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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

We study the effect of X-Stream, the new trading platform of the Colombian Stock Exchange since February 2009, on the quality of the stock market. 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. Starting from a proprietary database of transactional and order data from BVC, we use several econometric models to measure the effect of the new platform on daily and intraday volatility, liquidity (proportional bid-ask spread and price impact), and trading activity. The evidence suggests that X-Stream improved the liquidity and reduced the volatility of the overall market, especially of the most liquid stocks. These results support the investment on more sophisticated trading systems in Emerging Markets.

JEL: G10, G15, G19

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

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1. Introduction

On February 9, 2009, *Bolsa de Valores de Colombia* (BVC), the Colombian stock exchange, launched X-Stream; a stock trading platform, aimed to provide a faster, safer and more transparent operation. X-Stream replaced a very limited electronic platform operating since BVC begun on July 2001. X-Stream included several new features, including Call auctions for market closing, distinction between market and order limits, immediate order matching and volatility call auctions. It also replaced the continuous market for low liquidity stocks with two call auctions. Additionally, X-Stream offered increased operative efficiency, order processing capability, reliability and execution speed. Continuing with 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 on 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, Harris and Spatt, 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 on 2011, with Mexico projected to join 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 in 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 measure market quality variables such as liquidity, daily and intraday volatility and trading activity, before and after X-Stream started. The evidence suggests that X-Stream improved the liquidity 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 the former. The third section provides a theoretical background for market quality and discusses the most relevant empirical studies. The fourth section describes the methodology, and data used to empirically evaluate the impact of X-Stream on the market quality of BVC. The fifth section presents and explains the results and discusses some of the robustness tests performed on these results. Finally, the sixth section concludes.

2. 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 one, henceforth called preX-Stream, and the new trading platform, X-Stream, which replaced the former on February 9, 2009. Table 1 summarizes and compares the main features of both platforms.

PreX-Stream was essentially an order entry and matching electronic system. Every stock was traded in an order-driven continuous market without call auctions. Moreover, preX-Stream only allowed for limit orders. No other types, including market orders, were allowed (Author 2011). 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 ($P_1 \geq P_2$) and matching took place at 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 best outstanding order was not enough.

Moreover, matching did not occur immediately. Once an incoming order arrived the system started a 20 second microauction (provided that the order was compatible with one or a group of outstanding orders). The microauction allowed for a new incoming order to offer a better price in 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 were, matching took not less than 20 seconds and matching could not be guaranteed if a more aggressive order arrived in the 20 second window.

Pre-X-Stream also provided for cross trades, which allow a broker to execute simultaneously 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 for a temporary trading halt for changes in the price above or below 10% 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 1. X-Stream provides different trading setting for stocks classified as high and low liquidity. High liquidity stocks are traded in a continuous market, ended with a 5 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. It also allows defining 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, any incoming market or marketable limit order does not concede 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 2½ minute, a “volatility call auction” is started temporarily stopping the continuous market, 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 the stock or the entire market.

3. 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 focused on volatility and liquidity. (Chordia, Roll, and Subrahmanyam, 2001; Pagano, Peng and Schawrtz; 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 (Ozenbad, Schwartz and Wood, 2002). In other words, trading by itself creates volatility (Jones, Gautam, and Lipson; 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 turns means lower price impact for large orders. Higher liquidity is also related to higher resiliency: the quick reversion of temporary pricing disturbances not related to new information (Pastor and Stambaugh, 2003). Consequently, high liquidity mitigates transitory volatility making prices more informative (Hasbrouck, 2002) and more efficient (Chordia, Roll, and Subrahmanyam, 2008). Although liquidity is a multidimensional concept, the literature has focused on the proportional bid-ask spread and the price impact, being the best measures those based on transaction data. (Goyenko, Holden and Trczinka, 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 than 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 market design 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.

[1] The link between trading activity and market quality has been explored by Chordia, Roll and Subrahmanyam (2011) for US stock markets.

Regarding to the introduction of closing call auctions, the empirical study of Ko, Lee, and Chung (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 Schawrtz (2003), studying the stock option market on 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), not only reports an improvement on market quality on London Stock Exchange after the introduction of closing call auction, but also finds that the least active stocks experience the largest gains in market quality. Similar results have been reported for Singapore Exchange (Chang, Rhee, Stone and Tang; 2008), Borsa Italiana and Paris Bourse (Kandel, Rindi and Bossetti; 2011), and NASDAQ (Pagano, Peng and Schawrtz; 2013). On the contrary, Camilleri and Green (2004) present evidence on the reduction of volatility and improvement of efficiency and liquidity on 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 leads to higher opportunity costs. Higher execution speeds enhance the efficiency of price formation (Boehmer and Kelley, 2009). The faster the trading mechanisms, the more transparent the price formation is (Barclay, Hendershott, and McCormick, 2003). As for empirical studies, Riordan and Storkenmaier (2012), find that increasing trading speed in Deutsche Boerse reduced bid-ask spread and made prices more efficient, especially in small and medium size stocks. On the contrary, Hendershott and Moulton (2011) present 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, there is no previous empirical study testing 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.

4. Methodology and data

To test for the effect of X-Stream on BVC stock market quality the following variables will be 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 (Benett and Wei 2006, Liu and Zhu 2009, Pagano and Schwartz 2003).

The effect of X-Stream on daily volatility is tested on ARMA-GARCH models for daily returns at stock level. For those models, daily returns were calculated from both closing and opening prices. Intraday volatility on the continuous market is measured for stocks classified as high liquidity; this is, excluding the closing price on X-Stream. Intraday volatility is measured in two alternative ways. First, as the standard deviation of 5-min interval returns $r_{k,di}$ in a given day *d*, for a stock *i*:

$$INTRADAY\ VOLAT_{di} = \sigma(r_{k,di}) \qquad [1]$$

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

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

We expect a reduction of the volatility of the Colombian stock market after the implementation of X-Stream for the following four reasons: a) Matching at the current price, rather than at the new price, should reduce price variations coming from large orders, b) immediate matching, instead of the 20 second microauction, should allow for small orders to be more frequently matched at quotes. c) 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, d) 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 use two liquidity measures based on intraday prices. First, bid-ask spreads are estimated by using Roll's (1984) measure, based on the well-known bounce of prices between ask and bid prices. This measure, validated by Goyenko et al (2009) as a proxy of liquidity, is usually estimated on daily prices. However, we make the most of intraday prices by estimating Roll's (1984) measure on 5 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:

$$BID\_ASK\_SPREAD_{di} = 2\sqrt{cov(\Delta P_{k,di}, \Delta P_{k-1,di})} \qquad [3]$$

The proportional Bid-Ask Spread is then calculated normalizing [3] by the average of the 5-min interval last prices P_k on day d .

Secondly, we estimate the price impact based on the measure of Hasbrouck (2009), already used in previous microstructure studies in BVC (AUTHOR 2011). This measure is calculated as the slope P_Impact_{di} of the regression of returns against net trading imbalances, both measured in 5 minute periods, estimated at the stock-day level as follows:

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

The net trading imbalance is defined as $S_{k,di} = \sum_t sign(V_{t,k,di})\sqrt{P_{t,k,di} \times |V_{t,k,di}|}$, 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 positive (negative) intraday returns $r_{k,di}$.Therefore, P_Impact_{di} is a measure for the average effect of trading imbalance on prices. This procedure requires identifying whether a transaction is 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.

[2] Goyenko et al (2009) calculated the Roll's (1984) measure based on daily closing prices. Doing it at 5 minute intervals should be more efficient not only for more frequent sampling, but also for discarding the noisy effect of day-to-day jump on prices.

A positive effect on liquidity, associated with lower bid-ask spreads and price impact, is expected from X-Stream for the following three reasons: a) Matching at the current price, rather than at the new price, represents lower price impact for orders larger than the quote depth. b) Increased speed of execution might increase competition between liquidity providers, leading to lower bid ask-spreads. c) 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 US (Chordia, Roll and Subrahmanyam, 2001; Grullon, Kanatas and Weston, 2004) and Colombia (Author 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: a) 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. b) Dropping the 20-second window and eventual microauction allows for more frequent trading in the continuous market. c) Higher liquidity should attract more trading, especially from short-term strategies, due to the reduction of costs.

Two intraday databases have been supplied 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 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 is possible to learn the exact time for any trade took place 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 6 as low liquidity. Since X-Stream started on February 9, 2009, we define a "preX-Stream" three-month period from November, 1, 2008 to 31 January, 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 adapting to the new transaction platform.

5. Results.

Effects on volatility

To measure the effect of X-Stream on intraday volatility, 5-min 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 1 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

[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, that allows measuring the intraday bid-ask spread. Since 2011, Bloomberg offers such an intraday database for Colombia, but can be accessed for the last six months only.

simple t-test for mean-difference, we investigate if the averages are significantly different between the two periods.

[Insert Table 1]

Results in table 1 show that for 14 out of 25 stocks and for the overall set, intraday volatility, measured as the 5-min return standard deviation, decreased after X-Stream start, significantly increasing only for one stock. This effect is particularly noticeable 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 Pre-X-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 of Table 1. 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 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 1), to some extent attributable to a migration of trading to the closing call auction. However, that's not the case for the least traded stocks in Table 1 since most of them reported more trades on 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 both open and closing prices[5]. To estimate the X-Stream effect, we include 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 2 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. The corresponding results for opening price returns are available upon request. Those results 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 and cannot be explained by the reduction of trading activity on the continuous market for some of those stocks. 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, and neither can be explained by lower trading activity on the continuous market.

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[4]. We acknowledge the existence of more elaborate models that allow a better estimation of intra-day volatility, as the stochastic volatility models discussed in Alizadeh, Brand and Diebolt (2002) and Ter Hortes, Rodriguez, Gzyl and Molina (2012). However, we stick to the models used in our study because they have been used in previous market quality studies (see, for example, 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.

In contrast, none of the six low liquidity stocks show a negative significant effect of X-Stream on the variance in table 2, on the contrary, two report a significant positive effect. Similar results are obtained on the opening price return models (omitted).

[Insert Table 2]

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 volatility peak of 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 short run. In 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 to qualitatively alter the results reported above.

Effects on liquidity

Tables 3 and 4 present the results for the two liquidity measures on the samples before and after X-Stream, the bid-ask spread estimated on 5-minute trading prices by the Roll's measure (1984) [3] and the Dynamic Price impact [4] based on Hasbrouck (2009). Table 3 presents a reduction on the proportional bid-ask spread statistically significant at the 5% for the overall set and for 11 individual stocks, suggesting an improvement of liquidity after the starting of X-Stream. It's interesting to note the significant increase of liquidity on 5 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.

[Insert Table 3]

In turn, the results of the average price impact in table 4 suggest and important reduction on the overall sample, but 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, it's remarkable the reduction of price impact on three of the most actively traded stock such as PFBCOLOM, BCOLOMBIA and GRUPOSURA, in spite of the contemporaneous drop on the number of trades on the continuous market.

[Insert Table 4]

[6] We thank both anonymous referees for each of these suggestions.

The strong association between trading activity and liquidity can be appreciated on tables 3 and 4, as a more actively traded stock tend to have lower proportional bid-ask spreads and price impact, a well-known relation on the literature (Chordia et al 2002). Therefore, an improvement on liquidity upon X-Stream can be attributed to a contemporaneous increase on trading activity, at least for the less 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, Kanatas and Weston (2004) on US Stocks. The panel data model is the following:

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

Where X_{id} is either liquidity measure for stock i on day d, proportional bid-ask spread and the log of the price impact. As controls we include the number of trades, $NTRADES_{id}$, the continuous daily return $RETURN_{id}$, and as a measure of volatility, $VOLAT_{id}$, the max-min range of intraday prices, calculated as in [2]. We also include a measure of volatility controls for the decrease of stock market volatility after crash associated with the Lehman Brother bankruptcy on September 2008. We include a dummy variable, $D_{\geq 9\ Feb\ 2009}$, to test for the effect of X-Stream[7]. This model was estimated for 20 high liquidity stocks and also separately for the 10 most traded and 10 less traded stocks.

The results of model [5] are presented in Table 5. The measures of trading activity and volatility present highly significant coefficients, with the expected signs, consistent with the theory and previous empirical studies (see more detail on AUTOR 2010 and 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% level and their economic magnitude is important. Specifically, X-Stream is related to a decrease between 0,05% and 0,12% on the average proportional bid-ask spread (against a 0,63% overall average in table 3), and to decrease to half on the price impact. This reduction on liquidity is observed even after controlling for the higher trading activity and lower volatility in some stocks, which in turn contributed to improve liquidity.

[Insert Table 5]

Effects on trading activity

Finally, to estimate the effect of X-Stream on trading activity, for each stock a Kolmogorov-Smirnoff test (K-S) is 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 on 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 on trading activity upon X-Stream, four of them the highly traded BCOLOMBIA, ECOPETROL, GRUPOSURA and INVERARGOS. On the other hand, seven stocks presented a statistically significant reduction on number of trades: BOGOTA, ETB, GRUPOAVAL, ISAGEN, TABLEMAC and VALOREM, five of them are some of the less traded high-

[7] Hausman test is used for the null hypothesis of random effects against the alternative of fixed effects.

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 less traded to the more traded.

6. Conclusions

This study presents compelling evidence of an advance on the market quality of the Colombian stock market associated to the introduction of the trading platform X-Stream. The market quality improvement 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 employed which control the effect of confounding factors. Nevertheless, there is evidence of trading migration from some of the less traded high liquidity to the most traded ones. As for the market quality measures for low liquidity stocks, to the extent they could be tested, present no significant improvement from X-Stream. 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. Likely, those features contributed to the gains on market quality.

The results of this study contribute to the market microstructure literature as a case in which an important overhaul of the trading platform that enhances competition and price formation 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 the 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.

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Table 1. Comparing former and current trading platforms in BVC

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 5-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.
It allows only limit orders, defining direction, quantity and price. 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 • 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.	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 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. It can be manipulated.	Closing price given by the 5-min 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: 3 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 2½ 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 1 . Intraday volatility before and after X-Stream, measured as the intraday standard deviation [1]

	Before X-Stream (Nov, 1, 2008 to Jan, 31, 2009)				X-Stream (March 9 to June 9, 2009)			
Stock	**Total number of trades.**	**Number of trading days**	**Average intraday volatility**		**Total number of trades.**	**Number of trading days**	**Average intraday volatility**	
ECOPETROL	33849	54	0,25%		16903	61	0,17%	***
PFBCOLOM	9336	54	0,34%		7510	61	0,18%	
BCOLOMBIA	3603	53	0,38%		1855	60	0,30%	***
ISA	3357	54	0,43%		2583	61	0,35%	**
GRUPOSURA	3011	54	0,42%		2137	61	0,30%	***
FABRICATO	3009	54	0,69%		3247	61	0,48%	
ISAGEN	2377	54	0,42%		5608	61	0,24%	
CEMARGOS	2306	54	0,59%		1598	60	0,39%	***
EXITO	2027	50	0,46%	*	937	61	0,53%	
INVERARGOS	1841	53	0,55%		1140	61	0,49%	
ETB	1502	53	0,54%		4417	61	0,34%	
GRUPOAVAL	1249	54	0,86%		2088	61	0,52%	***
COLTEJER	1225	53	0,84%		1070	60	0,78%	
INTERBOLSA	1179	54	1,17%		780	47	0,87%	*
BNA	1096	51	0,53%		868	38	0,62%	
COLINVERS	890	49	0,52%		979	59	0,48%	
TABLEMAC	756	45	0,96%		2146	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%		1099	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%	***

*, **, ***: 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 levels of 10%, 5% and 1%, respectively.

TAble 2. Effect of X-Stream on daily volatility using a AR(1)GARCH(1,0) model on daily returns based on closing prices.

	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

Only results for the variance equations are shown, those for the mean equation are omitted.
.*, **, ***: statistically significantly at levels of 10%, 5% and 1%, respectively

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

	Before X-Stream (Nov, 1, 2008 to Jan, 31, 2009)				X-Stream (March 9 to June 9, 2009)			
Stock	Total number of trades.	Number of observations	Average proportional bid-ask spread		Total number of trades.	Number of observations	Average proportional bid-ask spread	
ECOPETROL	33849	53	0,24%		16903	60	0,18%	*
PFBCOLOM	9336	36	0,35%		7510	54	0,16%	***
BCOLOMBIA	3603	38	0,36%		1855	46	0,29%	*
ISA	3357	42	0,37%		2583	59	0,38%	
GRUPOSURA	3011	39	0,33%		2137	50	0,30%	
FABRICATO	3009	44	0,67%		3247	50	0,49%	**
ISAGEN	2377	47	0,39%		5608	57	0,24%	***
CEMARGOS	2306	34	0,58%		1598	43	0,39%	**
EXITO	2027	37	0,45%	**	937	54	0,59%	
INVERARGOS	1841	41	0,49%		1140	53	0,52%	
ETB	1502	40	0,58%		4417	53	0,34%	***
GRUPOAVAL	1249	39	1,03%		2088	43	0,56%	**
COLTEJER	1225	50	0,88%		1070	53	0,68%	
INTERBOLSA	1179	44	1,21%		780	38	0,77%	*
BNA	1096	44	0,58%		868	33	0,52%	
COLINVERS	890	39	0,48%		979	54	0,47%	
TABLEMAC	756	30	0,81%		2146	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%		1099	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%	**

*, **, ***: 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) at levels of 10%, 5% and 1%, respectively.

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

	Antes X-Stream (1-nov-08 a 31-En-09)			En X-Stream (9-mar a 9-Jun-09)			
Stock	Total number of trades.	Number of observations	Average dynamic price impact	Total number of trades.	Number of observations	Average dynamic price impact	
ECOPETROL	33849	54	0,003%	16903	61	0,003%	
PFBCOLOM	9336	54	0,007%	7510	61	0,005%	***
BCOLOMBIA	3603	53	0,020%	1855	60	0,013%	*
ISA	3357	54	0,023%	2583	61	0,016%	
GRUPOSURA	3011	53	0,020%	2137	61	0,008%	***
FABRICATO	3009	54	0,036%	3247	61	0,019%	***
ISAGEN	2377	54	0,037%	5608	61	0,011%	***
CEMARGOS	2306	53	0,022%	1598	60	0,015%	
EXITO	2027	50	0,027%	937	61	0,016%	
INVERARGOS	1841	53	0,030%	1140	57	0,023%	
ETB	1502	53	0,054%	4417	61	0,013%	***
GRUPOAVAL	1249	53	0,143%	2088	61	0,028%	**
COLTEJER	1225	50	0,085%	1070	59	0,035%	***
INTERBOLSA	1179	53	0,021%	780	41	0,045%	
BNA	1096	48	0,015%	868	30	0,041%	
COLINVERS	890	46	0,016%	979	58	0,012%	
TABLEMAC	756	41	0,086%	2146	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%	1099	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%	

*, **, ***: 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) at levels of 10%, 5% and 1%, respectively.

Table 5. X-Stream effect on panel data regressions [5] of daily liquidity measures

	Proportional bid-ask spread, by Roll's measure (1984)			Dynamic Price Impact by Hasbrouck (2009)		
Sample:	20 stocks	10 more actively traded	10 less actively traded	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
$D_{\geq 9\ Feb\ 2009}$	-0,05% **	-0,05% **	-0,12% ***	-42% ***	-48% ***	-41% ***
Panel data:	Fixed effects	Fixed effects	Fixed effects	Random effects	Random effects	Random effects
N	1771	923	848	1773	1019	754
R^2	0,279	0,255	0,330	0,430	0,505	0,277