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Market quality and structural changes in the trading system

The case of X-Stream on the Colombian stock exchange

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Abstract

Purpose – The purpose of this paper is to study the effect of X-Stream, the new trading platform of the Colombian Stock Exchange since February 2009, on the market quality.
Design/methodology/approach – The authors test the effect of X-Stream on market quality variables, such as liquidity (bid-ask spread and price impact), daily and intraday volatility and trading activity, using mean tests, panel data and conditional variance models. The authors use a proprietary database of transactions and orders from the exchange.
Findings – The evidence suggests that X-Stream improved the liquidity and trading activity and reduced the volatility of the overall market, especially of the most liquid stocks.
Practical implications – These results support the investment on more sophisticated trading systems in emerging markets.
Originality/value – Contributing to the literature on market quality, this paper provides novel evidence of the effect of reforms on market design, trading rules and operational capabilities on a small and low-liquidity emerging stock market.

Keywords Liquidity, Market microstructure, Market quality, Trading activity, Trading systems, Volatility

Paper type Research paper

Resumen

Se investiga el efecto de la plataforma de transacción de acciones de BVC, X-Stream, en la calidad del mercado accionario a partir de su lanzamiento en Febrero del 2009. Partiendo de una base de datos transaccional de BVC, se emplean varios modelos econométricos para medir el efecto de la nueva plataforma en las volatilidades diaria e intradiaria, la liquidez (margen proporcional de oferta y demanda e impacto en el precio) y la actividad bursátil. La evidencia demuestra que X-Stream mejoró la liquidez y redujo la volatilidad del mercado accionario como un todo, pero especialmente en las acciones más líquidas. Esta investigación contribuye a la literatura en calidad de mercado al aportar nueva evidencia sobre el efecto de los cambios de diseño, reglas de transacción y capacidades operacionales en un mercado accionario de reducidos tamaño y liquidez. De esta manera, sirve como argumento para justificar inversiones en sistemas avanzados de transacción en mercados emergentes.

Introduction

On February 9, 2009, Bolsa de Valores de Colombia (BVC), the Colombian Stock Exchange, launched X-Stream; a stock trading platform, aimed at providing a faster,

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safer and more transparent operation. X-Stream replaced a very limited electronic platform operating since BVC began in July 2001. X-Stream incorporated several new features, including call auctions for market closing, distinction between market and order limits, immediate order matching and volatility call auctions. Besides, it replaced for low liquidity stocks the continuous market with opening and closing call auctions. Moreover, X-Stream offered increased operative efficiency, order processing capability, reliability and execution speed. Contributing to the literature on market quality, this paper examines the effect of X-Stream on the Colombian Stock Exchange.

The worldwide trend for technological, organizational and regulatory changes on financial markets has spurred an interest in the design and operation of faster and more efficient trading platforms (Madhavan, 2000). According to international experiences, improved trading platforms lead to enhanced features in market quality, such as lower execution times, increased liquidity, depth and market efficiency (Angel *et al.*, 2011). The study of the market quality of BVC is even more interesting because of its ongoing integration with the stock exchanges of Lima and Santiago into the *Mercado Integrado Latinoamericano* (MILA) started in 2011, with Mexico joining in 2014. As a larger stock market, MILA is expected to become a more attractive venue for foreign investors. Indeed, the implementation of X-Stream as a more sophisticated transaction platform has been presented as a required step for BVC to join MILA. X-Stream has also enabled BVC innovations such as e-trading (on 2009), future contracts on stocks (2010), Exchange Traded Funds (2011) and short sales (2012).

This paper presents evidence of the impact of X-Stream on the Colombian stock market. Specifically, we measured market quality variables such as liquidity, volatility and trading activity, before and after X-Stream started. The evidence suggests that X-Stream improved the liquidity and trading activity and reduced the volatility of the overall market, especially of the most liquid stocks.

This paper is organized as follows. The second section describes the most relevant features of X-Stream and its predecessor, emphasizing the improvements brought by X-Stream. The third section provides a theoretical background for market quality and discusses the most relevant empirical studies. The fourth section presents the methodology and data used to empirically evaluate the impact of X-Stream on the market quality of BVC. The fifth section explains the results and discusses some of the robustness tests performed on these results. Finally, the sixth section concludes.

BVC trading platforms, preX-Stream and X-Stream

We will describe the most relevant features of the two electronic trading platforms that have been used by BVC: the former, henceforth referred to as preX-Stream, and the new trading platform, X-Stream, which replaced the former on February 9, 2009. Table I summarizes and compares the main features of both platforms.

PreX-Stream was essentially an order entry and matching electronic system as described in Agudelo (2011). Every stock was traded in an order-driven continuous market without call auctions. Moreover, preX-Stream only allowed for limit orders, excluding any other types, most notably market orders. Orders were defined by direction (buy or sell), price, and quantity, always with unlimited execution time and could be entered, deleted, matched or modified in either price or quantity. Matching took place at the new price, meaning the price of the incoming order, rather than at the current price, i.e. the price of the outstanding order on the limit order book. For example, an incoming buy order at price P_1 was matched with the best outstanding sell at price P_2, provided there was price compatibility ($P_1 \geqslant P_2$) but matching took place at

PreX-Stream	X-Stream
From July 3, 2001 to February 6, 2009	From February 9, 2009
Continuous electronic market for all stocks. No call auctions	High-liquidity stocks are traded in a continuous electronic market with a five-minute closing call auction Low-liquidity stocks traded only in 30-minute call auctions at both at session opening and closing
Previous to any matching, a 20-second microauction is activated, allowing for new orders to offer better prices in either side of the trade. No immediate order matching	Immediate order matching
Only limit orders are allowed. No execution or duration options, all orders were "until cancelled"	It allows market orders, limit orders, "at best" orders and stop orders. Different execution options: "fill or kill", "fill and kill". Duration options: good until cancelled, until day, until hour, immediate, session
Price-time priority matching, at the new price To match an order at the current quote the exact price should be manually entered	Price-time priority matching, at the current price To match an order at the current quote an "at best" order should be entered.
Orders are executed at the new price. For the fastest execution of a buy (sell) order with quantity exceeding the ask (bid) depth, it should be entered with a price high (low) enough, to reach further levels of the limit order book. This implied some price concession to current limit orders	Orders are not necessarily executed at the same price. For immediate execution of a buy (sell) order with quantity exceeding the ask (bid) depth, a market or marketable limit order can be placed. No price concession to current limit orders
Closing price given by the last trade.	Closing price given by the five-minute closing call auction, ended within a 30 seconds window. Closing price less prone to manipulation
Cross trades are allowed	Cross trades are not allowed
Order processing speed: three orders per second	Order processing speed: 2,000 orders per second
Frequent temporary or permanent halts, when price changes exceed limits	When price changes exceed limits, the continuous market is temporally replaced by a two-and-a-half minute call auction ("volatility call auction")
Limited technological platform, prone to crashes, incompatible with order routing	More robust and reliable technological platform. Compatible with order routing, allowing for e-trading and algorithmic trading

Table I.
Comparing former and current trading platforms in BVC

P_1, the new price. Any remaining quantity could be matched with compatible outstanding orders, but always at the new price. This meant that large size incoming orders might have to concede prices to outstanding orders to be executed in a single trade whenever the depth of the corresponding quote (best outstanding order) was smaller.

Moreover, matching did not occur immediately. Once an incoming order arrived compatible with the quote, the system started a 20-second microauction.

The microauction allowed for a new incoming order to offer a better price on either side of the trade, freezing the other side. If a more competitive order entered, the system opened a new 20-second microauction and so forth. Matching occurred if no new incoming order offered a better price in the 20-second window. Thus, every trade was preceded by one or a series of 20-second auctions. The microauction implied that, no matter how aggressive an incoming order, its matching took not <20 seconds and could not happen at all if a more aggressive order arrived in the 20-second window.

PreX-Stream also provided for cross-trades, which allow a broker to simultaneously execute a buy and a sell order for the same quantity. Cross-trades were matched at the outstanding mid-price. Additionally, the system included circuit breakers that provided a temporary trading halt for changes in the price above or below 10 percent of a reference price. Permanent halts for the session could be activated if the volatility on prices continued.

X-Stream is a more sophisticated order electronic trading platform, with higher order execution capability and processing speed as summarized in Table I. X-Stream provides two different trading settings for stocks. High-liquidity stocks are traded in a continuous market, ended with a five-minute closing call auction. The closing call auction is randomly closed within a 30-second window to hinder closing price manipulation. In turn, low-liquidity stocks are traded only in 30-minute call auctions at session opening and closing. All call auctions clear at a single price using an algorithm that maximizes traded volume.

Unlike the former platform, X-Stream allows several order types such as market, limit, "at best" and stop orders. Limit and "at best" orders can be specified as "fill and kill" or "fill or kill," depending on whether partial fulfillment is accepted or not. Optionally, it also allows the definition of a minimum quantity to be matched as well as a hidden quantity. Besides, X-Stream does not allow for cross-trades, all orders have to be executed against the limit order book. Furthermore, the continuous market of X-Stream matches orders at the current price, that is, the price of the outstanding limit order in the electronic book. Therefore, no incoming market or marketable limit order concedes a price to outstanding limit orders. This clearly simplifies the execution of large trades and lowers the effective transaction cost.

In X-Stream, instead of trading halts, whenever price changes exceed established limits a "volatility call auction" is started temporarily stopping the continuous market for two-and-a-half minutes, but admitting new limit orders to enter. As a result, the volatility call auction allows for an orderly price discovery in times of high volatility. The auction is randomly closed in a 30-second window to deter price manipulation. In some rare circumstances, the administrator can suspend the trading session for a particular stock or for the entire market.

Background on market quality

Measuring market quality

Market quality is a set of attributes that define the proper operation of a trading market, including effective trade execution, transparency in price formation, high liquidity and low transaction costs. Market quality depends both on the design and capabilities of the trading platform and on the rules of the market. To measure market quality the literature has mainly focussed on volatility and liquidity (Chordia *et al.*, 2001; Pagano *et al.*, 2013).

Low volatility is a very important aspect of market quality. Whereas volatility related to the arrival of news is desirable, volatility coming from the arrival of buys

and sells or from the execution of large orders should be mitigated (Ozenbas *et al.*, 2002). In other words, trading by itself creates volatility (Jones *et al.*, 1994). To some extent, volatility depends on market design. For example, volatility is affected by the bid-ask spread (Roll, 1984), hence trading market rules can indirectly alter volatility via liquidity (Madhavan, 1992). Besides, a market design that provides for a smoother incorporation of relevant information in prices should lead to a more efficient price formation and lower volatilities (Hendershott and Moulton, 2011).

Liquidity includes at least three dimensions: low transaction costs, high-trade execution speed and the ability to trade large quantities at low cost (Harris, 2003). Liquid assets are cheaper to trade and can be used for short-term trading and arbitrage strategies. High liquidity means not only tighter bid-ask spreads but also large depth at the quotes and at different levels of the limit order book, which in turn means a lower price impact for large orders. Higher liquidity is also related to higher resiliency; that is, the quick reversion of temporary disturbances on prices not related to new information (Pastor and Stambaugh, 2003). Consequently, high liquidity mitigates transitory volatility making prices more informative and efficient (Chordia *et al.*, 2008). Although liquidity is a multidimensional concept, the literature has focussed on the proportional bid-ask spread and the price impact, ideally based on transaction data (Goyenko *et al.*, 2009).

Finally, trading activity, measured as trading volume or number of trades, is the final result of interactions between agents in the market. Although it has not been usually deemed as a market quality variable, we argue that it might serve as an indirect measure. We should expect that improvements on liquidity, transparency in price formation, and execution speeds attract more trading, which in turn should increase liquidity and price efficiency[1].

Previous studies

The three main changes brought by X-Stream were the closing call auctions, higher execution speed, and the introduction of different types of orders. Similar studies on market design changes and their effects on market quality have been dedicated to other financial markets around the world.

Regarding to the introduction of closing call auctions, the empirical study of Ko *et al.* (1995) in Korea suggest that those mechanisms have reduced incentives to manipulate the closing price, and improved the price formation, reflected in lower volatility. Pagano and Schwartz (2003), studying the stock option market in the Paris Bourse, report that the closing call auction improves price revelation and market efficiency by taking option prices closer to their theoretical values. Chelley-Steeley (2008), reports an improvement in market quality in the London Stock Exchange after the introduction of closing call auction, and finds that the least active stocks experience the largest gains in market quality. Similar results have been reported for the Singapore Exchange (Chang *et al.*, 2008), Borsa Italiana and Paris Bourse (Kandel *et al.*, 2011), and NASDAQ (Pagano *et al.*, 2013). In contrast, Camilleri and Green (2009) present evidence on the reduction of volatility and improvement of efficiency and liquidity in the National Stock Exchange of India after the suspension of opening and closing call auctions. These authors argue that call auctions might not necessarily improve stock trading in a low-liquidity market.

Faster order processing should reduce transaction costs and facilitate security trading, leading to economic gains in risk sharing, investment and consumption (Pastor and Stambaugh, 2003; Acharya and Pedersen, 2005). Not surprisingly, order

processing speed is an important factor in the competition between exchanges for order flow (Hendershott and Moulton, 2011). In a similar vein, Stoll (2006) argues that delays in order execution lead to higher opportunity costs. Higher execution speeds enhance the efficiency of price formation (Boehmer and Kelley, 2009; Barclay *et al.*, 2003). As for empirical studies, Riordan and Storkenmaier (2012), find that increasing trading speed in Deutsche Boerse reduced the bid-ask spread and made prices more efficient, especially in small- and medium-size stocks. In contrast, Hendershott and Moulton (2011) evidence that the introduction of a more sophisticated trading platform in NYSE improved efficiency but widened bid-ask spreads due to an increase of information asymmetry.

Finally, to the extent of our knowledge, no previous empirical study have tested the isolated effect of more sophisticated type of orders to a given financial market. Nevertheless, the introduction of new trading systems usually includes new types of orders, as in Paris Bourse (Demarchi and Foucault, 2000) and NASDAQ (Pagano and Schwartz, 2005). New order types and new execution options should allow the users to optimize trading strategies and commit fewer mistakes. A more friendly and sophisticated trading platform should lure more trading activity, lowering information asymmetry and improving market quality.

Methodology and data

To test for the effect of X-Stream on BVC stock market quality, the following variables were measured at the stock-day level: volatility, calculated both on daily and intraday returns, liquidity as bid-ask spread and price impact, and trading activity as the number of trades. Those variables have been used in previous studies on market quality (Bennett and Wei, 2006; Liu and Zhu, 2009; Pagano and Schwartz, 2003).

The effect of X-Stream on daily volatility was tested using ARMA-GARCH models for daily returns at stock level. For those models, daily returns were calculated from both closing and opening prices. Intraday volatility was measured for stocks classified as high liquidity on the continuous market that is, excluding the closing price on the X-Stream period. Intraday volatility was measured in two alternative ways. First, as the standard deviation of five-minute interval returns $r_{k,di}$ in a given day d, for a stock i:

$$INTRADAY\ VOLAT_{di} = \sigma\left(r_{k,di}\right) \tag{1}$$

Second, as the max-min range of intraday prices normalized by the closing price, requiring at least, two trades to be calculated:

$$MAX\_MIN_{di} = \frac{(Pmax_{di} - Pmin_{di})}{Pclosing_{di}} \tag{2}$$

We expected a reduction of the volatility of the Colombian stock market after the implementation of X-Stream for the following four reasons. First, matching at the current price, rather than at the new price, should reduce price variations coming from large orders. Second, immediate matching, instead of the 20-second microauction, should allow for small orders to be more frequently matched at quotes. Third, a more efficient trading platform should lead to more competitive quotes, lowering the intraday bid-ask bounce, which in turn decreases intraday volatility as in Roll (1984).

Finally, the closing call auction eliminates the closing bid and ask prices and should lead to better price formation, both factors contributing to lower daily volatility.

We used two liquidity measures based on intraday prices. First, bid-ask spreads are estimated by using Roll's (1984) measure, based on the well-known bid-ask bounce. This measure, validated as a liquidity proxy by Goyenko *et al.* (2009), is usually estimated on daily prices. However, we make the most of intraday prices by estimating Roll's (1984) measure on five-minute interval prices, which should deliver a better measure of the bid-ask spread[2]. Calling ΔP_k the difference between the last prices of intervals k and $k-1$, the bid-ask spread is proxied as follows:

$$BID\_ASK\_SPREAD_{di} = 2\sqrt{cov\left(\Delta P_{k,di}, \Delta P_{k-1,di}\right)} \tag{3}$$

The proportional bid-ask spread was then calculated normalizing (3) by the average of the five-minute interval prices P_k on day d.

Second, we estimated the price impact based on the measure of Hasbrouck (2009), already used in previous microstructure studies in BVC (Agudelo 2011). This measure was calculated as the slope P_Impact_{di} of the regression of returns against net trading imbalances, both measured in five-minute periods, estimated at the stock-day level as follows:

$$r_{k,di} = P\_Impact_{di} \times S_{k,di} + a_{di} + \varepsilon_{k,di} \tag{4}$$

The net trading imbalance was defined as $S_{k,di} = \sum_t sign\left(V_{t,k,di}\right)\sqrt{P_{t,k,di} \times \left|V_{t,k,di}\right|}$, where $V_{t,k,di}$ represents the signed volume of trade "t" on the interval k, and $P_{t,k,di}$ the corresponding price. A positive (negative) $S_{k,di}$, indicating a net buying (selling) pressure, is expected to cause a positive (negative) intraday return $r_{k,di}$. Therefore, P_Impact_{di} is a measure for the average effect of trading imbalance on prices. This procedure requires the identification of each transaction as a buy or a sell, depending on the incoming market or marketable limit order, which can be found from the BVC order databases for both before and after X-Stream start.

A positive effect on liquidity, measured by lower bid-ask spreads and price impact, is expected from X-Stream for the following three reasons:

(1) matching at the current price, rather than at the new price, represents lower price impact for orders larger than the quote depth;

(2) an increased speed of execution might increase competition between liquidity providers, leading to lower bid-ask spreads; and

(3) as an indirect effect: if X-Stream lowers volatility and increases trading activity, this should benefit liquidity. Ho and Stoll (1981) and Grossman and Miller (1988) microstructure models imply that lower volatility and higher market activity reduces inventory costs for agents. Those relations have been widely supported in previous empirical studies in USA (Chordia *et al.*, 2001; Grullon *et al.*, 2004) and Colombia (Agudelo 2011).

Market activity, measured by the daily number of trades by stock, $NTRADES_{id}$, should have benefited from X-Stream, for the three following reasons:

(1) Closing and opening call auctions should more efficiently gather the supply and demand of a given stock, leading to more trades. This effect should be better for stocks classified as low liquidity and for the less traded high-liquidity stocks.

(2) Dropping the 20-second window and eventual microauction allows for more frequent trading in the continuous market.

(3) Higher liquidity should attract more trading, especially from short-term strategies.

Two intraday databases were provided by BVC for this study: The transaction database from January 2007 to December 2010, and the order database, from October 2008 to June 2009. The BVC transaction database compiles individual trades, with the name of the stock, price, volume and execution order, and is used for measuring the effect of X-Stream on market activity. In turn, the BVC order database compiles every entry, deletion, modification and matching of orders in the market, including time, quantity, price (not for market orders), type of duration and type of execution. From this database, it is possible to learn the exact time for any trade, as well as to classify the trade as a buy (sell), if the new order was a buy (sell) and the outstanding order a sell (buy)[3].

From both databases, subscription rights and other special securities were deleted, for a total of 41 stocks. Due to thin trading other stocks were discarded. Finally, intraday volatility and liquidity measures were estimated to 25 high-liquidity stocks, whereas trading activity and daily volatility models were run for 28 stocks, 22 classified as high liquidity and six as low liquidity. Since X-Stream started on February 9, 2009, we define a "preX-Stream" three-month period from November 1, 2008 to January 1, 2009, a "transition" period, from February 1 to March 8, 2009, and a "X-Stream" three-month period, from March 9 to June 9, 2009. The "transition" period was suggested by BVC to account for the learning and adaptation process to the new transaction platform.

Results

Effects on volatility

To measure the effect of X-Stream on intraday volatility, five-minute return standard deviation (1) and the normalized max-min price range (2) are calculated at daily frequency for the selected stocks in both periods considered. Table II compares the averages of the intraday volatility measure (1) for each of the 25 stocks on both periods. We also include the means for the set of 25 stocks in the last row. Using a simple *t*-test for mean-difference, we investigated whether the averages are significantly different between the two periods.

The results in Table II show that for 14 out of 25 stocks and for the overall set, intraday volatility, measured as the five-minute return standard deviation, decreased after X-Stream start, significantly increasing only for one stock. This effect is apparent not only in some of the most traded stocks as ECOPETROL, BCOLOMBIA, ISA and GRUPOSURA, but also in some of the least traded high-liquidity stocks in the PreX-Stream sample, such as TABLEMAC, CORFICOLCF, CHOCOLATES, BVC, PFBCREDITO, BOGOTA and ENKA.

The results of the intraday volatility measured by the max-min range (2) are not presented for brevity but are available upon request. These results are qualitatively similar to those in Table II. The max-min range, significantly decreased upon X-Stream for the overall set of stocks, as well as individually for 12 out of 25, and did not increased significantly for any. This effect was more significant for seven of the most traded stocks in the preX-Stream sample.

Since there is a well-known positive relationship between volatility and trading activity (Jones *et al.*, 1994) the decrease on intraday volatility upon X-Stream can be

Stock	Before X-Stream (November 1, 2008-January 31, 2009) Total number of trades	Number of trading days	Average intraday volatility (%)	X-Stream (March 9-June 9, 2009) Total number of trades	Number of trading days	Average intraday volatility (%)
ECOPETROL	33,849	54	0.25	16,903	61	0.17***
PFBCOLOM	9,336	54	0.34	7,510	61	0.18
BCOLOMBIA	3,603	53	0.38	1,855	60	0.30***
ISA	3,357	54	0.43	2,583	61	0.35**
GRUPOSURA	3,011	54	0.42	2,137	61	0.30***
FABRICATO	3,009	54	0.69	3,247	61	0.48
ISAGEN	2,377	54	0.42	5,608	61	0.24
CEMARGOS	2,306	54	0.59	1,598	60	0.39***
EXITO	2,027	50	0.46*	937	61	0.53
INVERARGOS	1,841	53	0.55	1,140	61	0.49
ETB	1,502	53	0.54	4417	61	0.34
GRUPOAVAL	1,249	54	0.86	2,088	61	0.52***
COLTEJER	1,225	53	0.84	1,070	60	0.78
INTERBOLSA	1,179	54	1.17	780	47	0.87*
BNA	1,096	51	0.53	868	38	0.62
COLINVERS	890	49	0.52	979	59	0.48
TABLEMAC	756	45	0.96	2,146	60	0.70**
CORFICOLCF	706	50	0.65	582	58	0.51*
CHOCOLATES	658	47	0.60	579	59	0.42**
BVC	618	44	1.06	1,099	50	0.72**
PFBCREDITO	400	42	1.04	454	53	0.53***
BOGOTA	340	40	0.90	419	53	0.49***
ENKA	173	12	3.15	256	30	1.16**
VALOREM	125	14	1.29	246	24	1.15
MINEROS	87	6	1.84	115	17	0.78
Overall			0.82			0.54***

Table II.
Intraday volatility before and after X-Stream, measured as the intraday standard deviation (1)

Note: *,**,***If the average volatility is statistically significantly lower than the average for the other period, using a non-paired *t*-test (paired for the overall test) at significance levels of 10, 5 and 1 percent, respectively

explained by a lower trading activity on the continuous market. This could be a plausible explanation for the most actively traded stocks many of which presented fewer operations for the continuous market (Table II), to some extent attributable to a migration of trading to the closing call auction. However, that is not the case for the least traded stocks in Table II since most of them reported more trades in the X-Stream period. Consequently, this analysis is complemented by modeling the daily volatility with closing and opening prices as follows[4].

Following Liu and Zhu (2009) an ARMA(1,0)-GARCH(1,0) model on daily returns is estimated for individual stocks, using alternatively open and closing prices[5]. To estimate the X-Stream effect, we included dummies both in the mean and the variance equations, with a value of zero before the X-Stream starting date (February 9, 2009), and one afterwards. Table III presents the results of the coefficients for the variance equation of the models estimated on closing price returns. The results suggest that X-Stream is significantly associated to a reduction of daily volatility for 19 out of 22 high-liquidity stocks, and in no case associated to a significant increase.

	Variance equation			
	Dummy	Constant	ARCH(1)	Number of daily returns
High-liquidity stocks				
BCOLOMBIA	−1.619***	-6.930***	0.140	159
BOGOTA	−1.687***	−7.268***	0.0894	157
BVC	−0.522**	−7.120***	0.0954	152
CEMARGOS	−1.449***	−7.094***	0.222	159
CHOCOLATES	−1.624***	−7.771***	0.103	159
COLINVERS	0.0220	−8.800***	0.699***	158
COLTEJER	0.181	−9.181***	0.600*	159
CORFICOLCF	−0.896***	−7.783***	0.149	158
ECOPETROL	−1.434***	−7.693***	0.258*	159
ENKA	−1.792	−5.458***	−0.00846***	124
ETB	−0.995***	−7.860***	0.278*	159
EXITO	−0.202	−8.251***	0.448**	158
FABRICATO	−0.963***	−7.029***	0.238	159
GRUPOSURA	−1.742***	−7.502***	0.334***	159
INTERBOLSA	−0.659***	−8.106***	0.0808	159
INVERARGOS	−1.247***	−7.203***	0.0298	159
ISA	−0.964***	−8.033***	0.329**	159
ISAGEN	−1.573***	−7.661***	0.200	159
PFBCOLOM	−1.496***	−6.870***	0.131	159
PFBCREDITO	−1.491***	−7.336***	0.196*	156
TABLEMAC	−0.896***	−6.643***	0.247*	158
VALOREM	−0.709***	−6.799***	0.111	129
Low-liquidity stocks				
BBVACOL	0.412	−6.587***	0.0358	57
ODINSA	3.481	−6.233	0.545**	64
PAZRIO	0.423	−6.064***	−0.0198	118
PFCORFICOL	1.216***	−8.757***	0.783*	77
PROMIGAS	0.178	−7.671***	0.331*	73
VILLAS	2.363***	−6.829***	0.192*	75

Notes: Only results for the variance equations are shown, those for the mean equation are omitted. *,**,***Statistically significant at 10, 5 and 1 percent level, respectively

Table III.
Effect of X-Stream on daily volatility using a AR(1)GARCH(1,0) model on daily returns based on closing prices

The corresponding results for opening price return, available upon request, show statistically significant reductions on volatility for 24 out of 25 high-liquidity stocks after the start of X-Stream. The drop on the closing price daily volatility for high-liquidity stocks is likely associated to the introduction of the closing call auction. In turn, the drop of opening price daily volatility is not related to any call auction, but to the improved matching on the continuous market, since high-liquidity stock trading opens with no call auction.

In contrast, none of the six low-liquidity stocks show a negative significant effect of X-Stream on the variance in Table III and, in fact, two report a significant positive effect. Similar results are obtained in the opening price volatility models (omitted).

Two robustness tests are run on the volatility results[6]. First, the decrease on stock volatility after the X-Stream start could be explained by the overall decrease in stock market volatilities around the world after the volatility peak associated to the

Lehman Brothers bankruptcy on September 2008. To control for this, the time series ARMA(1,0)-GARCH(1,0) are re-estimated including the VIX variable on the conditional variance equation. VIX, a volatility index calculated by the Chicago Board of Exchange, is an average measure of implicit volatility for SP500 options for 30 days and is widely used as a measure of worldwide stock market volatility. In the omitted results, available upon request, 19 out of 22 stocks present a negative effect of the X-Stream dummy on closing price daily volatility, statistically significant for 13 of them, in spite of a very strong effect of VIX on the variance for 21 stocks. Finally, we examined the upside bias on volatility estimation possibly resulting from the minimum tick, especially for stocks with low price-to-minimum-tick ratio and low intraday volatility (Gottlieb and Kalay, 1985). In a separated analysis, available upon request, we used Gottlieb and Kalay's (1985) results along with the estimated intraday volatilities (1) and the minimum ticks on BVC, which depend on the range of prices. We found that the effect of the minimum tick on the intraday volatility is negligible and does not qualitatively alter the results reported above.

Effects on liquidity

Tables IV and V present the results for the two liquidity measures of the samples before and after X-Stream, the bid-ask spread estimated on five-minute trading prices by Roll's (1984) measure (3) and the dynamic price impact (4) based on Hasbrouck (2009). Table IV presents a reduction of the proportional bid-ask spread statistically significant at the 5 percent confidence level for the overall set and for 11 individual stocks, suggesting an improvement of liquidity after the starting of X-Stream. It is interesting to note the significant increase of liquidity on five stocks, including in the top most traded stocks of the preX-Stream sample, in spite of an important reduction of trades on the continuous market.

In turn, the results of the average price impact in Table V suggest an important reduction on the overall sample, but one that is not statistically significant. The results for individual stocks show a statistically significant decrease in 11 out of 25 stocks and no significant increase on any stock. Once more, the reduction of price impact on three of the most actively traded stocks – PFBCOLOM, BCOLOMBIA and GRUPOSURA – in spite of the contemporaneous drop in the number of trades on the continuous market is remarkable.

The strong association between trading activity and liquidity can be appreciated in Tables IV and V, as a more actively traded stock tends to have lower proportional bid-ask spreads and price impact, a well-known relation in the literature (Chordia *et al*, 2001). Therefore, an improvement on liquidity upon X-Stream can be attributed to a contemporaneous increase in trading activity, if only for the least traded high-liquidity stocks. To investigate this, the two liquidity measures are regressed in a panel data at the day-stock level to measure the effect of the X-Stream while controlling by trading activity, measured by the number of trades. Similar models have been used for Grullon *et al.* (2004) on US stocks. The panel data model is the following:

$$X_{id} = \alpha + \beta_1 \log(NTRADES_{id}) + \beta_2 VOLAT_{id} + \beta_3 RETURN_{id} + \beta_3 D_{\geqslant 9\ Feb\ 2009} + \mu_i + \varepsilon_{id} \quad (5)$$

where X_{id} is either of the two liquidity measures for stock i on day d: the proportional bid-ask spread or the log of the price impact. As controls, we included the number of trades, $NTRADES_{id}$, the continuous daily return $RETURN_{id}$, and as a measure of

Stock	Before X-Stream (November 1, 2008-January 31, 2009) Total number of trades	Number of observations	Average proportional bid-ask spread (%)	X-Stream (March 9-June 9, 2009) Total number of trades	Number of observations	Average proportional bid-ask spread (%)
ECOPETROL	33,849	53	0.24	16,903	60	0.18*
PFBCOLOM	9,336	36	0.35	7,510	54	0.16***
BCOLOMBIA	3,603	38	0.36	1,855	46	0.29*
ISA	3,357	42	0.37	2,583	59	0.38
GRUPOSURA	3,011	39	0.33	2,137	50	0.30
FABRICATO	3,009	44	0.67	3,247	50	0.49**
ISAGEN	2,377	47	0.39	5,608	57	0.24***
CEMARGOS	2,306	34	0.58	1,598	43	0.39**
EXITO	2,027	37	0.45**	937	54	0.59
INVERARGOS	1,841	41	0.49	1,140	53	0.52
ETB	1,502	40	0.58	4,417	53	0.34***
GRUPOAVAL	1,249	39	1.03	2,088	43	0.56**
COLTEJER	1,225	50	0.88	1,070	53	0.68
INTERBOLSA	1,179	44	1.21	780	38	0.77*
BNA	1,096	44	0.58	868	33	0.52
COLINVERS	890	39	0.48	979	54	0.47
TABLEMAC	756	30	0.81	2,146	39	0.69
CORFICOLCF	706	43	0.61	582	45	0.50
CHOCOLATES	658	41	0.53	579	45	0.52
BVC	618	32	1.03	1,099	39	0.59*
PFBCREDITO	400	37	0.85	454	49	0.41***
BOGOTA	340	31	0.79	419	46	0.45
ENKA	173	10	1.85	256	25	1.22
VALOREM	125	14	0.36	246	20	0.82
MINEROS	87	5	0.00**	115	14	0.95
Overall		25	0.63		25	0.52**

Note: *,**,***If the average proportional bid-ask spread is statistically significantly lower than the average for the other period, using a non-paired *t*-test (paired for the overall test) with significance levels of 10, 5 and 1 percent, respectively

Table IV.
Bid-ask spreads before and after X-Stream, measured as the Roll's (1984)measure (3)

volatility, $VOLAT_{id}$, the max-min range of intraday prices, calculated as in (2). Including volatility in the model should control for the decrease of stock market volatility upon the Lehman Brother bankruptcy in September 2008. We included a dummy variable, $D_{\geqslant 9 \text{ Feb } 2009}$, to test for the effect of X-Stream. This model was estimated for 20 high-liquidity stocks and also separately for the ten most traded and ten less traded stocks.

The results of model (5) are presented in Table VI. The measures of trading activity and volatility present highly significant coefficients, with the expected signs, consistent with the theory and previous empirical studies (for further details see Agudelo, 2011). On the other hand, the return presents the expected negative coefficient for the three bid-ask spread models, but not for the price impact models.

Interestingly, the results of the dummy variable suggest that the start of X-Stream is related to an improvement on liquidity, shown by a negative sign of the dummy in all the three samples. The corresponding effects are significant at least at the 5 percent

Stock	Antes X-Stream (November 1, 2008 a 31-January-09) Total number of trades	Number of observations	Average dynamic price impact (%)	En X-Stream (March 9 a June 9, 2009) Total number of trades	Number of observations	Average dynamic price impact (%)
ECOPETROL	33,849	54	0.003	16,903	61	0.003
PFBCOLOM	9,336	54	0.007	7,510	61	0.005***
BCOLOMBIA	3,603	53	0.020	1,855	60	0.013*
ISA	3,357	54	0.023	2,583	61	0.016
GRUPOSURA	3,011	53	0.020	2,137	61	0.008***
FABRICATO	3,009	54	0.036	3,247	61	0.019***
ISAGEN	2,377	54	0.037	5,608	61	0.011***
CEMARGOS	2,306	53	0.022	1,598	60	0.015
EXITO	2,027	50	0.027	937	61	0.016
INVERARGOS	1,841	53	0.030	1,140	57	0.023
ETB	1,502	53	0.054	4,417	61	0.013***
GRUPOAVAL	1,249	53	0.143	2,088	61	0.028**
COLTEJER	1,225	50	0.085	1,070	59	0.035***
INTERBOLSA	1,179	53	0.021	780	41	0.045
BNA	1,096	48	0.015	868	30	0.041
COLINVERS	890	46	0.016	979	58	0.012
TABLEMAC	756	41	0.086	2,146	60	0.035*
CORFICOLCF	706	46	0.066	582	54	0.032**
CHOCOLATES	658	43	−0.013	579	56	−0.022
BVC	618	38	0.217	1,099	48	0.042*
PFBCREDITO	400	36	0.061	454	42	0.054
BOGOTA	340	33	−0.023	419	47	0.145
ENKA	173	9	1.425	256	24	0.359
VALOREM	125	6	0.210	246	20	0.095
MINEROS	87	3	−0.205	115	9	0.127
Overall.		25	0.095		25	0.047

Table V.
Price impact before and after X-Stream, measured as the dynamic price impact of Hasbrouck (2009) measure (4)

Note: *,**,***If the average dynamic price impact is statistically significantly lower than the average for the other period, using a non-paired *t*-test (paired for the overall test) with significance levels of 10, 5 and 1 percent, respectively

Sample	Proportional bid-ask spread, by Roll's (1984) measure (3) 20 stocks	10 more actively traded	10 less actively traded	Log of Dynamic price impact by Hasbrouck (2009) measure (4) 20 stocks	10 more actively traded	10 less actively traded
log($NTRADES_{id}$)	−0.00213***	−0.00179***	−0.00245***	−0.90***	−0.82***	−1.09***
$VOLAT_{id}$	0.240***	0.151***	0.318***	29.7***	23.4***	36.3***
$RETURN_{id}$	−0.006**	0.001	−0.005*	−0.20	2.78*	−0.24
$D_{\geqslant 9\ \text{Feb}\ 2009}$	−0.05%**	−0.05%**	−0.12%***	−42%***	−48%***	−41%***
Panel data	Fixed effects	Fixed effects	Fixed effects	Random effects	Random effects	Random effects
n	1,771	923	848	1,773	1,019	754
R^2	0.279	0.255	0.330	0.430	0.505	0.277

Table VI.
X-Stream effect on panel data regressions (5) of daily liquidity measures

Note: *,**,***Statistically significant at levels of 10, 5 and 1 percent, respectively

level and their economic magnitude is important. Specifically, X-Stream is related to a decrease of between 0.05 and 0.12 percent on the average proportional bid-ask spread and about half on the price impact. This reduction on liquidity is observed even after controlling for the above reported higher trading activity and lower volatility in some stocks, which in turn contributed to improving liquidity (Table VI).

Effects on trading activity

Finally, to estimate the effect of X-Stream on trading activity, for each stock a Kolmogorov-Smirnoff test (K-S) was applied on the distribution of daily number of trades, $NTRADES_{id}$, for both samples, before and after X-Stream. Each distribution includes the trades on the opening (for low-liquidity stocks) and closing call auctions. The null hypothesis posits that both samples come from the same distribution; therefore, a rejection of the null implies a structural change in trading activity brought by the start of X-Stream. The results, omitted for the sake of brevity and available upon request, show that seven of the high-liquidity stocks show a statistically significant increase in trading activity upon X-Stream, four of them being the highly traded BCOLOMBIA, ECOPETROL, GRUPOSURA and INVERARGOS. On the other hand, seven stocks presented a statistically significant reduction in number of trades: BOGOTA, ETB, GRUPOAVAL, ISAGEN, TABLEMAC and VALOREM, five of them are some of the least traded high-liquidity stocks of the market. In all the other cases, including low-liquidity stocks, the tests are inconclusive. Summarizing, the K-S test suggests that, in terms of trading activity, X-Stream might have caused some trading migration within the high-liquidity stocks, from the least traded to the most traded.

Conclusions

This study presents compelling evidence of an improvement on the market quality of the Colombian stock market associated to the introduction of the trading platform X-Stream. This included lower intraday and daily volatilities, higher trading activity, as well as higher liquidity, measured as lower bid-ask spreads and price impact. The impact of the new platform is particularly strong in high-liquidity stocks. These results are robust to alternative measures of market quality and to different models that control for the effect of confounding factors. We identify clear gains from X-Stream over the former trading platform, such as the higher order execution speed, a more transparent price formation, lower manipulation of closing price, and more flexibility to execute trading strategies that likely explain the gains on market quality. Nevertheless, there is evidence of trading migration from some of the less traded high-liquidity stocks to the most traded ones. In turn, the market quality measures for low-liquidity stocks, to the extent they could be tested, present no significant improvement from X-Stream.

The results of this study contribute to the market microstructure literature as a case in which an important overhaul of the trading platform leads to better market quality. Most significantly, those positive effects are reported in a small emerging market, unlike the previous literature. For emerging stock exchanges, this paper is a case study that documents and provides a methodology to measure the gains derived from investing in modernizing trading platforms. Specifically, the improvement of liquidity leads to transaction cost savings for the market participants, especially for those that demand liquidity with market orders, as well as for institutional investors, because of their large trade sizes.

Notes

1. The link between trading activity and market quality has been explored by Chordia *et al.* (2011) for US stock markets.
2. Goyenko *et al.* (2009) calculated the Roll's (1984) measure based on daily closing prices. Doing it at five-minute intervals should be more efficient not only because of more frequent sampling, but also for discarding the noisy effect of the day-to-day jump in prices.
3. To the extent of our knowledge, for the period of interest, there is not a comprehensive database of trades and quotes for the Colombian stock market similar to TAQ in US markets, which allows for measuring the intraday bid-ask spread. Since 2011, Bloomberg offers such an intraday database for Colombia, but it can be accessed for the last six months only.
4. We acknowledge the existence of more elaborate models that allow a better estimation of intraday volatility, as the stochastic volatility models discussed in Alizadeh *et al.* (2002), and ter Horst *et al.* (2012). However, we stick to the models used in our study because they have been used in previous market quality studies (see, e.g. Liu and Zhu, 2009). Using the same models allows our results to be directly compared with those of similar studies in other countries. Moreover, the robustness tests conducted suggest that our results are robust to the volatility measure employed.
5. Initially, we selected stocks that four months before and four months after X-Stream started (allowing for the one-month transition period) had traded at least in 100 days. For non-trading days the last price was assumed. Finally, after stability and goodness-of-fit tests, the models based on close (open) prices could be estimated for 22 (25) high-liquidity and 6 (6) low-liquidity stocks.
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