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One size fits all? High frequency trading, tick size changes and the implications for exchanges: market quality and market structure considerations

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Abstract This paper offers a systematic review of the empirical literature on the implications of tick size changes for exchanges. Our focus is twofold: first, we are concerned with the market quality implications of a change in the minimum tick size. Second, we are interested in the implications of changes in the minimum tick size on market structure. We show that there is a large body of empirical literature that documents a decrease in transaction costs following a decrease in the minimum tick size. However, even though market liquidity increases, the incentive to provide market making activities decreases. We document a strong link between the minimum tick size regulations and the recent increase in high frequency trading activity. A smaller tick enhances the price discovery process. However, the question of how multiple tick size regimes affect market liquidity in a fragmented market remains to be answered. Finally, we identify topics for future research; we discuss the empirical literature on the minimum trade unit and the recent calls for a minimum resting time for quotes.

Keywords Tick size · Market quality · Microstructure · High frequency trading · Trading costs · Minimum trade unit

JEL Classification G14 · G18

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1 Introduction

In many respects, and until recently, changes on the minimum tick size regulations appeared to have been fuelling the race to the bottom for transaction costs. This was primarily the case in the US markets since 2001—that is, since the adoption of decimal pricing that slashed costs in terms of a reduction in bid–ask spreads. In this literature review, we critically discuss the implications of changes in tick size regulations on market quality and market structure.

Our focus is twofold: First, we are concerned with the market quality implications of a change in the minimum tick size. In particular, we present the empirical literature concerned with the effect of minimum tick size regulations on trading costs and liquidity. The vast majority of the empirical literature has documented a decrease in spreads and an increase in liquidity following a tick size reduction. However, one stream of the literature is also concerned with the effect of this reduction to quoted depth and the ability of the market to absorb large trades. In addition, we document the strong link between the minimum tick size regulations and the recent increase in high frequency trading (HFT). As it will be noted, a small minimum tick size allows high frequency traders (HFTRs) to implement their strategies, whilst a larger relative tick size leads to larger profit by HFTRs due to increased trading activity. Finally, we discuss the implication of the minimum tick size on market volatility.

Second, we are interested in the implications of changes in the minimum tick size on market structure, i.e., the effects of the minimum tick size regulation in different market settings. To this end, we are concerned with the effect of tick size changes on the price discovery process, market making and market quality indicators. As we will discuss in the following sections, the decrease in tick sizes has enhanced the price discovery process but has de-incentivised market makers to provide liquidity. The latter has triggered the recent pilot study by the Securities and Exchange Commission (SEC) to increase the tick size for a sample of less liquid stocks. We subsequently focus on the implications of a change in tick size on market design and also on the interaction between market players, especially between retail and institutional investors.

To an extent, our motivation for this review stems from the SEC's recent introduction of a pilot study for certain small capitalization stocks traded on the NYSE for which the minimum tick size would be increased (see SEC 2014a).[1] We are therefore in the midst of a potential change in policy in the US stock exchanges that may reverse the changes implemented since 2001. However, in our view, a second recent proposal that is related to the minimum tick size regulations—and is an obvious area for future research—is the suggested changes to the minimum resting time which asks and bids would be required to have on the limit order book. These proposed changes are mostly associated with the implementation of MiFiD II in Europe's financial markets and have, as their primary goal, the curling of HFT in Europe (see Stafford and Barker 2014).

In this literature review, our focus is more on the impact of the minimum tick size regulations on market structure and market quality than on the effect of minimum tick size changes on trading activity and transaction costs. Why the choice to focus on market structure and market quality? The literature is overwhelmingly positive on the effect of decimalisation and the general decrease in tick sizes on transaction costs. However, the problem with a small tick size is that, while the results of low transaction costs are felt by

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[1] See also Weild et al. (2012).

market participants at an absolute level (i.e. market participants receive smaller transaction costs), the same also applies for market quality. That is, transaction costs have reached a point that may be harmful for the welfare of the exchange. One example of the above is the increased need from the exchanges to provide a constant flow of liquidity in a stable environment; however, the lower the transaction costs, the smaller the incentive of market makers to support the exchange on that task. Therefore, our paper is different from previous studies on the effect of decimalization on trading costs as our goal is to synthesize the literature with market structure and market quality in mind. Thus, we are very keen to offer a perspective to academics, policy regulators and market participants on where the current and future research in this area may develop.

The review is structured as follows: Sect. 2 gives a general outline of the surveyed papers and discusses our methodological approach to this literature review. Section 3 discusses in detail the empirical literature, and Sect. 4 discusses related research on the minimum trade unit. Section 5 concludes the review but, crucially, it also discusses opportunities for future research.

2 An outline of the surveyed papers and structure of this literature review

2.1 An outline of the surveyed papers

The majority of papers concerned with the minimum tick size focus on minimum tick size changes and, in particular, on the implementation of decimal pricing in the US exchanges in April 2001. Methodologically most studies investigate the effect of tick size changes after controlling for certain stock and exchange characteristics (see Ahn et al. 2007; Bacidore 1997; Chakravarty et al. 2005). In particular, studies rely on one of the following sets of samples:

1. Longitudinal studies, that is, studies which report statistics before and after a tick size change on the same set of assets (see Gibson et al. 2003; Goldstein and Kavajecz 2000; Jiang et al. 2009). This set of studies benefits from studying the same set of assets, however there is also a risk associated with comparing assets in different sample periods.
2. Cross-sectional studies, that is studies that compare assets that are affected by a minimum tick size change with assets for which the tick size is unchanged and trade in either the same exchange (see Chakravarty et al. 2004; Griffiths et al. 1998) or in a separate exchange (Bessembinder 2003; Chung et al. 2004a; Jiang et al. 2009). The latter set of papers relies on a set of matching methods to produce a set of assets that are comparable across the two exchanges.
3. A third set of studies relies on assets that are cross-listed, that is assets that are trading on more than one exchange where the change affects trading in only one of the exchanges (see Lin et al. 2009; Oppenheimer and Sabherwal 2003). This is also related to a more recent set of studies concerned with the association of the minimum tick size regulations and the incidence of HFT, in addition to the interaction of market systems (see Bartlett and McCrary 2013; Mahmoodzadeh and Gençay 2014; O'Hara et al. 2014).

Most studies rely on trade and quote (TAQ) data in order to produce reliable estimators of bid–ask spreads, an indicator of liquidity and trading costs (see Coughenour and Harris 2004; Schultz 2000). Nevertheless, a smaller set of published papers use daily data (see Al-

Yahyaee 2013; Chung et al. 2005) and a second subset of studies use full limit order book data (see Pan et al. 2012). The majority of published papers use NYSE and NASDAQ TAQ data (see Chou and Chung 2006; Jones and Lipson 2001; Johnson et al. 2014; O'Hara et al. 2014), and some more recent studies use the national best bid and offer (NBBO) US data. There are also variations in the sample time period. A number of studies attempt to predict the effect of the (then) proposed implementation of decimal pricing on market structure and market quality (see Harris 1991, 1994), whereas most studies are concerned with the ex-post realization of a decrease in the minimum tick size (see Chan and Hwang 2002; Chung et al. 2002; Zhao and Chung 2006). Finally, the most common financial instrument used is common stocks (see Chung et al. 2004; Gerace et al. 2012; Hagströmer and Nordén 2013), but more recent papers which focus on HFT also rely on foreign exchange data (see Mahmoodzadeh and Gençay 2014). A limited number of published papers use mutual fund data (see Bollen and Busse 2006) or data from derivatives exchanges (see ap Gwilym et al. 2005; Stone 2009; Chueh 2000).

2.2 Structure of the literature review

An obvious way to present the papers in this literature review is in a chronological order. To an extent, this is a logical approach but one which is largely ineffective: conveying the effect of tick size changes on exchanges becomes increasingly difficult unless the focus is on the main feature of exchanges. To this end, for the purposes of this literature review, we classify research as falling in the following categories with respect to the implications of their findings in market quality and market structure:

1. Market quality: we rely on the definition of market quality used by the London Stock Exchange to discuss the effect of minimum tick size changes on market quality indicators.[2] In this respect, market quality is represented by liquidity, transaction costs and volatility. To this end, our discussion focuses on each one of these market characteristics interchangeably. In addition, we look at two aspects of market quality that are crucial in the implementation of an optimal tick size. The first relates to execution speed, and refers to HFT. The literature makes a special case on the effect of minimum tick size changes on the success of HFT. The second aspect refers to the effect of the minimum tick size changes on market making. The literature generated by the exchanges is very critical regarding the dire consequences which slashing the minimum tick size has on the ability of market makers to continue supporting the illiquid stocks and initial public offerings (IPOs).

2. Market structure: crucially, the implementation of the minimum tick size in different market settings determines the success of the regulatory policy of tick size changes. We therefore focus on the way different markets have adjusted to the minimum tick size (the markets) and also the way in which different market participants are affected by the changes (the players). To this end, we also discuss how the minimum tick size changes have altered the interaction between a limit order-book market and dark pools. An important feature of market structure is the facilitation of the price discovery process and in this literature review, we review the papers that show the relationship between the minimum tick size regulations and the price discovery process.

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[2] London Stock Exchange, "How Can Market Quality Be Determined" http://www.londonstockexchange.com.

Rather than discussing the papers in detail, we summarize them in separate tables according to their main implications for market structure and market quality. That is, whilst there are obviously some papers whose main findings relate to two or more topics, we focus on the consequences of the findings for our main themes of the literature review. Focusing on market structure and market quality meant dropping a small number of papers that make little or no contribution in these two areas. Our hope is that readers of this literature review will be able to formulate a good understanding of the tick size regulations and the effect of tick size changes on the microstructure of financial markets which will inform their future research.

3 Detailed review of the literature on minimum tick changes

3.1 Effect of tick size changes on market quality indicators

3.1.1 Tick size changes and trading costs

In Table 1, we present the first set of studies which focus on the implications for trading costs of a minimum tick change. In Panel A, we present the set of studies focussing on a minimum tick size decrease and in Panel B, we focus on studies that discuss the implications for trading costs of a large minimum tick size. In each panel, references are grouped by sample, and then in ascending order by end date of the used sample. This is done in order to group together studies that have focused on the same market, and to identify within that group any trends emerging over time.

This set of studies focuses mainly on the US decimalization, so the bulk of work is conducted with TAQ data relating to US exchanges. In Panel A, the main findings overall support the hypothesis that a smaller tick size leads to narrower bid–ask spreads. The paper by Harris (1991) originally established that a large tick size may act as a binding constraint for the lower-priced stocks, hence what is important is not only the nominal value of the tick size but also its relative value, namely the value of the tick size in relation to the stock price: the greater the stock price, the less binding is the tick size. Kurov and Zabotina (2005) show that the minimum tick size may act as a binding constraint for the very liquid contracts, however, Bollen and Whaley (1998) and Hsieh et al. (2008) show that whilst spread costs fall following a reduction in tick size, market depth also falls which may increase trading costs for larger trades overall.

In Table 1, Panel B, we present the studies that are concerned with the impact of an artificially large tick size on trading costs. The empirical literature around this subject is relatively limited but one important issue arises: the tendency of investors to use a smaller set of prices which effectively increases the minimum tick size. Studies in this area clearly show that there is a strong positive relationship between execution costs and price clustering (Bessembinder 1997). Ikenberry and Weston (2008) show that this artificially large minimum tick is a product of a fundamental human bias for the more prominent numbers.

In terms of the implications for market structure and in particular with regard to trading costs, the evidence suggests that a decrease (increase) in tick size leads to a decrease (increase) in trading costs, especially for the low-priced shares (Van Ness et al. 2000). However, negotiation costs also increase as the minimum tick increases. Finally, if the use of a tick size has an embedded human bias, then the evidence suggests that a tick size

Table 1 Empirical studies on the effect of a tick size change on trading costs

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/ frequency	Main finding(s) after tick size reduction	Implications of a smaller tick for market structure
Panel A: The effect of a minimum tick size decrease on trading costs					
Harris (1991)	All stocks greater or equal than $1	Jan 63–Dec 87	CRSP	A smaller tick size acts as a binding constraint for lower-priced stocks	Increases the costs of negotiating
Graham et al. (2003)	NYSE firms that pay cash dividends	Jan 96–Aug 00 and Jan 01–Dec 01	CRSP	Abnormal ex-dividend day returns increase in the 1/16 and decimal pricing eras, relative to the 1/8 era	Results against the theory that spreads are the dominant transaction cost for ex-day traders
Kurov and Zabotina (2005)	CME (S&P 500), NASDAQ (index and E-mini futures)	Jan 02–Dec 02	CTR & trades	The minimum tick size acts as a binding constraint for the very liquid contracts	Results in lower trading costs
Gwilym and Alibo (2003)	FTSE100 stock index futures	Jan 97–Dec 99	TAQ LIFFE	A structural change in price clustering following the move to automated trading	A small tick is an important factor in reducing observed bid–ask spreads
Lau and McInish (1995)	SEE (5)	Jul-94	TAQ SEE	The reduction in tick size decreased bid-ask spreads	Tick size clearly associated with trading costs
Van Ness et al. (2000)	AMEX (98), NASDAQ (804), NYSE (1051)	Jan 97–Apr 97	TAQ US	The decrease in tick size led to a reductions in spreads and depth and an increase in the number of quotes	The introduction of sixteenths of a dollar had an immediate impact on equity trading costs in U.S. markets
Bollen and Whaley (1998)	NYSE (2852)	May 97–Jul 97	TAQ US	Following the reduction in tick size both bid/ ask spreads and market depth at the prevailing bid/ask quotes have fallen	Leads to lower investor trading costs, with the largest gains being experienced for low price shares and for small trade sizes
Hsieh et al. (2008)	TAIEX	Sep 04–Aug 05	TEJ	Market liquidity increased following the reduction in tick size	Tick size reduction leads to an increase in market efficiency

Table 1 continued

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/ frequency	Main finding(s)	Implications of discreteness for market structure
Panel B: The effect of a large minimum tick size on trading costs					
Chung et al. (2011)	KSE (651)	Apr 03–Jun 03	TAQ KSE & US	Large tick sizes imposed on high-priced stocks are significant binding constraints on bid-ask spreads	The artificially imposed large tick sizes are associated with large trading costs
Bessembinder (1997)	NASDAQ and NYSE (300pairs)	Apr 94–Dec 94	TAQ US	A strong positive relationship between execution costs and price-rounding frequencies for NASDAQ issues but not for NYSE issues.	Price-rounding conventions increase trade execution costs
Ikenberry and Weston (2008)	NYSE (1920), NASDAQ (1851)	Jul 02–Dec 02	TAQ US	Evidence of a more fundamental human bias for prominent numbers	Tick size changes may have only a minor effect on the prevailing transaction prices

ASX Australian Stock Exchange, *CME* Chicago Mercantile Exchange, *CRSP* Center for Research in Security Prices, *CTR* Computerized Trade Reconstruction, *EBS* Electronic Broking Services, *HKEx* Hong Kong Stock Exchange, *ISE* Istanbul Stock Exchange, *ISSM* refer to the Institute for the Study of Securities Markets, *KLSE* Kuala Lumpur Stock Exchange, *KSE* Korea Stock Exchange, *MSM* Muscat Securities Market (Oman), *NASTRAQ NASDAQ* Trade and Quote Data, *NBBO* National Best Bid and Offer, *NZX* New Zealand Stock Exchange, *OMXS* Stockholm Stock Exchange Index, *OPRA* Option Price Reporting Authority, *SEE* Stock Exchange of Singapore, *SET* Stock Exchange of Thailand, *SEHK* Stock Exchange of Honk Kong, *SFE* Sydney Futures Exchange, *SOD* Summary of Deposits, *TAIEX* Taiwan Stock Exchange, *TAQ* Trade and Quotes, *TEJ* Taiwan Economic Journal, *TRTH* refer to Thomson Reuters Tick History, *TSE* Toronto Stock Exchange

decrease may not have the desired effect since traders would still continue to use the artificially large tick size.

3.1.2 Tick size changes and market liquidity

In Table 2, we consider the studies that focus on the implications of change in tick size on asset liquidity. From a methodological perspective, there is an overlap in the methods employed for the studies included in Tables 1 and 2 as for both sets of studies the bid–ask spread is the main variable of interest. The classification as to whether a study is more relevant to trading costs or liquidity is based on self-selection, namely we allow the study itself to identify its main contribution to the literature. Also, for reasons of clarity, we avoid double-entries across the two tables.

Studies that investigate the effect of a tick size change on liquidity are conducted across a range of markets and instruments, and over a relatively long time-span. As anticipated, most studies report that a decrease in tick size has positive implications for liquidity. In particular, decreasing the tick size almost always increases liquidity for the more heavily-traded stocks (Hameed and Terry 1998 and Anderson and Peng 2014) and for stocks with a larger relative tick size (Aitken and Comerton-Forde 2005). Ahn et al. (1996) show that the decrease in tick size has no impact on the liquidity of infrequently traded stocks. Further, a number of studies show that a smaller tick size leads to an increase in negotiation costs which might, to an extent, mitigate the benefits of an increased liquidity (see Hameed and Terry 1998).

The majority of studies in Table 2 show that both spreads and depths at the best quote decline following a tick size decrease. In relation to the latter, ap Gwilym et al. (2005) show that the benefit of a smaller monetary spread outweighs the reduction in quoted depth. Also, traders who tend to trade on the best bid and ask experience an increase in liquidity, yet the opposite effect may be experienced by larger traders (Chung et al. 2005 and Cai et al. 2008). Verousis et al. (2016) show that the ability of the options market to absorb large trades diminishes following a tick size reduction. The latter observation reflects the fact that larger traders may exhaust the depth at the best ask and bid, but only a limited number of studies focus on the effect of tick size changes on asset depth beyond the first level of the limit order book (see Table 2 below). Evidently, this is a shortcoming in the literature to date, which is somewhat mitigated by the use of effective spreads as a hybrid measure of liquidity.

3.1.2.1 Tick size changes and effects on market making

What is of particular interest to changes in the minimum tick size and market structure is the relationship between the former, and market making activities. The professional literature clearly identifies the decrease in the minimum tick size as one of the main reasons why market making has become unprofitable with wider consequences regarding ability to support illiquid stocks and initial price offerings (IPOs). In Table 3, we present the studies that relate the change in the minimum tick size with market making.

Theoretically, Bernhardt and Hughson (1996) show that discreteness—the existence of the minimum tick size—limits competition, whilst also permitting market makers to offer profitable quotes. The question is therefore, do minimum tick size changes make market making more profitable?

Table 3a shows the studies that investigate the implications for market making when there is a decrease in the minimum tick size. Studies in this area show that a decrease in

Table 2 Empirical studies on the effect of a minimum tick size on liquidity

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s) after tick size reduction	Implications of a smaller tick for market structure
Hameed and Terry (1998)	SES (238)	Jan 80–Jul 94	Daily data	A negative relationship between tick size and price clustering	Lowers trading costs and improves liquidity in the case of actively traded stocks but increases negotiation costs for the thinly traded stocks
Chung et al. (2005)	KLSE (812)	Jan 96–Dec 01	Daily data	Wider spreads and less quote clustering for stocks that are subject to larger mandatory tick sizes	A larger tick for higher priced stocks is detrimental to market liquidity but this effect is mitigated by lower negotiation costs
Al-Yahyaee (2013)	All MSM stocks	Jan 97–Jun 10	Daily data	An increase (decrease) in ex-day premiums (abnormal returns)	An improvement in liquidity and reduction in execution costs in a futures market setting
Harris (1994)	NYSE and AMEX (529)	Jan 89–Dec 89	ISSM	A decline in spreads and depths	Benefits the small liquidity-demanding traders but hurts the large liquidity-demanding traders
Aitken and Comerton-Forde (2005)	ASX (674)	Oct 95–Feb 96	TAQ ASX	An increase in liquidity	A clearer benefit for stocks with a larger relative tick size
Gwilym et al. (2005)	UK long gilt futures	Aug 97–Oct 98	TAQ LIFFE	A drop in the monetary value of the spread	The benefit of narrower monetary spreads outweigh the reduction in quoted depth
Alampieski and Lepone (2009)	SFE (3, 10 year bonds, 90-day Bill Futures)	Dec 06–Mar 07	TAQ SFE	A decline in spreads, depths and a reduction in execution costs	An improvement in liquidity and reduction in execution costs in a futures market setting
Anderson and Peng (2014)	NZX (34)	Sep 10–Aug 11 and May 11–May 12	TAQ SIRCA	A decline in spreads and depths but a smaller increase in liquidity for smaller firms	A clearer benefit for the larger, more active stocks
Cai et al. (2008)	TokyoSE (226)	Jan 97–Dec 97	TAQ TokyoSE	Liquidity effects are asymmetric for tick-increasing and tick-decreasing events	Benefits less the small limit-order traders who do not exhaust the depth at the best quote
Ahn et al. (1996)	AMEX (304), NYSE (377)	Jun 92–Nov 92	TAQ US	A decrease in quoted and effective spreads	A reduction in trade size but no impact on the liquidity of infrequently traded stocks

Table 2 continued

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/ frequency	Main finding(s) after tick size reduction	Implications of a smaller tick for market structure
Chung et al. (2004)	NYSE (2603)	Aug 00–Jan 01	TAQ US	A larger liquidity benefit for stocks with higher proportions of one-tick spreads and odd-sixteenth quotes, and more frequent trading before decimalization	Increases price competition and reduces binding constraints: sub-penny pricing may further reduce the spreads of high-volume, low-risk, or low-priced stocks
Gerace et al. (2012)	HKEx (40)	Jan 05–Jan 06	TRTH	A decline in spreads and depths	Improves market liquidity
Verousis et al. (2016)	NYSE LIFFE	Jan 09–Mar 10	TAQ LIFFE	Option liquidity increased but at a decreasing rate with option moneyness	The ability of the market to absorb large trades diminishes

Acronyms are defined in Table 1

Table 3 Empirical studies on the effect of a tick size change on market making

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/ frequency	Main finding(s) after tick size reduction	Implications of a smaller tick for market structure
Panel A: The effect of a minimum tick size decrease on market making activities					
Stone (2009)	US options (26)	Aug 06–Aug 07	TAQ OPRA	A narrower bid-ask spread redistributes the gains of innovation from the exchanges' market makers to investors	Decreases the willingness of market makers to trade farther-from-the-strike securities
Porter and Weaver (1997)	TSE (480)	Mar 96 and May 96	TAQ TSE	A negligible impact on internalization and member profits	A smaller tick might result in higher commission profits
Bacidore (2001)	TSE (318)	12 Feb–14 Jun 96	TAQ TSE	Traders have a smaller incentive to improve the quality of their information hence a drop in the adverse selection component of the spread	Shifts economic rents and reduces costly information acquisition
MacKinnon and Nemiroff (2004)	TSE (167)	Jan 96–Jul 96	Trades TSE	A very large decline in the profits to liquidity providers	Given a decision to provide liquidity, an agent has an incentive to do so at smaller price increments (e.g., a smaller spread), but there is a greatly reduced incentive to provide liquidity in the first place.
Bacidore (1997)	TSE (489)	Feb 96–Jun 97	TAQ TSE	A reduction in spreads when the tick size is large	Leads to an increase in liquidity but a decrease in liquidity providers' profits
He and Wu (2005)	NYSE (116)	Aug 00–Sep 00 and Dec 00–Jan 01	TAQ US	A reduction in market-making and rounding error costs, but not in public news costs	A decline in market makers' costs for supplying liquidity reduces spreads
Coughenour and Harris (2004)	NYSE (1181)	Dec 00 and Feb 01–Mar 01	TAQ US	Decimalization relaxed the public order precedence rule and led to more price aggressiveness by the specialists	No change in the average specialist gross trading profits. Specialist participation increased for stocks where the cost and opportunity of obtaining order precedence were relatively expensive and scarce prior to the tick change
Bessembinder (2003)	NASDAQ and NYSE (300 pairs)	Jan 01 and Apr 01–Aug 01	TAQ US	Post-decimalization execution costs are similar across NASDAQ and NYSE stocks	Does not affect liquidity supply

Table 3 continued

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/ frequency	Main finding(s) after tick size reduction	Implications of a smaller tick for market structure
Chung and Van Ness (2001)	NASDAQ (134)	Oct 96–Sep 97	TAQ US	A decline in spreads	Makes it less costly for market makers to manage their inventories
Chung et al. (2004c)	NASDAQ and NYSE (517 pairs)	May 01	TAQ US	Post-decimalization, the relative sizes of NASDAQ and NYSE spreads depend largely on the averaging methods	For low-volume stocks, specialists reduce execution costs but for large stocks competing dealers provide more benefits
Charoenwong et al. (2016)	NYSE (230 IPOs)	Jan 98–Dec 04	TAQ US	Relation between spreads and IPO underpricing becomes negative	Benefits from the increased price competition are felt more by hot IPOs

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s)	Implications of a larger tick for market structure
Panel B: The effect of a large minimum tick size on trading costs					
Bollen et al. (2003)	S&P 500 futures	Nov 05–Oct 98	CTR	The increase in tick size led to an increase in the bid–ask spread and a reduction in trading volume	A large tick increases market maker revenue
Angel (1997)	NYSE and AMEX (1160 splits)	Jan 84–Dec 93	TAQ US	Idiosyncratic risk, firm size, and visibility of the firm affect the optimal relative tick size	Provides an incentive for dealers to make markets and for investors to provide liquidity by placing limit orders
Anshuman and Kalay (1998)	Theory	Theory	Theory	The minimum tick causes time-varying bid-ask spreads, asymmetric commissions, and market breakdowns	The minimum tick permits a competitive market maker to realize economic profits that help recoup fixed costs

Table 3 continued

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s)	Implications of a larger tick for market structure
Gibson et al. (2003)	NYSE (415)	Dec 00–Mar 01	TAQ US	Decimalisation led to a decrease in order-processing costs but not to adverse selection and inventory costs	A large tick size allows market makers to enjoy spreads that are larger than their actual costs

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s)	Implications of discreteness for market structure
Panel C: The effect of discreteness on market making					
Chordia and Subrahmanyam (1995)	NYSE (24)	Jan 88–Dec 91	ISSM	The practice of payment-for-order flow and the possibility of inferior execution can arise naturally in response to a finite tick size	A smaller tick will make the competition for order flow more transparent and redirect orders to the least cost provider of market marking services
Christie and Schultz (1994)	NASDAQ & NYSE (100 pairs)	Jan 91–Dec 91	ISSM	Spreads in the minimum tick are non-existent for a majority of NASDAQ stocks	Market makers may collude to impose an artificially higher tick size than the minimum tick size permitted
Bourghelle and Declerck (2004)	Euronext Paris (232)	Oct 98–Mar 99	TAQ Euronext	An increasing but convex relationship between the relative tick size and the relative spread	A change in tick size changes the level of transparency in liquidity supply
Chung et al. (2004b)	NASDAQ (3242)	Nov 00 and Jun 01	TAQ NASTRAQ	Spreads are positively related to the proportion of internalized volume	A smaller tick size leads to lower order preferencing

Table 3 continued

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s)	Implications of discreteness for market structure
Ascioglu et al. (2010)	TokyoSE (1656)	Jul 04–Feb 07	TAQ TokyoSE	Trade size, the number of trades, and price are the most important determinants of whether the minimum tick size is a binding constraint	Tick size rules should be set based on trading activity and price, rather than price alone
Ahn et al. (2007)	TokyoSE (3785)	Jan 98–Jul 98	TAQ TokyoSE	A decrease in quoted and effective spreads but no increase in trading volume	The minimum tick size creates and maintains economic rents for liquidity providers
Ball and Chordia (2001)	NYSE (14)	Feb 97–Nov 97	TAQ US	Observed prices and quoted spreads do not correspond to the equilibrium prices and true spreads that would exist in a market with no minimum tick size	For large stocks, most of the quoted spread is attributable to price rounding
Panel D: The effect of a tick size change on broker activities					
Schultz (2000)	NASDAQ & NYSE (235 splits)	Apr 93–Mar 94	TAQ US	An increase in trading costs, and weak evidence that costs of market making decline following splits	A large relative tick provides a motive for brokers to promote a stock
Kadapakkam, Krishnamurthy and Tse (2005)	NYSE (526 splits), NASDAQ (722 splits)	Jan 95–Dec 96, Jan 98–Dec 99 and Feb 01–Dec 02	TAQ US	Post-decimalization, the increase in spreads, the decrease in the average buy order size and the increase in the frequency of small transactions are smaller in magnitude after the split than before decimalization	

Table 3 continued

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s)	Implications of discreteness for market structure
Chou, Lee and Chen (2005)	NYSE (724 splits)	Jan 96–May 00	CRSP	Abnormal ex-split day returns decrease and abnormal trading volumes increase	Short-term traders arbitrage activities increase as costs decrease

Acronyms are defined in Table 1

tick size leads to a decrease in market making profits. In particular, Stone (2009) shows that a narrower bid–ask spread redistributes profits from market makers to investors. Bessembinder (2003) also noted that reducing the minimum tick size on NASDAQ equates execution costs of the dealer market with a limit order book market, *without* having an adverse effect on liquidity supply. A number of interesting patterns in market structure do arise though: in dealer markets, the mechanism through which a reduction in the tick size leads to an increase in spreads is via a decrease in liquidity providers' profits (He and Wu 2005 and Bacidore 1997). That reduction in profits reduces the incentive of market makers to provide accurate information, therefore the adverse selection component of the spread decreases (Bacidore 2001) whilst also making it easier for market makers to manage their inventories (Chung and Van Ness 2001). Furthermore, market makers are still able to provide liquidity although the incentive to do so is greatly reduced (Stone 2009 and MacKinnon and Nemiroff 2004). A crucial finding for market structure is that, for low-volume stocks, the existence of specialists leads to a reduction in trading costs whereas for large stocks, competition amongst dealers proves more beneficial for the market (Chung et al. 2004c). Interestingly, in a recent study, Charoenwong et al. (2016) show that decimalisation has not affected the flipping strategy of institutions for cold IPOs. However, institutions are found to flip more hot-IPOs post-decimalisation due to the lower cost of flipping for IPOs that have substantial price increases in aftermarket trading.

In Table 3, Panel B, we present the studies that have focused on the implications which increasing the minimum tick size has on market making. Studies in this area have shown that increasing the tick size (1) leads to an increase in market making profits and hence to an increase in liquidity supply by the latter (Bollen et al. 2003) and Anshuman and Kalay 1998) and (2) helps market makers to recover fixed costs. At the same time, Angel (1997) shows that in a large tick regime, investors are able to supply liquidity by placing limit orders. In Table 3, Panel C, we conclude this section by presenting the studies concerned with the general implications of a minimum tick on market making activities. Ball and Chordia (2001) show empirically that, with the existence of a minimum tick, prices and spreads do not correspond to the equilibrium prices which would exist without a minimum tick size. Crucially, all studies in this field indicate that pricing and competition on exchanges largely depend on the regulations governing the minimum tick size. Chordia and Subrahmanyam (1995) demonstrate that the existence of a finite minimum tick leads naturally to a curtailing of competition via the payment-for-order-flow practices. More importantly, Christie and Schultz (1994) show that the minimum tick may artificially arise due to market maker collusion, and both Bourghelle and Declerck (2004) and Chordia and Subrahmanyam (1995) show that a change in the tick size alters the level of transparency in liquidity supply.

Finally, in Table 3, Panel D, we present the two studies that discuss the implications of a tick size change on broker activities. Crucially, stock splits increase the relative tick size which, as explained above, leads to an increase in market making profits. As a consequence, brokers may have a greater incentive to promote a stock that has seen an increase in its relative tick size because they may capture some of the additional benefit generated by market makers.[3] Whilst there are only two empirical studies in this field, they both show that an increase in the relative tick size supports the broker promotion hypothesis. Importantly, Chou et al. (2005) show that abnormal ex-split day returns decrease and abnormal ex-split trading volume increases post-decimalisation which confirms the

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[3] The increased revenue can be captured either by payment-for-order flow agreement, or by brokerage houses operating separate in-house market making operations (Schultz 2000).

hypothesis that arbitrageurs engage in more trading activities as transaction costs are reduced.

3.1.3 Tick size changes, execution speed and HFT

Until recently, a largely overlooked component of liquidity was execution speed. In this respect, there are only a handful of earlier studies that investigate the implications for execution speed of a change in the minimum tick size (see Coughenour and Harris 2004). However, this field is now clearly a future area of research as execution speed is the cornerstone of HFT. In Table 4, we present the studies that investigate the implications of a change in the minimum tick size for the occurrence and profitability of HFT strategies. In Table 4, Panel A, we discuss the studies which relate HFT to a small tick size, and in Panel B we refer to studies which relate HFT to a large relative tick size.

In Table 4, Panel A, all studies uniformly agree that a reduction in the minimum tick size leads to an increase in HFT. Mahmoodzadeh and Gençay (2014) show that HFT profitability increases as a smaller tick affords HFTRs the opportunity to front-run individual (manual) traders by implementing sub-penny strategies. A direct implication of the latter is an increase in spreads for the manual traders and a decrease in spreads for the HFTRs. Coughenour and Harris (2004) show that front-running is easier for low-priced stocks and Uno and Shibata (2011) show that the decrease in spreads is also accompanied by an increase in adverse selection costs. So, crucially, the speed of quote adjustment substantially increases after a minimum tick size decrease (Chung et al. 2008). As we will discuss in Sect. 5.2, the suggested minimum resting time regulations target the speed of quote adjustment with an intention to limit HFT. A further area of interest originates from the interaction of HFT with alternative trading systems (or dark pools). To this end, Bartlett III and McCrary (2013) and O'Hara et al. (2015) show that there is often a trade-off between HFT and trading in alternative venues: reducing the tick size leads to an increase in HFT (that is, an increase in displayed liquidity) and a decrease in trading in alternative trading systems (that is, a decrease in un-displayed liquidity). The authors further argue that the recent proposal to increase the minimum tick size for small capitalization stocks may potentially harm organized exchanges and HFT and shift trading to alternative trading systems. In Table 4, Panel B, we show the studies that discuss the implications of a large tick size for HFT and market structure. All studies show that a large relative tick size attracts more HFTRs, thus increasing the latter's liquidity provision. Hagströmer and Nordén (2013) demonstrate that the share of trading activity attributed to HFT strategies increases with the minimum tick size. O'Hara et al. (2015) show that, in contrast to the recent SEC proposals, in today's "high frequency" markets, there is little evidence that stocks with a higher relative tick size (a large tick size relative to the stock price) have greater liquidity. Equally, Yao and Ye (2015) show that a large relative tick size decreases liquidity but increases HFT liquidity provision. From a market microstructure perspective, the latter result has wide implications: increasing the tick size in order to enhance liquidity for the least-active stocks may attract more liquidity supply from HFTRs but the authors find no evidence that it will attract more trading volume. Clearly, this area is under-researched and future research will show how liquidity provision works in both this and alternative market settings.

Table 4 Empirical studies on the effect of a minimum tick size change on execution speed and HFT

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s) after tick size reduction	Implications of a smaller tick for market structure
Panel A: The effect of tick size decrease on execution speed and HFT					
Mahmoodzadeh and Gençay (2014)	EBS (4 currency pairs)	May 11–Oct 11	EBS TAQ and depth	A reduction (increase) in spreads for HFTs (manual traders)	Provides HFTrs with the opportunity to implement sub-penny jumping strategies, front-running manual traders
Uno and Shibata (2011)	TokyoSE (1457)	Dec 09–Jan 10	TAQ TokyoSE	A drop in spreads and an increase in adverse selection costs	Leads to a shift towards more HFT
Coughenour and Harris (2004)	NYSE (1811)	Dec 00–Feb 01	TAQ US	Front-running is easier for the low priced stocks but specialist profits in other stocks decrease	Leads to an increase HFT profits for specialists handling low priced stocks
Chung et al. (2008)	NYSE (1450), NASDAQ (2713)	Oct 05–Dec 05	TAQ US	The speed of quote adjustment increases after decimalization	Tick size has a significant impact on the speed of quote adjustment
Bartlett III and McCrary (2013)	US exchanges (962)	Jan 01–Dec 11	TAQ US	Sub-penny pricing is associated with more HFT and a decrease in the trading of un-displayed liquidity	A reform to change the tick sizes should be accompanied by limitations on exchanges' maker/taker fees in order to minimize possible market manipulation
Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s)	Implications of a large relative tick for market structure
Panel B: The effect of a large minimum tick on market making					
Hagströmer and Nordén (2013)	OMXS30 (30)	Feb 10–Mar 12	ITCH	A large tick size makes market making more profitable and arbitrage trading more costly	Increases the share of trading activity due to market-making HFTs

Table 4 continued

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s)	Implications of a large relative tick for market structure
Yao and Ye (2015)	NASDAQ and NYSE (117 pairs)	10/10/2014	NASDAQ TotalViewITCH	A large relative tick size decreases liquidity but increases HFT liquidity provision	Attracts more liquidity by HFTs and increases market making revenue
O'Hara et al. (2015)	NYSE (360)	May 12–Jun 12	TAQ US	A larger relative tick size does not substantially enhance stock liquidity	HFTs participate more in trading for stocks with larger relative tick sizes

Acronyms are defined in Table 1

3.1.4 Tick size changes and volatility

This last sub-section on market quality indicators investigates the effect of a change in tick size on volatility. In Table 5, we present the studies that show the reaction to volatility of a change in the minimum tick size or equivalently the level of price discreteness. Most studies confirm that a large tick size has a negative impact on volatility. Hau (2006) shows that a larger tick size increases the costs of speculation[4] and overall stock return volatility. Ke et al. (2004) show that the tick size is more binding on volatility in the middle of the trading day and Jiang et al. (2009) show that the effect of tick size on volatility is more pronounced on dealer markets rather than on limit order markets. Münnix et al. (2010) demonstrate the minimum tick size has a wider impact on the microstructure of financial returns. Crucially, the tick size can alter the tail behaviour of the return distribution; a larger tick size can lead to heavier tails. In relation to the latter and the effect of a minimum tick size on price diffusion, La Spada et al. (2011) show that a decrease in tick size leads to more volatility clustering, or equivalently to a higher return autocorrelation.[5]

3.2 Effect of tick size changes on market structure

3.2.1 Effect of tick size changes on market design

3.2.1.1 Tick size changes' effects on market design   In this section, we survey the studies that investigate the implications of a tick size change on market design. We sort studies first by sample, and then in ascending order by end date of the used sample. As expected, several studies present results that may be classified to more than one sub-section but we avoid any overlap by focusing on the main implications for market structure and market quality. In Table 6, the main focus is on how the implementation of the minimum tick size rules affects trading across different trading mechanisms.

Clearly the majority of work on market design involves a comparison of NASDAQ with NYSE, thus most studies concentrate on the comparison of samples between the two exchanges. Nevertheless, the study by Huang and Stoll (2001) concentrates on the differences between NYSE, an auction market, and LSE, a dealer market. The authors argue that microstructure characteristics, such as the tick size, are endogenous to market structure; that is the difference between an auction and a dealer market. Empirically, the findings of Huang and Stoll (2001) are confirmed by Chung and Chuwonganant (2002) who show that execution costs are lower in auction markets than they are in dealer markets. Theoretically, for a dealer market, Kadan (2006) shows that the welfare of investors is a function of the number of dealers in the market; if the number of dealers in the market is large, investors will prefer a small tick size. The latter result is in contrast to the policy of reducing the tick size across all contracts because if the number of dealers in a stock is small, then setting a large tick size may benefit investors.

The studies that investigate the effect of tick size changes on the NYSE show that a decrease in tick size leads to a reduction in spreads and depths at the best quote. Bacidore et al. (2003) argue that a smaller tick leads to less displayed liquidity on the order book, but that that has no effect on execution quality. Goldstein et al. (2010) show that

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[4] In Table 4, Panel B, Hagströmer and Nordén (2013) show that a larger tick makes arbitrage trading more costly (see also Chen et al. 2009).

[5] On a related subject, French and Foster III (2002) show that the decrease in tick size does not affect the observed increase in stock return variance following a stock split.

Table 5 Empirical studies on the effect of a minimum tick size on volatility

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/ frequency	Main finding(s) after tick size reduction	Implications of discreteness for market structure
French and Foster III (2002)	AMEX (1590 splits)	Jan 96–Dec 98	CRSP	Reduction not one of the causes of observed increases in stock return variances following stock splits	Does not affect the post-split variance increase
Hau (2006)	CAC40 Index stocks	Jan 95–Dec 99	TAQ Paris Bourse	Intraday volatility of individual stocks increases by more than 30% due to tick size variations	A larger tick increases stock return volatility and increases the costs of speculation
Ke et al. (2004)	TaiwanSE (80)	Jan 98–Dec 99	TAQ TaiwanSE	A larger tick size is associated with a wider bid–ask spread, larger volatility, and more negative autocorrelation	A larger tick size tends to be binding when bid–ask spreads are narrower and return volatility is smaller in the middle of the trading period
Jiang et al. (2009)	NASDAQ and NYSE (895 pairs)	May 01–Jul 01	TAQ US	Post-decimalization, NASDAQ volatility and costs are higher than for NYSE stocks	The differences cannot be attributed to the characteristics of the stocks traded in the two markets
Münnix et al. (2010)	NYSE (50)	Jan 07–Dec 07	TAQ US	The tick size contributes to the decay of the correlation coefficient towards smaller return intervals	The tick size has a large impact on the structure of financial return distributions
La Spada et al. (2011)	NYSE (5)	±100 Jun 97 and Jan 01	TAQ US	Reducing the tick size leads to an increase in return autocorrelation	A decrease in tick size leads to more clustered volatility.

Acronyms are defined in Table 1

Table 6 Empirical studies on the effect of a minimum tick size on market design

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s) after tick size reduction	Implications of a smaller tick for market structure
Alexander and Peterson (2002)	NYSE (230,134 pairs of short-sell orders)	Jun 97–Jul 97	NBBO	Decimalization led to a better execution of short market order but to a worse execution for short at-the-quote limit orders	A small tick is in contrast with the objectives of the Uptick Rule
Chakravarty et al. (2004)	NYSE (79)	Oct 00–Mar 01 and Apr 00–Jun 00	NBBO	Decimalization led to a decrease in depth and spreads	Reduces binding constraints and increases price competition
Kadan (2006)	Theory	Theory	Theory	Change depends on the number of dealers in the market	Change will have an ambiguous effect on spreads
Bacidore et al. (2003)	NYSE (158 pairs)	Dec 00–Feb 01	SOD & NYSE Master Files	A decrease in limit order size and an increase in limit order cancellations	Less displayed liquidity on the limit order book but execution quality is not affected
Goldstein et al. (2010)	NYSE (300)	Jun 00 and Mar 01	TAQ	NBBO participation by non-NYSE venues declined	A venues ability to attract trades improves as the tick decreases
Chan and Hwang (2002)	SEHK (638)	May 96 and Dec 97	TAQ SEHK	Following a tick size reduction, spreads decrease and depths increase	Increases market quality in a pure order-driven market
Huang and Stoll (2001)	LSE and NYSE (19 pairs)	Jan 95–Dec 95	TAQ US & TAQ LSE	Spreads and quote sizes are related to the absence of tick sizes in dealer markets	Market characteristics are endogenous to the market structure
Bessembinder (2000)	NASDAQ (765)	Jan 95–Dec 95	TAQ US	Quoted and effective bid–ask spreads drop when tick size decreases. There is no evidence of a reduction in liquidity with the smaller tick size	Changes in the tick size can affect equilibrium spreads on a dealer market and the relation between tick size and market quality is more complex than the imposition of a constraint on minimum spread widths
Biais et al. (2010)	NASDAQ & ISLAND (7 pairs)	Mar 00 and Jun 01	NASDAQ	Spreads fell for both markets after NASDAQ decimalization	Competition among markets complements competition among traders

Table 6 continued

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s) after tick size reduction	Implications of a smaller tick for market structure
Ronen and Weaver (2001)	AMEX (324)	Apr 97–Jun 97	TAQ Amex	A reduction in the minimum tick decreases spreads and volatility but not depth	Improves market quality but also encourages queue-jumping in the order book
Chung and Chuwonganant (2002)	NYSE (2223)	May 97–Jul 97	TAQ US	The minimum price variation is a binding constraint on absolute spreads even after the tick-size reduction, especially for low-price and/or large-volume stocks	Reduces price rigidity and increases price competition
Chung and Chuwonganant (2004)	NASDAQ (2073), NYSE (2242)	May 97–Jul 97	TAQ US	Smaller tick sizes are valuable in reducing market friction only if market makers compete on price with public traders	Execution costs are lower in auction markets than in pure dealer markets
Zhao and Chung (2006)	NYSE (1746)	Nov 00	TAQ US	Decimalization led to an increase in information-based trading	Raises the informational efficiency of asset prices
Chien et al. (2014)	TaiwanSE(50)	Nov 04–May 05	TEJ	A thinner order book and a decrease in its information content	Lowers the incentive to offer liquidity and reduces the relative information content of the order book
Portniaguina et al. (2006)	Simulation	Simulation	Simulation	A smaller tick size facilitates the specialist's ability to step ahead of the limit order book, resulting in a reduction in the cumulative depth of the limit order book at prices above the minimum tick	Leads to an increase in the specialist participation and specialist profit increases slightly for small market orders, and considerably for large market orders

Acronyms are defined in Table 1

decimalisation increases quote competition between exchanges. Chan and Hwang (2002) argue that market quality increases on a limit order book market after the tick size decrease. However, regarding dealer markets, Bessembinder (2000) argues that the relationship between tick size and market quality is relatively more complex than is hypothesized. In relation to the latter, Chakravarty et al. (2004) and Chung and Chuwonganant (2002) show that the smaller tick increases price competition on the limit order book, hence reducing price rigidity, and Zhao and Chung (2006) show that a smaller tick increases the informational efficiency of prices. The latter is clearly related to price discovery studies which will be discussed in Sect. 3.2.2. With regard to the implications of a tick size change to market structure, Alexander and Peterson (2002) show that a small tick is in contrast with the objectives of the Uptick Rule.[6] In addition, a smaller tick size encourages front-running in the limit order book (Ronen and Weaver 2001 and Portniaguina et al. 2006). Finally, Biais et al. (2010) show the effect of the tick size change on market structure through the change in competition between Island and Nasdaq. In particular, their study shows that Island traders undercut competition with Nasdaq traders by taking advantage of a finer tick size and spreads decreased further in Island after the reduction in the tick size for Nasdaq stocks.

3.2.1.2 Effect of tick size changes on institutional versus retail traders   In Table 7, we present the set of studies that discuss the implications of a minimum tick size change both for institutional traders and for retail traders. One difficulty with this type of study is the definition of institutional traders. Papers in this field either infer institutional traders by classifying trade size (see Oppenheimer and Sabherwal 2003 and Lin et al. 2009) or they use proprietary datasets which directly classify trader types (see Bollen and Busse 2006 and Chakravarty et al. 2005).

Clearly, the most significant finding of this literature is that a reduction in tick size does not have a uniform effect across all trader types. On a limit order market such as the Hong Kong Stock Exchange or the NYSE, reducing the tick size leads to a deterioration in market depth and hence a decrease in liquidity for the larger institutions (Pan et al. 2012 and Goldstein and Kavajecz 2000). In relation to the latter, Lin et al. (2009) show that if an exchange facing competition from a another exchange reduces its tick size then institutional order flow may potentially migrate to the competing exchange. Oppenheimer and Sabherwal (2003) and Chakravarty et al. (2005) report that retail traders appear to be trading more frequently with a smaller tick size.[7] Conversely, institutional traders trade less frequently and also fragment their orders at a lesser rate (less stealth trading) which in turn decreases adverse selecting costs for large and medium sized trades. Jones and Lipson (2001) show that the move to a smaller tick size increases execution costs for institutional investors. However, Chakravarty et al. (2005) document that—whilst in general the finding of Jones and Lipson (2001) is correct—for the institutional investors who work their orders over multiple days, trading costs declined. Finally, Bollen and Busse (2006) document an increase in trading costs for large orders originating from pension funds, mutual funds and hedge funds, hence confirming the finding that institutional investors may be damaged by a move to a finer price grid.

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[6] The Uptick rule allowed the short selling of securities on upticks only. The rule was eliminated in 2007 and in 2010, SEC introduced the Alternative uptick rule which imposes restrictions on the stocks that are triggered by a circuit breaker only. See http://www.sec.gov/news/press/2010/2010-26.htm.

[7] For the stock exchange of Thailand, Pavabutr and Prangwattananon (2009) show that retail trading activites are not affected by the minimum tick size decrease.

Table 7 Empirical studies on the effect of a minimum tick size on institutional versus retail trading

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/ frequency	Main finding(s) after tick size reduction	Implications of a smaller tick for market structure
Bollen and Busse (2006)	US exchanges (440 US mutual funds)	Jan 97–Nov 97, Apr 00–Aug 00 and Apr 01–Aug 01	Daily	For large orders from pension funds, mutual funds, and hedge funds, tighter bid–ask spreads do not necessarily imply lower trading costs	An increase in trading costs for some actively managed funds.
Pan et al. (2012)	HKEx (200)	Apr 06–Oct 06	HKEx: order book depth	An increase in the transaction costs for large institutions	Decreases liquidity for the more liquid stocks on a pure limit order market
Goldstein and Kavajecz (2000)	NYSE (100)	May 97–Sep 97	SuperDOT NYSE	A decline in spreads and a decline in depths throughout the entire limit order book	Benefits (worse off) more retail orders (larger orders)
Pavabutr and Prangwattananon (2009)	SET (79)	Oct 01–Nov 01	TAQ SET	The tick reduction is associated with a decline in spreads, quoted and accumulated market depths	Has no significant impact on retail investors' trading activities
Griffiths et al. (1998)	TSE (60)	Jan 96–Jul 96	TAQ TSE	The tick size reduction led to significantly lower returns on non-block and small trades for the upstairs traders and the designated market markers	Smaller returns for upstairs traders and market makers
Oppenheimer and Sabherwal (2003)	TSE and US Exchanges (126 cross-listed)	Jan 01–Feb 01 and Mar 01–Apr 01	TAQ US and TSE	Post-US decimalization, US trading of TSE cross-listed stocks increases but this increase is not at the expense of TSE volume.	Leads to a decrease in spreads and an increase in retail-sized trading
Lin et al. (2009)	Paris (15), NYSE (16)	Jan 01–Feb 01	TAQ US and Euronext	Decimalization made the US market less competitive for institutions trading French stocks	Leads to a migration of institutional order flow
Jones and Lipson (2001)	NYSE (1690)	±100 days around Jun 97	TAQ US	Realized execution costs increased for institutional trades	It may lead to a reduction of liquidity for institutional trades

Table 7 continued

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/ frequency	Main finding(s) after tick size reduction	Implications of a smaller tick for market structure
Chakravarty et al. (2005)	NYSE (34)	Nov 00–Jan 01	TAQ US (Plexus)	Post-decimalization institutional trading costs declined, more so for stocks where the minimum tick sizes were likely to have been binding.	Benefits those institutions that are working their orders on the exchange floor
Chakravarty et al. (2005)	NASDAQ and NYSE (304 pairs)	Jan 01–Feb 01	TAQ US	Post-decimalization, the percentage of the spread due to the adverse selection component increased but the dollar adverse selection cost decreased	Leads to less stealth trading and less institutional trading overall

Acronyms are defined in Table 1

3.2.1.3 Tick size changes and dark pool trading There are a limited (but increasing) number of studies that investigate the implications for market structure in a trading environment that is characterized by market fragmentation. In particular, the element of interest here is the provision of liquidity when an exchange competes with an alternative trading system, such as a dark pool on which there is no regulated minimum tick size. From a theoretical perspective, Buti et al. (2013) investigate how the tick size affects liquid and less liquid stocks on the limit order book. The authors show that reducing the tick size may have detrimental effects on less liquid stocks which disappear if the limit order book faces competition from alternative trading systems. Crucially, these results tend to support SEC's proposed plans to increase the tick size for the less liquid stocks. These results are confirmed empirically in Werner et al. (2015). It is worth mentioning that these results complement the findings of Bartlett and McCrary (2013) and O'Hara et al. (2015), discussed in Sect. 3.1.3. In particular, the findings of the latter show how HFTRs are responsible for the shift in liquidity from a dark pool to the limit order book because they increase the supply of liquidity following a tick size decrease. However, the question of how multiple tick size regimes affect market liquidity in a fragmented market remains to be answered.

3.2.2 Effect of tick size changes on the price discovery process

In this section, we present the studies that investigate the effects of changes in the tick size on the price discovery process. Studies in this area focus on the interaction of trading between the spot and derivatives contracts. We present the set of studies in Table 8.

The empirical literature agrees that a decrease in the minimum tick size enhances the price discovery process (Chen and Gau 2009; Beaulieu et al. 2003 and Chou and Chung 2006). In particular, Beaulieu et al. (2003) and Chou and Chung (2006) also document an increased participation of funds in the price discovery process following a decrease in the minimum tick size. Booth and Yüksel (2006) confirm the above findings for the Istanbul stock exchange. Finally, Chen et al. (2009) show that a small tick reduces the willingness of arbitrageurs to initiate arbitrage trades, a finding that is related to the profitability of investments in a small tick size regime and leads to a loss in pricing efficiency.[8]

4 Related research: the minimum trade unit and odd-lot trading

In this section, we discuss the empirical literature on a subject closely related to the minimum tick size regulations. The minimum trade unit (MTU) refers to the minimum amount of shares that can be traded in a single transaction. In most stock exchanges the MTU is equal to one share. Notable examples of equity markets where the MTU is not one share are the Toronto, Tokyo, Hong Kong, and Taiwan exchanges. Research on the MTU is scant but, as recent research has documented, the pervasiveness of HFT has shifted the interest to this field as HFTRs tend to trade on relatively small quantities. We therefore present the empirical papers in the field with the intention to inform the reader of a possible future topic for research. We present the studies on the MTU in Table 9, Panel B.

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[8] In two related studies, Jakob and Ma (2004) and Graham et al. (2003) investigate the effect of a tick size decrease on the ex-dividend day stock price behaviour, showing that the existence of a minimum tick is not responsible for the ex-dividend price behaviour, that is the empirical finding that prices drop by less than the dividend amount on the ex-dividend date (see also Bali and Hite, 1998).

Table 8 Empirical studies on the effect of a minimum tick size on price discovery

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/ frequency	Main finding(s) after tick size reduction	Implications of a change in tick for market structure
Booth and Yüksel (2006)	ISE (28)	Jan 98–Feb 99	TAQ ISE	The high frequency of one-tick price changes appears to be the reason for the existence of limited amount of price clustering	An increase in the tick size does not enhance precise price setting
Chen and Gau (2009)	TAIEX (Spot, futures and options)	Nov 04–Jun 05	TAQ TaiwanSE	A decrease in spreads and an enhancement in the price discovery process	A smaller tick size enhances the price discovery process
Beaulieu et al. (2003)	TSE35 (Index, IPU and Index Futures)	Aug 91–Oct 91	TAQ TSE	An increase in the role of funds in the price discovery process	
Chou and Chung (2006)	S&P500, NASDAQ100 ETFs and E-mini futures	Oct 00–Apr 01	TAQ US	A decrease in market depth and spreads, an increase in the adverse selection component of the spread and in the role of ETFs in the price discovery process	
Chen et al. (2009)	SPDR, QQQ ETFs and S&P500, NASDAQ100 E-mini futures	Jul 00–Jul 01	TAQ US and Tick Data Inc	Decimalization weakened the ability and the willingness of arbitrageurs to initiate arbitrage trades	Leads to a deterioration in the efficiency of the cash/futures pricing system

Acronyms are defined in Table 1

Amihud et al. (1999) investigate the effect of voluntary reductions in the MTU at the Tokyo Stock Exchange; they find an increase both in liquidity and valuation associated with MTU reductions. Hauser and Lauterbach (2003) test the asset pricing effects of MTU

Table 9 Empirical studies on the minimum transaction size

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main effect(s) of MTU reduction	Implications of an MTU reduction for market structure
Panel A: Empirical research on the minimum trade unit (MTU)					
Amihud, Mendelson and Uno (1999)	Tokyo Stock Exchange (66)	Jan 91–Dec 96	Daily	Increase in valuation and liquidity	Companies can increase their investor base, valuation efficiency and liquidity by reducing MTU
Hauser and Lauterbach (2003)	Tel Aviv Stock Exchange (987)	Jun 98–Feb 00	Daily	Increase in valuation. The same effect is not found for the most illiquid stocks	
Gozluklu et al. (2015)	Borsa Italiana (55)	Dec 01–Feb02	TAQ	Increase in liquidity and decrease in adverse selection costs	The removal of the MTU constraint facilitates the participation of retail traders. This has beneficial effects on liquidity and adverse selection costs

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s)	Implications of odd-lot trading for market structure
Panel B: Empirical research on odd-lot trading					
Wu (1972)	NYSE (100)	Jan 37–Dec 67	Weekly	Steady decrease in the proportion of odd-lot trading	Odd-lot traders trade against the market and are therefore price stabilizers
Lakonishok and Maberly (1990)	NYSE (all listed)	Jan 62–Dec 86	S&P daily	Odd-lot trading is higher on Mondays than in the other days	Individual investors may contribute to the Weekend effect
Dyl and Maberly (1992)	NYSE (all listed)	Dec 66–Jan 86	S&P daily	The ratio of odd-lot sales to odd-lot purchases substantially decreases at the turn of the year and such decrease is highly significant in explaining turn or the year returns	Individual investors may contribute to the January effect

Table 9 continued

Reference	Market(s) (no. of assets)	Period(s) (approximate)	Sample/frequency	Main finding(s)	Implications of odd-lot trading for market structure
O'Hara et al. (2014)	NASDAQ (120)	Jan 08–Dec 09	TAQ	Odd-lot transactions are common and substantially contribute to price discovery	Empirical analyses with TAQ data may lead to biased results
Johnson et al. (2014)	NASDAQ (3401)	Jul 10–Mar 11	TAQ	Intentional odd-lot trades contribute more to price discovery than circumstantial odd lot trades	Relative importance of intentional odd-lot trading

Acronyms are defined in Table 1

changes at the Tel Aviv Stock Exchange; their results show an increase (decrease) in price level and demonstrate mixed evidence regarding the change in price noisiness after MTU reductions (increases). Gozluklu et al. (2015) examine the natural experiment of Borsa Italiana (the main Italian Stock Exchange), where in 2002 the MTU was reduced to one share by the exchange; they find a substantial increase in liquidity and a concurrent decrease in adverse selection costs after the event.

Related to the research on the MTU, a handful of studies examine the effects and the sources of odd-lot trading; these papers mostly focus on the US markets. Odd-lot trades are those trades which are executed at a size lower than the round lot, and they are subject to different handling and reporting rules than the round lot. A recent SEC Release (SEC 2014b) discusses odd lot trading in US markets and how it was affected by changes in reporting requirements. We present the set of empirical studies in this field in Table 9, Panel B. Wu (1972) provides an early study of odd-lot trading and its trend over time. Some papers use odd-lot trades as a proxy for individuals' transactions and investigate time of the week and of the year price anomalies (see Dyl and Maberly 1992; Lakonishok and Maberly 1990). After the advent of high frequency trading however, the assumption that odd-lots are mainly originated by individual investors is inappropriate; accordingly, O'Hara et al. (2014) show that odd-lot trading is partly attributable to HFT and they document a bias in empirical studies which ignore odd-lots. Developing O'Hara et al. (2014), Johnson et al. (2014) compare circumstantial odd-lots and intentional odd-lots.

4.1 Research on the minimum trade unit

At the Tokyo Stock Exchange, changes in the MTU are voluntary, as they are decided by a meeting of the companies' directors. Amihud et al. (1999) examine the effects of voluntary reductions in the MTU in the Japanese equity market. Consistent with the view that companies reduce the MTU in order to increase the investor base, the results show an increase in the number of individual investors after the MTU reductions. Amihud et al. (1999) also document positive cumulative abnormal returns after both the announcement and the actual reduction in the MTU. Furthermore, they find that trading volume and liquidity, measured by the Amihud's illiquidity ratio, increase after the MTU changes. Amihud et al. (1999) argue that the value and liquidity effects are due to the increase in the investor base; specifically, if more investors hold the stock, information availability on the fundamental value increases, thereby increasing both liquidity and valuation.

Hauser and Lauterbach (2003) examine a set of changes—both increases and decreases, decided by an exchange board—in the MTU at the Tel Aviv Stock Exchange between 1998 and 1999. After MTU increases they find a decrease in trading volume, which is used as a proxy for the investor base, a decrease in valuation and an increase in return volatility, which is used as a proxy of price noisiness; after MTU decreases, they document an increase in trading volume, an increase in valuation and an increase in return volatility. They also estimate a model relating stock returns around the MTU changes to changes in trading volume, which is used as a proxy of trading volume, and in return volatility; consistent with Merton's (1987) model, the coefficient of volume change is positive and the coefficient of volatility change is negative. The cross-sectional variation of the results reveals further interesting differences; in particular, extremely thin trading stocks lose value after an MTU reduction and drive the increase in price noisiness when considering the whole sample. Hauser and Lauterbach (2003) argue that an increase in investor base can be detrimental to value if the joining traders are predominantly noise traders or speculators.

In January 2002, the MTU was reduced to one share for the all the stocks listed on Borsa Italiana. Gozluklu et al. (2015) examine the effects of this natural experiment on market quality. They show that liquidity, measured by the bid–ask spread at the first five levels of the order book substantially decreases after the MTU reduction. Furthermore, they document a decrease in adverse selection costs, measured by the price impact of trades (Hendershott et al. 2011) and by the adverse selection component of the spread (see Glosten and Harris 1988). On the other hand, informational efficiency measured using random walk tests and in the context of the Hasbrouck (1993) model, is not significantly affected by the microstructure change. Finally they show that retail trading activity, measured by following Barber et al. (2009) approach and by the proportion of online trading, substantially increases. Gozluklu et al. (2015) compare their results to the predictions of a model with liquidity providers operating under asymmetric information. The model shows that when the MTU constraint is removed, those small liquidity traders that could not hedge their endowment shock in a regime with a MTU, can now perfectly hedge it and enter the market; the increased trading activity of these uninformed agents leads to a reduction in adverse selection costs, which determines a spread decrease.

4.2 Research on odd-lot trading

An early study by Wu (1972)[9] examines odd-lot trading between 1937 and 1967. One of the main findings is the steady decline in the proportion of odd-lot trading in the period considered. The paper also documents that odd-lot traders are predominantly net buyers and that they trade against the market. Wu (1972) argues that odd-lots are mostly traded by small investors who are not able to afford to trade on a round-lot basis.

Similarly, a group of studies use odd-lot trading as a proxy for individual investor trading and investigate its effect on market anomalies based on time of the week or time of the year. Lakonishok and Maberly (1990) find that odd-lot trading is higher on Mondays and that the increase in odd-lot trading is driven by sell transactions; they argue that this pattern might partly explain abnormally negative returns over the weekend, which represent a market anomaly often referred to as the "weekend effect". Dyl and Maberly (1992) examine the role of individual investors in the determination of the "January effect", i.e. the tendency of small stocks to earn higher returns in January; they find that the ratio of odd-lot sales to odd-lot purchases substantially decreases at the turn of the year, and that the decrease is highly significant in explaining turn or the year returns.

More recently, O'Hara et al. (2014) investigate the bias arising from the exclusion of odd-lots in TAQ using data from 2008 and 2009. First, they document that a non-negligible amount of trades are odd-lots. Importantly, they find that odd-lots are more likely to occur when trades are initiated by HFTRs; this indicates that in today's markets caution should be exercised when interpreting odd-lot trading as a proxy for individual investor trading. The authors report that 25% of price discovery is accounted for by odd-lot trades; this result suggests that analyses of market efficiency which ignore odd-lots are likely to be substantially biased.[10]

Motivated by O'Hara et al. (2014), Johnson et al. (2014) examine the sources and the informativeness of odd-lot trading in a period between 2010 and 2011. In particular, they compare intentional odd-lot trades (the original order is submitted as an odd-lot) and

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[9] See also the discussion by Stevenson (1973).

[10] Starting from December 9th, 2013, odd-lot transactions in all National Market System stocks are reported to the consolidated tape. Previously, they were not included.

circumstantial odd-lot trades (the original order is submitted for 100 or more shares and subsequently divided into multiple transactions, at least one of which is an odd lot). They first find that slightly more than half of all odd-lot transactions are circumstantial. Johnson et al. (2014) also document that intentional odd-lot trades contribute more to price discovery, calculated using the weighted price contribution, than circumstantial odd-lot trades; moreover, the contribution to price discovery increases when non-high frequency traders provide liquidity, or when high frequency traders transact with non-high frequency traders.

5 Conclusion

5.1 Some concluding remarks

The purpose of this literature review was to discuss the studies which investigate the effect of tick size changes on two main aspects of exchanges: market structure and market quality indicators. In this section, we conclude the literature review, discuss the implications of a possible introduction of a minimum resting time for quotes for exchanges, and discuss areas for future research. We have argued that the problem with a small tick size is that it has reached a level that may be potentially harmful to the welfare of exchanges. SEC's action to introduce a pilot plan for the most illiquid stocks trading at NYSE reflect the latter observation—there have been many calls since the US decimalization where small tick sizes are quoted as the main reason why market making has become unprofitable with wider consequences around the support of illiquid stocks and IPOs. With this observation in mind, we chose to synthesize the literature with respect to the effect of tick size changes on market structure and market quality.

Our focus is twofold: First, we are concerned with the market quality implications of a change in the minimum tick size. In particular, we present the empirical literature that is concerned with the effect of minimum tick size regulations on trading costs and liquidity. The vast majority of the empirical literature has documented a decrease in spreads and an increase in liquidity following a tick size reduction. However, a stream of the literature is also concerned with the effect of this reduction on quoted depth and the ability of the market to absorb large trades. Also, we document the strong link between the minimum tick size regulations and the recent increase in HFT. A small minimum tick size allows HFTRs to implement their strategies, whilst a larger relative tick size leads to larger profit by HFTRs due to increased trading activity.

Second, we are interested in the implications of changes in the minimum tick size on market structure. To this end, we show that the decrease in tick sizes has enhanced the price discovery process but disincentivised market makers to provide liquidity. Also, the welfare of dealers and investors is a function of the number of dealers in the market; if the number of dealers in the market is large, investors will prefer a small tick size. Institutional investors are also adversely affected by a small tick size; reducing the tick size leads to a deterioration in market depth and hence a decrease in liquidity for the larger institutions. Thus, reducing the tick size may lead to the flight of institutional investor trading to smaller tick size trading venues, yet recent studies show that HFTRs are responsible for the shift in liquidity from a dark pool to the limit order book as they increase the supply of liquidity following the tick size decrease.

Finally, this literature review discussed the empirical literature related to minimum trade size regulations and odd-lot trading. Studies in the field show that reducing the MTU leads to an increase in investors' base which has a positive effect on information availability, thereby increasing both liquidity and valuation. With respect to odd-lot trading, a limited set of recent studies shows that in today's "high frequency markets", odd-lots' contribution to price discovery has increased substantially due to their use by HFTRs.

5.2 The debate on the minimum resting time

The minimum resting time indicates the minimum amount of time an order must stay in a limit order book to remain valid. A minimum resting time has often been advocated as a way to reduce systemic risk in markets where high frequency trading is widespread. Critics of this proposal argue that orders subject to a minimum resting time are exposed to higher risk and therefore introducing a minimum resting time would induce traders to widen the spreads. The debate on the minimum resting time was spurred by the "Flash Crash" of May 6, 2010, which is considered by many as partly due to high frequency traders. Recently, during the discussions for the MiFID revision in the European Parliament, one of the most controversial proposals was the introduction of a minimum resting time equal to 500 ms. MiFID II does not include this proposed change.[11]

Very little research investigates the effects of a minimum resting time for orders; specifically, we are aware only of two working papers, which use simulated markets and do not find conclusive evidence that market participants benefit from a minimum resting time. The first contribution is provided by Lee et al. (2011); they develop a market simulation where an asset is traded in multiple markets and in which market makers trade with three types of traders: random limit order submitters, trend following agents that apply similar strategies, and arbitrageurs. The design considered is a modification of Lee et al. (2010), who examine position limits as a way to stabilize markets. One of the main results is that patterns similar to the aforementioned flash crash are due to the domination of trading strategies that are responding in the same way to the same set of market variables. The findings of Lee et al. (2011) suggest that reducing the speed of order submission does not reduce the order imbalance which leads to flash crashes. Furthermore, Lee et al. (2011) argue that reducing the speed of order submission induces adjustments which may decrease liquidity. The problem is exacerbated in presence market fragmentation, where traders can move across different markets as a response to differences in speed regulation. The second study, by Brewer et al. (2014), examines call auctions, minimum resting time, and circuit breakers (the options considered after shutting the trading are: a one-time call auction, a series of temporary call markets, clear books, temporary suspension of trading for ten seconds without clearing the books) as mechanisms to reduce volatility caused by flash crashes and to facilitate recovery after a crash. They simulate a limit order market with buy and sell orders with random values arriving at random times. A flash crash is induced by introducing a very large order to the market. The three mechanisms tested help to limit volatility and aid the recovery of liquidity. The results show that call auctions are the most effective mechanism to limit the adverse effect of flash crashes. Brewer et al. (2014) caution that the results on minimum resting time are highly dependent on the conditions

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[11] In a report for the UK Government Office for Science, Farmer and Skouras (2012) discuss the economic implications of the proposed minimum resting time regulations on exchanges. The authors argue that whilst the measure is in the right direction, the measure itself is ineffective.

simulated; in particular, if quick cancellations of orders do not cause instabilities, the results may not hold.

5.3 Possible future research topics

In this review, we have identified several areas for future research. The decision of SEC to introduce a pilot study in the US is sufficient to generate a number of interesting studies in the area that will evaluate the outcomes of a "reverse decimalization" policy. It remains to be seen what the future policy will be on minimum tick size changes for illiquid stocks. Similarly, there is a gap in the empirical literature on the incentives of market makers to support IPOs. Future research in this field should identify the willingness of market makers to continue offering market making activities in a low-tick regime. The latter however should be studied in parallel with the presence of HFTRs.

In particular, this literature review clearly identified a shift in market making activities that are substituted by HFTRs. Given that HFTRs are more active in a small-tick size environment, future research needs to look in more detail how HFTRs interact with other investors in markets where the tick size is relatively large and in different market structures. A further area that is still under-researched is the effect of minimum tick sizes on the profitability of smart order routing systems (SORSs); MiFiD in Europe has led to an unprecedented market fragmentation and there is no empirical research which considers the pricing mechanism of individual exchanges in the presence of order fragmentation. The latter is also related to the research in dark pool trading which is still very under-developed.

Furthermore, extant empirical research on the effects of changes in the MTU has focused on time periods before the advent of HFT. HFTRs have been shown to trade at a small size. Small orders are used by HFTRs, for example, to split a larger order or to detect hidden liquidity (O'Hara et al. 2014). Accordingly, O'Hara et al. (2014) find that odd-lot trades are more likely to occur if trades are initiated by HFTRs. On a related note, Koznan and Tham (2012) argue that minimum trade size restrictions may take out arbitrageurs in a high frequency environment. Investigating how the activity of high frequency traders is related to the effects of changes in the MTU is an interesting area for future research.

The proposed implementation of a minimum resting time policy makes it clear that policymakers are concerned with the volume of HFT. However, as we have seen in this literature review, HFTRs have replaced market makers for the more liquid stocks. To date, there is no paper that addresses the issue of an optimal tick size in an environment in which retail investors interact with HFTRs. To conclude, it is our view that we are entering a new phase of policy that will have more idiosyncratic characteristics. With that, we believe that policy regulators are becoming more concerned with how certain policies affect certain areas of the market; future research on tick size changes will identify how market structure is clearly associated with each one of these market segments. The implementation and success of these changes remains to be seen, generating a wide scope for fruitful research in the area.

Finally, the literature on the effect of tick size changes and firm characteristics is relatively scarce. For example, Fang et al. (2009) show that changes in the tick size affect firm characteristics (tick size changes affects liquidity and price informativeness which eventually affects firm value) or Edmans et al. (2013) that suggest tick size changes affect governance. Future research needs to focus on the effect of tick size changes on the value of the firm, therefore linking the market microstructure literature with asset pricing and corporate governance studies. From a policy perspective, clearly regulators have been primarily concerned with the effect of tick size changes on the trading price of the firm.

However, the above papers demonstrate that the decision to change the minimum tick size ultimately has an effect on firm valuation.

References

Ahn HJ, Cao CQ, Choe H (1996) Tick size, spread, and volume. J Financ Intermed 5:2–22

Ahn HJ, Cai J, Chan K, Hamao Y (2007) Tick size change and liquidity provision on the Tokyo stock exchange. J Jpn Int Econ 21:173–194

Aitken M, Comerton-Forde C (2005) Do reductions in tick size affect market liquidity? Account Finance 45:171–184

Alampieski K, Lepone A (2009) Impact of a tick size reduction on liquidity: evidence from the Sydney futures exchange. Account Finance 49:1–20

Alexander GJ, Peterson MA (2002) Implications of a reduction in tick size on short-sell order execution. J Financ Intermed 11:37–60

Al-Yahyaee KH (2013) The effect of a reduction in price discreteness on ex-day stock returns in a unique environment. J Int Financ Mark Inst Money 23:283–294

Amihud Y, Mendelson H, Uno J (1999) Number of shareholders and stock prices: evidence from Japan. J Finance 54:1169–1184

Anderson HD, Peng Y (2014) From cents to half-cents and its liquidity impact. Pac Account Rev 26:160–176

Angel JJ (1997) Tick size, share prices, and stock splits. J Finance 52:655–681

Anshuman VR, Kalay A (1998) Market making with discrete prices. Rev Financ Stud 11:81–109

ap Gwilym O, Alibo E (2003) Decreased price clustering in FTSE100 futures contracts following a transfer from floor to electronic trading. J Futures Mark 23:647–659

ap Gwilym O, McManus I, Thomas S (2005) Fractional versus decimal pricing: evidence from the UK Long Gilt futures market. J Futures Mark 25:419–442

Ascioglu A, Comerton-Forde C, McInish TH (2010) An examination of minimum tick sizes on the Tokyo stock exchange. Jpn World Econ 22:40–48

Bacidore JM (1997) The impact of decimalization on market quality: an empirical investigation of the Toronto stock exchange. J Financ Intermed 6:92–120

Bacidore JM (2001) Decimalization, adverse selection, and market maker rents. J Bank Financ 25:829–855

Bacidore JM, Battalio RH, Jennings RH (2003) Order submission strategies, liquidity supply, and trading in pennies on the New York stock exchange. J Financ Mark 6:337–362

Bali R, Hite G (1998) Ex-dividend day stock price behavior: discreteness or tax-induced clienteles? J Financ Econ 47:127–159

Ball CA, Chordia T (2001) True spreads and equilibrium prices. J Finance 56:1801–1835

Barber B, Odean T, Zhu N (2009) Do retail trades move markets? Rev Financ Stud 22:151–186

Bartlett RP III, McCrary J (2013) Shall we haggle in pennies at the speed of light or in nickels in the dark? How minimum price variation regulates high frequency trading and dark liquidity. Working paper, Berkeley School of Law

Beaulieu MC, Ebrahim SK, Morgan IG (2003) Does tick size influence price discovery? Evidence from the Toronto stock exchange. J Futures Mark 23:49–66

Bernhardt D, Hughson E (1996) Discrete pricing and the design of dealership markets. J Econ Theory 71:148–182

Bessembinder H (1997) The degree of price resolution and equity trading costs. J Financ Econ 45:9–34

Bessembinder H (2000) Tick size, spreads, and liquidity: an analysis of Nasdaq securities trading near ten dollars. J Financ Intermed 9:213–239

Bessembinder H (2003) Trade execution costs and market quality after decimalization. J Financ Quant Anal 38:747–777

Biais B, Bisiere C, Spatt C (2010) Imperfect competition in financial markets: an empirical study of Island and Nasdaq. Manag Sci 56:2237–2250

Bollen NPB, Busse JA (2006) Tick size and institutional trading costs: evidence from mutual funds. J Financ Quant Anal 41:915–937

Bollen NPB, Whaley RE (1998) Are "teenies" better? J Portf Manag 25:10–24

Bollen NPB, Smith T, Whaley RE (2003) Optimal contract design: for whom? J Futures Mark 23:719–750

Booth GG, Yüksel A (2006) Price resolution in an emerging market: evidence from the Istanbul stock exchange. Eur J Financ 12:137–152

Bourghelle D, Declerck F (2004) Why markets should not necessarily reduce the tick size. J Bank Financ 28:373–398

Brewer P, Cvitanic J, Plott C (2014) Minimum resting times vs. call markets and circuit breakers. Working paper, Caltech

Buti S, Rindi B, Wen Y, Werner IM (2013) Tick size regulation and sub-penny trading. Working paper, available at SSRN 2324862

Cai J, Hamao Y, Ho RYK (2008) Tick size change and liquidity provision for Japanese stock trading near ¥1000. Jpn World Econ 20:19–39

Chakravarty S, Wood RA, Van Ness R (2004) Decimals and liquidity: a study of the Nyse. J Financ Res 27:75–94

Chakravarty S, Panchapagesan V, Wood RA (2005a) Did decimalization hurt institutional investors? J Financ Mark 8:400–420

Chakravarty S, Van Ness B, Van Ness R (2005b) The effect of decimalization on trade size and adverse selection costs. J Bus Finance Account 32:1063–1081

Chan KC, Hwang CY (2002) The impact of tick size on the quality of a pure order-driven market: evidence from the Stock Exchange of Hong Kong. Working paper, in 2002 NTU International Conference on Finance

Charoenwong C, Ding D, Thong TY (2016) Decimalization, IPO aftermath, and liquidity. Rev Quant Financ Acc 47:1303–1344

Chen YL, Gau YF (2009) Tick sizes and relative rates of price discovery in stock, futures, and options markets: evidence from the Taiwan stock exchange. J Futures Mark 29:74–93

Chen WP, Chou RK, Chung H (2009) Decimalization, ETFs and futures pricing efficiency. J Futures Mark 29:157–178

Chien CY, Liao TH, Lee HC (2014) The information content of the thinner order book following tick size reduction. Manage Financ 40:218–233

Chordia T, Subrahmanyam A (1995) Market making, the tick size, and payment-for-order flow: theory and evidence. J Bus 68:543–575

Chou RK, Chung H (2006) Decimalization, trading costs, and information transmission between ETFs and index futures. J Futures Mark 26:131–151

Chou R, Lee WC, Chen SS (2005) The market reaction around ex-dates of stock splits before and after decimalization. Rev Pac Basin Financ Mark Polic 8:201–216

Christie WG, Schultz PH (1994) Why do NASDAQ market makers avoid odd-eighth quotes? J Finance 49:1813–1840

Chueh H (2000) Price clustering in the Nikkei 225 stock index futures contract on the SIMEX: an intraday empirical analysis. Rev Pac Basin Financ Mark Polic 3:519–533

Chung KH, Chuwonganant C (2002) Tick size and quote revisions on the NYSE. J Financ Mark 5:391–410

Chung KH, Chuwonganant C (2004) Tick size, order handling rules, and trading costs. Financ Manage 33:47–62

Chung KH, Van Ness R (2001) Order handling rules, tick size, and the intraday pattern of bid–ask spreads for Nasdaq stocks. J Financ Mark 4:143–161

Chung KH, Van Ness B, Van Ness R (2002) Spreads, depths, and quote clustering on the NYSE and Nasdaq: evidence after the 1997 securities and exchange commission rule changes. Financ Rev 37:481–505

Chung KH, Charoenwong C, Ding DK (2004a) Penny pricing and the components of spread and depth changes. J Bank Financ 28:2981–3007

Chung KH, Chuwonganant C, McCormick DT (2004b) Order preferencing and market quality on NASDAQ before and after decimalization. J Financ Econ 71:581–612

Chung KH, Van Ness B, Van Ness R (2004c) Trading costs and quote clustering on the NYSE and NASDAQ after decimalization. J Financ Res 27:309–328

Chung KH, Kim KA, Kitsabunnarat P (2005) Liquidity and quote clustering in a market with multiple tick sizes. J Financ Res 28:177–195

Chung KH, Chuwonganant C, Jiang J (2008) The dynamics of quote adjustments. J Bank Financ 32:2390–2400

Chung K, Kang J, Kim JS (2011) Tick size, market structure, and market quality. Rev Quant Financ Acc 36:57–81

Coughenour J, Harris L (2004) Specialist profits and the minimum price increment. Working paper, University of Delaware

Dyl E, Maberly E (1992) Odd-lot transactions around the turn of the year and the January effect. J Financ Quant Anal 27:591–604

Edmans A, Fang V, Zur E (2013) The effect of liquidity on governance. Rev Financ Stud 26:1443–1482

Fang V, Noe T, Tice S (2009) Stock market liquidity and firm value. J Financ Econ 94:150–169

Farmer JD, Skouras S (2012) Minimum resting times and transaction-to-order ratios. Working paper, Government Office for Science Working Paper (No. BIS/12/1064)

French DW, Foster TW III (2002) Does price discreteness affect the increase in return volatility following stock splits? Financ Rev 37:281–293

Gerace D, Smark C, Freestone T (2012) Impact of reduced tick sizes on the Hong Kong stock exchange. J New Bus Ideas Trends 10:54–71

Gibson S, Singh R, Yerramilli V (2003) The effect of decimalization on the components of the bid–ask spread. J Financ Intermed 12:121–148

Glosten L, Harris L (1988) Estimating the components of the bid–ask spread. J Financ Econ 21:123–142

Goldstein MA, Kavajecz KA (2000) Eighths, sixteenths, and market depth: changes in tick size and liquidity provision on the NYSE. J Financ Econ 56:125–149

Goldstein M, Shkilko A, Van Ness B, Van Ness R (2010) Inter-market competition for NYSE-listed securities under decimals. Rev Quant Financ Acc 35:371–391

Gozluklu AE, Perotti P, Rindi B, Fredella R (2015) Lot size constraints and market quality: evidence from the Borsa Italiana. Financ Manage 44:905–945

Graham JR, Michaely R, Roberts MR (2003) Do price discreteness and transactions costs affect stock returns? Comparing ex-dividend pricing before and after decimalization. J Finance 58:2611–2635

Griffiths MD, Smith BF, Turnbull DA, White RW (1998) The role of tick size in upstairs trading and downstairs trading. J Financ Intermed 7:393–417

Hagströmer B, Nordén L (2013) The diversity of high-frequency traders. J Financ Mark 16:741–770

Hameed A, Terry E (1998) The effect of tick size on price clustering and trading volume. J Bus Finance Account 25:849–867

Harris L (1991) Stock price clustering and discreteness. Rev Financ Stud 4:389–415

Harris L (1994) Minimum price variations, discrete bid–ask spreads, and quotation sizes. Rev Financ Stud 7:149–178

Hasbrouck J (1993) Assessing the quality of a security market: a new approach to transaction-cost measurement. Rev Financ Stud 6:191–212

Hau H (2006) The role of transaction costs for financial volatility: evidence from the Paris Bourse. J Eur Econ Assoc 4:862–890

Hauser S, Lauterbach B (2003) The impact of minimum trading units on stock value and price volatility. J Financ Quant Anal 38:575–589

He Y, Wu C (2005) The effects of decimalization on return volatility components, serial correlation, and trading costs. J Financ Res 28:77–96

Hendershott T, Jones CM, Menkveld AJ (2011) Does algorithmic trading improve liquidity? J Finance 66:1–33

Hsieh TY, Chuang SS, Lin CC (2008) Impact of tick-size reduction on the market liquidity—evidence from the emerging order-driven market. Rev Pac Basin Financ Mark Polic 11:591–616

Huang RD, Stoll HR (2001) Tick size, bid–ask spreads, and market structure. J Financ Quant Anal 36:503–522

Ikenberry DL, Weston JP (2008) Clustering in US stock prices after decimalisation. Eur Financ Manag 14:30–54

Jakob K, Ma T (2004) Tick size, NYSE rule 118, and ex-dividend day stock price behavior. J Financ Econ 72:605–625

Jiang CX, Kim JC, Wood RA (2009) A comparison of volatility and bid–ask spread for NASDAQ and NYSE after decimalization. Appl Econ 43:1227–1239

Johnson H, Van Ness B, Van Ness R (2014) An analysis of all, intentional, and circumstantial odd-lot transactions. Working paper, Kansas State University

Jones CM, Lipson ML (2001) Sixteenths: direct evidence on institutional execution costs. J Financ Econ 59:253–278

Kadan O (2006) So who gains from a small tick size? J Financ Intermed 15:32–66

Kadapakkam PR, Krishnamurthy S, Tse Y (2005) Stock splits, broker promotion, and decimalization. J Financ Quant Anal 40:873–895

Ke MC, Jiang CH, Huang YS (2004) The impact of tick size on intraday stock price behaviour: evidence from the Taiwan stock exchange. Pac Basin Financ J 12:19–39

Koznan R, Tham WW (2012) Execution risk in high-frequency arbitrage. Manag Sci 58:2131–2149

Kurov A, Zabotina T (2005) Is it time to reduce the minimum tick sizes of the E-Mini futures. J Futures Mark 25:79–104

La Spada G, Farmer JD, Lillo F (2011) Tick size and price diffusion. In: Abergel F, Chakrabarti BK, Chakraborti A, Mitra M (eds) Econophysics of order-driven markets. Springer, Milan, pp 173–187

Lakonishok J, Maberly E (1990) The weekend effect: trading patterns of individual and institutional investors. J Finance 54:1015–1044

Lau ST, McInish TH (1995) Reducing tick size on the stock exchange of Singapore. Pac Basin Financ J 3:485–496

Lee B, Cheng S, Koh A (2010) An analysis of extreme price shocks and illiquidity among systematic trend followers. Rev Futures Mark 18:385–419

Lee B, Cheng S, Koh A (2011) Liquidity withdrawal and the "Flash Crash". Working paper, Singapore Management University

Lin BX, Michayluk D, Oppenheimer HR, Sabherwal S (2009) French and US trading of cross-listed stocks around the period of US decimalization: volume, spreads, and depth effects. Int Rev Financ Anal 18:223–231

MacKinnon G, Nemiroff H (2004) Tick size and the returns to providing liquidity. Int Rev Econ Financ 13:57–73

Mahmoodzadeh S, Gençay R (2014) Tick size change in the wholesale foreign exchange market. Working paper, Simon Fraser University, BC

Merton R (1987) A simple model of capital market equilibrium with incomplete information. J Finance 42:483–511

Münnix MC, Schäfer R, Guhr T (2010) Impact of the tick-size on financial returns and correlations. Phys A 389:4828–4843

O'Hara M, Saar G, Zhong Z (2015) Relative tick size and the trading environment. Working paper, Cornell University

O'Hara M, Yao C, Ye M (2014) What's not there: odd lots and market data. J Finance 69:2199–2236

Oppenheimer HR, Sabherwal S (2003) The competitive effects of US decimalization: evidence from the US-listed Canadian stocks. J Bank Financ 27:1883–1910

Pan W, Song FM, Tao L (2012) The effects of a tick-size reduction on the liquidity in a pure limit order market: evidence from Hong Kong. Appl Econ Lett 19:1639–1642

Pavabutr P, Prangwattananon S (2009) Tick size change on the stock exchange of Thailand. Rev Quant Financ Acc 32:351–371

Porter DC, Weaver DG (1997) Tick size and market quality. Financ Manage 26:5–26

Portniaguina E, Bernhardt D, Hughson E (2006) Hybrid markets, tick size and investor trading costs. J Financ Mark 9:433–447

Ronen T, Weaver DG (2001) 'Teenies' anyone? J Financ Mark 4:231–260

Schultz P (2000) Stock splits, tick size, and sponsorship. J Finance 55:429–450

SEC (2014a) Plan to implement a tick size pilot program. SEC, Washington

SEC (2014b) Odd lot rates in a post-transparency world. SEC, Washington

Stafford A, Barker A (2014) EU clampdown on 'flash boy' traders turns technical. The financial times, Retrieved from http://www.ft.com

Stevenson RA (1973) Odd lot trading in the stock market and its market impact: a comment. J Financ Quant Anal 8:527–533

Stone E (2009) Regulated technology diffusion: the SEC and the impact of 'penny pricing' in electronic options trading. Working paper, available at SSRN 1479602

Uno J, Shibata M (2011) Speed of trade and liquidity. Working paper, in 24th Australasian finance and banking conference 2011

Van Ness B, Van Ness R, Pruitt S (2000) The impact of the reduction in tick increments in major U.S. markets on spreads, depth, and volatility. Rev Quant Financ Acc 15:153–167

Verousis T, ap Gwilym O, Voukelatos N (2016) The impact of a premium-based tick size on equity option liquidity. J Futures Mark 36:397–417

Weild D, Kim E, Newport L (2012) The trouble with small tick sizes. Capital market series. Grant Thorton, Chicago

Werner IM, Wen Y, Rindi B, Consonni F, Buti S (2015) Tick size: theory and evidence. Working paper, available at SSRN 2485069

Wu KW (1972) Odd lot trading in the stock market and its market impact. J Financ Quant Anal 7:1321–1344

Yao C, Ye M (2015) Why trading speed matters: a tale of queue rationing under price controls. Working
    paper, available at SSRN 2478216
Zhao X, Chung KH (2006) Decimal pricing and information-based trading: tick size and informational
    efficiency of asset price. J Bus Finance Account 33:753–766