent variable corresponds to proxies for volume and liquidity described in section 4.1. The regression is applied to the introduction of the tax on Italian stocks with a market capitalization above €500 million, and the event date is therefore 01.03.2013. Standard errors (in parentheses) are clustered by stock and time and as usual ***, **, * denote statistical significance at the 1%, 5% and 10% level.

		Stock tax		Derivative tax	
Stock		0% - 25%	75% - 100%	0% - 25%	75% - 100%
Trading activity					
	log volume	-0.142	-0.089	0.001	-0.006
		(0.123)	(0.077)	(0.009)	(0.007)
Liquidity					
	log depth	0.002	-0.111**	0.061***	0.043***
		(0.075)	(0.045)	(0.016)	(0.015)
	quoted spread	0.605**	0.222	0.145	0.530***
		(0.282)	(0.181)	(0.239)	(0.203)
	effective spread	0.276**	0.103	0.124	0.196**
		(0.113)	(0.077)	(0.107)	(0.097)
	realized spread	0.240***	0.064	0.096	0.146*
		(0.086)	(0.055)	(0.082)	(0.080)
	price impact	0.005	0.017	0.009	0.033
		(0.026)	(0.020)	(0.035)	(0.021)

Table 10: Causal Impact of the French FTT by Quantiles

This table presents the estimates for the coefficient $\beta^{permanent}$ from specification (R.1) of small and large firms for stocks. The respective proxy is sampled for the 25% smallest and the 25% largest firms, measured by market capitalization. Note that for France, we use the flexible model described in footnote 20. The dependent variable corresponds to proxies for volume and liquidity described in section 4.1. The regression is applied to the introduction of the tax on French stocks with a market capitalization above €1 billion, and the event date is therefore 01.08.2012. Standard errors (in parentheses) are clustered by stock and time and as usual ***, **, * denote statistical significance at the 1%, 5% and 10% level.

Stock		0% - 25%	75% - 100%
Trading activity			
	log volume	-0.228***	-0.013
		(-0.084)	(-0.067)
Liquidity			
	log depth	-0.021	-0.054
		(0.055)	(-0.063)
	quoted spread	-0.900	1.636***
		(0.927)	(-0.527)
	effective spread	0.164	0.471***
		(0.292)	(-0.156)
	realized spread	0.235	0.086
		(0.176)	(-0.085)
	price impact	-0.222	0.257**
		(0.155)	(-0.099)

Table 11: Causal Impact of the Spanish FTT

This table presents the estimates for the coefficient β from specification (R.1) of small and large firms for stocks. The respective proxy is sampled for the 25% smallest and the 25% largest firms, measured by market capitalization. The dependent variable corresponds to proxies for volume and liquidity described in section 4.1. The regression is applied to the introduction of the tax on Spanish stocks with a market capitalization above €1 billion and the event date is therefore 16.01.2021. Standard errors (in parentheses) are clustered by stock and time and as usual ***, **, * denote statistical significance at the 1%, 5% and 10% level.

Stock		0% - 25%	75% - 100%
Trading activity			
	log volume	-0.253***	-0.368***
		(0.067)	(0.079)
Liquidity			
	log depth	0.005	0.041
		(0.040)	(0.062)
	quoted spread	-0.063	0.120**
		(0.110)	(0.047)
	effective spread	-0.041	0.039**
		(0.043)	(0.017)
	realized spread	-0.036	0.034**
		(0.031)	(0.015)
	price impact	0.023	0.002
		(0.031)	(0.007)

7.5 Robustness Results

Figure 5: Graphical illustration of Robustness Results for the Log of Trading Volume

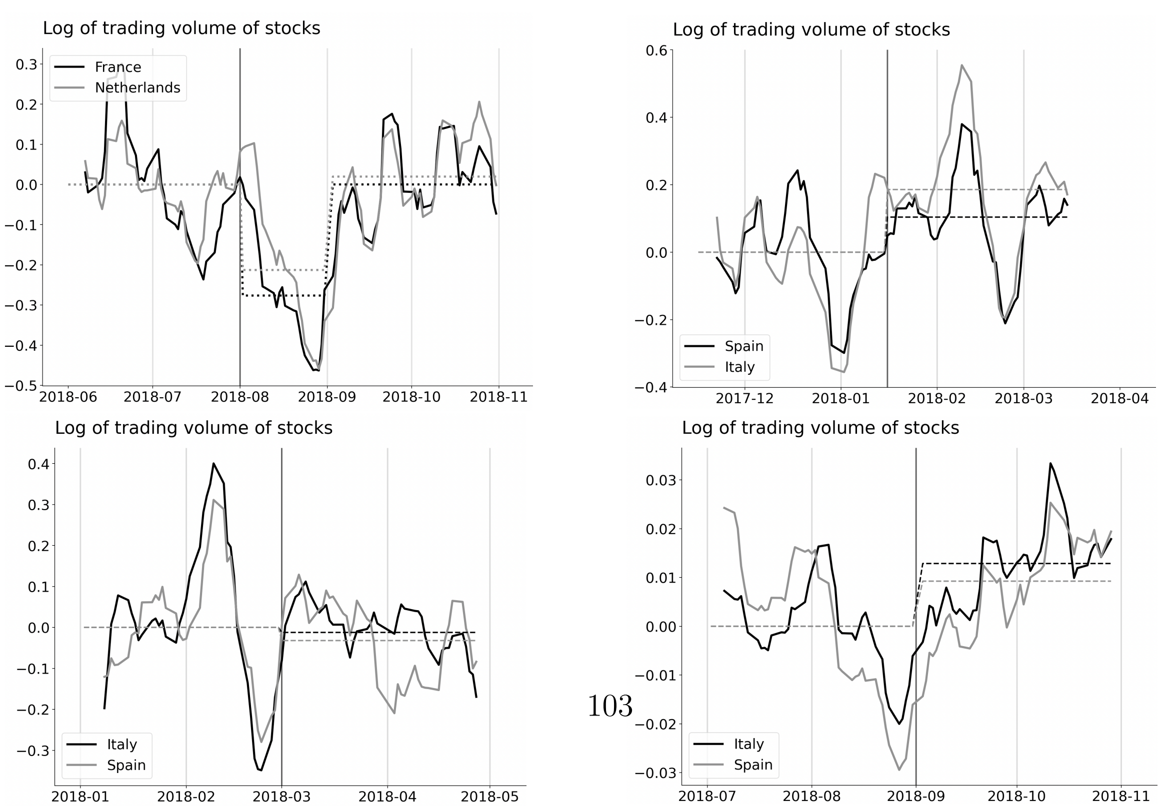


Table 12: Causal Impact of the French FTT

This table presents the estimates for the coefficient $\beta^{permanent}$ from specification (R.1) (Note that for France we use the flexible model described in footnote 20) where the dependent variable corresponds to proxies for volume and liquidity described in section 4.1. The regression is applied on the dates of the introduction of taxes in France, Italy and Spain. Standard errors (in parenthesis) are clustered by stock and time and as usual ***, **, * denote statistical significance at the 1%, 5% and 10% level.

		France 01.08.2018	Italy 01.03.2018	Italy 01.09.2018	Spain 16.01.2018
Trading activity					
	log volume	-0.027	0.010	0.004	-0.082
		(0.050)	(0.069)	(0.004)	(0.058)
Liquidity					
	log depth	-0.0003	-0.231***	0.008	0.455***
		(0.051)	(0.053)	(0.011)	(0.084)
	quoted spread	0.397	0.988	0.412	-0.693
		(0.597)	(0.876)	(0.431)	(0.674)
	effective spread	0.187	0.004	0.055	-0.014
		(0.186)	(0.293)	(0.169)	(0.316)
	realized spread	0.268	-0.244	0.128	-0.141
		(0.210)	(0.264)	(0.148)	(0.244)
	price impact	0.123*	0.366***	0.009	-0.048
		(0.074)	(0.109)	(0.095)	(0.103)
# treated		82	74	74	50
# control		29	50	50	74
# observations		12054	10166	10166	10291

7.6 Market Making Exemption

The main difference in terms of the market making exemption used in Italy, France and Spain lies in the definition of the activities that fall within the scope of market making provided in the respective bills outlining the tax policy. While the latter two countries provided their own definition of "market-making activities" within the law, the Italian authorities decided to follow European legislation for the purpose of the definition of market making. Specifically, the Italian law defining the scope of the tax specifically refers to the definition of market making given in article 2(1)(k) of the Short Selling Regulation (SSR) as interpreted by the European Securities and Markets Authority (ESMA). The definition of market making activities given in the SSR is limited to activities, performed by investment firms, credit institutions or third country entities, such as (i) "posting firm, simultaneous two-way quotes of comparable size and at competitive prices, with the result of providing liquidity on a regular and ongoing basis to the market, (ii) as part of its usual business, by fulfilling orders initiated by clients or in response to clients' requests to trade and (iii) by hedging positions arising from the fulfilment of tasks under points (i) and (ii). The article additionally states that the institution performing these activities needs to "be a member of a trading venue or of a market in a third country". This definition clearly does not cover the entire scope of activity of a market maker, as it e.g. does not include proprietary trading. Additionally, in order to be granted an exemption based on this definition, market makers need to notify the relevant authorities (CONSOB in Italy) at least 30 calendar days before they first intend to use the exemption. While these definitions and rules for the exemption of market makers defined in article 2(1)k of the SSR are very limiting, the ESMA guidelines for the interpretation of these definitions is even narrower. For example, the ESMA guidelines, in terms of the membership requirement, state that a condition for the exemption is that "the market maker is a member of a trading venue where the financial instrument in question is admitted to trading or traded and in which it conducts a market making activity in that instrument". This interpretation therefore excludes, among other things, all activities on instruments that are not admitted to trading or traded on any venues (such as OTC products). This interpretation further extends to hedging activities, therefore limiting the possibility for market makers to hedge using OTC derivatives. While what presented here is not an exhaustive description of the SSR regulation and the interpretation guidelines defined by ESMA[29], it is clear that this

[29] see "V. Salvadori di Wiesenhoff, Italian Financial Transaction Tax Implications of the Evolving Regulatory Landscape: The Exemption for Market Makers, 20 Derivs. & Fin. Instrums. 1 (2018), Derivatives Financial Instruments IBFD" for a detailed discussion.

is a very restrictive and narrow definition of market making activities. For this reason, many member states as well as other authorities decided to not comply with the ESMA Guidelines. This is not the case for the CONSOB and the Bank of Italy, which decided to fully comply with the ESMA Guidelines and their definition of market making for the purpose of the exemption used in the context of the FTT.

Instead of complying with European authorities in the definition of market making, France and Spain introduced their own definitions within the respective laws that introduced the FTT. While the pure definition of market making itself largely follows the one provided by article 2(1)(k), the main different lies in the interpretation of this definition, which allows for a much wider scope of application of the definition itself. While we do not intend to provide an exhaustive discussion of the specific differences, a few examples that differ from the ESMA Guidelines are (i) the market maker does not need to a member of the specific trading venue in which he wishes to trade a certain instrument (ii) the activity of market making is also allowed for instruments traded outside of regulated venues (therefore hedging in OTC markets is allowed) (iii) proprietary trading is allowed within the scope of market making activities.

It is therefore clear that there exists a large disparity in the definition/interpretation of market making activities used for the exemptions in Italy, France and Spain. This disparity most likely weight heavily against market making activity in Italy, as the narrow interpretation and strict burden of proof introduced by the law certainly complicated the provision of liquidity, at the very least relative to the French and Spanish case.

7.7 List of Stocks

List of Treatment and Control firms - Italian FTT			
Italy	Italy	Spain	Spain
A2A	Ind. Macchine Automatiche	Abertis Infrastructuras	Let's GOWEX
ACEA	Indesit Co.	Abengoa	Grifols
Amplifon	Iren	ACS	Iberdrola
Atlantia	Intesa Sanpaolo	Acerinox	Indra Sistemas
Banca Generali	Italcementi	Corp Financera Alba	Industria de Diseno Textil
Banca Popolare di Sondrio	Interpump Group	Almirall	Liberbank
Brembo	Luxottica Group	Amadeus IT Holding	Mapfre
Buzzi Unicem	Mediobanca	Acciona	Duro Felguera
Soc. Catt. di Assicurazioni	Mediaset	BBVA	Melia Hotels International
Credito Bergamasco	Piaggio & Co.	Bankia	NH Hotel Group
Compagnie Industriali Riunite	Parmalat	Bankinter	Obrascon Huarte Lain
Davide Campari - Milano	Prysmian	Bolsas y Mercados Espanoles	Deoleo
UniCredit	RCS MediaGroup	CaixaBank	Banco Popular Espanol
Banca Carige	Recordati	Construcciones y Aux. d. F.	Promotora de Informaciones
Danieli & Co.	Salini Impregilo	CIE Automotive	Prosegur Cia de Seguridad
DeLonghi	Finmeccanica	Campofrio Food Group	Red Electrica Ciro
Enel Green Power	Saipem	Distribuidora Int. d. A.	Repsol
Credito Emiliano	Snam	Ebro Foods	Banco de Sabadell
Banca Pop. dell'E. Romagna	Saras	Endesa	Banco Santander
Enel	Telecom Italia	Enagas	Sacyr
Eni	Tod's	Ence Energia y Celulosa	Telefonica
ERG	Terna Rete Elettrica Nazionale	Elecnor	Mediaset Espana
EXOR	Unione di Banche Italiane	Faes Farma	Tecnicas Reunidas
Fiat	Unipol Gruppo Finanziario	Fomento de Constr.	Vidrala
Geox	UnipolSai	Ferrovial	Viscofan
Hera		Grupo Catalana Occidente	Zardoya Otis

List of Treatment and Control firms - French FTT		
France	France	Netherlands
Accor	Icade	Aalberts Industries NV
Aeroports de Paris	Iliad	AMG Advanced Metallurgical Group
Air France-KLM	Imerys	APERAM
Air Liquide	Ingenico Group	Arcadis
Alcatel-Lucent	Ipsen	ArcelorMittal
Alstom	JCDecaux	ASML Holding NV
Altarea	Kering	Corbion
Areva	Klepierre	Corio NV
Arkema	Lafarge	Delta Lloyd
Atos	Lagardere	Gemalto NV
AXA	Legrand	Heineken NV
BioMerieux	L'Oreal	Hunter Douglas
BNP Paribas	LVMH M. H. Louis Vuitton Mercialys	ING Groep NV
Bollore	Metropole Television Natixis	Koninklijke Ahold NV
Bourbon	Quadient	Koninklijke Philips Electronics NV
Bouygues	Nexans	Koninklijke Vopak NV
Bureau Veritas	Orange	Nutreco NV
Cap Gemini	Orpea	PostNL
Carrefour	Pernod Ricard Peugeot	RELX
CGG	Remy Cointreau Renault	Royal Dutch Shell PLC
Christian Dior	Rexel	STMicroelectronics NV
CIC	Rubis	TNT Express NV
Cie de Saint-Gobain	Sanofi	ThromboGenics
Cie du Cambodge	Schneider Electric	Unilever NV
CNP Assurances	SCOR	Wolters Kluwer NV
Colas	SEB	
Credit Agricole	Societe Television Francaise	
Danone	Somfy	
Dassault Aviation	Technip	
Dassault Systemes	Thales	
Edenred	Valeo	
Eiffage	Vallourec	
Electricite de France	Veolia Envi ronnement	
Eramet	Vicat	
Eurazeo	Vilmorin & Cie	
Financiere de L'Odet	Vinci	
Fonciere Des Regions	Virbac	
Gecina	Vivendi	
GDF Suez	Wendel	
Groupe Eurotunnel	Zodiac Aerospace	
Havas	Suez Environnement	
Hermes International		

List of Treatment and Control firms - Spanish FTT			
Spain	Spain	Italy	Italy
Acciona	Laboratorios Farm. Rovi	A2a	Interpump
Acerinox	Mapfre	Acea	Intesa Sanpaolo
ACS	Melia Hotels International	Amplifon	Iren
Aena, S.M.E.	Merlin Properties Socimi	Anima Holding	Italgas
Almirall	Naturgy Energy Group	Atlantia	Italmobiliare
Amadeuts IT Group	NH Hotel Group	Autogrill	Juventus FC
amrest holidngs	Pharma Mar	Azimut	Leonardo
Applus Services	Prosegur CIA. De seguridad	B M.Paschi Siena	Maire Tecnimont
Banco BVA	Red Electrica Corporacion	B P di Sondrio	Marr
Banco de Sabadell	Repsol	Banca Generali	Mediaset
Banco Santander	Sacyr	Banco Bpm	Mediobanca
Bankia	Siemens gamesa	BB Biotech	Moncler
Caixabank	Solaria Energia	Bca Mediolanum	Nexi
Cash	Telefonica	Bff Bank	Piaggio
Cellnex Telecom	Unicaja Banco	Bper Banca	Pirelli & C
Logista	Vidrala	Brembo	Poste Italiane
CIE Automotive	Viscofan	Brunello Cucinelli	Prysmian
Construcc. De Ferrocarriles	Zardoya Otis	Buzzi Unicem	Rai Way
Corporacion Financiera Alba		Campari	Recordati
Ebro Foods		Cattolica Assicurazioni	Reply
Enagas		Covivio	S. Ferragamo
Endesa, Socieda Anonima		Danieli & C	Saipem
Euskatel		Datalogic	Salcef Group
Faes Farma		De'Longhi	Sesa
Ferrovial		Diasorin	Snam
Fluidra		Enav	Sol
Fomento de C. Y C.		Enel	Stellantis
Gestamp Automocion		Eni	STMicroelectronics
Grifols		Erg	Tamburi
Grupo Catalana Occidente		Exor	Telecom Italia
Iberdrola		Ferrari	Technogym
Indra Sistemas		Fincantieri	Tenaris
industria De Diseno Textil		FinecoBank	Tod's
International Consolidat		Generali	Unicredit
Laboratorios Alba		Gvs	UnipolSai