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Abstract

Large-value payment systems (LVPS) often have a tiered structure where only a limited number of banks have direct access to these systems and every other institution accesses the system through agency arrangements with the direct participants. As such, a high degree of tiering is often perceived as being associated with credit and operational risks. In this paper we use data around five recent de-tiering events in the United Kingdom's LVPS (CHAPS), to assess the impact of de-tiering on these risks as well as on liquidity usage. We find that the impact of de-tiering is largest on credit risk, where average intraday exposures between first and second-tier banks drop by anywhere between £0.3 billion and £1.5 billion per bank, while the cost of insuring against losses arising from these exposures drops by about £4 million to £19 million per bank, per year. On the other hand, the impact of these de-tiering events on operational risk and liquidity usage appears to be economically small.

Key words: Payment systems, tiering.

JEL classification: E42, G23.

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1 Introduction

Large-value payment systems (LVPS) often have a tiered structure where a limited number of (first-tier) banks have direct access to these systems and act as correspondents for every other (second-tier) institution wishing to make or receive a payment (see Figure 1). The degree of tiering in a payment system is of interest to policy makers and regulators because of its potential effects on credit risk (between first- and second-tier members), liquidity risk, as well as operational risk. The CPMI-IOSCO *Principles for Financial Market Infrastructures*, for example, point out that the dependencies and risk exposures inherent in tiered arrangements in financial market infrastructures can present risks to their smooth functioning, as well as to their participants and to financial markets more broadly (CPMI-IOSCO, 2012).
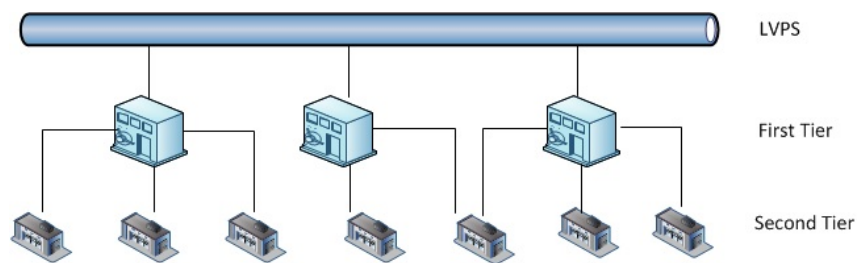

Figure 1: A tiered structure. "First-tier" banks with direct access to the payment system act as correspondents for other, "second-tier" institutions.

There is substantial variation in the degree of tiering across the world's LVPSs. Table 1 shows activity summary statistics in some of these systems along with their degree of tiering as captured by the ratio of the number of first-tier to total system participants.[1] As one can see, the UK's Clearing House Automated Payment System (CHAPS) is the most tiered system, while Switzerland's SIC and Japan's BOJ-NET are the least tiered ones, with all participating banks having direct access. This variation in tiering across payment systems is partly due to historical reasons but it may also reflect participation costs or other economic incentives along with regulatory mandates.

In the case of CHAPS, policy discussions have highlighted the merits of reducing the level of tiering. For example, in a recent assessment, the IMF stated that "De-tiering helps address (for its part) the too-big-to-fail nature of banks and will bring the U.K. more in line with international practices in, for example, the EU and the United States, where most banks have direct access to the RTGS system", and was of the view that "further de-tiering is needed" (IMF, 2016). And, although there has been an increase in the number of CHAPS direct members, from 14 in 2007 to 26 in 2017, the question remains as to what the impact of de-tiering has been so far and whether more de-tiering would be desirable.

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[1] Because of the structural differences across different financial systems, this ratio only provides a relative measure of tiering. For a more accurate picture other factors may need to be taken into account, like the fact that some participants with direct access may still choose to operate through correspondent banks.

Table 1: Activity and degree of tiering of major LVPSs in 2016. This table shows average daily values (in £billion) and volumes in different LVPSs along with the numbers of first-tier banks and total participating institutions as well as the ratio of the two according to the BIS *Statistics on payment, clearing and settlement systems in the CPMI countries* (2016) and payments systems' disclosure and annual reports. For TARGET2, the number of indirect participants does not include branches of indirect or direct participants. In 2017, the number of direct participants in CHAPS increased to 26.

Country	System	Settlement type	Average daily payments (£bn)	Average daily volume	First-tier banks (F)	Total participants (approx.) (N)	F/N
UK	CHAPS	Gross	299	149,008	24	5,400	0.0044
USA	CHIPS	Net	1,075	438,095	49	8,305	0.0059
EU	TARGET2	Gross	1,614	351,548	1,004	7,031	0.0143
Canada	LVTS	Net	96	32,103	17	82	0.207
Australia	RITS	Gross	88	44,325	60	87	0.69
USA	FEDWIRE	Gross	2,387	566,667	6,930	7,866	0.88
Switzerland	SIC	Gross	116	1,749,206	350	350	1
Japan	BOJ-NET	Gross	782	67,063	536	536	1

Our paper is the first to use data around actual de-tiering events to quantify the economic effects of tiering, in one of the world's largest RTGS payment systems. In particular, we examine the impact of five recent CHAPS de-tiering events on bank credit, liquidity and operational risks.[2] Previous attempts to assess these risks have been based exclusively on simulations. Simulation studies however typically use models that do not capture banks' strategic behavior and therefore are less realistic. Instead, we look at actual bank behavior around these de-tiering events and, as such, we are able to capture equilibrium outcomes and more accurately characterize the impact of de-tiering. Additionally, we provide monetary estimates of the expected costs associated with each of the above risks and of the way these costs change after the de-tiering events. For credit risk, we do this by estimating what a bank would be expected to have to pay in order to insure itself against the intraday exposures that arise as a result of tiering. For liquidity and operational risks, we estimate the opportunity costs of deployed liquidity and of payments that are delayed as a result of operational outages respectively.

Our findings suggest that the de-tiering events mostly affect the magnitude and cost of intraday credit risk between first and second-tier banks. More precisely, we find that de-tiering reduces average intraday exposures, between first and second-tier banks, by anywhere between £0.3 billion and £1.5 billion for each affected bank.[3] Maximum intraday exposures are reduced by up to £2.7 billion per bank. The associated reductions in the implied insurance premia fluctuate between £4 and £19 million per bank, per year, depending on whether the bank is one joining the first tier, or a legacy first-tier one of whose clients joins the first tier.

Additionally, de-tiering does not seem to cause liquidity costs to increase as the amount of liquidity deployed by first-tier banks is statistically uncorrelated with the de-tiering

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[2]Throughout the paper we refer, for simplicity, to the cost of liquidity usage as "liquidity risk".

[3]That is, either for a second-tier bank that joins the first tier or a first-tier bank one whose clients joins the first tier.

events. In any case, the cost of liquidity appears to be economically small in CHAPS so that any further potential increases to liquidity usage, due to de-tiering, are unlikely to be economically significant. Similarly, we also find that the expected monetary cost resulting from individual bank operational outages is small, to the extent that de-tiering can only have, in expectation, minor incremental effects on operational risk. Other possible effects of de-tiering such as on bank resolution, on competition or on legal risk, are out of the scope of our analysis.

The rest of the paper is organized as follows. In Section 2 we review the relevant literature. In Section 3 we describe the institutional characteristics of CHAPS and the data used in our analysis. In Section 4 we describe the methodology for assessing credit, liquidity and operational risks associated with de-tiering and present the results as applied to CHAPS. Section 5 concludes.

2   Literature review

Our paper is related to previous studies that have sought to explain the economic rationale of tiering in LVPSs and analyze its effects on credit risk and liquidity usage.

A number of papers rationalize tiering using monitoring efficiency arguments. For example, in characterizing an efficient payment system, Rochet and Tirole (1996) argue that such a system should enable bilateral intraday overdrafts similar to the ones that exist between correspondent and client banks in a tiered payment system. This enables the banks to take advantage of the soft information that they may have about their counterparties and helps overcome the inefficiency in credit provision caused by the uniformity of the central bank's overdraft rules. Related to that, Jackson and Manning (2007) show that a central bank can optimally require collateral for all intraday lending that it does, even if only a subset of participants are safe and have low collateral costs. This is because the riskier participants can benefit indirectly from central bank credit by corresponding through the safe banks in a tiered structure. Kahn and Roberds (2009) develop an explicit theory of tiering which shares elements of that intuition. They set up a static model where banks seek to meet their payment obligations to each other but need to account for settlement risk (i.e. the risk that bank A makes a payment to bank B but does not receive its dues because bank B has in the meantime defaulted). One solution is for banks to post collateral, which is expensive. Alternatively, banks may monitor each other and tiering is one way to achieve this in a decentralized system, as less reliable banks settle through more reliable ones who act as their monitors. Chapman, Chiu and Molico (2013) build on this intuition in a dynamic setup. In their paper, first-tier banks observe the credit history of their second-tier clients which allows them to better assess their creditworthiness. This, in turn, allows for a more efficient allocation of credit.

Given the implications of tiering on bank intraday liquidity, our paper is also related to studies that model bank intraday liquidity management in payment networks. The seminal paper here is Bech and Garratt (2003) who show that in order to minimize

liquidity costs, banks may strategically delay their outgoing payments, potentially giving rise to socially inefficient equilibria. Abbink et al. (2017) provide laboratory evidence of such equilibria and show that inefficient equilibria tend to be stable i.e., once banks start collectively delaying payments, it is difficult to get them to change their behavior.

Our paper is more closely related to a literature that has sought to empirically assess the impact of LVPS tiering on intraday credit risk and liquidity usage. Not surprisingly, many of these studies use data from CHAPS, since CHAPS is one of the most tiered systems in the world. Bank of England (2004a) and Harrison, Lasaosa and Tudela (2005) are the first to assess the size of unsecured intraday credit exposures of first-tier CHAPS banks toward their second-tier clients. They both find that, under normal circumstances, these exposures are not large and, as a result, the credit risk that accrues to first-tier banks is not material. However, there are instances when these exposures can be larger, if short-lived. For example, Bank of England (2004a) reports that, according to the 2003 correspondent banking survey, the largest recorded intraday exposure to a single second-tier bank for that year was between £3.5 and £4 billion. And Harrison, Lasaosa and Tudela (2005) calculate that under more extreme assumptions, substantial credit risk can arise. Lasaosa and Tudela (2008) employ the Bank of Finland Payments Simulator (BoFPS) to see how credit risk and liquidity savings are affected when up to seven of the smallest first-tier CHAPS banks join the second tier. They find that while there is an increase in credit risk arising from intraday overdrafts as well as an increase in liquidity efficiency, both of these effects are economically small. Similar results are obtained by Arculus, Hancock and Moran (2012) who also use the BoFPS calibrated this time to the Australian LVPS, a system characterized by very little tiering. Their simulations show limited liquidity benefits resulting from increased tiering and the authors attribute this to the usage of a Liquidity Savings Mechanism which helps first-tier banks economize on liquidity. Adams, Galbiati and Giansante (2010) seek to understand what role liquidity costs play in a bank's decision to access directly or indirectly an RTGS system. The authors assume that banks trade off a higher liquidity cost, if they are on the first tier, versus a flat fee paid to the their correspondent bank and determined by a Nash bargaining rule, if they are on the second tier. Calibrating this model to CHAPS data, the authors are able to generate realistic tiering patterns suggesting that liquidity cost is a likely driver of tiering. Our paper adds significantly to this literature by analyzing the effect of actual de-tiering events as opposed to running simulations. As such, our paper provides cleaner evidence on the impact of tiering since it makes no assumptions about bank behavior.

Another relevant stream of the literature is that on the impact of operational incidents in payment systems. Bech and Garratt (2012) show theoretically that such incidents can render the payment system illiquid by causing participants' behavior to change. In particular, in cases of wide-scale disruptions that affect multiple participants, banks may choose to withhold payments which can result in a breakdown of payment coordination and a dry-up of liquidity. Bedford, Millard and Yang (2004) use simulation techniques to study the impact of such outages in CHAPS. They conclude that the system exhibits a

high level of resilience, reflecting the effectiveness of the operational risk controls that are in place and the ample amount of liquidity available in the system. Merrouche and Schanz (2009) investigate instances of isolated operational outages where a stricken bank is able to receive but unable to send payments. In those instances, the bank may act as a liquidity sink if other banks continue making payments to it. Using data from CHAPS, the authors find that during outages, healthy banks on average reduce their payment outflows to the stricken bank by 40%. This substantially reduces the risk of spillover from the outage as less liquidity becomes trapped. Benos, Garratt and Zimmerman (2012) estimate the expected amount and replacement cost of foregone liquidity during such incidents in CHAPS. They find that the expected cost of liquidity shortages is economically small at about £6-7K per bank, per day. This is consistent with the evidence from other RTGS systems: Berge and Christophersen (2012) show that while a disruption among the four largest banks of the Norwegian settlement system (NBO) could impact the ability of other banks to make payments, this effect is significantly reduced if banks quickly stop making payments to the stricken bank so that it does not become a liquidity sink. And Clarke and Hancock (2012) show that the liquidity-saving features of the Australian RTGS, such as the bilateral-offset algorithm, minimize the impact of outages by reducing the overall reliance of the system on available liquidity.

Finally, our paper is related to a number of more recent empirical studies of bank behavior and liquidity usage in CHAPS. While these studies do not explicitly examine tiering, their findings on CHAPS liquidity usage are largely influenced by the high degree of CHAPS tiering. Benos, Garratt and Zimmerman (2014) find that concerns about counterparty risk caused some CHAPS banks to delay outgoing payments to other CHAPS banks that were perceived as being at risk. As a result, payment coordination and recycling dropped and CHAPS banks were forced to deploy more liquidity to meet their payment obligations. Denbee, Garratt and Zimmerman (2015) show that smaller CHAPS banks tend to provide more liquidity than larger ones relative to their payment flows and this effect became more pronounced after Lehman's default. Benos and Harper (2016) show that the degree of payment recycling in CHAPS has not been affected by the larger amount of available liquidity in the form of reserves that has resulted from the Bank of England's QE program. Among other things, Benos and Harper (2016) attribute this to the high degree of tiering in CHAPS which makes it relatively easier for banks to coordinate their payments.

3 Institutional details, data and notation

The Clearing House Automated Payment System (CHAPS), is the UK's same-day high-value payment system. CHAPS uses a Real Time Gross Settlement (RTGS) system where each individual payment is settled in real time across its first-tier banks' settlement accounts at the Bank of England. It is the only UK payment system that guarantees real time finality on any value, in central bank money. CHAPS is one of the largest

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RTGS systems in the world, offering risk-free and irrevocable same-day payments to meet the Sterling RTGS payment requirements of its 26 direct participants. CHAPS is also a critical mechanism for ensuring liquidity in the financial markets as it is used by banks for Sterling inter-bank loans. Most of the daily value processed by CHAPS is from wholesale transactions where CHAPS acts as the portal through which international Sterling flows take place. CHAPS is used by banks, building societies and other payment service providers to pay each other. This includes payments for house purchases, although this represents only around 1% of the daily value processed.[4]

As mentioned earlier, CHAPS is a highly tiered system. This is partly because of historical reasons and in particular regulatory restrictions on joint-stock banking which were in place in the 19th century. These gave the Bank of England a monopoly on joint-stock banking, prevented other banks from expanding and meant that country banks needed to have a London correspondent account in order to settle payments in London and in other regions (Norman, Shaw, and Speight, 2011). Another reason for the high degree of tiering in CHAPS has to do with the status of London as a financial center where international banks feel comfortable with corresponding banking, along with the fact that the technical and liquidity costs associated with direct participation may have discouraged banks from becoming direct members (Finan, Lasaosa and Sunderland, 2013).[5]

Tiering in CHAPS has often been thought to introduce unnecessary credit and operational risks and, as a result, the Bank of England has encouraged the expansion of CHAPS membership (Bank of England, 2004b; Salmon, 2011). In line with this, the number of direct members (in Sterling payments) increased from 12 in 2004 to 18 in 2011. More broadly, the international standards set out by CPMI-IOSCO in the *Principles for Financial Market Infrastructures* (CPMI-IOSCO, 2012) also highlighted the risks that the dependencies and exposures inherent in tiered arrangements can create and provided guidance on how market infrastructures could address them. As a result, over the recent years, additional initiatives have been taken to further reduce the degree of tiering in CHAPS. In 2012, for example, CHAPS introduced tiering criteria by which indirect participants processing payments above certain threshold may be required to become direct members and correspondent banks have been made responsible for monitoring the extent to which their second tier clients have exceeded these thresholds.[6]

Our study focuses on five recent de-tiering events whereby five second-tier banks joined

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[4]See: http://www.chapsco.co.uk/about-chaps/who-uses-chaps-system. For a more detailed description of CHAPS attributes as well as of other RTGS systems, see Manning, Nier and Schanz (2009).

[5]In recent years CHAPS has reduced the costs of direct participation. There is no joining fee and the annual shareholder charge is split equally amongst participants (it is currently £18,589 per participant). In addition to this, a direct participant has to pay a participation charge, which is based on prior year volumes, as well as the costs of holding a Bank of England settlement account (an ongoing £15,000 management fee plus debit item charges), and the SWIFT tariff fees (see: http://www.chapsco.co.uk/access/access-chaps/participation-costs). On aggregate, these costs seem relatively moderate, even for a low volume institution. However, operational participation may be costly: a direct participant needs to comply with the technical and operational requirements of the system which predominantly relate to connectivity and compatibility (e.g., a connection to the SWIFT payment messaging network, SWIFT interfaces), resilience, financial stability and security. The cost implications of technical and operational requirements together with the credit and liquidity risk management requirements of direct participation can be particularly onerous for smaller players (FCA-PSR, 2014).
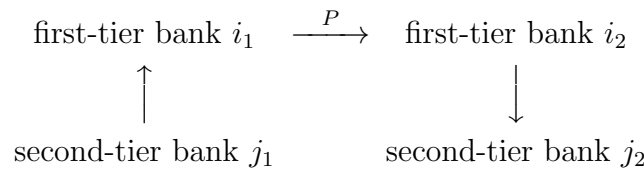
[6]For more details see: http://www.chapsco.co.uk/media/press-releases/chaps-reduces-risks-within-payment-system-one-year-introduction-tiering

the first tier and, as a result, the number of first-tier CHAPS members increased from 17 to 22 (Table 2).[7] Our sample period is from 20 September 2010 (a month before the first event) to 12 February 2016, with a total of 1365 days.

Table 2: De-tiering events in CHAPS. The table shows all instances of second-tier banks who joined the first tier between 20 September 2010 and 12 February 2016.

De-tiered banks	De-tiering date
BNP	13 July 2015
Bank of New York	19 May 2014
Handelsbanken	11 November 2013
State Street	17 September 2012
Bank of America	18 October 2010

To study the impact of these de-tiering events, we use data on all payments sent through CHAPS on a daily basis, over the above-mentioned time period.[8] The data include information on the identities of the first-tier senders and receivers, the identities of their client banks (for payments made or received on behalf of second-tier banks) and the value and timing of payments aggregated at one-minute intervals. The graphic below summarizes the structure of the data:

$$\text{first-tier bank } i_1 \quad \xrightarrow{P} \quad \text{first-tier bank } i_2$$
$$\uparrow \qquad\qquad\qquad\qquad \downarrow$$
$$\text{second-tier bank } j_1 \qquad \text{second-tier bank } j_2$$

In our analysis, we treat branches and legal entities that belong to the same parent company as a single entity. Finally, although we observe payments by first-tier banks on behalf of second-tier ones, we do not observe the time of the payment message received by the first-tier banks. As such, we do not know if and by how long first-tier banks delay the execution of their customers' orders. Throughout, we denote by $P_{st}^{OUT/IN}(i,j)$ the cumulative amount paid/received by the first-tier bank i on behalf of second-tier bank j, on day s and up to time t:

$$\text{bank } i \quad \xrightarrow{P_{st}^{OUT}(i,j)} \quad \text{bank } k \qquad\qquad \text{bank } k \quad \xrightarrow{P_{st}^{IN}(i,j)} \quad \text{bank } i$$
$$\uparrow \qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \downarrow$$
$$\text{bank } j \qquad\qquad\qquad\qquad\qquad\qquad\qquad \text{bank } j$$

Figure 2 shows aggregate values and volumes of daily payments made in CHAPS as well as values and volumes of payments made on behalf of second-tier banks. Aggregate

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[7]Information about the banks that have joined CHAPS in recent years can be found in http://www.chapsco.co.uk/media/press-releases.

[8]During this period, CHAPS was open during a 10 hour and 20 min window each business day, opening for payments at 06:00. Participants are not obliged to be open for business at 06:00 but must be open by 08:00 and must be sending payments by 10:00. As of 20 June 2016, the Bank of England Real Time Gross Settlement System (RTGS), which processes CHAPS payments, is open for an extra hour and 40 minutes, closing at 18.00 instead of 16.20.

payment values are in the range of £139bn-£426bn between 2011 and 2016 while payment volumes fluctuate between 60 and 90 thousand messages daily. Payments on behalf of second-tier banks are almost half of total payments, which is suggestive of the high degree of tiering in CHAPS. It is noteworthy that payments on behalf of second-tier banks do not appear to change after each of the de-tiering events. This is mainly because the new first-tier banks continue, to a large extent, to make payments via their correspondent banks.
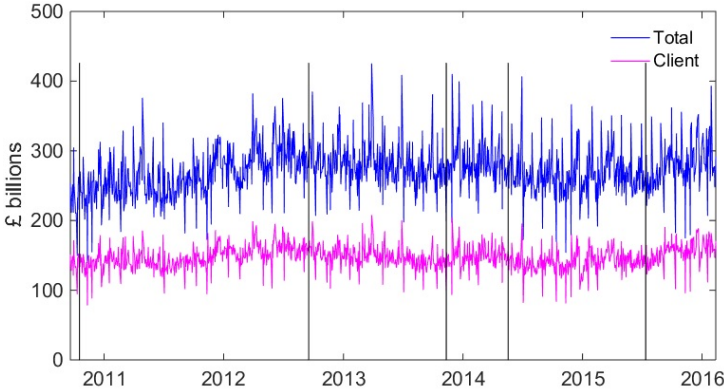
(a) Daily payment values (in £billion)
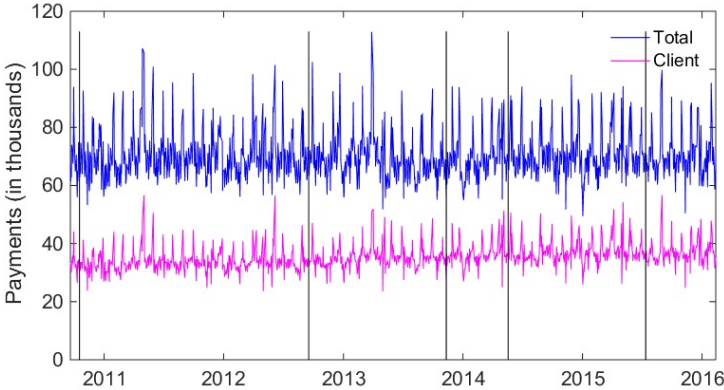
(b) Daily payment volumes (in 000s of payments)

Figure 2: CHAPS daily payment values and volumes. The blue lines show total values and volumes and the pink lines show values and volumes of payments made on behalf of second-tier client banks. The sample period is September 2010 to February 2016. The vertical lines indicate de-tiering events.

4   Analysis and Results

In this section we define and calculate metrics of credit, liquidity and operational risks associated with tiering and study the impact that the five de-tiering events had on the magnitude of these risks. In theory, the degree of tiering should be related with credit, liquidity and operational risks, borne by first and second-tier banks, as follows:

1) *A less tiered structure should decrease credit risk*

    This is because when a first-tier CHAPS bank makes (receives) a payment on behalf of a second-tier client, it does so without receiving (sending) immediately any funds from (to) its second-tier client. Instead, all dues are netted at the end of the day. This effectively creates an intraday exposure between the banks of the two tiers and should one bank default during the day, the other is liable to potential losses arising from this exposure. Thus, we should observe a reduction in credit risk after each of the de-tiering events in our sample.

2) *A less tiered structure should increase liquidity cost*

    This is firstly because of pooling. In a tiered structure, any funds received by a first-tier bank on behalf of its clients can be used intraday to fund outgoing payments of the first-tier bank that are made on behalf of either itself or another client bank. This means that the first-tier bank will have to deploy less of its own liquidity (in the form of reserves and collateral posted with the Bank of England) to meet its payment obligations. Thus, by forcing payments to flow only between fewer (first-tier) banks, tiering effectively creates a liquidity pool that can be utilized by first-tier banks to make other CHAPS payments. Second, it is possible for first-tier banks to internalize payments that are made between two of its clients. This means that a payment between client A and client B of the same CHAPS first-tier bank can be settled outside of CHAPS by making a book entry in the balance sheet of the first-tier correspondent bank and without the need to deploy liquidity. The above arguments suggest that one should expect a rise in the cost of liquidity after each of the de-tiering events.

3) *A less tiered structure should decrease operational risk resulting from individual bank outages.*

    This is because tiering creates operational dependencies. When a first-tier bank experiences an outage and as a result cannot make (or receive) payments, neither can its second-tier clients. In other words, any individual bank outages at the first-tier level affect second-tier banks' ability to make or receive payments. However, a more tiered payment system should cope better against a *system-wide* outage whereby no first-tier bank can send or receive payments. This is because, in more tiered structure, a larger number of payments are internalized and therefore are not reliant on access to the LVPS.

In what follows, we empirically test these hypotheses and attempt to quantify the associated risks.

4.1 Credit risk

Credit risk between first and second-tier banks arises when banks extend intraday credit to each other. The risk materializes if/when a bank fails to pay the (netted) amounts due at

the end of the business day. Credit risk arises for both first and second-tier institutions:[9]

- First-tier banks usually offer intraday overdraft facilities to their client banks when making outward payments on their behalf. This creates credit risk for first-tier banks since, in case of a client bank default, the first-tier bank loses any intraday credit provided.

- Conversely, a second-tier bank is exposed to its settlement bank when it holds positive intraday balances with it. This happens when the first-tier bank receives more payments than it sends on behalf of its second-tier client. In this case, a default by the first-tier bank could result in the loss of any positive balances in the client's account.

For any first-tier bank that has one or more clients joining the first-tier, we expect its credit risk to decrease, all else being equal, simply because de-tiering reduces the number of its second-tier members. Similarly, the intraday credit exposures of a second-tier bank to its settlement bank(s) should be reduced once the second-tier bank joins the first-tier. These exposures will not necessarily become zero as the joining bank may still choose to obtain intraday credit from its former first-tier correspondent(s).[10] To quantify the credit risk that arises between first and second-tier banks we make the following assumptions:

a) Any payments due between first and second-tier banks are paid off at the end of the business day. To our knowledge, this is precisely how dues between first- and second-tier CHAPS banks are settled.

b) Intraday credit between first and second-tier banks is mostly unsecured. Anecdotal evidence suggests that this is indeed the case between first and second-tier banks. To the extent that intraday credit is collateralized, the intraday exposures that we calculate are an overestimate of the loss given default (LGD).

c) For each bank, there cannot be multiple simultaneous counterparty defaults. We make this assumption because, in practice, the likelihood of multiple same-day defaults is extremely low.

Apart from examining how intraday exposures change as a result of de-tiering, we also quantify credit risk by calculating what it would cost a bank to insure itself against any losses arising from these exposures. In doing so, we assume that the price of insurance is actuarially fair in the sense that it equals the expected cost to the insurer. Under this (mild) assumption, not only is the insurance premium equal to the expected value of the loss, but a risk-averse bank will also want to fully insure any potential losses.[11]

Therefore, the expected cost of credit risk will equal the cost of insuring against any losses that arise as a result of intraday exposures if/when a counterparty fails. In particular, for each bank i, the Sterling expected cost of its credit risk on day s, will be:

$$\mathbb{E}[\text{Credit Risk Cost}]_{is} = \text{LGD}_{is} \times \text{IP}_s \tag{1}$$

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[9]Of course, intraday credit risk may also arise between first-tier banks. Jurgilas and Zikes (2014) document a positive price for unsecured intraday credit among CHAPS banks.

[10]The joining bank will also still be exposed to *their* clients which were previously on the third tier and are now on the second-tier. These exposures will not change as a result of a de-tiering event.

[11]See: Mas-Colell, Whinston and Green (1995), pages 187-88.

where LGD is the Loss Given Default and IP is the insurance premium. On aggregate, the expected credit risk cost on day s will then be:

$$\mathbb{E}[\text{Credit Risk Cost}]_s = \sum_i \mathbb{E}[\text{Credit Risk Cost}]_{is} \tag{2}$$

where the sum is across all (or a subset of) banks in the system. The daily LGD is a function of the intraday exposures between banks. We next estimate these exposures, both for first- and second-tier banks.[12]

4.1.1 Intraday exposures between first and second-tier banks

One way to estimate the LGD of first-tier bank i, in case of second-tier bank j default on day s, is by the (time-weighted) average intraday credit exposure of bank i to its client j on that day. This is the average net debit position of bank i versus bank j:

$$\text{Avg\_Exposure}_{ijs} = \frac{1}{N} \sum_{t \in T} \max\{P_{st}^{OUT}(i,j) - P_{st}^{IN}(i,j), 0\} \tag{3}$$

where $P_{st}^{OUT/IN}(i,j)$ is the cumulative amount paid/received by bank i on behalf of bank j on day s and up until time t, $T = \{t_1, ..., t_N\}$ is a time partition of the business day and N is the number of time intervals in the partition.[13] An upper bound for the LGD is the maximum credit exposure of bank i to bank j, on day s:

$$\text{Max\_Exposure}_{ijs} = \max_{t \in T}\{\max\{P_{st}^{OUT}(i,j) - P_{st}^{IN}(i,j), 0\}\} \tag{4}$$

These maximum exposures are typically short-lived; so while they are indicative of the potential intraday credit risks that might arise, they are economically less relevant than the average intraday exposures.

Given our assumption of at most one counterparty defaulting on any given day, we calculate for each bank i the maximum, across all its second-tier clients, of the above two metrics:

$$\text{Avg\_Exposure}_{is} = \max_j\{\text{Avg\_Exposure}_{ijs}\} \tag{5}$$

$$\text{Max\_Exposure}_{is} = \max_j\{\text{Max\_Exposure}_{ijs}\}$$

In using maxima to calculate daily exposures, we conservatively assume that the defaulting second-tier bank is the one to which the first-tier correspondent has the largest intraday exposure.

We then calculate in a similar manner the credit risk that accrues to second-tier banks. Letting $P_{st}^{IN/OUT}(i,j)$ be defined as before, the average and maximum credit exposures of

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[12]For computational convenience, we do this using only payments that are larger than £10mn. After applying this threshold we are still able to capture around 90% of the total daily value of payments made.

[13]In our case, there are $N = 9$ hourly intervals.

second-tier bank j to its settlement bank i on day s is:

$$\text{Avg\_Exposure}^*_{ijs} = \frac{1}{N} \sum_{t \in T} \max\{P^{IN}_{st}(i,j) - P^{OUT}_{st}(i,j), 0\} \tag{6}$$

$$\text{Max\_Exposure}^*_{ijs} = \max_{t \in T} \max\{P^{IN}_{st}(i,j) - P^{OUT}_{st}(i,j), 0\}$$

where $T = \{t_1, t_2, ..., t_N\}$ is again a partition of the business day.

Given that some second-tier banks have multiple first-tier correspondents, we take, as before, the maximum bilateral exposure across all first-tier institutions associated with second-tier bank j:

$$\text{Avg\_Exposure}^*_{is} = \max_j \{\text{Avg\_Exposure}^*_{ijs}\} \tag{7}$$

$$\text{Max\_Exposure}^*_{is} = \max_j \{\text{Max\_Exposure}^*_{ijs}\}$$

To estimate the magnitude of intraday exposure changes following each of the de-tiering events, we estimate the following panel specification separately for affected first- and second-tier banks:

$$Exposure_{is} = a + bEvent_{is} + cSONIA_s + u_i + e_{is} \tag{8}$$

where i denotes banks, s denotes days, $Exposure$ is any of the variables defined in equations (5) and (7), $Event$ is a bank-specific de-tiering event dummy and SONIA (Sterling Over-Night Index Average) is the effective reference overnight rate for unsecured transactions in the Sterling market. In this setup, the coefficient of interest is b. Negative values of b would suggest a decline in intraday exposures arising between first- and second-tier banks.

In Table 3 we report the results of this estimation. In columns (1)-(4) we report results for first-tier banks that had one of their second-tier clients joining the first tier. The estimated coefficients of de-tiering event dummy are generally negative and their significance tends to increase with the inclusion of controls. Also, they tend to be larger for $Max\_Exposure$ consistent with expectations, since it is typically the largest clients that join the first tier. In terms of magnitudes, they suggest that daily intraday exposures drop on a daily basis by £0.3 - £1.1 billion on average for each of the affected first-tier banks and depending whether one measures average or maximum intraday exposures. In columns (5)-(8) we report results for the second-tier banks that join the first tier. The coefficients of the de-tiering event dummy are again negative but only borderline significant. Furthermore, they are larger in magnitude than those of first-tier banks. The estimated coefficients suggest that second-tier bank intraday exposures drop by £1.46 -£2.7 billion daily on average for each bank, although this cannot be strongly statistically associated with the de-tiering events.

4.1.2 Estimating the cost of credit risk

We next estimate the expected cost of the credit risk, as per equation (2), that arises as a result of the intraday exposures between first and second-tier banks. We use the

Table 3: Bank intraday exposures around de-tiering events. This table shows fixed-effects estimation results of specification (8). The specification is estimated separately for first- and second-tier banks. The dependent variable is any of the variables defined in equations (5) and (7), $Event$ is a bank-specific de-tiering event dummy and $SONIA_s$ is the Sterling Overnight Index Average rate. Standard errors are clustered by bank. The time period is 20/9/2010 to 12/2/2016. *, ** and *** denote significance at 10%, 5% and 1% levels respectively.

| | First tier to second tier | | | | Second tier to first tier | | | |
| | Avg_Exposure | | Max_Exposure | | Avg_Exposure* | | Max_Exposure* | |
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
$Event$	0.1046	-0.3177	-0.2299	-1.1142**	-1.4557	-1.4934	-2.6630	-2.7140
	(0.64)	(-1.65)	(-1.08)	(-3.62)	(-1.69)	(-1.65)	(-1.81)	(-1.72)
$SONIA$		-10.8193**		-22.6519**		-0.9598		-1.2991
		(-3.58)		(-3.46)		(-0.66)		(-0.37)
$Const$	3.9037***	9.0665***	7.4756***	18.2848***	1.6871**	2.1499	3.0015**	3.6279
	(64.33)	(6.71)	(94.71)	(6.13)	(3.97)	(1.98)	(4.14)	(1.58)
R^2	0.001	0.099	0.002	0.140	0.335	0.336	0.386	0.386
N	5460	5460	5460	5460	6825	6825	6825	6825

average daily CDS spread of the CHAPS banks as a proxy of the premium (IP) required to insure any losses associated with a bank's default. For this, we use the price of the 5-year contract as this is the most liquid term. In averaging the CDS spreads, we also assume that the insurance premium is the same across institutions. We also note that CDS spreads involve an implicit assumption about the recovery rate and that this assumption may yield different spreads than, for example, those obtained directly from credit rating implied probabilities. Another caveat to the use of CDS spreads is that they reflect market's risk appetite, rather than the risk appetite of the regulator. While we are aware of these limitations, we believe they are unlikely to change the order of magnitude of the effect that we wish to quantify. Thus, we estimate the insurance premium as:

$$IP_s = \frac{1}{I} \sum_{i \in I} CDS_{is} \tag{9}$$

where I is the number of CHAPS banks for which there is a traded CDS contract and CDS_{is} is the daily annualized spread of the 5-year contract of bank i.

To calculate the change in the cost of intraday credit risk, we multiply each of the estimated $Event$ dummy coefficients from Table 3 with the time-average, minimum and maximum daily values of the insurance premium. These cost changes, expressed in £000s per bank, per day, are shown in Table 4. As one can see, the reduction in the expected costs of the intraday exposures between first and second-tier banks, as a result of reduced tiering, averages between £11K and £135K per bank, per day (first row). This cost reduction is higher for second-tier banks since these also experience the largest reductions in intraday exposures after they join the first tier. In annual terms, the reduction in costs as shown in the first row, for example, amount to anywhere between £2.9 million and £33.7 millions for each bank. The numbers corresponding to the minimum/maximum

CDS spreads observed during our sample period (0.53% and 2.94% respectively) constitute a lower/upper bound for these cost reductions since we effectively assume that, every day in our sample period, the insurance premium attains its minimum/maximum value respectively. Again, depending on the way the intraday exposures are calculated, the associated daily cost reductions are at least as high as between £6.7K and £57.5K and at most as high as between £27K and £319K per bank on a daily basis.[14]

Table 4: Changes in the cost of insuring intraday credit exposures. We multiply each of the estimated *Event* dummy coefficients from Table 3 with the time-average, minimum and maximum daily insurance premium. The resulting costs are expressed in £000's per bank, per day. The time period is 20/9/2010 to 12/2/2016.

| | *CDS (%)* | First tier to second tier | | | | Second tier to first tier | | | |
| | | Avg_Exposure | | Max_Exposure* | | Avg_Exposure* | | Max_Exposure* | |
	(annual)	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Avg	1.24	5.19	-15.76	-11.40	-55.26	-72.20	-74.07	-132.08	-134.61
Min	0.53	2.22	-6.74	-4.87	-23.62	-30.86	-31.66	-56.46	-57.54
Max	2.94	12.30	-37.36	-27.04	-131.03	-171.19	-175.62	-313.17	-319.17

We finally look at system-wide intraday exposures (and their associated costs) arising across all CHAPS banks so as to get a better sense of the overall magnitude of these costs. For this, we add up all the individual bank average and maximum intraday exposures as defined in equations (5) and (7):

$$\text{Avg\_Exposure}_s = \sum_{i \in FT} \text{Avg\_Exposure}_{is} + \sum_{j \in ST} \text{Avg\_Exposure*}_{js} \qquad (10)$$

$$\text{Max\_Exposure}_s = \sum_{i \in FT} \text{Max\_Exposure}_{is} + \sum_{j \in ST} \text{Max\_Exposure*}_{js}$$

where *FT* and *ST* denotes the set of all first and second-tier banks.[15] We also calculate the daily expected costs of the system-wide intraday exposures at the prevailing insurance premia by multiplying the system-wide exposures with the cross-bank average CDS spread:

$$\mathbb{E}[\text{Credit Risk Cost}]_s = \text{Exposure}_s \times \text{IP}_s \qquad (11)$$

where "Exposure" is either "Avg_Exposure" or "Max_Exposure". Figure 3 plots the daily aggregate intraday exposures that arise between all first and second-tier banks along with the average daily annualized, 5-year CDS spread and the product of the two which, as per equation (11), is our estimate of the daily cost of insuring against a potential loss.[16] As is evident from Figure 3(c), the aggregate cost of insurance fluctuates between £1 million and £6 million daily for all banks in aggregate (or £250 million - £1.5 billion annually).

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[14]Annually, this cost reduction is between £1.2 and £14.4 million at minimum and £6.8 and £79.8 millions at maximum for each bank.

[15]The sets are adjusted after each detiering event to include the new first-tier banks and exclude them from the second tier.

[16]In other words, it is the amount that all banks collectively would have to pay every day to insure themselves against losses arising from their intraday exposures.
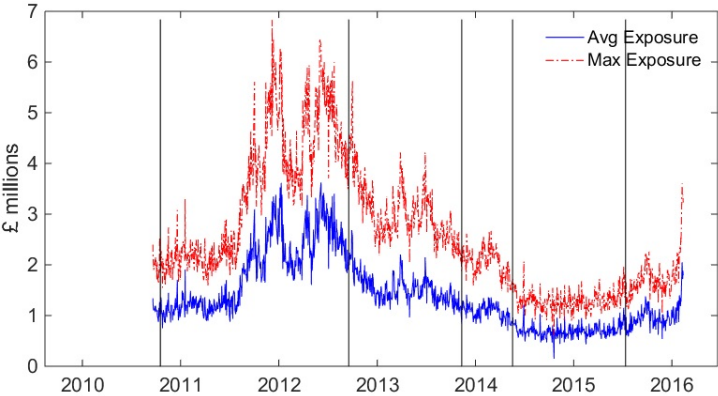
The effect of the detiering events is less visible here both because this calculation also includes (first and second-tier) banks that were not affected by the events as well as because overall costs are largely driven by the prevailing CDS spreads.
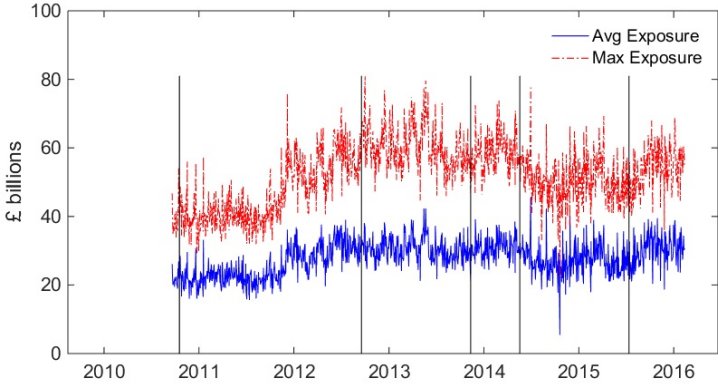
(a) Daily aggregate intraday exposures
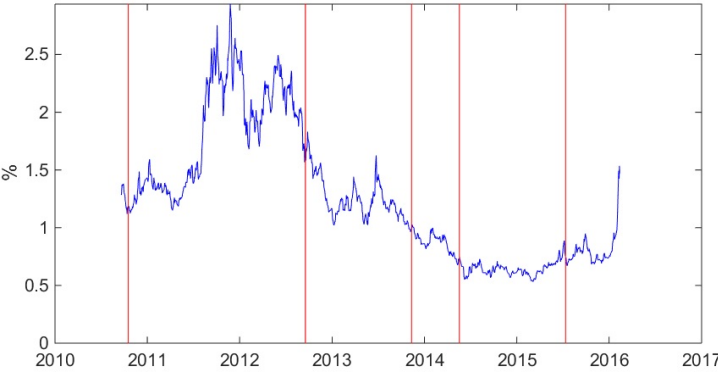
(b) Daily average CDS spread (%, annualized)

(c) Daily expected cost of credit risk

Figure 3: (a) Aggregate daily intraday credit exposure (Avg_Exposure$_s$ and Max_Exposure$_s$) arising between all first and second-tier institutions. Avg_Exposure$_s$ and Max_Exposure$_s$ are defined in equation (10)(b) Average daily CDS spread across CHAPS banks (%, annualized). (c) Aggregate expected daily cost of credit risk (in £millions) as per equation (11) as calculated using Avg_Exposure (blue line) and Max_Exposure (red dotted line). The vertical lines denote the de-tiering events. The time period is from 20/9/2010 to 12/2/2016.

4.2 Liquidity cost

When a first-tier bank assumes a net debit position (i.e. pays more than it receives), it deploys its own liquidity to make up for the difference. To make payments in those instances, the bank may either use its reserves, or borrow intraday from the Bank of England on a collateralized basis. In either case, deploying own liquidity has an opportunity cost because reserves and collateral could potentially be used elsewhere and be remunerated. Therefore, the cost of own liquidity usage is the opportunity cost associated with reserves and collateral held by CHAPS banks for the purpose of meeting their payment obligations. As we explained earlier, de-tiering should in theory lead to higher liquidity costs both because there is less opportunity for first-tier banks to recycle clients' incoming payments, in order to make their own payments (pooling), and because there is less scope for settling payment obligations between clients of the same first-tier bank on the latter's books rather than through CHAPS (internalization). In this section, we assess the impact of the detiering events in our sample on the cost of liquidity usage among CHAPS banks.

Based on the above discussion, the liquidity cost of first-tier bank i, on day s is :

$$\text{Liquidity Cost}(\pounds)_{is} = \text{Liquidity Deployed}_{is} \times \text{Opportunity Cost}_s \qquad (12)$$

where Liquidity Deployed is a function of the bank's net debit positions attained during the day. The aggregate liquidity cost across all CHAPS banks is then:

$$\text{Aggr. Liquidity Cost}(\pounds)_s = \sum_i \text{Liquidity Cost}(\pounds)_{is} \qquad (13)$$

where the sum is over all first-tier banks active on day s.

The resources that banks hold to meet their daily liquidity needs are used whenever the cumulative amount of outgoing payments exceeds that of incoming payments. And given that these resources are pledged for the entire day, the amount of liquidity deployed by a CHAPS bank equals the maximum net debit position attained during the day, regardless if this liquidity is deployed for only a brief period of time. Thus, if $P_{ist}^{OUT/IN}$ is the cumulative amount paid/received by first-tier bank i, on day s and up to time t, the liquidity deployed by this bank is then:

$$\text{Liquidity Deployed}_{is} = \max_t \{\max\{P_{ist}^{OUT} - P_{ist}^{IN}, 0\}\} \qquad (14)$$

It is worth noting here that the deployed liquidity is calculated using all first-tier bank payments, i.e. both the payments made/received on its own behalf as well as those made/received on behalf of its clients.[17]

To assess the impact of de-tiering on the cost of liquidity, we first look at the deployed liquidity of those first-tier banks that had a client joining the first tier. Figure 4 shows the frequency distribution of daily deployed liquidity across each of the affected first-tier banks before and after the de-tiering events. Figure 4 shows that after the de-tiering events, affected first-tier banks seem to be using more of their own liquidity, consistent with what

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[17]Also notice that second-tier banks do not use any of their own liquidity to make payments since they have no access to CHAPS. All of the liquidity required for their payments is provided for by their first-tier correspondents.

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one would expect. For example, while prior to the de-tiering events affected first tier banks do not deploy any of their own liquidity about 35% of the time, this number drops to 25% after the de-tiering events. However, the overall amounts of deployed liquidity are generally small. Aside from the fact that on about of 30% of all days (before and after the de-tiering events), affected banks do not deploy any liquidity at all, even when they do deploy their own liquidity, the amounts used almost never exceed £5 billions per bank. These amounts are small compared to the average daily payments of about £43 billion that each of these banks make.
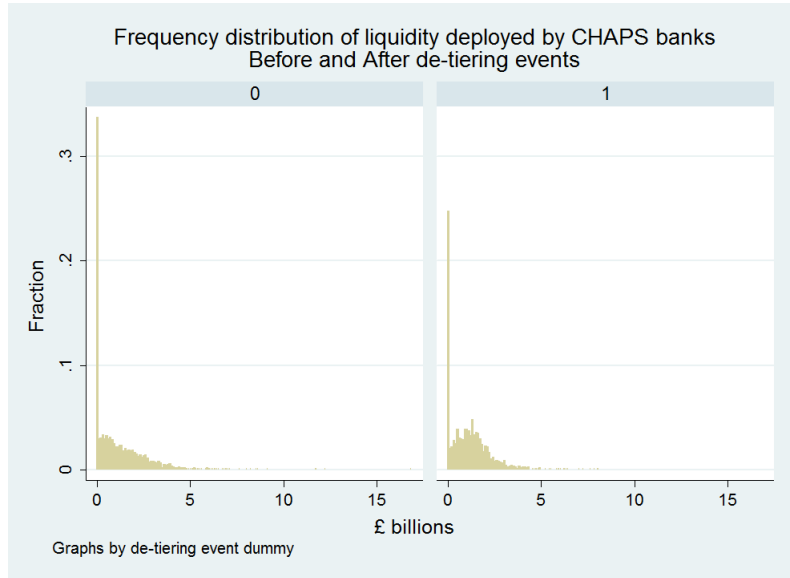

Figure 4: Frequency distribution of daily deployed liquidity before and after the de-tiering events by each of those first-tier banks with a client who joins the first tier. The sample period is 20/9/2010 to 12/2/2016.

To more formally assess the impact of de-tiering on liquidity costs, we next estimate a panel fixed-effects model of deployed liquidity across these affected, first-tier, banks:

$$LIQDEPL_{is} = a + bEvent_{is} + cPmts_{is} + dSONIA_s + u_i + e_{is} \qquad (15)$$

As before, i denotes banks, s denotes days, $LIQDEPL$ is the amount of liquidity deployed as defined in equation (14), $Event$ is the bank-specific de-tiering event dummy[18], $Pmts$ is the amount of payments made by each bank and $SONIA$ is the Sterling Overnight Index Average rate. The last two variables are included as controls as one would expect the amount of liquidity used to be higher with payments made and lower with the interbank borrowing cost.

It is also worth noting that any effects on the liquidity usage of those first-tier banks with joining clients would primarily be because of the absence of pooling as these banks would not be able to use the incoming payments of their joining clients after each of the de-tiering events. Internalization should not affect these first-tier banks as the onus would

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[18]In one case, a single first-tier bank was affected by two de-tiering events. In that case, this dummy takes the value 1 only after the second de-tiering event. It ignores the first de-tiering because it happened very early in our sample period.

instead primarily be on the joining second-tier clients to supply the liquidity required for their own payments.

Table 5 shows the results of this estimation. As one can see from the estimated coefficients of the *Event* dummy, while de-tiering is associated with increased amounts of deployed liquidity by affected first-tier banks, the effect is not statistically significant. This could be because the high degree of tiering gives first-tier banks access to alternative client liquidity even after one of their bigger clients has joined the first tier. Such an explanation would be consistent with the large number of days with zero liquidity usage that we observe. The other control variables are also statistically insignificant.

Table 5: CHAPS bank own liquidity usage around de-tiering events. This table shows fixed-effects estimation results of specification (15). The specification is estimated only for first-tier banks. $LIQDEPL$ is defined in equation (14), $Event_s$ is a bank-specific de-tiering event dummy, $SONIA_s$ is the Sterling Overnight Index Average rate and $Pmts_{is}$ is the daily amount of payments made by each bank. Standard errors are clustered by bank. The time period is 20/9/2010 to 12/2/2016. *, ** and *** denote significance at 10%, 5% and 1% levels respectively.

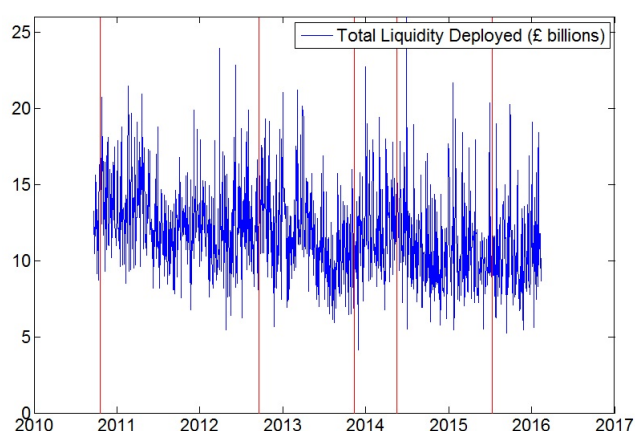|	Liquidity Deployed (LIQDEPL)			
	(1)	(2)	(3)	(4)
Event	0.0325	0.0830	0.1650	0.2594
	(0.12)	(0.45)	(0.46)	(0.94)
SONIA		1.2929		2.1797
		(0.55)		(0.79)
Pmts			0.0267	0.0286
			(1.84)	(1.81)
Const	1.0789***	0.4620	-0.1277	-1.2526
	(11.04)	(0.45)	(-0.19)	(-0.83)
R^2	0.000	0.002	0.023	0.027
N	5460	5460	5460	5460

Finally, we look at the impact of the de-tiering events on aggregate liquidity usage which is the sum of the liquidity usage of all first-tier banks. We do this because we want to capture any additional effects of detiering on deployed liquidity arising from reduced internalization. Figure 5 shows the amounts of aggregate liquidity deployed by those banks that are consistently on the first-tier during our sample time (i.e. excluding the joining banks) as well as of all banks that are on the first tier at any point in time. Legacy first-tier banks deploy less of their own liquidity over time but this appears to be partly offset by the liquidity that new entrants deploy. As a result, and despite daily fluctuations between £10 and 20 billions, deployed liquidity across all banks remains relatively stable during our sample time. The de-tiering events do not appear to be associated with sizeable changes in aggregate deployed liquidity.[19]

To quantify the cost of liquidity usage by CHAPS banks, we use the Overnight Index

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[19]We also formally test this in time-series regressions. The regression results confirm the absence of any significant effects of de-tiering on aggregate liquidity usage. The regression results are available upon request.
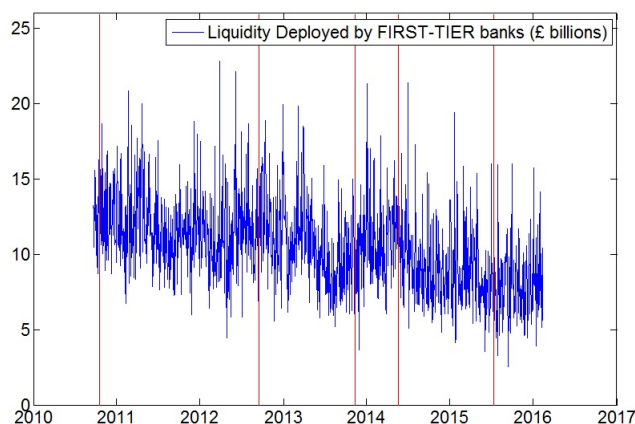
(a) Legacy first-tier banks


(b) All first-tier banks

Figure 5: (a) Aggregate liquidity deployed (in £billions) of legacy first-tier banks, and of (b) all banks. Aggregate liquidity deployed is the sum of individual CHAPS bank deployed liquidity as defined in equation (14). The vertical lines denote de-tiering events. The time period is from 20/9/2010 to 12/2/2016.

Average (SONIA) rate as a proxy for the opportunity cost of own liquidity usage. The rationale is that the liquidity used to make payments could be alternatively loaned out in the interbank market. Figure 6 plots the SONIA rate over our sample period and the daily aggregate cost of deploying liquidity, as calculated by equation (13). The figure shows that this cost fluctuates between £15K and £40K daily for all CHAPS banks.

Overall, de-tiering does not seem to have had a sizeable effect on the amounts of deployed liquidity of first-tier banks, while the associated cost of deploying this liquidity appears, in any case, to be relatively small.

4.3 Operational risk

Finally, we attempt to assess and quantify the amount of operational risk associated with the tiered structure of CHAPS. The Basel Committee defines operational risk as the risk of losses resulting from inadequate or failed internal processes, from human error, or from external events. This definition includes legal risk but excludes strategic and reputational
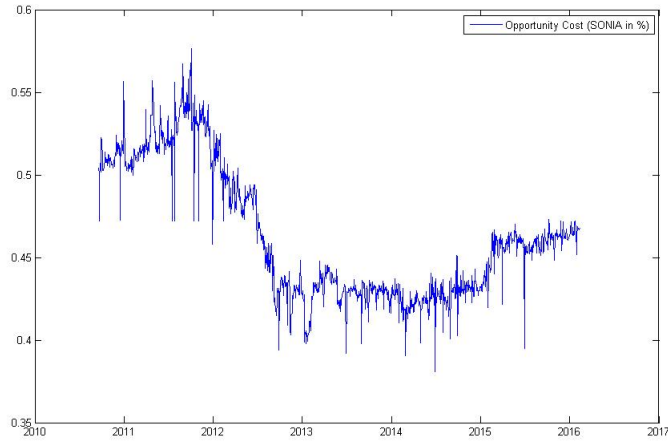
(a) SONIA (%)
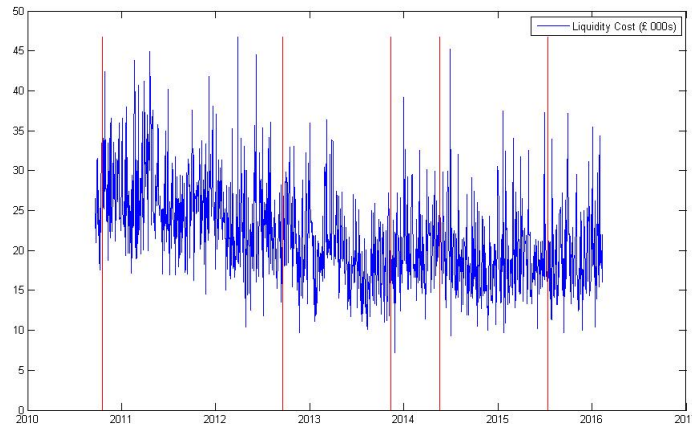
(b) Actual liquidity cost

Figure 6: (a) SONIA (in %, annualized), (b) Daily aggregate liquidity cost (in £thousands) Aggregate liquidity cost is defined in equation (13). The vertical lines denote de-tiering events. The time period is from 20/9/2010 to 12/2/2016.

risk (BCBS, June 2011). In our analysis, we are concerned about the risk of individual first-tier banks operational outages.[20] When a first-tier bank experiences an operational outage that prevents it from sending or receiving payments from other banks, the second-tier clients of the stricken bank would also not be able to make or receive payments to any other banks that are not clients of the same stricken bank. Thus, as tiering decreases, an operational outage at the first-tier would affect fewer banks in the second-tier but the probability of observing an outage on any particular day will increase.

We measure the cost of operational risk as the expected opportunity cost of the delayed payments that accrues to the banks receiving these payments. In focusing on the opportunity cost of delayed payments, we make the following assumptions:

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[20]We do not consider outages of the entire payment system where all first-tier institutions are affected. If anything, a less tiered system is more vulnerable to a system-wide outage as there is less scope for payments across second-tier banks to be internalized.

a) During an outage, a stricken bank may receive but may not send payments (potentially becoming what is known as a *liquidity sink*). This is consistent with the CHAPS outage record where about 90% of observed outages involve banks which cannot make but can receive payments.

b) No defaults can occur as a result of payment delays associated with an outage. In other words, if a bank fails to make a payment because of an outage, then we assume that this bank will not be forced into default by the bank expecting to receive that payment. We assume that, in those instances, any binding contractual obligations can be renegotiated. This assumption is based on the observation that no bank in the UK has so far been driven into default because of an operational incident.

c) There is neither reputational cost nor any gain whatsoever to the sender of a delayed payment. While reputational costs may exist, we abstract away from them in our analysis as they are hard to quantify.

d) Payments on behalf of second-tier banks are uniformly distributed during the day so that only the duration (and not the time) of the outage matters. This assumption is justified by the use of throughput rules in CHAPS where banks must, on average over the course of each month, make at least 50% of their outgoing payments by noon and 75% of their payments by 2:30pm.

We note that the degree of tiering is unrelated to the cost incurred by the counterparty of a first-tier bank whose own payments are delayed because of an operational outage. For this reason, we only consider delays in payments by first-tier banks that are made on behalf of their second-tier clients.

4.3.1 The expected cost of operational risk

As mentioned above, to calculate the expected cost of operational risk, we only consider delayed payments by first-tier banks that are made on behalf of their second-tier clients. Let $P_{sT}^{OUT}(i,j)$ be the cumulative amount of payments made by bank i on behalf of bank j on day s. Also, let $\tilde{X}_i$ be the random number of outages that affect bank i on each day, $\tilde{D}$ be the random duration of each outage and let r_s be the daily cost of overnight unsecured borrowing as captured by the SONIA rate. Then, an estimate of the daily expected opportunity cost that accrues to the recipients of payments that are being delayed, because of an outage of bank i on day s, is:

$$\mathbb{E}[\text{Operational Risk Cost}]_{is} = \left[\sum_j P_{sT}^{OUT}(i,j) \right] \times (\bar{X}_i \times \bar{D}) \times (r_s \times \bar{D}) \qquad (16)$$

where $\bar{X}_i$ and $\bar{D}$ are the means of $\tilde{X}_i$ and $\tilde{D}$ respectively.[21] This expression effectively calculates the fraction of total daily payments that are subject to delays and multiplies it with the opportunity cost that corresponds to the expected time-delay. The daily

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[21] This expression implicitly assumes that the payments are uniformly distributed through the day.

aggregate expected cost of operational risk, across all first-tier banks, is the sum of the individual bank expected costs:

$$\mathbb{E}[\text{Operational Risk Cost}]_s = \sum_i \mathbb{E}[\text{Operational Risk Cost}]_{is} \qquad (17)$$

We calculate this expression using data on daily payments and on the number and duration of operational outages among CHAPS banks, which is collected and maintained by the Bank of England. The average number of outages and their durations are estimated every year to account for any changes in these means as a result of the de-tiering events during our sample time.

Table 6 shows summary statistics of the daily values of the expected cost of operational outage, as per equation (17), for each of the years in our sample. On average, the expected aggregate opportunity cost of delayed payments fluctuates between £3K and £15K daily, an economically small amount. Furthermore, this cost is not declining (or increasing) over time so that it appears to be unrelated to the degree of tiering in CHAPS. Given the small size of this effect, we forego a more formal statistical test of changes in the cost of operational risk after each of the de-tiering events.

Table 6: Summary statistics of daily expected costs of operational risk (in £000's) as per equation (17).

Statistics	2010	2011	2012	2013	2014	2015	2016
Mean	7.7	8.4	8.4	5.9	3.2	9.7	14.7
Std	1.0	1.0	0.9	0.6	0.3	1.1	1.5
Min	4.6	5.9	5.6	4.2	1.6	6.4	10.4
Max	10.3	12.6	11.3	8.5	4.2	13.2	18.1

In conclusion, given the assumptions stated at the beginning of this section, it appears that the overall economic effect of payment delays associated with operational risk is small. Furthermore, de-tiering does not seem to have any impact on this cost.

5   Conclusions

In this paper we use data from CHAPS, the UK LVPS to study the impact of correspondent banking (known as tiering) on credit, liquidity and operational risk. To this end, we exploit five de-tiering events that occurred in CHAPS over the past several years and, as such, ours is the first study to capture actual (rather than simulated) effects associated with changes in a tiered payment structure.

For each of the risks being examined, we estimate the economic significance of any changes in these risks. The cost of credit risk is estimated by the cost of insuring against the losses arising from any intraday exposures toward a defaulting correspondent bank, while the costs of liquidity and operational risks are approximated by the opportunity cost of holding liquid assets and of the delayed receipt of payments respectively.

Our results suggest that the CHAPS de-tiering events in our sample bring about a reduction in the intraday exposures between first and second-tier banks in the order of

£0.3 billion to £1.5 billion per bank. Consequently, the cost of insuring against losses arising from these intraday exposures also drops. We estimate this cost reduction to be, for average intraday exposures, between £4 and £19 million per bank, per year. There are several reasons why this cost reduction is not larger. First, when moving to the first tier, most banks continue, to some degree, to obtain (and supply) intraday credit from (to) their former corresponding banks. Second, for the legacy first-tier banks, this is largely because of our assumption that at most one second-tier client may default on a given day. This assumption implies that even after a client bank joins the first tier, its correspondent will still be exposed to what used to be the second largest client. Thus, in instances where the client banks are of similar size, the correspondent's exposure to its single largest client may not change substantially.

We also find that the effect of the de-tiering events on the amount and cost of bank deployed liquidity is also small. This is both because the actual amounts of deployed liquidity in CHAPS are modest (presumably due to payment recycling) but also because the opportunity cost of holding liquid assets is low over our sample period. Finally, the opportunity cost incurred by the recipients of payments that are delayed, because of operational incidents, is also small. In assessing the impact of a tiered structure on operational risk, we assume that such unintentional payment delays do not result in contractual obligations being breached and payers being forced into default by their counterparties.

Although it is not clear if the above effects would be smaller or larger if CHAPS were to be further de-tiered, our findings do suggest that the tiered structure of CHAPS is primarily associated with intraday credit risk and that otherwise it does not appear to be associated with substantial liquidity or operational risks.

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