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THE LIQUIDITY OF A DIVERSIFIED PORTFOLIO

DISCUSSION NOTE

In this note, we assess the trading liquidity of a globally diversified equity and fixed income portfolio.

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SUMMARY

- This note provides an assessment of the trading liquidity of a globally diversified equity and fixed income portfolio. We follow a bottom-up approach, estimating trading volumes at the security level and aggregating these along a number of dimensions.

- Obtaining reliable estimates of trading volumes for bonds is complicated by the decentralised nature of the fixed income market. We attempt to address this issue by merging data from several sources, and complement this with a model to impute trading volumes for bonds with missing data.

- We find notable regional differences in trading volumes in equities, with the US standing out as the most liquid market. Similarly, we find notable differences in trading volumes across segments in fixed income, with nominal government bonds in major developed markets and corporate bonds being on opposite sides of the liquidity spectrum.

- To illustrate the liquidity requirements induced by large portfolio changes, we look at a set of sizable asset class transitions, from fixed income into equities, equal to 10, 50 and 100 billion dollars (approximately 2, 10, and 20 basis points of the FTSE Global All Cap index market capitalisation). We find that a large investor is able to implement the largest of the considered portfolio transitions within a two-year period, if implemented at a moderate pace.

- While equity trading volumes tend to be stable, fixed income trading volumes, with the exception of nominal government bonds in developed markets, tend to decrease in periods marked by worsened liquidity conditions. A combination of large market size and stable trading volumes makes nominal government bonds in major currencies a natural source of liquidity.

1. Introduction

Trading liquidity is a key consideration when changing the exposures of a portfolio, and is defined as the ability to execute sizable transactions with limited price impact. This note provides an assessment of the trading liquidity of a globally diversified equity and fixed income portfolio. To do this, we estimate the time required for implementing portfolio transitions, which is a function of *trading volumes* and the *degree of market participation*.

While the academic literature on the transaction cost aspect of liquidity in particular market segments is vast, less work has been done on the *quantity* aspect of liquidity and on the evaluation of liquidity in the context of a broadly diversified equity and fixed income portfolio.[1] One reason for this is the lack of reliable data on trading volumes, especially in fixed income. This is mainly due to the decentralised nature of the fixed income market, where trading is primarily conducted over-the-counter. As a result, available datasets only cover certain regions, and even in these regions data providers report only a fraction of actual trading volumes. We attempt to address this issue by merging data from several sources and adjusting reported volumes to reflect the incomplete coverage.[2]

To illustrate the liquidity requirements induced by large portfolio transitions, we look at an asset class transition, from fixed income into equities, equal to 10, 50 and 100 billion dollar, which approximately corresponds to 2, 10 and 20 basis points of the market value of the FTSE Global All Cap index. For simplicity, the equity and fixed income portfolios we use are represented by the GPFG's benchmark indices. We further assume that the portfolio transition is implemented by trading every stock and bond in these indices according to its index weight, without the use of derivatives.[3]

In the first part of the analysis, we evaluate liquidity using recent data (January 2015-October 2016) to provide an assessment of current liquidity conditions. We find that an investor is able to implement the largest of the considered portfolio transitions within a two-year time period, while trading at a moderate market participation rate (0.5 per cent of average daily volumes (ADV)).

The second part of the note examines the time required to implement a large portfolio transition under worsened liquidity conditions. We evaluate liquidity in the period surrounding the bankruptcy of Lehman Brothers (September-December 2008) and in the initial phase of the eurozone sovereign debt crisis (July-December 2011). We find that trading volumes in government

1 We focus on trading volumes only in this note, leaving an analysis of transaction costs and price impact for larger portfolio transitions for potential future work.

2 Specifically, we use monthly bond-level trading volume data from TRAX to estimate a model which allows us to impute trading volumes for bonds with missing data and adjust for differences in coverage within the dataset. To evaluate our model, we compare imputed trading volumes with the aggregated trading volume data obtained from regulators and trade bodies in a number of countries. The model performs well in matching the reported trading volumes, even for markets with low TRAX coverage, e.g. Japanese government bonds.

3 This assumption is admittedly not consistent with the way most asset managers would implement such a transition, but it is consistent with the aim of providing a conservative estimate of liquidity needs for large portfolio transitions.

bonds in developed markets were stable in both periods. Other segments of fixed income, such as emerging-market Treasuries, G4 (EUR, GBP, JPY, USD currencies) government-related or corporate bonds, experienced significant drops in trading volumes.

The rest of this note is structured as follows. The next section describes the data. Section 3 outlines the methodology we use to obtain estimates of trading volumes. Section 4 discusses trading liquidity in equities, while Section 5 discusses trading liquidity in fixed income. In Section 6, we stress-test liquidity in equities and fixed income by examining the period surrounding the bankruptcy of Lehman Brothers and the initial phase of the eurozone sovereign debt crisis.

2. Data

This section describes the collection of datasets we use throughout the note. Additional details on the datasets are provided in Appendix B.1.

For simplicity, we use the GPFG's benchmark indices to represent the equity and fixed income portfolios, based on the instruments included as at October 2016.[4] For the stress-testing exercises, we use the benchmark indices as at December 2008 (Lehman bankruptcy) and December 2011 (eurozone sovereign debt crisis), adjusted to ensure that they are comparable to the current universe.[5]

For equities, we source constituent data from FTSE and FactSet, and trading volume data from FactSet. To get a timely estimate of trading volumes without too much short-term noise, we calculate ADVs using data from 1 January 2015 to 31 October 2016.[6] We use free-float-adjusted shares outstanding to calculate stock-level turnover ratios.

For fixed income, we source constituent data from Barclays and Bloomberg. Bond-level data on trading volumes are sourced from TRAX and TRACE, with more details provided below. In addition, we obtain aggregated trading volume data from the following national regulators and trade organisations: Deutsche Finanzagentur, the Japanese Security Dealers Association, SIFMA (US data) and the UK Debt Management Office. We use the data from these

4 GPFG's benchmark is based on the FTSE Global All Cap index for equities and the Bloomberg Barclays Global Aggregate index for fixed income, with some customizations. For the purpose of this note, the most important customizations are that, relative to the original indices, GPFG's equity benchmark is tilted towards Europe with a 2.5 times higher weight vs. the US, and GPFG's fixed income benchmark has a fixed weight on credit (30%) vs. government bonds (70%), with government bond currency weights based on (investability-adjusted) GDP as opposed to market capitalisation. For further details, see GPFG's management mandate at http://www.nbim.no/en/the-fund/governance-model/management-mandate/.

5 To ensure comparability, we remove asset-backed securities, mortgage-backed securities and commercial mortgage-backed securities, in addition to non-supranational bonds in the government-related bond segment. We use the universes as of December to be consistent with the analysis of current liquidity conditions. Using the universes as of the start of the periods does not affect our results.

6 We estimate trading volumes for stocks with missing trading volume data by applying an average turnover ratio in the respective size, sector and region bracket. This approximation is needed for a small number of mostly small-cap stocks only and does not significantly impact the aggregate figures.

agencies to verify our estimates of trading volumes obtained from TRAX and TRACE.

TRAX dataset

We obtain trading volumes from the post-trade services of TRAX. According to TRAX, this dataset covers around 65 percent of the European fixed income market. The coverage of trading volumes in other regions is substantially lower and varies markedly from currency to currency. The TRAX coverage is largely driven by regulatory requirements, as it mostly captures trades that involve a counterparty with a reporting obligation to the UK regulator. We adjust trading volumes reported by TRAX upwards to account for coverage differences across currencies and bond segments. We discuss the details of this upward adjustment in Appendices A and B.

The data are provided at the individual security level and are aggregated to daily, weekly and monthly frequencies. We obtain monthly trading volumes for the period from January 2007 to October 2016. The monthly TRAX data cover around 80 percent of the bonds included in the Bloomberg Barclays Global Aggregate index. Of the 40,000 bonds that were in the Bloomberg Barclays Global Aggregate index in the period from January 2007 to May 2016, around 33,000 are covered in the TRAX dataset. We provide more details on the TRAX coverage in Appendix B.

TRACE dataset

The National Association of Securities Dealers (NASD) introduced its Trade Reporting and Compliance Engine (TRACE) in July 2002 to increase price transparency in the US corporate debt market. TRACE collects and disseminates information on secondary market transactions in publicly traded TRACE-eligible securities (investment-grade, high-yield and convertible corporate debt), representing all over-the-counter market activity in these bonds. A detailed overview of the TRACE dataset is provided in Dick-Nielsen (2009). We obtain historical transaction-level data from January 2007 to October 2016 from MarketAxess, which also cleans the data of various errors and duplicates, see e.g. Dick-Nielsen (2014) for a review of necessary adjustments to the TRACE dataset. Investment-grade bond trades larger than 5 million dollars are not disseminated. Instead of the actual size for these large trades, TRACE reports the capped volume at 5 million dollars together with an estimate of the trade size which is based on historical trading volumes. In our calculations, we consider the capped volumes instead of the estimated ones, which makes our liquidity assessment conservative. TRACE covers around 95 percent of dollar-denominated corporate bonds included in our fixed income universe as at October 2016.

3. Methodology

This section briefly outlines the methodology we use to estimate trading volumes for equities and bonds at the security level. We subsequently aggregate the security-level estimates to evaluate the feasibility of various portfolio transitions.

Throughout the note, we abstract from two practical considerations. First, sizable portfolio transitions are often implemented with the help of derivatives, e.g. futures, which tend to be more liquid than cash instruments. Second, asset managers do not necessarily invest in all securities in their benchmarks, and often replicate the exposures using more liquid instruments. For both reasons, our analysis provides a conservative assessment of trading liquidity.

Illustrative portfolio transitions

To illustrate the liquidity requirements induced by large portfolio transitions, we look at an asset class transition, from fixed income into equities, equal to 10, 50, and 100 billion dollars, which approximately corresponds to 2, 10 and 20 basis points of the market value of the FTSE Global All Cap index.[7] To arrive at the required trading volumes for individual securities, we use the instrument weights from the benchmark indices described in Section 2.[8]

Determining trading volumes

Trading volume data for stocks tend to be more accurate and easier to obtain than those for bonds. Assessing trading liquidity in fixed income instruments is more complicated for several reasons. First, unlike with equities, most issuers have multiple bond issues outstanding, often with bond-specific features such as embedded call options, which makes the trading volumes vary from bond to bond for the same issuer. Second, data on bond trading volumes are scarce, with a large number of bonds having no trading volume data available. Finally, trading in bonds is decentralised, which is the main reason why the coverage of trading volumes in any dataset is significantly less than complete and varies across regions and market segments. Consequently, it is difficult to obtain precise security-level estimates of trading volumes.

We attempt to address these issues by proceeding as follows. First, we use monthly trading volumes obtained from TRAX to estimate a model that identifies the key drivers of trading volumes at the security level, using bonds included in the Bloomberg Barclays Global Aggregate index as at October 2016 and for which TRAX has trading volume data available. We model bond trading volumes through a "turnover ratio", which is defined as the monthly trading volume divided by the bond's nominal amount outstanding. The turnover ratio makes trading volumes of individual bonds comparable across currencies and sizes. We then model turnover ratios through a combination of bond- and market-specific features. Part of this step is to control for differences in coverage by the TRAX dataset across currencies and segments. Subsequently, we use this model to impute the trading volumes for each bond in the benchmark. Finally, we use the model to motivate the allocation of each bond to a particular liquidity group, with the goal of simplifying the analysis. We provide more details on the model and the aggregation procedure in Appendix A.

7 Free-float-adjusted market capitalisation of FTSE Global All Cap index as at October 2016.

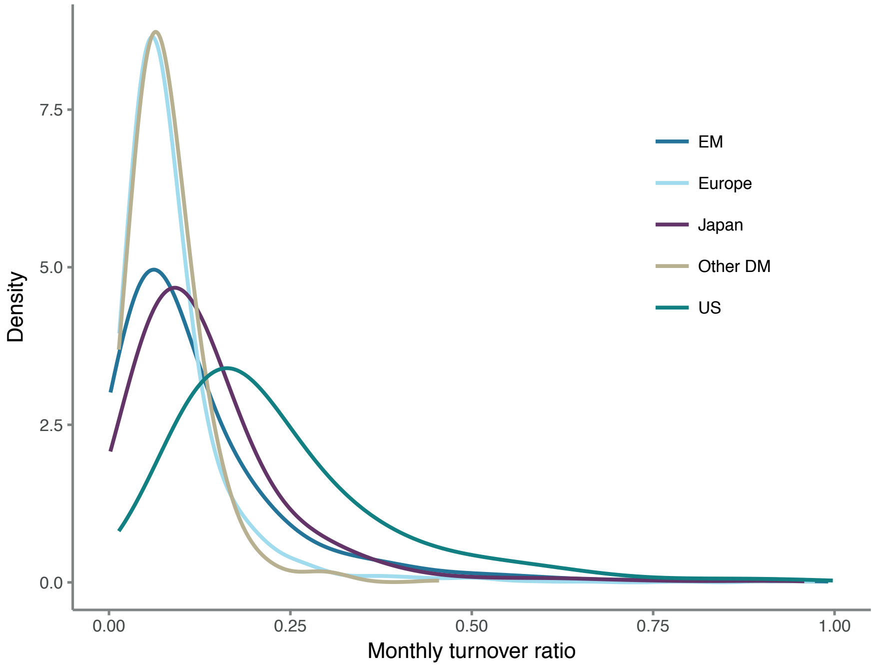
8 In equities, the weights in the FTSE Global All Cap index and the fund's benchmark differ due to the benchmark's overweight in European stocks. The choice of weighting scheme is important to the extent there are significant differences in liquidity across regions, discussed in Section 4.

4. Measuring trading liquidity in global equity markets

This section discusses trading volumes for a global equity portfolio.

To understand the variation in trading volumes across regions and size segments, we study free-float-adjusted monthly turnover ratios. To do this, we construct density functions for monthly turnover ratios split by region which are shown in Figure 1. The graph indicates a substantial variability in (relative) trading volumes across regions, with trading intensity in US stocks standing out from the rest in terms of both average and variability.[9]

Figure 1: Distribution of the free-float-adjusted monthly equity turnover ratios by region, January 2015-October 2016 data



Source: FactSet, NBIM calculations

A key metric for assessing a portfolio transition is the time required to trade all stocks in the portfolio to the target allocation. This depends on a stock's turnover ratio and the investor's market participation rate. We assess the time required to complete a transition from fixed income to equities by cumulating the fraction of the portfolio's transition, assuming a market participation rate ranging from 0.1 to 2 percent of ADV, which is applied uniformly across all stocks. We consider the transition completed once 95 per cent of the required trading has been executed. Figures 2 and 3 show the cumulative transition of 10 and 50 billion dollars, respectively. The smaller transition of 10 billion can be completed within one month with market participation at 0.5 percent or higher. A transition of 50 billion dollars can be completed within 100 trading days only if the market participation rate is higher than 1 percent.

9 One concern related to the low average turnover ratio of European stocks is that this might be driven by a few countries. This does not seem to be the case, since the distributions of turnover ratios across major European markets are quite similar.

Figure 2: Cumulative transition for equities (10 billion dollars) for different percentages of ADV, based on January 2015-October 2016 data

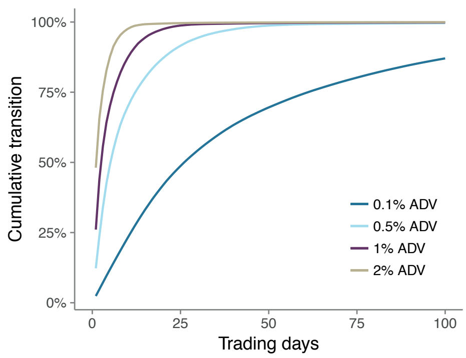
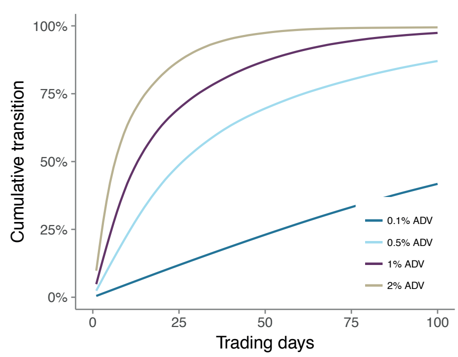


Figure 3: Cumulative transition for equities (50 billion dollars) for different percentages of ADV, based on January 2015-October 2016 data



Source: FactSet, FTSE, NBIM calculations

Figure 4 shows the cumulative completion rate of the largest transition we consider, 100 billion dollars, for up to 500 trading days, or approximately two years. It indicates that, for the largest of our illustrative transitions, only with the slowest trading profile is the portfolio transition not completed within two years.

Figure 5 illustrates the regional differences in the cumulative completion rate, assuming a market participation rate of 0.5 of percent of ADV. As already shown in Figure 1, US equities are very liquid, and the transition therefore takes the shortest time there. On the opposite side of the spectrum are European and emerging-market stocks, where the transition takes longer at the same participation rate. Besides the lower relative turnover ratios of European stocks mentioned earlier, one of the reasons that the transition takes longer in Europe is that the fund's benchmark, which we use as a proxy for a global equity portfolio, has a higher implied ownership share in Europe than in other regions.

Figure 4: Cumulative transition for equities (100 billion dollars) for different percentages of ADV, based on January 2015-October 2016 data

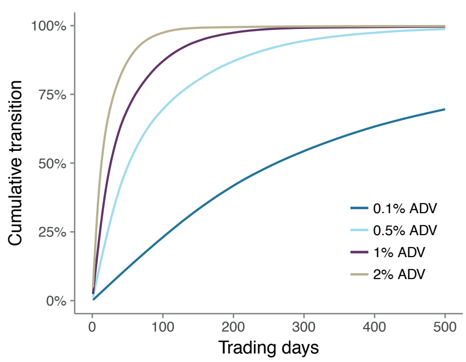
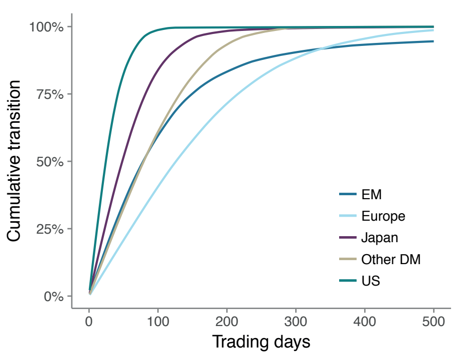


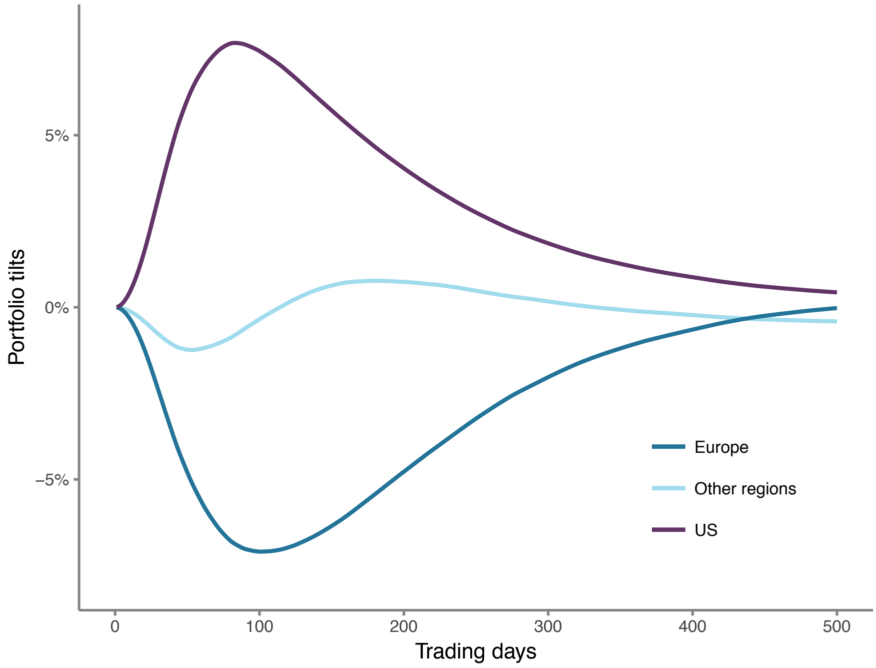
Figure 5: Cumulative transition for equities (100 billion dollars) across regions with market participation at 0.5 percent of ADV, based on January 2015-October 2016 data



Source: FactSet, FTSE, NBIM calculations

The transition discussed above is implemented assuming a uniform degree of market participation across all segments. This assumption means that there will be quite sizeable regional tilts during the transition, given the regional differences in turnover ratios illustrated in Figure 1. In Figure 6, we show the size of this tilt as a fraction of the transition size, together with the two largest contributors: European and US equities.

Figure 6: Equity portfolio tilts during transition as a fraction of transition size, market participation at 0.5 percent of ADV, transition size 100 billion dollars, based on January 2015-October 2016 data



Source: FactSet, FTSE, NBIM calculations

5. Measuring trading liquidity in global fixed income markets

This section discusses trading volumes for a global fixed income portfolio.

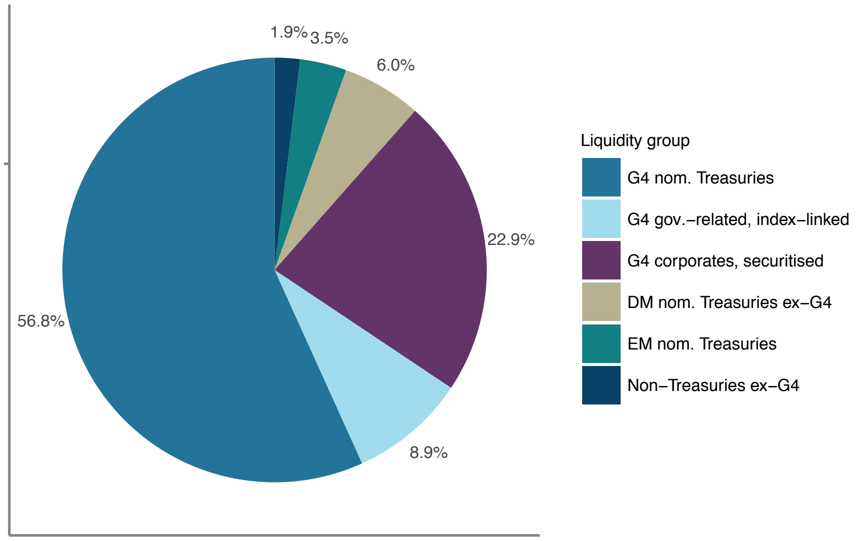
As mentioned in Section 3, trading volume data for bonds are less complete than those for equities, and we therefore need to rely partly on a model to obtain estimates of trading volumes. We model bond trading volumes through a "turnover ratio", which we define as the monthly trading volume divided by the bond's nominal amount outstanding. We then model turnover ratios through a combination of bond- and market-specific features, while controlling for differences in the TRAX coverage across regions and currencies. The details of this model are provided in Appendix A. In addition to imputing trading volumes at a bond level, the model helps us identify the key drivers of trading liquidity which we use to motivate the allocation of each bond to a particular liquidity group, with the goal of simplifying the analysis.

Guided by the model results, and taking institutional/geographical characteristics into account, we split the market into the following liquidity groups:

1. *G4 (EUR, GBP, JPY, USD) nominal government bonds.* These markets share several attributes that are related to liquidity, such as large size and asset homogeneity. We include Germany, France, Italy, and Spain from the eurozone in this group.
2. *Government-related and inflation-linked bonds issued in G4 currencies.* This market segment is smaller and less homogeneous than nominal G4 government bonds, and thus less liquid.
3. *Corporate and securitised bonds issued in G4 currencies.* This category includes both developed- and emerging-market issuers. Bonds in this segment are more differentiated and smaller on average than government or government-related bonds.
4. *Non-G4 developed-market nominal government bonds (AUD, CAD, CHF, DKK, NZD, SEK and small EUR-denominated nominal government bonds).* Government bonds in these markets are sizable and homogenous relative to other segments in the same currency, yet the markets are smaller than G4. This group also includes the remaining smaller eurozone government bond markets.
5. *Emerging-market nominal government bonds (CLP, CZK, HKD, ILS, KRW, MXN, MYR, PLN, RUB, SGD, THB and TRY).* Besides their smaller size compared to G4 developed-market government bonds, emerging-market bonds carry a substantial currency and sovereign credit risk.
6. *Non-G4 inflation-linked, government-related, securitised and corporate bonds (AUD, CAD, CHF, DKK, NZD, SEK and emerging-market currencies).* These market segments are small, more fragmented, and often dominated by local investors.

Figure 7 shows the relative size of each liquidity group within the fixed income portfolio we evaluate. The largest segment is G4 nominal Treasury bonds, at around 57 percent. These are followed by corporate and securitised debt issued in G4 currencies, at around 23 percent. Overall, debt issued in G4 currencies constitutes 89 percent of the global fixed income market. In the subsequent sections, we discuss trading liquidity at the level of liquidity groups. Of particular importance are G4 nominal Treasuries, which most likely will be the primary source of liquidity in a portfolio transition. It should be noted that some of the liquidity groups have quite small allocations, so their contribution to a large transition will be small regardless of their liquidity.

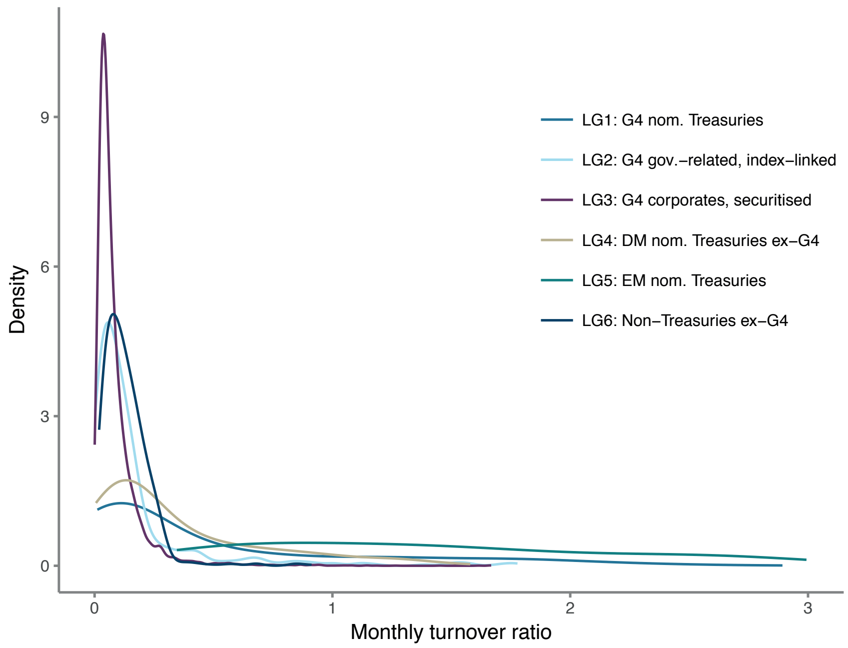
Figure 7: Liquidity groups in the fund's benchmark by index weight, as at October 2016



Source: Bloomberg Barclays Indices, NBIM calculations

Figure 8 shows the density of turnover ratios by liquidity group. The turnover ratios are imputed using the model presented in Table A-1. The variation of turnover ratios across liquidity groups appears to be higher than the variation in stock turnover ratios reported in Figure 1, but comparisons of fixed income and equity turnover ratios should be interpreted with caution given that those for bonds are *estimated* while those for equities are not. In particular, nominal government bonds appear to be distinct from the rest of the bond market, in terms of both a higher average and a higher dispersion of turnover ratios.

Figure 8: Distribution of estimated monthly fixed income turnover ratios by liquidity group, based on January 2015-October 2016 data



Source: Bloomberg, Bloomberg Barclays Indices, TRACE, TRAX, NBIM calculations

Similarly to equities, we assess the speed of a fixed income portfolio transition with market participation assumptions ranging from 0.1 to 2 percent of ADV. We start by evaluating the transition sizes of 10 and 50 billion dollars, cf. Figures 9 and 10. The results are similar to the cumulative transitions of equities reported in Figures 2 and 3. We therefore focus our subsequent analysis on the largest transition size.

Figure 9: Cumulative transition for fixed income (10 billion dollars) for different percentages of ADV, based on January 2015-October 2016 data

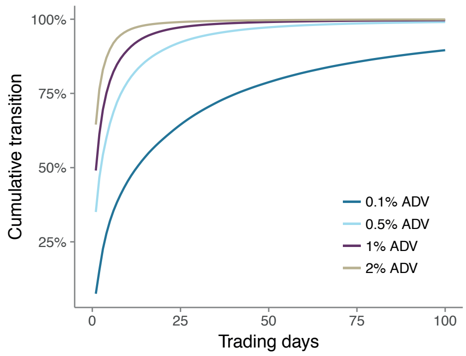
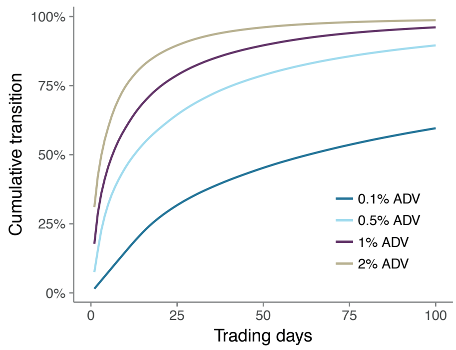


Figure 10: Cumulative transition for fixed income (50 billion dollars) for different percentages of ADV, based on January 2015-October 2016 data



Source: Bloomberg, Bloomberg Barclays Indices, TRACE, TRAX, NBIM calculations

Figure 11 shows the cumulative completion rate for up to 500 trading days (approximately two years) for all considered market participation rates. Similar to the equity results, the figures indicate that the largest transition can be completed within a two-year period for all but the slowest trading profile.

Figure 11: Cumulative transition for fixed income (100 billion dollars) for different percentages of ADV, based on January 2015-October 2016 data

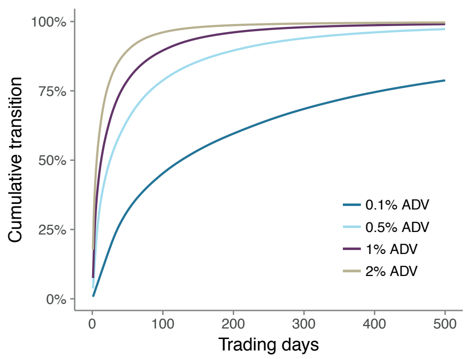
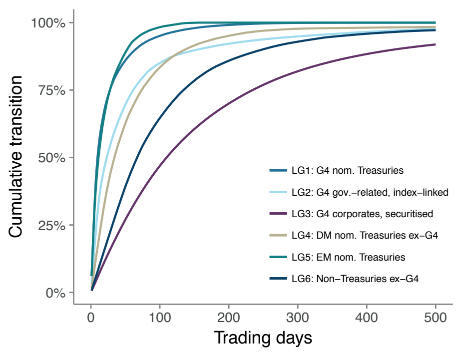


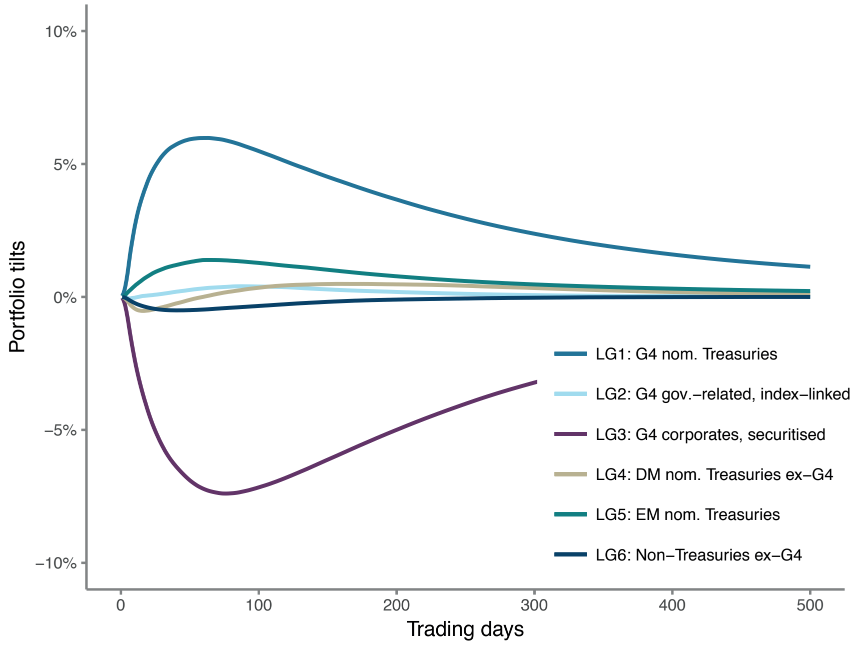
Figure 12: Cumulative transition for fixed income (100 billion dollars) by liquidity group with market participation at 0.5 percent of ADV, based on January 2015-October 2016 data



Source: Bloomberg, Bloomberg Barclays Indices, TRACE, TRAX, NBIM calculations

Figure 12 breaks down the transition by liquidity group assuming a market participation rate of 0.5 percent of ADV. The figure illustrates the superior liquidity of G4 nominal government bonds. While the local-currency government bonds in emerging markets also appear to be very liquid in this graph, it should be noted that these numbers are *estimated* and their *importance* as a source of liquidity in the portfolio is limited by the small size of this segment, as illustrated in Figure 7. Figure 12 also highlights substantial differences between G4 nominal Treasuries and corporate bonds. To put these differences into perspective, Figure 13 shows the size of portfolio tilts by liquidity group as a fraction of the transition size. Not surprisingly, G4 nominal government bonds introduce a sizable positive tilt while the lower liquidity of G4 corporate bonds causes a negative tilt with a larger magnitude.

Figure 13: Fixed income portfolio tilts during transition as a fraction of transition size, market participation at 0.5 percent of ADV, transition size 100 billion dollars, based on January 2015-October 2016 data



Source: Bloomberg, Bloomberg Barclays Indices, TRACE, TRAX, NBIM calculations

Liquidity in G4 government bonds

Given the importance of G4 government bonds for implementing portfolio transitions, we provide more details on liquidity dynamics in this segment. We assess turnover ratios of G4 government bonds, which we compute as the monthly aggregate turnover divided by the debt outstanding, over time. Aggregate turnover data are from external sources and do not rely on our model-based estimates of trading volumes. The eurozone debt market is represented by the German government bond market, arguably the most liquid market of the eurozone member countries in this particular period.

Figure 14 shows the historical development of annual turnover ratios for G4 government bonds. Turnover has been on a declining trajectory in all G4 markets in the post-crisis period. The decline in turnover ratios has been attributed to a multitude of factors. First, and most importantly, is increased government debt issuance, especially in Japan, the UK and the US. Second, balance sheets of dealers in government bonds have become more constrained in the post-crisis period. Finally, the non-conventional monetary policies of G4 central banks may have played a role in lowering the turnover in government bonds by diverting the flow to higher-yielding substitutes.

The plot illustrates the superior liquidity of US Treasuries, whose monthly turnover ratio averaged 2x in the period 2007-2015, while the corresponding numbers for UK gilts and German bunds are 0.4x and 0.5x, respectively. G4 nominal Treasuries still constitute by far the most liquid part of the fixed income universe.

Figure 14: Monthly turnover ratio in G4 government bonds, US Treasuries on the right axis, all other markets on the left axis

Source: TRAX, JSDA, UK DMO, SIFMA, MoF Japan, BoJ, Bloomberg Barclays Indices, NBIM calculations

6. Stress-testing liquidity sourcing

It is conceivable that a portfolio transition needs to be implemented during a period with significantly worsened liquidity conditions, such as the period surrounding the bankruptcy of Lehman Brothers or the eurozone sovereign debt crisis. Hence, it is useful to study the liquidity of the equity and fixed income portfolio under such conditions. For the purposes of the analysis below, the "Lehman period" starts in September 2008 and ends in December 2008, and the eurozone sovereign debt crisis starts in July 2011 and ends in December 2011.

In some aspects, fixed income tends to be more susceptible to liquidity deterioration than equities. This is because most of the trading in fixed income is conducted through intermediaries, which tend to scale down market-making activities if they are adversely impacted by worsened funding liquidity conditions.

Several studies compare liquidity conditions in "normal times" and crisis periods. Friewald, Jankowitsch, and Subrahmanyam (2012) document that around 14 percent of corporate bond spread changes are related to liquidity effects, and that the economic impact of liquidity is significantly larger in crisis periods. Acharya, Amihud, and Bharath (2013) study the exposure of US corporate bond returns to liquidity shocks in the period 1973-2007 in a regime-switching model. They find that periods of high illiquidity stress largely coincide with NBER-dated recessions.

We provide estimates of transition speeds in these two episodes in the same structure as in Sections 4 and 5 to ensure comparability. For the same reason, we also assume that the size of the portfolio transition is 100 billion dollars.

In the first step, we assess the feasibility of a portfolio transition during the Lehman period (Figure 15) and during the eurozone sovereign debt crisis (Figure 16). In both cases, we show the cumulative equity and fixed income portfolio transition assuming a market participation rate of 0.5 percent of ADV. Several observations stand out. First, trading in equities does not seem to deteriorate significantly relative to estimates of trading volumes in the most recent period. Quite the contrary, the Lehman episode saw more trading than the recent period. Second, trading in fixed income is significantly lower in the Lehman period than the estimates from the most recent data. Common to both crisis periods is that the transition of the fixed income portfolio could not be completed within a two-year period. This is mainly due to the less liquid segments, which virtually stopped trading during these periods.

Figure 15: Cumulative transition for equity and fixed income with market participation at 0.5 percent of ADV during the Lehman bankruptcy period, transition size 100 billion dollars, based on September-December 2008 data ("recent" estimates based on January 2015-October 2016 data)

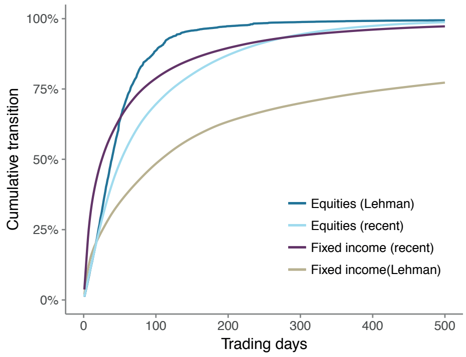
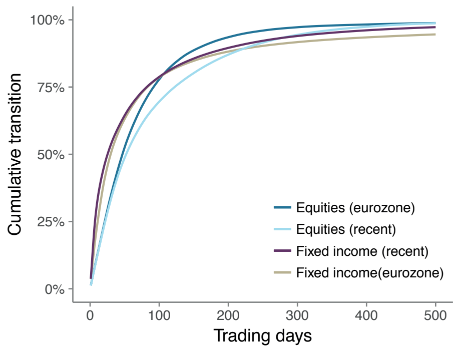


Figure 16: Cumulative transition for equity and fixed income with market participation at 0.5 percent of ADV during the eurozone sovereign debt crisis, transition size 100 billion dollars, based on July-December 2011 data ("recent" estimates based on January 2015-October 2016 data)



Source: Bloomberg, Bloomberg Barclays Indices, FactSet, TRACE, TRAX, NBIM calculations

To better understand the fall in fixed income trading volumes, Figure 17 shows the cumulative transition of the fixed income portfolio by liquidity group for the Lehman bankruptcy period. Figure 18 displays the equivalent breakdown for the eurozone sovereign debt crisis. Comparing these figures to the cumulative portfolio transition in the most recent period reported in Figure 12, it seems that the drop in trading is mostly driven by emerging-market government bonds and G4 government-related and corporate bonds. Importantly, the liquidity provided by developed-market nominal Treasury bonds remains consistently high, even in stressed liquidity conditions.

Figure 17: Cumulative transition for fixed income across segments with market participation at 0.5 percent of ADV during the Lehman bankruptcy period, transition size 100 billion dollars, based on September-December 2008 data

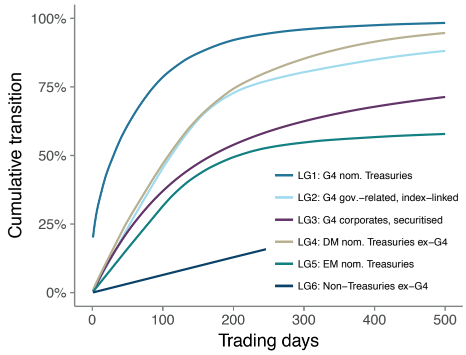
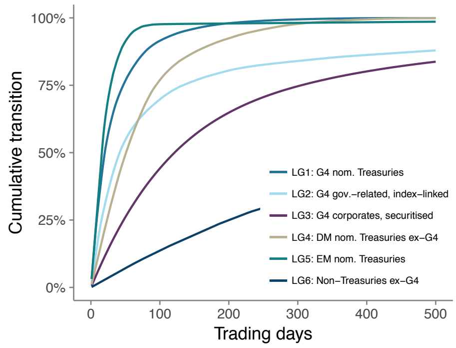


Figure 18: Cumulative transition for fixed income across segments with market participation at 0.5 percent of ADV during the eurozone sovereign debt crisis, transition size 100 billion dollars, based on July-December 2011 data



Source: Bloomberg, Bloomberg Barclays Indices, TRACE, TRAX, NBIM calculations

7. Summary

This note provides an assessment of the trading liquidity of a globally diversified equity and fixed income portfolio. To illustrate the liquidity requirements induced by large portfolio transitions, we assess asset class transitions, from fixed income into equities, equal to 10, 50 and 100 billion dollars (approximately 2, 10 and 20 basis points of the FTSE Global All Cap index market capitalisation).

In the first part of the analysis, we evaluate liquidity using recent data (January 2015-October 2016) to provide an assessment of current liquidity conditions. We find that an investor is able to implement the largest of the considered portfolio transitions within a two-year time period while trading at a moderate market participation rate (0.5 percent of ADV).

We show how trading liquidity changes in times of financial stress by studying the periods surrounding the Lehman bankruptcy and the eurozone sovereign debt crisis. While equity trading volumes are stable in periods of worsened liquidity conditions, fixed income trading volumes, apart from nominal government bonds in developed markets, are lower than usual in these episodes. A combination of large market size and stable trading volumes makes nominal government bonds in major currencies a natural source of trading liquidity.

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Appendix A

This appendix outlines the model that identifies the key drivers of fixed income trading volumes at the security level, and the allocation of each bond to a particular liquidity group.

We model bond trading volumes through a "turnover ratio", which is defined as the monthly trading volume divided by the bond's nominal amount outstanding. The turnover ratio makes trading volumes of individual bonds comparable across currencies and sizes. We then model turnover ratios through a combination of bond- and market-specific features, while controlling for differences in TRAX coverage across regions and currencies. The explanatory variables are listed and discussed below.

Bond-specific characteristics:

- *Bond size* – measured by the nominal amount outstanding in billions of dollars. Larger bonds are generally more liquid, as documented in Chakravarty and Sarkar (2003) and Hong and Warga (2000).
- *Asset homogeneity* – measured as one minus the ratio of a bond's market value to the total market value of all of the issuer's bonds outstanding. The aim of this measure is to capture the relative size of a particular issuance for any issuer. For large issuers, such as G4 governments, asset homogeneity is close to one. If an issuer has only one bond outstanding, asset homogeneity is zero. This variable can be theoretically justified by search frictions, see e.g. Duffie, Garleanu, and Pedersen (2005).
- *Simplicity in determining the cash flow profile* – approximated by a collection of bond features:
  - Senior debt indicator: taking a value of one if the bond is senior and zero otherwise.
  - Callable indicator: taking a value of one if the bond is callable and zero otherwise.
  - Inflation-linked indicator: taking a value of one if the bond's cash flows are linked to a consumer price index and zero otherwise. The empirical literature has shown that inflation-linked bonds are less liquid than nominal bonds, see e.g. Pflueger and Viceira (2015).

  Intuitively, bonds with simpler cash flow profiles tend to be more liquid.
- *Credit quality* – measured by the option-adjusted spread and credit rating.[10] We use the credit spread and the composite rating to capture a more forward-looking and a more backward-looking view of credit quality, respectively. Previous empirical evidence suggests a role for credit quality in determining trading volumes, see e.g. Wang and Wu (2015).
- *Bond age* – measured in years. Bond age is widely considered to be an important determinant of bond liquidity, see e.g. Hotchkiss and Jostova (2007). We also include the square of age in the model to account for potential non-linear effects of bond age on trading volumes.
- *Bond time to maturity* – measured in years. This is a proxy for interest rate risk. All else equal, higher interest rate risk is negatively related to trading liquidity, as discussed in Hotchkiss and Jostova (2007).

10 We code the rating categories linearly starting at Baa3=10 to Aaa=1. The benchmark index includes only investment-grade bonds.

Market-specific characteristics:

- *Emerging-market indicator* – taking a value of one if the bond issuer's country is classified as an emerging market by Bloomberg Barclays and zero otherwise. The purpose of this variable is to go beyond the bond-specific characteristics and capture potential liquidity differentials that might arise due to the emerging-market classification.
- *Local government debt indicator* – taking a value of one if the bond is classified as local government debt and zero otherwise.
- *Market size* – measured as the market value of all bonds in a given currency and market segment (government, corporate, government-related, and securitised bonds) in billions of dollars.

Controls for TRAX coverage:

- *EUR, USD, JPY, GBP currency indicator variables* – capture the differences in the coverage of TRAX across currencies, and other effects that are specific to the respective market segment. For G3 currencies (EUR, USD, GBP), we include a currency indicator variable for each segment to allow for a differentiated coverage of TRAX data across these currencies and market segments. JPY-denominated debt is represented by a single indicator variable as the differences across segments are insignificant and the size of the non-government bond segments is small relative to G3 currencies. The indicator variables take a value of one if the bond is denominated in the respective currency and belongs to one of the four segments and zero otherwise. To avoid collinearity, we do not include an indicator variable for UK nominal gilts in the model, and the estimated coefficients on other indicator variables should be interpreted relative to the U.K. nominal gilts. We select the UK gilt market as a basis because of its high coverage in TRAX.
- *Indicator variables for other currencies* – other developed markets in Europe (CHF, DKK, NOK, SEK), emerging market currencies (CZK, ILS, PLN, RUB, ZAR), Australia/New Zealand, Asian, and other Americas currencies (CAD, CLP, MXN).
- *Geographical region indicator variables* – it is possible that differences in the coverage of trading volumes by the TRAX dataset also vary across regions. For this reason, we include an indicator variable for each region: Americas; Asia Pacific (APAC); Europe, Middle East and Africa (EMEA); and supranational issuers. Each indicator variable takes a value of one if a bond is issued by an entity based in the respective region and zero otherwise. To avoid collinearity, we exclude the EMEA indicator variable from the regression.

Using the variables above, we estimate the following log-linear model for monthly turnover ratios:

$$log(TR_i) = \beta\ bond\ characteristics +\ \gamma\ market\ characteristics + \delta\ controls + \varepsilon_i$$

where TR_i denotes the average monthly turnover ratio of bond *i* as reported by TRAX. We compute the average turnover ratio as a simple average of reported monthly trading volumes in the period from January 2015 to

October 2016 divided by the bond's amount outstanding.[11] We estimate the regression on the broadest available universe of bonds (Bloomberg Barclays Global Aggregate index) to increase the precision of estimates. Thereafter, we apply these estimates to the narrower set of bonds we use. We use the estimated parameters to impute trading volumes, after removing the effects of differentials in TRAX coverage:

$$log(\widehat{TR}_i) = \hat{\beta}\ bond\ characteristics + \hat{\gamma}\ market\ characteristics$$

To estimate the model for imputing fixed income trading volumes, we consider bonds that are included in the Bloomberg Barclays Global Aggregate index at October 2016 and for which TRAX has trading volume data available. This gives us a sample of 14,673 out of 17,792 bonds included in the Bloomberg Barclays Global Aggregate at that point. Regression results for the model are reported in Table A-1 below. Most of the coefficients have intuitive signs, and a combination of bond- and market-specific determinants together with the control variables explains 57 percent of the variation in average log turnover ratios of individual bonds. Keeping the heterogeneity of the bond index in mind, the model seems to fit the data rather well.

Table A-1: Determinants of the turnover ratio at the bond level – regression results

Regressor	Estimate	Standard error	t-value
Constant	-1.886	0.187	-10.09
Bond size	0.013	0.002	5.72
Asset homogeneity	0.587	0.051	11.45
Senior debt indicator	-0.160	0.050	-3.21
Callability indicator	-0.149	0.028	-5.39
Inflation-linked indicator	-0.228	0.108	-2.10
Credit spread	0.001	0.0002	4.86
Rating	-0.014	0.006	-2.56
Bond age	-0.353	0.006	-58.56
Bond age squared	0.013	0.0003	38.41
Bond maturity	-0.007	0.001	-5.08
Emerging-market indicator	1.114	0.043	25.94
Local government indicator	1.608	0.104	15.54
Market size	-0.297	0.021	-14.43
Controls for TRAX coverage (reported in the Appendix B.1)			
Adjusted R-squared	0.57		
Number of observations	14 673		

Source: Bloomberg Barclays Indices, NBIM calculations, TRAX

The most important determinants of turnover ratios are bond size, asset homogeneity, bond age and whether a bond is classified as a local government or emerging-market bond. The loadings on these determinants have intuitive signs – a larger and more recently issued bond from a frequent issuer tends to trade more often, all else equal. One exception seems to be market size, which has a negative loading. The negative sign should be

11 We work with turnover ratios averaged over a recent sample period and a cross-sectional regression as opposed to an unbalanced panel regression to avoid modelling seasonality and trends. While interesting, these issues are not directly relevant to the questions we address in this note.

interpreted jointly with the other size-related determinants, however, such as asset homogeneity and bond issue size, both of which have intuitive signs. Importantly, most of the currency, segment and regional indicator variables are negative and statistically significant, in line with the substantial regional differences in TRAX coverage, see Table B-1 in Appendix B.1. Geographical adjustments are all relative to UK gilts, the omitted indicator variable.

A good model fit, together with intuitive loadings on determinants of the turnover ratio, allows us to proceed with the estimation results. We use the estimated determinants of the turnover ratio in two ways. First, we use the estimated currency and geographical effects reported in Table B-1 to remove some of the impact of the incomplete TRAX coverage by imputing bond-level trading volumes. Second, the regression results provide a basis for dividing the fixed income universe into a small number of homogenous liquidity groups.

Estimating trading volumes at the bond level

We are able to obtain reliable estimates of monthly trading volumes for a number of segments of the fixed income market. These include dollar-denominated corporate bonds from TRACE, and euro- and sterling-denominated bonds from TRAX. Given that the TRACE dataset contains all trades in dollar-denominated corporate bonds, we do not make any adjustments to reported trading volumes of these bonds.

For the TRAX data, we proceed as follows. First, we establish that TRAX covers approximately 70 percent of trading in euro- and sterling-denominated bonds.[12] In Appendix B.2, we provide a detailed assessment of the coverage in selected segments of the euro and sterling fixed income market with the help of aggregated trading volumes from other sources, e.g. debt management offices. In the next step, we lift bond-level trading volumes for all bonds reported by TRAX by a factor 1/0.7=1.43 to reflect the incomplete coverage. We use these upwardly-adjusted trading volumes for euro- and sterling-denominated bonds.

For bonds in other segments, we use the estimates reported in Table A-1 to impute trading volumes based on bond- and market-specific characteristics. This approach is based on the assumption that currency and regional indicators capture differences in TRAX coverage, and that all systematic variation in turnover ratios is captured by the bond- and market-specific characteristics.[13] Clearly, this is a strong assumption, since there are likely to be effects other than variation in TRAX coverage that are correlated with these currency indicator variables. However, there are several observations indicating that our adjustment does not lead to significant biases.

First, none of the regression coefficients on the sterling-related indicator variables are statistically significant, see Table B-1 in Appendix B.1. This means that there do not seem to be any segment-specific effects in sterling-

12 TRAX claims to cover around 65 percent of European fixed income.

13 To impute trading volumes at a bond level, we apply the estimated bond- and market-specific coefficients provided in Table A-1 to the corresponding observables while leaving out the control variables. In this way, we approximate a world in which the TRAX dataset has full coverage in all segments and currencies.

denominated bonds.[14] Second, adding control variables to the regression that only includes bond- and market-specific variables does not significantly change the regression coefficients on bond- and market-specific variables, but it more than doubles the adjusted R-squared (results not reported for brevity). To further evaluate the robustness and the representativeness of our estimates, Appendix B.2 compares our aggregated estimates for a number of important segments of fixed income that have low TRAX coverage (e.g. Japanese government bonds, dollar- denominated corporate bonds, US Treasuries) with statistics provided by regulators and dealer associations.

14 Recall that UK gilts represent a basis relative to which the estimates of currency and market control variables are interpreted. Since these control variables are not statistically significant for non-gilt GBP-denominated bonds, this indicates that the currency and market control variables mostly capture the variation in TRAX coverage.

Appendix B

The appendix provides additional details on the model that we use to adjust trading volumes for bonds, and its verification using aggregated trading volumes from various independent sources.

B.1. Adjusting trading volumes for TRAX coverage

The TRAX dataset does not fully cover all trading volumes across currencies, since TRAX only includes trades that are reported to the UK regulator. This introduces systematic patterns in the degree of coverage of trading volumes in the dataset. We therefore need to adjust the volumes upwards to obtain undistorted estimates of total trading volumes at the bond level. The details of the model are provided in Appendix A. Coefficient estimates for bond- and market-specific variables are reported in Table A-1. The estimates for the control variables are reported in Table B-1 below.

Table B-1: Coverage adjustment of TRAX dataset across currencies, estimated from a log-linear model for turnover ratios at the bond level

Regressor	Estimate	Standard error	t-value
Corporates x USD indicator	-0.67	0.23	-2.94
Treasuries x USD indicator	-2.87	0.17	-17.13
Gov.-related x USD indicator	-1.07	0.19	-5.71
Securitised x USD indicator	-0.37	0.27	-1.36
Corporates x EUR indicator	-0.18	0.18	-1.01
Treasuries x EUR indicator	0.92	0.19	4.79
Gov.-related x EUR indicator	-1.14	0.18	-6.22
Securitised x EUR indicator	-1.43	0.18	-7.96
Corporates x GBP indicator	-0.06	0.18	-0.36
Gov.-related x GBP indicator	-0.30	0.19	-1.58
Securitised x GBP indicator	-0.26	0.21	-1.24
JPY indicator	-2.50	0.18	-13.55
DKK indicator	-3.58	0.32	-11.19
SEK indicator	-3.42	0.24	-14.09
CHF indicator	-2.38	0.18	-13.43
NOK indicator	-2.75	0.32	-8.52
AUD indicator	-1.70	0.18	-9.42
NZD indicator	-2.46	0.24	-10.28
CAD indicator	-3.66	0.18	-20.72
SGD indicator	-2.99	0.23	-12.84
HKD indicator	-6.20	0.39	-15.69
THB indicator	-5.47	0.27	-20.63
KRW indicator	-7.55	0.37	-20.16
MYR indicator	-5.19	0.23	-22.63
PLN indicator	-2.11	0.33	-6.45
ZAR indicator	-2.08	0.23	-9.16
CZK indicator	-3.96	0.31	-12.60
RUB indicator	-3.26	0.33	-9.90
ILS indicator	-3.61	0.35	-10.22
MXN indicator	-4.12	0.32	-12.86
CLP indicator	-2.68	1.13	-2.37
Supranational indicator	0.93	0.06	15.94
Americas indicator	-0.37	0.03	-12.06
APAC indicator	-0.07	0.04	-1.89

Source: Bloomberg Barclays Indices, TRAX, NBIM calculations

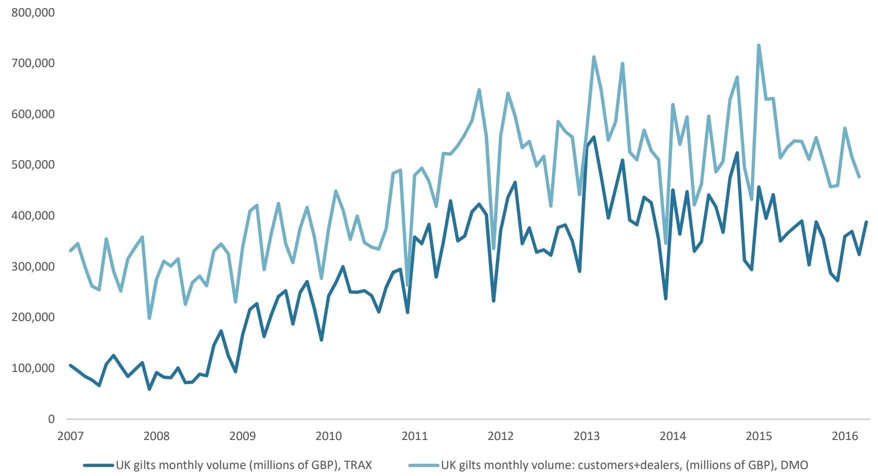
B.2. Reconciling TRAX trading volume data

This appendix discusses the coverage of trading volumes in the TRAX dataset. We also assess the robustness of our estimates using aggregated data in a number of markets.

TRAX coverage in Europe

An important question is how representative the trading volumes obtained from TRAX are of total trading in the respective part of fixed income. We address this issue by comparing monthly trading volumes from two different sources for segments where these data are available. We start with UK gilts, for which the UK Debt Management Office (DMO) publishes aggregated gilt trading volumes at a weekly frequency.[15] Figure B-1 below compares monthly trading volumes for gilts from the TRAX dataset and DMO. While the data from the DMO are consistently higher, as one would expect, given that TRAX coverage is not complete, the dynamics are virtually identical – the correlation coefficient of both series is 0.94. This indicates that a level adjustment is sufficient to correct the coverage of TRAX data to total trading volume. The coverage of TRAX in the post-crisis period starting in January 2010 is 70 percent – in line with our assumptions.

Figure B-1: Comparison of trading volumes for UK gilts, TRAX and DMO, monthly data, 2007-2016

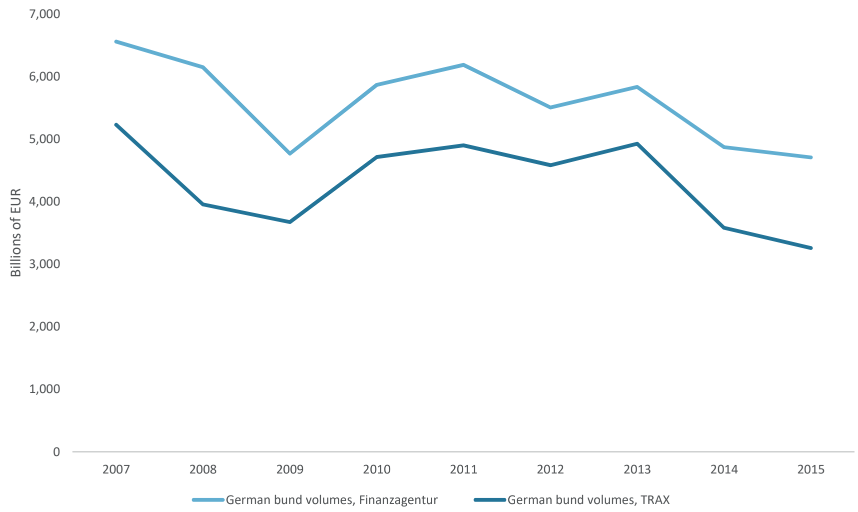


Source: UK DMO, TRAX, NBIM calculations

Similarly, most German government debt is traded and/or reported in London, and the coverage of TRAX data is consistently around 70-80 percent of total annual volumes, as shown in Figure B-2 below. Deutsche Finanzagentur only provides semi-annual trading volumes.

15 http://www.dmo.gov.uk/index.aspx?page=Gilts/Turnover

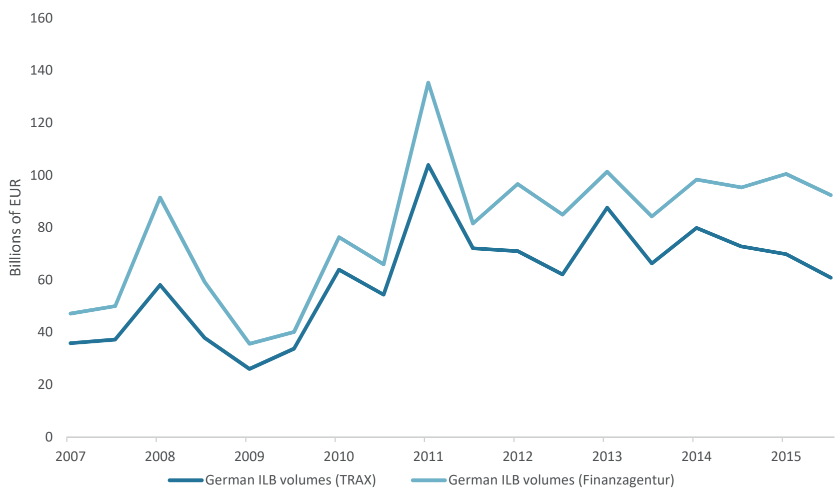
Figure B-2: Comparison of trading volumes for German government bonds, TRAX and Deutsche Finanzagentur, annual data, 2007-2016



Source: Deutsche Finanzagentur, TRAX, NBIM calculations

However, it may be that the coverage of the TRAX dataset varies significantly for some segments within the German government bond market. To address this concern, we compare the coverage of German government inflation-linked bonds (ILB) by TRAX. Figure B-3 shows the semi-annual data for the period 2007-2015. The correlation between these two series is 0.95, and TRAX covers 76 percent of total trading volumes, in line with the coverage of nominal government bonds.

Figure B-3: Comparison of trading volumes for German inflation-linked government bonds, TRAX and Deutsche Finanzagentur, semi-annual data, 2007-2016



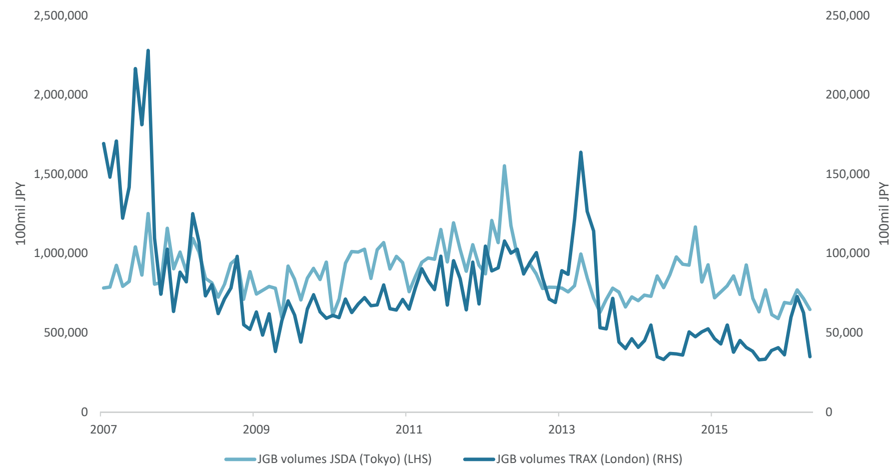
Source: Deutsche Finanzagentur, TRAX, NBIM calculations

Evaluating imputed trading volumes

For bonds other than euro- and sterling-denominated bonds, where we consider TRAX trading volumes directly, we use imputed trading volumes in our analysis. To evaluate the robustness and representativeness of our estimates, we compare our aggregated estimates with the statistics provided by regulators or dealer associations.

Japanese government bonds
The coverage of trading in the Japanese government bond market by TRAX is low, as most of the trading takes place in Tokyo between domestic investors with only a small fraction of trading being reported in London. Hence, the scope for imprecise estimates is large. Figure B-4 compares aggregated trading volumes in Tokyo and London. The correlation between these two series is 0.42, and the coverage of Japanese government bond trading volumes by TRAX in the post-crisis period starting in January 2010 is 7.8 percent.

Figure B-4: Comparison of trading volumes in Japanese government bonds, TRAX and JSDA, monthly data, 2007-2016 (note that each series has its own scale)

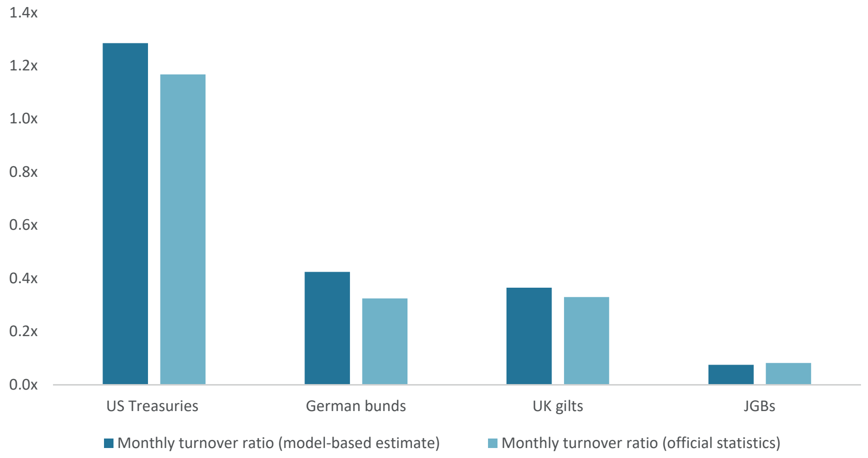


Source: JSDA, TRAX, NBIM calculations

Dollar-denominated corporate bonds
Thanks to the TRACE dataset, we can compare estimates of trading volumes from our TRAX-based model with the actual volumes from TRACE at the bond level. Our estimates are conservative for this segment of the market at around 34 percent of the TRACE reported trading volumes.

Estimates of turnover ratios in G4 government bond markets
To assess the accuracy of the model for imputing trading volumes outlined in Appendix A, we aggregate the bond-level estimates of trading volumes in G4 government bond markets and compare these to aggregated trading volumes obtained from official statistics. Figure B-5 shows estimated monthly turnover ratios for G4 government bond markets together with turnover ratios from official statistics. Despite the relatively low TRAX coverage in some of these markets, the model seems to fit the aggregated data fairly well.

Figure B-5: Comparison of reported and estimated monthly turnover ratios in G4 government bond markets. Estimates are based on January 2016-February 2017 data from TRAX. Official statistics are based on 2014-2015 data from regulators. Both official statistics and estimates include inflation-indexed bonds



Source: TRAX, JSDA, UK DMO, SIFMA, MoF Japan, BoJ, Bloomberg Barclays Indices, NBIM calculations