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Correlated Portfolio Inventory Risk of Liquidity Providers: Frictions and Market Fragility*

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1. The Academic and Policy Questions

Limit order book ("LOB") markets are now the dominant exchange structure for equity trading globally. Unlike affirmatively obliged old-world NYSE Specialists or London/NASDAQ market makers, the *de-facto* 'market-maker' in LOB markets emerges endogenously and voluntarily to provide liquidity to other traders; i.e., be ready and willing to buy when someone wants to sell a stock, and to sell when someone wants to buy a stock. We label such a *de-facto* 'market-maker' as a 'voluntary liquidity provider' (hereafter "VLP"). A VLP is, in aggregate, a net liquidity provider, trading on its own account with incoming buy and sell orders, bearing the risk of unbalanced inventory exposures, and earning the premium for doing so (Anand and Venkataraman, 2016; Menkveld, 2013; Glosten, 1994). The cost of providing liquidity depends largely on the risk of VLP inventory positions.

Typically, a VLP simultaneously participates in multiple securities. Ho and Stoll (1983) show that, for markets with multiple liquidity providers, possibly with heterogeneous beliefs, a VLP's trading and liquidity provision in a stock is a function of her *"equivalent portfolio inventory*" in that stock – rather than just her inventory in that stock. This *equivalent portfolio inventory* (hereafter "correlated portfolio inventory" or just "portfolio inventory") includes the effect of her correlated inventory risk exposures from the other stocks in her portfolio. This *equivalent portfolio inventory* is ***not*** the same as the unconditional sum of all stock inventories held. It is *stock-specific*, representing overall portfolio inventory after accounting specifically for the *correlations with that particular stock*.

Hence, a stock's liquidity would be a function not only of the liquidity providers' inventory in that stock, but also of their inventory in *other correlated* securities. The management of these liquidity providers' correlated portfolio inventories can arguably be a significant source of contagion-induced fragility in equity markets, since liquidity shocks in one security can propagate to another security through this channel.

1.1 The Academic Question

Notwithstanding the intuitive appeal of Ho and Stoll (1983), Naik and Yadav (2003a) – the only other study (to our knowledge) to examine market-making in the context of correlated portfolio inventories – find that market-maker firms in the old pre-1997 pure dealer market on the London

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Stock Exchange overlooked inventory risks in correlated securities at the overall firm level, and argued that this could be due to organizational agency costs, difficulties in real-time communication amongst the firm's traders in a telephone-based trading environment, and their affirmative obligation constraints to always stand ready to provide liquidity at the level of individual stocks. On the other hand, VLPs in today's LOB markets' are typically not constrained by affirmative obligations, and positions' data across stocks is continually accessible contemporaneously in real time. Hence, one should expect to find support for Ho and Stoll (1983) from a liquidity provision perspective at the trading unit level.

However, in view of the voluntary nature of market-making in today's LOB markets, VLPs could also deviate from a pure market-making strategy and adopt a more information-driven strategy. Specifically, VLPs could learn about a security's fundamental value from prices of other securities with correlated returns (Pasquariello and Vega, 2013; Cespa and Foucault, 2014). In such a scenario, they could potentially take similar positions across correlated stocks rather than the offsetting positions predicted by Ho and Stoll (1983).

Therefore, establishing the net influence of correlated inventories on the trading behaviour of VLPs is not necessarily unambiguous, and requires empirical analysis. *We accordingly investigate the cross-security implications of VLPs' portfolio inventory management in LOB markets with data on VLP trading accounts.*

1.2 The Policy Question

There has been great regulatory concern[1], in line with academic evidence, that LOB markets remain uncomfortably dependent on stability in the supply of liquidity from VLPs. This can be problematic, especially in peak load and stress periods.[2] In spite of this heightened regulatory concern, we know very little about the determinants of liquidity-induced market fragility in LOB markets. We also know very little about the impact of correlated trading of liquidity providers on market quality or fragility in liquidity supply. Papers that study inventory effects have largely investigated dealer markets with affirmatively obligated market-makers or specialists, and these cannot address fragility in the liquidity supplied by purely *voluntary* liquidity providers. For LOB markets, all we know in this context is that extreme levels of VLPs' inventory imbalances drive episodic market fragility.[3] In this context, we address the following question: *do large correlated portfolio inventories significantly increase the likelihood of market fragility, as measured using extreme price movements and transitory jumps in stock returns*? In other words, *are VLPs' correlated portfolio inventories a significant determinant of LOB market fragility?* In this context, our paper also has significant policy relevance in informing exchange and regulatory perspectives on affirmative obligations and designated market-making.

2. How Do We Contribute?

Our study contributes to several streams of the literature.

First is the literature on the effect of dealer inventories on their trading behavior. For example, Madhavan and Smidt (1993), Manaster and Mann (1996), Hansch, Naik, and Viswanathan (1998), Reiss and Werner (1998), and Naik and Yadav (2003b) document that differences in inventories across dealers on the LSE affect their trading with customers and with other dealers. However, these

[1] See, for example, CFTC-SEC Flash Crash Report: http://www.cftc.gov/ucm/groups/public/@aboutcftc/documents/file/jacreport_021811.pdf.
[2] See, for example, Bessembinder, Hao and Zheng (2015), Anand, Tangaard, and Weaver (2009), Menkveld and Wang (2013), and Raman, Robe, and Yadav (2018a, 2018b).
[3] See, Anand and Venkatraman (2016), Kirilenko et al. (2017), and Getmansky et al. (2018).

studies only consider the effect of individual stock-level inventories. In contrast, our focus is on market-makers' *portfolio-based* inventory control that incorporates correlated inventories in other stocks. Naik and Yadav (2003a) is, to our knowledge, the only directly relevant existing study on market-makers' portfolio-based inventory control; and our results are in sharp contrast with their results. One reason for the difference in results could be because their data was only at the *centralized* level of the whole (market-making) firm, not at the level of individual trading units within the firm, and these firms were so large that only about 15 market-making firms were responsible for all London market trades. The telephone-based OTC market structure would have also made it difficult to share real-time positions' data across stocks and across the firm's trading units. Naik and Yadav (2003a) were hence unable to test whether correlated portfolio inventories drove the primary-level decision-making of a trading unit within the firm, the level at which Ho and Stoll (1983) should apply with minimal confounding influences. In this paper, we use data that separately identifies each VLP trading account, and our VLPs are able to instantly trade electronically thereby enabling smooth, real-time monitoring and management of positions across stocks. Hence, we can cleanly test the predictions of Ho and Stoll (1983) for the trading of liquidity providers, and our results are strongly supportive.

Second, our study significantly contributes to our understanding of the effect of correlated portfolio inventories on market quality and fragility. Papers that study inventory effects have typically only considered NYSE specialists' or aggregate brokerage houses' inventory risks (Comerton-Forde et al., 2009; Coughenour and Saad, 2004). However, since NYSE specialists are affirmatively obligated to supply liquidity, studies focusing on NYSE specialists cannot answer questions about the influence of purely *voluntary* liquidity provider inventories on market fragility. When we turn to LOB markets, most empirical studies have ignored inventory costs altogether.[4] Recent studies by Anand and Venkatraman (2016), Kirilenko et al. (2017), and Getmansky et al. (2018) show that VLPs turning from liquidity providers to liquidity demanders due to unsustainable levels of inventory imbalances is an important precursor to episodes of market fragility. Our results show that, along with stock-level inventories, large correlated portfolio inventories significantly increase the likelihood of market fragility, measured using extreme price movements and transitory jumps in stock returns. VLPs' correlated portfolio inventories are a significant determinant of LOB market fragility.

Furthermore, while correlated trading of liquidity providers has received recent attention (Chabound et al, 2014), we know very little about the impact of such trading on market quality. Our result that episodes of market fragility are more likely when portfolio inventories are less dispersed across VLPs contributes to our understanding of the adverse effects on market fragility of correlated trading by liquidity providers. We contribute in informing academic, exchange, and regulatory perspectives on affirmative obligations and designated market-making by investigating VLPs' management of correlated inventory exposures across different securities.

Finally, our results provide a cleaner understanding of a supply-side channel for cross-security price pressures. Studies that examine the effect of inventories on price pressures have typically focussed only on stock-specific inventories (e.g., Hendershott and Seasholes, 2008; Hendershott and Menkveld, 2014). We build on this literature to show that, even after controlling for the effect of stock-level inventories, VLP positions in other correlated securities create significant cross-security price pressure. Another strand of literature uses aggregate order imbalance (OIB) data to examine cross-security price pressures (e.g., Andrade, Chang and Seasholes, 2008; Pasquariello and Vega, 2013; Friewald and Nagler, 2019). Given the lack of granular inventory data, these studies are unable to directly test the channels through which price pressures propagate across stocks. Cross-security price pressures could be brought about by the portfolio inventory management of liquidity

[4] See, for example, Biais et al. (1995), Hall and Hautsch (2004), and Ellul et al. (2007).

providers and/or the portfolio rebalancing of liquidity demanders.[5] It would be difficult to distinguish between these two sources while using only aggregate order imbalance data. In contrast, since we accurately track VLP inventories across stocks, and simultaneously control for other market-wide variables, our results provide a clearer picture of the precise role of portfolio inventory management of intermediaries in the transmission of price pressures across stocks.

3. What Data Do We Use?

In order to test the extent and the consequences of a liquidity provider's portfolio inventory management, we need to be able to identify each trader, and do so with a trader code that does not change for different stocks. Such trader identification is not easily provided by Exchanges. The data we use has been provided by the National Stock Exchange (NSE) in India, currently the second largest equity market globally on the basis of the total number of trades (as per World Federation of Exchanges website.) Besides complete information on trades and orders, our proprietary data includes masked trader identification, enabling us to calculate inventories of each trader in the market over time and across stocks. Specifically, our sample comprises all 50 stocks in NSE's NIFTY-50 index over a three-month period from April to June 2006. Access to more recent data was not forthcoming. As in the case of Anand and Venkataraman (2016), algorithmic trading was not allowed during our sample period as well. Given that portfolio-driven trading should be considerably easier and quicker to execute with algorithmic trading, each of our results should arguably be even stronger in presence of computerized decision-making and trade execution.

4. What Do We Find?

We document several interesting results.

First, VLPs' portfolio inventories mean revert significantly – more than 30% – faster than ordinary, stock-level inventories. Furthermore, consistent with the central predictions of the Ho and Stoll (1983), our analysis of order imbalances and order placement decisions show that a VLP is significantly more likely to place sell (buy) orders than buy (sell) orders in a stock to offset the excess positive (negative) correlated inventory risk exposure in the rest of her portfolio.

Second, we find that correlated portfolio inventory imbalances matter particularly when these imbalances are large, when stock returns are highly volatile, or when VLPs suffer abnormal losses in their portfolio holdings. Interestingly, consistent with the information hypothesis, we find that portfolio inventory imbalances matter significantly less for VLPs whose trading is more likely to be driven by informational reasons, relative to those who may be trading purely for market-making reasons.

Third, our panel regressions show that market liquidity improves when the variation in VLP correlated portfolio inventory levels across different VLPs is high. These results indicate that bid-ask spread in a stock would reduce when VLPs' inventories in other correlated stocks are more dispersed, because VLPs significantly long in these other stocks would reduce the ask prices in the stock and VLPs significantly short in these other stocks would increase the bid prices in the stock. Accordingly, we further find that greater aggregate accumulated positive (negative) portfolio inventory of VLPs is associated with greater depth on the sell-side (buy-side) of the order book than the buy-side (sell-side). Furthermore, consistent with predictions of Brunnermeier and Pedersen (2008) and Gromb and Vayanos (2002), we also find that bid-ask spreads worsen when the magnitude of VLPs' aggregate

[5] Several papers find evidence of supply-side (Coughenour and Saad, 2004; Comerton-Forde et al., 2010; and Karolyi et al., 2011) and demand-side (Koch, Ruenzi and Starks, 2015) sources of commonality in liquidity.

portfolio inventories are relatively high. These results continue to hold even after we control for measures of market-wide liquidity and informed trading.

Fourth, results from the Kalman-filter analysis of our state-space model show that correlated portfolio inventories are also a significant source of price pressures. After controlling for the effect of stock-level inventory, a one-standard deviation increase in portfolio inventories decreases returns by 5.4 basis points, which is almost double the average bid-ask spread. The effect of portfolio inventories is particularly high during periods of low dispersion of VLP portfolio inventories across different VLPs.

Finally, we find that liquidity providers' portfolio inventories influence the likelihood of market fragility. We identify episodes of market stress using two measures: extreme price movements (Brogaard et al., 2017) and transitory jumps in stock returns (Lee and Mykland, 2008). The likelihood and the number of extreme price movements or jumps in stock returns significantly increase with the magnitude of aggregate correlated portfolio inventories, and decrease with the dispersion of these portfolio inventories across different VLPs. A one-standard deviation increase (decrease) in the magnitude (dispersion) of aggregate portfolio inventories is associated with an increase (decrease) in the odds of observing an extreme price movements episode in the next time period by a factor of 14 (by 74%); and with an increase (decrease) in the odds of observing a transient jump in stock returns by about 44% (78%). Since extreme price movements and jumps in stock returns could also be due to information spillovers from other stocks, we control for market-wide informed trading in all our analyses. Further, to mitigate the concerns of reverse causality, wherein extreme price movements or transient jumps trigger traders to rebalance their portfolio and reduce portfolio inventories, we further employ vector autoregressive regressions. Consistent with our panel regression results, the impulse response functions show that EPMs and transient jumps in stock returns are higher in number following periods of large and correlated portfolio inventories.

5. Our Overall Conclusions

We have the following main conclusions. First, in accordance with the predictions of Ho and Stoll (1983), VLPs in LOB markets do manage their inventory risk on a *portfolio* basis in addition to a stock-by-stock basis. Second, a VLP's trading and order placement strategy is significantly influenced by her inventory in the other correlated securities in her portfolio. Third, consistent with information-driven objectives, the offsetting influence of correlated securities is less pronounced for VLPs whose trading is more likely to be driven by informational strategies. Finally, our results are consistent with the hypothesis that, even in the absence of algorithmic and high-frequency trading, as a security's liquidity worsens, it experiences greater cross-security price pressures and episodes of market stress when VLP positions in correlated securities are large and undispersed.

Overall, the bottom-line view that emerges from our results is that, while the management of correlated portfolio inventories in LOB markets with voluntary liquidity suppliers maximizes intermediaries' utility and capacity for liquidity provision, it is also inherently a source of significant market frictions, contagion, and liquidity fragility.

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