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Estimating endogenous liquidity using transaction and order book information

Philippe Durand

(Banque de France)

Yalin Gündüz

(Deutsche Bundesbank)

Isabelle Thomazeau

(Banque de France)

Editorial Board:

Klaus Düllmann
Heinz Herrmann
Christoph Memmel

Deutsche Bundesbank, Wilhelm-Epstein-Straße 14, 60431 Frankfurt am Main,
Postfach 10 06 02, 60006 Frankfurt am Main

Tel +49 69 9566-0

Please address all orders in writing to: Deutsche Bundesbank,
Press and Public Relations Division, at the above address or via fax +49 69 9566-3077

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Abstract:

We distinguish *exogenous* liquidity, which corresponds to the variability of bid-ask spreads for usual-sized transactions, from *endogenous* liquidity, which we interpret as the impact of liquidity on market prices when liquidating larger positions. Endogenous liquidity measures the risk that the realized price of a transaction may be different from the price before the transaction. We apply an endogenous liquidity-based model to order books and credit default swap (CDS) transactions in order to understand two different phenomena. An order book of equity prices has been utilized so as to reveal any “*not yet realized*” endogenous liquidity effects, i.e. any effects that become real if a new order is executed. Our results indicate that measuring the impact of the endogenous liquidity on the valuation of the portfolio is quite realistic. Second, we apply our model to a set of CDS transactions in order to find a “*realized*” endogenous liquidity component. We conclude that a realized systemic component is not present in realized CDS transactions, probably due to placing of iceberg orders, simply by slicing the large transactions into several small pieces to avoid liquidity constraints: Traders know perfectly where endogenous liquidity starts when they execute their transactions.

Keywords: Endogenous Liquidity, Volume Effect, Credit Default Swaps, Order Book.

JEL-Classification: G12.

Non technical summary

We distinguish *exogenous* liquidity, which corresponds to the variability of bid-ask spreads for usual-sized transactions, from *endogenous* liquidity, which we interpret as the impact of liquidity on market prices when liquidating larger positions. Although the presence of endogenous liquidity has been documented, it is currently not considered for the accounting valuation of portfolios. We apply a model, which is able to account for endogenous liquidity in order books of stocks and credit default swap (CDS) transactions, in order to explore two different phenomena in two steps. In a first step, we apply our model to equity prices in an order book to analyze any “*not yet realized*” endogenous liquidity effects, i.e. any significant relationship between prices and volume in the order book. Our results indicate that the quantification of the endogenous liquidity impact on the portfolio valuation is possible. Second, we apply our model to a set of CDS transactions in order to find a “*realized*” endogenous liquidity component, i.e. whether any significant relationship between prices and volume of transactions can be observed. No robust endogenous liquidity component could be identified on CDS transactions, showing probably that market participants know fully well where endogenous liquidity costs start, and prefer to split large transactions into several small ones. Nevertheless, the possibility of endogenous liquidity quantification from order books leads to important conclusions from this analysis. Incorporating endogenous liquidity into the mark-to-market valuation of portfolios would be useful for several reasons. Systemic risk would be reduced by (i) addressing issues associated with too-big-to-fail institutions and by (ii) mitigating herding behavior as endogenous prudential liquidity reserves would prevent institutions from accumulating similar exposure to the same risks. Finally, recognizing endogenous liquidity risk should penalize short positions as these are more exposed to endogenous liquidity via squeeze risk.

Nichttechnische Zusammenfassung

Wir unterscheiden zwischen *exogener* Liquidität, die der Variabilität von Geld-Brief-Spannen für ein übliches Transaktionsvolumen entspricht, und *endogener* Liquidität, die hier als der Einfluss der Liquidität auf die Marktpreise bei Auflösung größerer Positionen interpretiert wird. Obwohl das Vorhandensein endogener Liquidität dokumentiert ist, findet sie bei der bilanziellen Portfoliobewertung aktuell keine Berücksichtigung. Im vorliegenden Papier nutzen wir ein Modell, das die endogene Liquidität in Orderbüchern für Aktien- und Credit-Default-Swap-Transaktionen (CDS-Transaktionen) berücksichtigt, um in zwei Schritten die folgenden beiden Phänomene zu analysieren: Im ersten Schritt wird ein Orderbuch mit Börsenkursen zugrunde gelegt, um etwaige „*noch nicht realisierte*“ endogene Liquiditätseffekte, d. h. einen möglichen signifikanten Zusammenhang zwischen Kurs und Volumen im Orderbuch, zu untersuchen. Die Ergebnisse weisen darauf hin, dass eine Quantifizierung der Auswirkungen der endogenen Liquidität auf die Bewertung des Portfolios möglich ist. Anschließend wenden wir das Modell auf eine Reihe von CDS-Transaktionen an, um die „*realisierte*“ endogene Liquiditätskomponente aufzudecken, d. h. festzustellen, ob ein signifikanter Zusammenhang zwischen Kurs und Transaktionsvolumen nachweisbar ist. Es konnte keine robuste endogene Liquiditätskomponente bei CDS-Transaktionen identifiziert werden, was darauf schließen lässt, dass die Marktteilnehmer sehr genau wissen, an welchem Punkt endogene Liquiditätskosten entstehen, und große Transaktionen lieber in mehrere kleine Teilaufträge stückeln. Dessen ungeachtet lassen sich aus der Möglichkeit der Quantifizierung der endogenen Liquidität auf Basis von Orderbuchdaten für Aktien wichtige Schlussfolgerungen aus der Analyse ziehen: Eine Berücksichtigung der endogenen Liquidität bei der Portfoliobewertung zu Marktpreisen wäre aus mehreren Gründen sinnvoll. Das Systemrisiko würde insofern verringert, als a) Problemen im Zusammenhang mit systemrelevanten Instituten (der „Too-big-to-fail“-Problematik) entgegengewirkt und b) das Herdenverhalten begrenzt würde, da endogene bankaufsichtliche Liquiditätsreserven die Institute davon abhalten würden, dieselben Risiken in ähnlichem Umfang zu akkumulieren. Und schließlich dürfte die Berücksichtigung des endogenen Liquiditätsrisikos Short-Positionen sanktionieren, da diese über das Squeeze-Risiko stärker dem endogenen Liquiditätsrisiko ausgesetzt sind.

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Estimating Endogenous Liquidity Using Transaction and Order Book Information*

1. Introduction

The liquidity of instruments has been a key area of financial research on its own within the past decades, where theoretical and empirical studies have shown statistically significant effects of liquidity on asset prices. Recent research has treated the impacts of liquidity as fundamental and incorporated liquidity-adjusted modifications into the original Capital Asset Pricing Model (CAPM) framework (Acharya and Pedersen (2005)). There is also a vast literature on the implications of liquidation risk (Huang (2003); Duffie, Garleanu, Pedersen (2007); Longstaff (2009)). An important review of the literature on liquidity and asset prices can be found in Amihud, Mendelson and Pedersen (2005).

Although intense interest in the field of liquidity has given rise to theoretical and empirical research, the analyses were usually undertaken under the assumption that asset liquidity is exogenously given. Studies looking at endogenous asset liquidation costs with abnormal transaction sizes have not received adequate attention in the literature. A major contribution has been proposed by Cetin, Jarrow, Protter, and Warachka (2006). In their paper, the authors first model the liquidity using stochastic supply curves: consecutive purchases are executed at higher prices while consecutive sales are transacted at lower prices. The authors describe the impact of liquidity costs on

* **Philippe Durand**, Banque de France, Autorité de Contrôle Prudentiel, 61 Rue Taitbout, 01-2706, 75436 Paris Cedex 09, France. E-mail: philippe.durand@acp.banque-france.fr;

Yalin Gündüz, (Contact Author), Deutsche Bundesbank, Wilhelm Epstein Str. 14, 60431 Frankfurt, Germany. Phone: +49-69-9566-8163. E-mail: yalin.gunduz@bundesbank.de;

Isabelle Thomazeau, Banque de France, Autorité de Contrôle Prudentiel, 61 Rue Taitbout, 01-2706, 75436 Paris Cedex 09, France. E-mail: isabelle.thomazeau@acp.banque-france.fr.

This paper has been developed during the Trading Book Group (TBG) / Research Task Force (RTF) Joint Work Stream of the Basel Committee for Banking Supervision. We thank the participants of the TBG / RTF Joint Work Stream, the RTF Frankfurt Workshop in February 2011, the TBG Ottawa Meetings in August 2011, and the RTF Istanbul Workshop in December 2011 for their constructive comments. This study presents ideas of the authors, which are not necessarily those of Deutsche Bundesbank, of the Autorité de Contrôle Prudentiel, or of Banque de France.

the price of a European call option and calibrate the liquidity parameters they introduced on intraday equity price observations. A more recent study that incorporates constrained asset prices due to illiquidity is Wagner (2011). Our intuition overlaps with the results of the portfolio choice model presented in the paper, such that asset prices fall below the fundamentals when the supply of assets runs out in the short run.

In this study, we distinguish *exogenous* liquidity, which corresponds to the variability of bid-ask spreads for usual-sized transactions, from *endogenous* liquidity, which corresponds to the impact of liquidity on market prices when liquidating larger positions. We leave *exogenous* liquidity aside, which has intensively been studied in the literature through various analyzes, and focus on *endogenous* liquidity, which measures the risk that the realized price of a transaction may be different from the pre-transaction price in both normal and stress periods. This price will then depend on (i) the size of the position relative to the overall market, (ii) the direction (long or short) of the position with respect to those of the other actors, and (iii) the market depth. The concept is also shown to generalize to the case of collective liquidation or to the case where all market participants react in the same way, and therefore cause the overall one-way transaction size in the market to be large and illiquid.

The Basel Committee on Banking Supervision (BCBS) has already stated the necessity of taking *endogenous* liquidity into account for the valuation of portfolios in Articles 700 and 701 of the Basel II framework (BCBS(2006)) and in the Technical Document “Supervisory guidance for assessing banks’ financial instrument fair value practices” (BCBS(2009)), but probably it could be better specified, deepened, and expanded. On the other hand, current accounting rules do not allow *endogenous* liquidity to be recognized in the accounting results. For example, the November 2006 issue of the International Accounting Standards Board Discussion Paper (IASB(2006)) specifies that “the quoted price shall not be adjusted because of the size of the positions relative to trading volume”.

We apply an *endogenous* liquidity concept-based model to two sources in order to understand two different phenomena. An order book of equity prices has been used so as to reveal any *not-yet-realized* *endogenous* liquidity effects – effects that become real if a new order is executed. We show that there is a significant parameter for liquidity,

derived from the *not-yet-realized* transactions in the order book, which indicates the importance of endogenous liquidity and signals a high liquidity cost for large transaction sizes.

Second, we apply our model to a set of credit default swap (CDS) transactions in order to find a *realized* endogenous liquidity component. Our results indicate that a *realized* component is not present in CDS prices, since a large transaction would not actually have happened in first place due to the high costs of transacting, leaving us only with the realized transactions without endogenous liquidity. We conclude that it is highly probable that traders are placing “iceberg” orders in the CDS market, simply by slicing the large transactions into several small pieces to avoid liquidity constraints. A further explanation is that traders know exactly where endogenous liquidity starts when they execute their transactions.

We aim to fill the gap in the liquidity literature by presenting a simplified model to estimate the endogenous liquidity parameter of a portfolio. The intuitive model calculates a liquidity-adjusted price by making use of data made available from repositories and order books. Our results with *realized* and *not-yet-realized* endogenous liquidity have an important impact on the incorporation of liquidity in the market risk framework. Given its effects on prices, asset liquidity should definitely be a part of the regulatory framework, amendments to which are currently being developed by the Trading Book Group of the Basel Committee of Banking Supervision.

The rest of the study is organized as follows: Section 2 introduces the concept of endogenous liquidity in detail. Section 3 presents the theoretical modeling of endogenous liquidity parameter. While Section 4 brings in the results with *not yet realized* liquidity in order books into discussion, Section 5 looks at whether *realized* endogenous liquidity is priced in CDS transactions. The conclusion summarizes our findings and lays out issues for further research and for supervisory authorities.

2. Defining Endogenous Liquidity

Bangia, Diebold, Schuermann, and Stroughair (2002) and Bervas (2006) are among the studies which recognized the importance of distinguishing between exogenous and

endogenous liquidity in the sense that we define.¹ Below a certain size, transactions may be traded at the bid-ask price quoted in the market (exogenous liquidity), and above this size the transaction will be conducted at a price below the initial bid or above the initial ask, depending on the sign of the trade (endogenous liquidity). Figure 1 shows that there could be a threshold for the size of the transaction, above which endogenous (il)liquidity will happen. Trades below this threshold occur in accordance with the liquidity measured by the bid-ask spreads. However, there happens to be a further buffer above this threshold compared to the bid-ask spreads below the threshold.

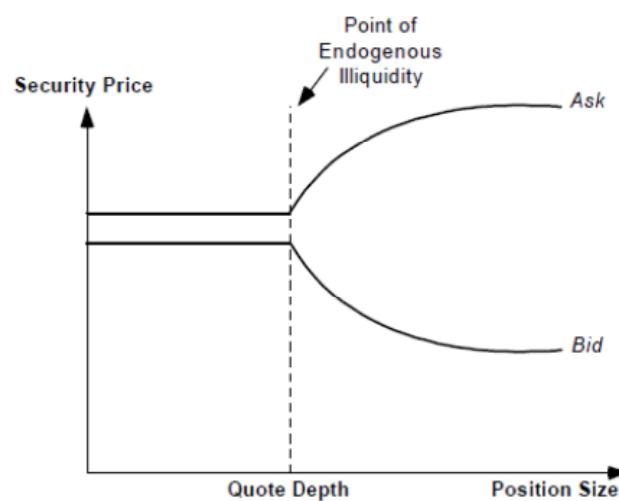


Figure 1. Bangia et al. (2002) representation of the endogenous liquidity.

Exogenous liquidity risk, which corresponds to a normal variation of bid-ask spreads under normal market conditions, can be easily integrated into a VaR framework. However, incorporating endogenous liquidity risk into a VaR computation is not straightforward from a theoretical point of view. The impact of the liquidation of a position on market prices may be highly significant, especially in financial institutions' trading books. Although the academic literature on portfolio valuation and VaR computation is quite rich, a small number of endogenous liquidity applications are present, since liquidity reserves are not held to be compliant with accounting standards. Among studies that looked at the implications of endogenous liquidity risk on portfolios and VaR frameworks, Jarrow and Protter (2005) and Rogers and Singh (2005), describe

¹ Our definition can be traced as an interpretation of the terminology of Nikolau(2009), where the author describes endogeneity to be the link of liquidity risk to the market conditions.

an optimal liquidation strategy and deduce a market value for the expected liquidation price.

While the usual bid-/ask cost is a linear function of the size of the transaction, this is no longer the case for endogenous liquidity costs. As a consequence, when we include endogenous liquidity, the price of a portfolio that is made of several sub-portfolios is no longer the sum of the price of each individual sub-portfolio. This result, though intuitive, contradicts current accounting practices.

3. The Model

In this section we introduce a simplified model which incorporates the estimation of the endogenous liquidity component and mention some possible extensions to the model.

3.1. General Presentation

Let us consider an investor holding a portfolio of quantity N ($N > 0$) of a single asset having a price S_0 at time T_0 . In the spirit of exponential demand and supply curves introduced by Cetin, Jarrow, Protter, and Warachka (2006), we model the endogenous liquidity to be represented by an exponential function $e^{-\lambda}$, λ being a positive or a null parameter. This parameter would represent the impact on the market of selling one unit of the asset, so its estimation depends particularly on the liquidation horizon chosen. The exponential decay assumption should cause the following observation. The first asset is sold at a price of S_0 . Because of the impact on the market of selling the first stock, the second stock may be sold at a price $e^{-\lambda}S_0$, and the n^{th} stock at $e^{-(n-1)\lambda}S_0$. In this model, we compute a sequential liquidation price of a portfolio, supposing that no other investor will liquidate his portfolio at the same moment: This price does not incorporate the impact of a systemic crisis, where all the investors would try to sell their portfolios at the very same second.

The valuation with the liquidity adjustment (V) of the portfolio is the sum of the prices of the assets. We then have:

$$V_{liquidity\ adjustment}(T_0) = \sum_{n=1}^{n=N} e^{-(n-1)\lambda} \times S_0 = \frac{1 - \exp(-\lambda N)}{1 - \exp(-\lambda)} S_0 \quad (1)$$

When λ tends to 0, $V_{liquidity\ adjustment}(T_0)$ coincides with the valuation without liquidity adjustments: $V_{no\ liquidity\ adjustment} = N \times S_0$. The price is then a linear function of the size of the position, and no second-order volume effects or liquidation costs are considered.

Let us now show how we can derive a simplified relationship from this equation. Using Taylor's expansion,

$$e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \dots, \quad -\infty < x < \infty \quad (2)$$

in equation (1) and assuming both $x = -\lambda N$ and $x = -\lambda$ to be small, we obtain:

$$\frac{V}{S_0} \left(1 - \frac{\lambda}{2}\right) = N \left(1 - \frac{\lambda}{2} N\right) \quad (3)$$

The same logic can be applied when buying a stock repetitively. This last equation provides a basic relationship between volumes and prices, and will be further developed in Section 5.1 for the special case of CDS transactions.

3.2. Extensions

This simple approach has been used by Cetin, Jarrow, Protter, and Warachka (2006) to better take into account the liquidity costs when pricing derivatives: for a cash product market maker, the endogenous liquidity costs is not necessarily the cost of unwinding his position, but the cost of hedging his positions. Using the same model, Possamai, Soner and Touzi (2010) obtain a Taylor expansion of these liquidity costs, which would allow to write an option price incorporating liquidity as a correction of its price ignoring the impact of liquidity.

In the same way, for highly correlated instruments (e.g. a portfolio of interest rate swaps in the same currency and on the same underlying), endogenous liquidity costs could be estimated on a portfolio basis, but not at a transaction level.

4. Results with “Not-Yet-Realized” Endogenous Liquidity

While Cetin, Jarrow, Protter, and Warachka (2006) use intraday transaction information to estimate the λ parameters introduced in Section 3, this section presents how they can be estimated using order book information. In our approach of modeling endogenous liquidity, we presume that order books and transactions contain different market information about the liquidity parameter. Order books, being a list of buy and sell orders, contain all the intentions of traders, although they are *not yet realized*. The order book does not provide real transaction prices, but prices on which traders and market makers agree to deal. So the endogenous liquidity coefficient measured on these data may correspond to the liquidity costs they would agree to include in their prices. This “raw” form of information should actually be a correct source to observe the (intended) effects of the transaction size on prices.

4.1. Order Book Datasets

Since full order book information is not readily available, we used the data from order books available on the Boursorama website, which gives real-time quotations of Euronext for the ten best buy and sell orders. Ten entities from various business sectors and sizes were selected: Accor (hotel industry), Axa (insurance company), BNP Paribas (banking), Boiron (pharmaceutical laboratories), Bouygues (telecommunications, construction), Carrefour (supermarkets), Fleury Michon (food manufacturing), LVMH (wines and spirits, fashion and leather goods, perfume and cosmetics, watches and jewelry), Peugeot (automobiles), Total (energy producer and provider). All these firms are from the CAC 40 except for the two smallest, Boiron and Fleury Michon. We retrieved close of business data from July 5 to July 29, 2011, which corresponds to a dataset of 19 trading days.

4.2. Estimation Methodology and Numerical Results for a Single Entity

The below methodology is used to estimate the value of the parameter λ for each entity and each day similarly. We present here the basic steps of the methodology, illustrating it with the particular case for only a single entity, Accor.

4.2.1. Extraction of Data

The daily closing price data were extracted from the available order books. The content of this extraction is illustrated in Table 1 as of July 5, 2011:

The first three columns correspond to selling orders (bids), whereas the final three columns show

Bid Orders	Bid Quantity	Bid Price	Ask Orders	Ask Quantity	Ask Price
2	3,507	31.150	1	20	31.200
1	1,278	31.145	1	1,142	31.215
1	2,845	31.135	1	800	31.220
2	10,011	31.130	3	11,529	31.245
1	7,350	31.125	1	20	31.250
1	575	31.120	1	9,012	31.285
3	7,062	31.100	3	7,363	31.290
1	8,392	31.095	2	9,945	31.295
2	9,509	31.090	2	645	31.300
1	3,964	31.080	1	746	31.310
15	54,493	TOTAL	16	41,222	TOTAL

Table 1. Boursorama order book close-of-business data for Accor on July 5, 2011.

intention for buying orders (asks). The columns *Orders* indicate how many orders have been placed for trading at a given price (respectively for sell and buy), and *Quantity* is the quantity of stocks corresponding to these orders (respectively for sell and buy). For a party adding a new order, these prices can be considered as marginal prices, i.e. if a party wants to sell 5,000 stocks, the price will be 31.150 for the first 3,507 stocks, 31.145 for the following 1,278, and 31.135 for the remaining part.

4.2.2. Estimation of the Liquidity Parameter

After the order book data were extracted, the order book marginal prices were plotted as a function of the cumulated quantity of stocks in the order book, with the following convention: the quantities of stocks N are positive for long positions (which have to be sold to be taken out of the order book), and negative for short positions (which have to be bought to be taken out). Figure 2 presents this function as of July 5, 2011.

As explained in Section 3, the model supposes that the marginal price S of a stock is linked to the quantity N by the following relationship, where S_0 is the first stock price:

$$S = e^{-(N-1)\lambda} S_0 \quad (4)$$

So, assuming that N is approximately equal to $N-1$, this relationship can be rewritten as:

$$\ln S = aN + b \quad (5)$$

where $a = -\lambda$ and $b = \ln S_0$. By fitting this function to the data from the order book, we obtained a value for λ . Table 2 presents the results of this process for each of the 19 days of our sample:

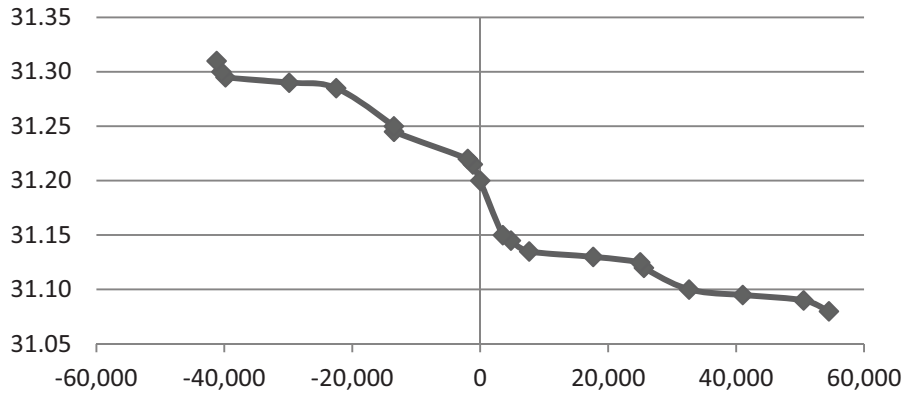


Figure 2. Stock prices versus cumulated quantity for Accor stocks, July 5, 2011.

July	05	06	07	08	11	12	13	14	15	18
$a = -\lambda$ (in 10^{-8})	-8.45	-7.65	-11.40	-7.01	-5.59	-6.75	-6.13	-8.57	-7.51	-6.35
σ (in 10^{-8})	0.56	0.53	0.79	0.30	0.48	0.46	0.48	0.65	0.23	0.66
$-\lambda / \sigma$	-15.20	-14.40	-14.40	-23.70	-11.50	-14.70	-12.70	-13.20	-32.90	-9.62
R^2	93%	92%	92%	97%	88%	92%	90%	91%	98%	84%

July	19	20	21	22	25	26	27	28	29
$a = -\lambda$ (in 10^{-8})	-7.40	-7.74	-8.28	-8.13	-7.13	-7.36	-7.48	-9.14	-14.00
σ (in 10^{-8})	0.43	0.29	0.44	0.84	0.85	0.66	0.38	0.62	1.25
$-\lambda / \sigma$	-17.40	-27.00	-18.80	-9.67	-8.39	-11.20	-19.90	-14.90	-11.20
R^2	94%	98%	95%	84%	80%	87%	96%	92%	87%

Table 2. Results of the regression between the marginal price and the cumulative quantity of Accor stocks for the July 5–29, 2011 period.

We observe that the R^2 coefficients, which measure the goodness-of-fit (i.e. the correlation between the theoretical and the empirical marginal prices), are quite high. On the other hand, the estimated λ parameters are quite small, mostly at the 10^{-8} level.

4.2.3. Descriptive Statistics for Lambda

We obtained a time series of λ in Section 4.2.2. We can plot the total quantity of stocks from the 10 best bid and asks in the order book and the lambda for the period of 19 days, as illustrated for Accor stocks in Figure 3.

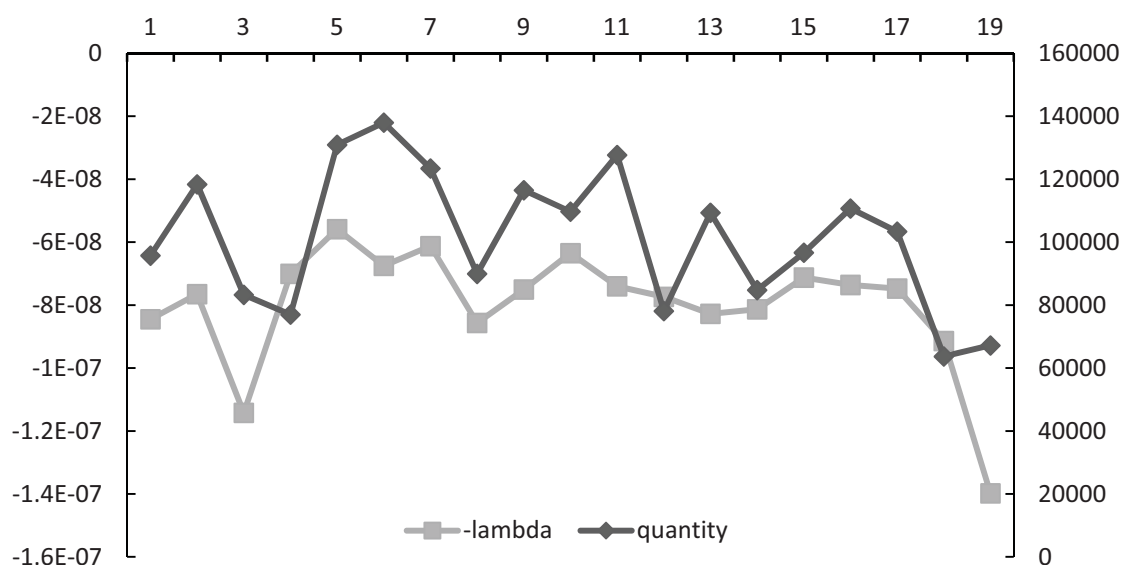


Figure 3. Time evolution of $-\lambda$ and of the total quantity of assets for the July 5–29, 2011 period.

In Figure 3, $-\lambda$ has been depicted instead of λ , since its correlation with the quantity of stocks is clearer. From this time series, we were able to compute several descriptive statistics, including:

- Average value of $-\lambda$: $-8.03E-08$,
- Standard deviation σ of the λ time series: $\sigma=1.86E-08$,
- Average stock price: 30.56,
- Correlation between $-\lambda$ and total quantity of stocks: $\rho(-\lambda, \text{Quantity}) = 0.65$,
- Weighted λ (i.e. average of the daily λ estimation weighted by the size of the corresponding order book): $7.75E-08$,

- Weighted σ (i.e. standard deviation of the weighted λ time series): 118.34,
- Weighted λ / price : weighted λ normalized by the average price of the stock: 2.37E-06.

4.2.4. Impact of Endogenous Liquidity

It is also possible to estimate the liquidity-adjusted price portfolios of different sizes, and the impact (in %) of the endogenous liquidity on their valuation, by making use of Equation (1). The results are shown in Table 3. Since the estimation of the λ parameter is based on the 10 best bids and 10 best asks, the calculation of the impact for large portfolios is only indicative.

Size of the position ² (EUR)	Adjusted price (EUR)	Difference (EUR)	Impact (%)
1,000,000	998,687	1,313	0.1%
10,000,000	9,869,748	130,252	1.3%
50,000,000	46,854,370	3,145,630	6.3%
100,000,000	87,939,581	12,060,419	12.1%

Table 3. Example of estimations of the impacts of the endogenous liquidity adjustments on the valuation of the portfolio for Accor.

4.3. Results for the Full Dataset

The same computations were performed for the nine other entities. Table 4 shows the results of the estimation process:

	λ (Average)	σ	λ/σ	weighted λ	weighted σ	$\frac{\text{weighted } \lambda}{\text{weighted } \sigma}$	$\frac{\text{weighted } \lambda}{\text{price}}$
Accor	8.03E-08	1.87E-08	4.30	7.75E-08	6.55E-10	118.34	2.37E-06
Axa	9.78E-09	2.24E-09	4.37	9.08E-09	1.00E-10	90.43	1.32E-07
BNP Paribas	5.99E-08	4.04E-08	1.48	2.96E-08	7.16E-10	41.32	1.40E-06
Boiron	1.35E-05	3.53E-06	3.84	1.30E-05	1.47E-07	88.29	4.00E-04
Bouygues	4.94E-08	1.11E-08	4.47	4.76E-08	4.08E-10	116.66	1.31E-06
Carrefour	1.56E-08	6.31E-09	2.47	1.44E-08	1.99E-10	72.33	3.18E-07
Fleury Michon	1.57E-05	2.68E-06	5.86	1.52E-05	7.36E-08	206.86	5.33E-04
LVMH	8.61E-08	2.23E-08	3.87	7.96E-08	4.61E-10	172.80	1.01E-05
Peugeot	7.00E-08	1.37E-08	5.11	6.76E-08	6.71E-10	100.78	2.01E-06
Total	1.95E-08	7.70E-09	2.53	1.74E-08	2.36E-10	73.94	6.79E-07

Table 4. Descriptive statistics for the 10 entities in the sample: λ , weighted λ values, and their corresponding standard deviations.

² The total market capitalization of Accor is around EUR 5 Billion, the daily volume of transactions is generally between EUR 1 Million and 50 Millions.

The λ/σ ratio is reasonable and the weighted λ /weighted σ ratio is quite high, which indicates a very good quality of the weighted λ estimation. Being independent from a split of equity, the weighted λ /price ratio can be compared across entities. The results in Table 4 show that it is a good indicator of the liquidity: the smallest values of this ratio correspond to the most liquid entities, whereas the highest values are obtained for the two less liquid (and also the smallest) entities of the sample, Fleury Michon and Boiron. Additionally, the correlations between $-\lambda$ and the size of the order book (in term of quantity of assets) are quite high, as shown in Table 5:

	$\rho_{(-\lambda, Quantity)}$
Accor	65.0%
Axa	82.5%
BNP Paribas	84.3%
Boiron	51.8%
Bouygues	73.1%
Carrefour	65.8%
Fleury Michon	82.1%
LVMH	82.1%
Peugeot	69.3%
Total	77.3%

Table 5. Correlations between $-\lambda$ and the total quantity of assets.

These high values indicate that the λ parameter was able to capture volume effects inside the order book. λ parameter, normalized by the price, is shown to be a good indicator of liquidity.

4.4. Conclusion for “Not-Yet-Realized” Endogenous Liquidity

This section concludes by summarizing the findings with not-yet-realized endogenous liquidity. Although the estimation of the liquidity parameter was undertaken on a very small set of data during a volatile period (July 5-29, 2011), it yielded some interesting conclusions:

- For each asset and for each end of day, a strong relationship has been found between quantities and prices, measured by a high R^2 coefficient from the regressions with these data.
- For each asset, the estimation of the λ parameter remains relatively stable and robust over the whole observation period, which even includes highly volatile days. When weighted by the size of the order book, the robustness of this estimation is even higher;
- The temporal evolutions show that the correlation between $-\lambda$ and the size of the order book is generally very high: the issues of estimating the λ parameter and the daily volume are extremely similar;
- When normalized by the price of the relevant stock, λ/price is a good indicator of its liquidity;
- The impact of the endogenous liquidity on the valuation of the portfolio using the estimated λ parameter seems quite realistic.

Extensions to our analysis should incorporate a larger sample of order books in order to generalize these results. Further studies should also control for variance similar to this analysis so as to avoid the effects of volatile periods.

5. Results with Realized Endogenous Liquidity

The question of whether our results with *not-yet-realized* order books can be extended to actually *realized* transactions is both theoretical and empirical. Does endogenous liquidity appear as an observable parameter in repetitive transactions? Does a dry-up in the market show up as a significant liquidity parameter in prices? Theoretically, a *realized* transaction is free of any liquidity constraints. It may have happened during a dry-up, yet nevertheless it happened because a counterparty could be found and a transaction size agreed. In a *realized* transaction, the counterparty facing illiquidity (i.e. sell side when there is a shortage of buyers) was able to find a buy-side counterparty.

Cetin, Jarrow, Protter, and Warachka (2006) estimated the endogenous liquidity from the price of *realized* intraday transactions in listed instruments. We extend this analysis by using the information created by the new trade repositories and estimate the endogenous liquidity component of OTC market credit default swaps (CDS). We base our analysis on a set of CDS transactions with the following extension of the model

presented in Section 3. We test empirically whether transaction size has an effect on the market portfolio of CDS transaction prices.

5.1. Application to CDS Transactions

If we now consider a CDS portfolio at time T_0 , S_0 being the price of one unit of CDS, we can write:

$$S_0 = Premium_0. \quad (6)$$

The valuation of the portfolio at T_0 is:

$$V(T_0) = Premium \times N \quad (7)$$

where N is the total notional of the portfolio. The *Premium*, i.e. the price for a notional N , is expressed in basis points. Therefore, the equation (3) becomes:

$$\frac{Premium}{Premium_0} \left(1 - \frac{\lambda}{2}\right) = 1 - \frac{\lambda}{2} N \quad (8)$$

Or:

$$Premium \approx Premium_0 - \frac{\lambda}{2} \times Premium_0 \times N \quad (9)$$

This equation suggests that a linear regression of the premium on the volume N (which is the notional amount of CDS) would reveal the parameter λ .

5.2. CDS Transaction Datasets

Our unique dataset comes from the Depository Trust & Clearing Corporation (DTCC), which claims to capture data on 99% of CDS transactions worldwide. In our analysis, we used information only from new trades, whereas DTCC provides assignment, amendment and termination data as well. The transactions in our set are spread out over the June 2009–December 2010 period.

We have used two distinct datasets in order to understand the effects of realized endogenous liquidity. The first dataset consists of single-name CDS transactions of the top 10 most liquid sovereigns in 2009 and 2010. These are Turkey, Greece, Spain, Italy, Portugal, Germany, France, UK, Brazil, Mexico, Russia and Argentina, in descending

order of the number of transactions. Russia and Argentina enter the top 10 only in 2009, whereas France and UK only show up in 2010. When the transactions of both years are merged, we find that 2,159 transactions have taken place where we observe a trade price.³ 2,059 of these trades are denominated in USD. Besides undertaking robustness checks with the EUR-denominated sample, we concentrate on USD-denominated trades due to their high dominance in the data. The total volume covered by this sample is USD 24.2 billion, and these 2,059 transactions have an average notional of USD 11.7 million.

The second dataset is constructed by choosing single names for which CDS trades exist. It has been decided to alternatively look at single names from a real investment bank portfolio⁴, instead of Top 10 liquid sovereign names. This larger dataset consists of 40,732 confirmed trades with a conventional spread from 126 distinct entities. Among other currencies of notional volumes in the sample, USD-denominated trades cover a volume of around USD 175 billion, whereas EUR-denominated trades have a total volume of around EUR 113 billion.

5.3. Empirical Results

We calibrated the λ parameter on DTCC data by making use of both datasets described in Section 5.2 and applying Equation (7) to them. With this simplifying relationship, λ should be ideally a significant positive parameter. Table 6 tabulates the results arising from regressing the CDS premiums on their volumes. On a given day, a number of 15 observations that have the same maturity, currency, and underlying entity were taken as a required minimum to be able to undertake the regression of the market portfolio.

³ One should note that these are transactions in which at least one counterparty is supervised in Germany.

⁴ The restriction that at least one counterparty is of German origin still holds. The name of the investment bank could not be published due to confidentiality restrictions.

No	Entity	n	Trade Date	Term. Date	Currency	Lambda	t-stat	p-value	Sig.
1	FRANCE	20	05-May-10	20-Jun-15	USD	-3.55E-10	-0.05	0.9593	
2	FRANCE	20	20-Dec-10	20-Mar-16	USD	3.20E-14	1.60	0.1262	
3	FRANCE	15	10-Dec-10	20-Dec-15	USD	-2.63E-14	-3.50	0.0032	**
4	GERMANY	60	28-Apr-10	20-Jun-15	USD	-2.77E-09	-2.08	0.0417	*
5	GERMANY	18	23-Apr-10	20-Jun-15	USD	-1.92E-09	-0.64	0.5312	
6	GREECE	152	19-Feb-10	20-Mar-15	USD	-8.01E-11	-0.10	0.9166	
7	GREECE	16	26-Feb-10	20-Mar-15	USD	-5.05E-10	-1.32	0.2064	
8	ITALY	16	10-May-10	20-Jun-15	USD	3.30E-09	0.60	0.5576	
9	SPAIN	18	10-Feb-10	20-Mar-15	USD	8.34E-10	1.22	0.2370	

(**) indicates significance at 99% level

(*) indicates significance at 95% level

Table 6. Parameter estimation results with the regressions using the first dataset.

In Table 6, it can be observed that all the observations have a minimum of 15 trades on a given day and a five-year initial maturity. The λ parameter is negative in six cases out of nine, and in only two cases significant, both being negative. This result can be interpreted to be due to either (i) selection of the 10 most liquid sovereign entities, so that no endogenous λ parameter indicating a liquidity premium is significant; (ii) selection of a highly liquid time period for CDS in general, which would exacerbate the effects in (i); (iii) selection of the market portfolio instead of individual counterparty portfolios, which mixes up the buy and sell (positive and negative) effects on the λ parameter, ending up in an “average”, but insignificant λ parameter; (iv) notional amounts in the regressions being smaller than a size leading to a price change: traders tending to split a large trade in several small orders to optimize liquidity costs; and (v) making use of *realized* transactions as a dataset, where actually no endogenous liquidity parameter is present, since the transactions have already been realized, possibly in smaller sizes.

In order to find out which of these conclusions can make sense, a second dataset, in which not only the liquid entities are present, is used. Despite this, a similar time period has been utilized due to data restrictions, and so the conclusion arising from (ii) cannot be ruled out yet. Table 7 presents the results with the second dataset arising from a benchmarking of a portfolio constructed by choosing single names for which CDS trades exist, as described in Section 5.2.

No	Entity	n	Trade Date	Term. Date	Currency	Lambda	t-stat	p-value	Sig.
1	AXA	18	14-Dec-10	20-Dec-15	EUR	1.51E-12	0.83	0.4188	
2	AXA	18	20-Dec-10	20-Mar-16	EUR	-2.64E-12	-1.12	0.2793	
3	CLARIANT AG	18	29-Nov-10	20-Dec-15	EUR	-3.14E-10	-0.81	0.4290	
4	CONTINENTAL AG	40	02-Feb-10	20-Mar-15	EUR	-7.10E-09	-2.37	0.0225	*
5	CONTINENTAL AG	28	31-Jul-09	20-Sep-14	EUR	-9.91E-10	-0.75	0.4622	
6	CONTINENTAL AG	16	29-Oct-09	20-Dec-14	EUR	1.31E-08	2.85	0.0117	*
7	ENEL S.P.A.	24	29-Jan-10	20-Mar-15	EUR	-6.22E-09	-1.11	0.2759	
8	ENEL S.P.A.	16	20-Oct-09	20-Dec-14	EUR	2.47E-09	1.60	0.1282	
9	ENEL S.P.A.	34	04-Feb-10	20-Mar-15	EUR	5.19E-10	0.34	0.7392	
10	FORD MOTOR CO	38	15-Sep-09	20-Sep-14	USD	5.92E-09	4.40	0.0001	**
11	FORD MOTOR CO	26	14-Sep-09	20-Sep-14	USD	-4.06E-14	-1.59	0.1241	
12	FORD MOTOR CO	16	05-Oct-09	20-Jun-12	USD	2.82E-15	2.75	0.0141	*
13	FORD MOTOR CO	16	09-Feb-10	20-Mar-15	USD	7.26E-09	1.49	0.1549	
14	FORD MOTOR CO	16	12-Jan-10	20-Mar-15	USD	2.44E-09	3.94	0.0012	**
15	FORD MOTOR CO	22	07-May-10	20-Jun-15	USD	1.08E-09	0.14	0.8908	
16	FORD MOTOR CREDIT	24	07-Apr-10	20-Jun-12	USD	-4.11E-09	-21.33	0.0000	**
17	GANNETT CO	22	30-Nov-09	20-Mar-12	USD	3.93E-10	12.18	0.0000	**
18	HSBC BANK PLC	20	17-Dec-10	20-Dec-14	EUR	4.67E-08	3.58	0.0019	**
19	HSBC BANK PLC	18	17-Dec-10	20-Mar-13	EUR	1.53E-08	0.62	0.5450	
20	INTESA SANPAOLO	16	29-Jan-10	20-Mar-15	EUR	-6.36E-09	-0.54	0.5983	
21	INTESA SANPAOLO	20	03-Dec-10	20-Dec-15	EUR	1.14E-07	3.27	0.0039	**
22	INTESA SANPAOLO	16	29-Nov-10	20-Dec-15	EUR	7.12E-08	1.15	0.2665	
23	JAPAN	120	25-Feb-10	20-Mar-15	USD	9.81E-10	17.05	0.0000	**
24	JAPAN	30	27-Jan-10	20-Mar-15	USD	-1.73E-10	-0.60	0.5512	
25	JAPAN	28	15-Apr-10	20-Jun-15	USD	-1.78E-09	-13.49	0.0000	**
26	JAPAN	24	22-Apr-10	20-Jun-15	USD	-5.52E-09	-7.83	0.0000	**
27	JAPAN	18	26-Jan-10	20-Mar-15	USD	9.97E-09	15.15	0.0000	**
28	JAPAN	16	09-Mar-10	20-Mar-15	USD	-4.42E-10	-0.14	0.8926	
29	JAPAN	16	28-Jan-10	20-Mar-15	USD	-3.78E-09	-1.37	0.1909	
30	JAPAN	26	29-Oct-10	20-Dec-15	USD	-7.71E-10	-29.18	0.0000	**
31	JAPAN	20	05-Oct-10	20-Dec-15	USD	-1.62E-09	-10.17	0.0000	**
32	JAPAN	16	22-Sep-10	20-Dec-15	USD	2.56E-09	0.35	0.7274	
33	JAPAN	24	06-May-10	20-Jun-15	USD	1.47E-09	2.16	0.0406	*
34	JPMORGAN CHASE	16	28-Apr-10	20-Jun-15	USD	3.39E-09	0.58	0.5722	
35	JPMORGAN CHASE	16	30-Apr-10	20-Jun-15	USD	1.89E-09	0.72	0.4845	
36	JPMORGAN CHASE	26	19-Oct-10	20-Dec-15	USD	1.99E-09	0.69	0.4942	
37	KINGDOM OF THAILAND	22	14-May-10	20-Jun-15	USD	-1.27E-09	-1.44	0.1633	
38	LLOYDS TSB BANK	32	14-May-10	20-Jun-20	EUR	3.62E-22	3.81	0.0006	**
39	LLOYDS TSB BANK	16	18-Oct-10	20-Dec-15	EUR	-2.30E-08	-0.60	0.5557	
40	LLOYDS TSB BANK	18	14-Dec-10	20-Dec-15	EUR	1.35E-12	1.10	0.2872	
41	LLOYDS TSB BANK	54	24-Nov-10	20-Dec-15	EUR	9.34E-10	0.66	0.5138	
42	LLOYDS TSB BANK	18	20-Dec-10	20-Mar-16	EUR	-3.55E-15	-0.36	0.7258	
43	MORGAN STANLEY	30	03-Dec-09	20-Jun-16	EUR	3.24E-14	1.60	0.1203	
44	MORGAN STANLEY	16	12-May-10	20-Jun-15	USD	-2.27E-09	-1.51	0.1504	
45	PORTUGAL TELECOM	34	04-Feb-10	20-Mar-15	EUR	2.82E-10	0.18	0.8545	
46	REP.OF PHILIPPINES	24	06-Aug-10	20-Sep-15	USD	-5.74E-10	-2.50	0.0196	*
47	REP.OF PHILIPPINES	16	05-Mar-10	20-Mar-15	USD	1.51E-09	1.69	0.1100	
48	SUPERVALU	18	22-Jul-10	20-Sep-15	USD	1.29E-09	4.85	0.0001	**
49	TELECOM ITALIA SPA	20	13-Apr-10	20-Jun-15	EUR	5.24E-09	0.87	0.3944	
50	THYSSENKRUPP AG	18	11-Feb-10	20-Mar-15	EUR	1.02E-08	1.28	0.2158	
51	UNITED BUS. MEDIA	26	16-Sep-10	20-Sep-15	EUR	3.00E-13	6.37	0.0000	**
52	UNITED BUS. MEDIA	24	21-Sep-10	20-Dec-15	EUR	-1.60E-22	-3.31	0.0029	**
53	VERIZON COMMS	16	01-Jul-09	20-Dec-11	USD	1.36E-14	1.21	0.2431	
54	WESTFIELD MNG	32	11-Feb-10	20-Dec-10	USD	-5.13E-14	-1.39	0.1740	

(**) indicates significance at 99% level

(*) indicates significance at 95% level

Table 7. Parameter estimation results with the regressions using the second dataset.

It is observed that the λ parameter is significant in 21 cases out of 54; however, in 9 out of 21 significances, the lambda has a negative sign. Besides that, the remaining positive significances are quite small: as a case in point, in the case of regression (10), a volume of USD 100 million changes the prices by only 0.296 bp. It could be concluded that any endogenous effect cannot be isolated.

These results strengthen the conclusion that CDS traders tend to split a large trade into several small orders to avoid liquidity costs (iv), which means that they have a clear idea of where the endogenous liquidity starts. Moreover, it can be more firmly stated that endogenous liquidity is not observed in a “realized” OTC transactions dataset (v). Using liquid CDS entities (i) or a liquid time horizon (ii) does not affect in any way the robustness of these results. Unfortunately, the number of individual counterparty transactions is still not enough to test the conclusion (iii), which remains unsolved. Since we are unable to distinguish buyer-initiated and seller-initiated trades, a mostly insignificant λ parameter may not be surprising. However, at the portfolio level of analysis, it can be stated that endogenous liquidity is not priced into credit default swap prices. This observation supports the findings of Longstaff, Mithal, and Neis (2005), who state that CDSs are contracts and not securities. Therefore, they can be arbitrarily created at any time, which makes them invulnerable to liquidity effects.

6. Conclusion and Implications on Supervision

Endogenous liquidity is a reality, but currently it is not considered for the accounting valuation of portfolios. Approaches to integrate it into this valuation, in particular using intraday prices on equities and for pricing derivatives products, exist. One of the difficulties lies in estimating the introduced endogenous liquidity parameter. In this paper, we tried to build a composite picture for estimation techniques by using either trade repositories for CDS or the order book for listed equities. No endogenous liquidity component could be identified on CDS transactions, showing probably that market participants know full well where endogenous liquidity costs start, and prefer to split large transactions into several small ones. On the other hand, the use of order book information made it possible to estimate not yet realized endogenous liquidity

parameters. Our study on the equity order book could probably be extended to other types of listed transactions, i.e. bonds or futures.

The evidence provided in our study shows that incorporating endogenous liquidity into the mark-to-market valuation of portfolios is feasible and realistic. Even if not recognized in the accounting results, it should be used to estimate prudential valuation, as requested by the BCBS; such that difference between prudent valuations and accounting valuations is taken from the capital, and the different risk measures (standardized or internal model) are estimated on these prudent valuations. Varying the value of the introduced endogenous liquidity parameters would give information on an institution's exposure to liquidity risk.

Introducing endogenous liquidity into the valuation of the portfolios would be extremely useful for several reasons:

- **Systemic risk** would be abated in two ways. First, it would help to address some issues associated with too-big-to-fail institutions. Indeed, the endogenous liquidity cost increases with the size of a position; as a result, the marginal profit of a new transaction will thus be negatively correlated to the size of the positions. Second, it would mitigate herding behavior as endogenous prudential liquidity reserves should prevent institutions from accumulating similar exposure to the same risks.
- The endogenous liquidity reserve would also help mitigate the **cyclicality** of the BCBS market risk framework. It would address, in particular the case of market stress affecting the realized price of transactions. Moreover, as introducing endogenous liquidity reserves would decrease the volatility of Profit and Loss (P&L), this would also contribute to reducing procyclicality.
- Taking valuation risk better into account should decrease the **volatility** of P&L, and thus dampen the incentives for short-term risk-taking.
- Recognizing endogenous liquidity risk should **penalize short positions**: since these are more exposed to endogenous liquidity via squeeze risk, introducing endogenous liquidity into the valuation should particularly penalize them.
- Endogenous liquidity should improve the computation of reserves. Although excluded from the current IFRS rules, these reserves could be accumulated for future

administrative costs as well. This will diminish upfront profits by some trading desks, and therefore will **impact traders' compensations** without necessarily decreasing the long-term profit of institutions.

- Finally, as adjusting the endogenous liquidity reserve would reduce the not-yet-realized part of the P&L but would not impact the realized part, it could represent a first step toward the **unification of prudential valuations/risk measures between the trading book and the banking book** (marked-to-market P&L converging towards accrued P&L).

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