Monetary policy transmission with interbank market fragmentation*

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Abstract

This paper shows how interbank market fragmentation disrupts the transmission of monetary policy. Fragmentation is the fact that banks, depending on their country of location, have different probabilities of default on their interbank borrowings. Once fragmentation is introduced into standard theoretical models of monetary policy implementation, excess liquidity arises endogenously. This leads short-term interest rates to depart from the central bank policy rates. Using data on cross-border financial flows and monetary policy operations, it is shown that this mechanism has been at work in the Euro-Area since 2008. The model is used to analyze conventional and unconventional monetary policy measures.

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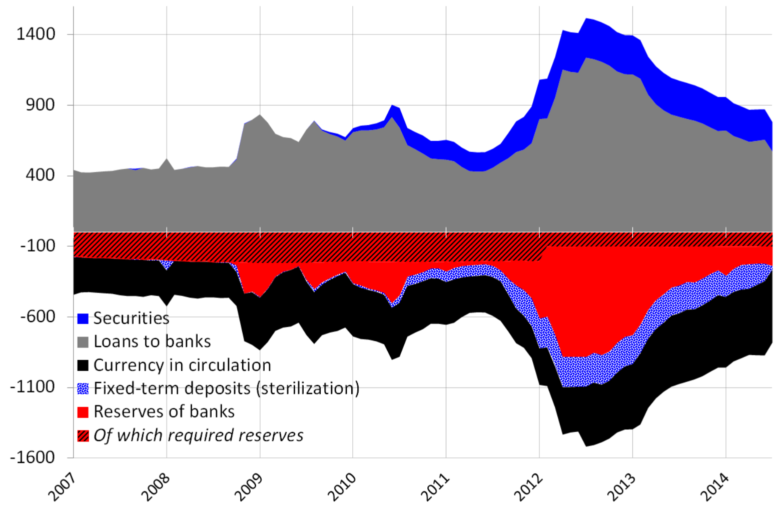
1 Introduction

Since 2008, the liquidity provided by central banks in many countries has increased dramatically. In most cases, this increase follows from the central bank expanding its balance sheet by purchasing a large amount of securities. This is what happened for instance in the United-States, in the United-Kingdom or in Japan. However, as can be seen from Figure 1, in the Euro-Area, the amount of securities bought by monetary authorities was limited from 2008 to late 2014. The increase in the money supply (measured as reserves of banks at the central bank) rather reflected higher borrowings of private commercial banks at the central bank. Thus, variations of the money supply in the Euro-Area are endogenous to private banks' behavior.

Figure 1: Simplified Eurosystem balance sheet (EUR, billion)



Source: ECB

Note: Assets of the central bank are counted as positive and liabilities as negative.

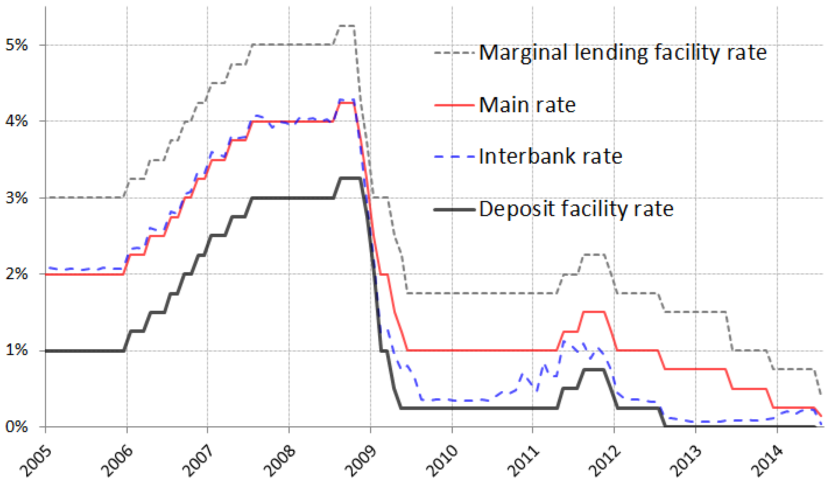
Fluctuations in liquidity (increases and decreases) have directly impacted interest rates. Figure 2 shows the evolution of the interbank rate with respect to the "corridor".[1] Contrary to the pre-crisis period where the interbank rate was tracking closely the central bank main interest rate, since 2008 it has deviated substantially from it. This can be seen for instance from three episodes. First, between March 2010 and February 2011, the rates of the central bank did not change at all, while the secured interbank rate increased by 64 basis points.[2]

[1]The corridor is the interval between the rate of the marginal lending facility (at which banks can borrow overnight from the central bank) and the rate of the deposit facility (at which banks can deposit funds). These two rates provide a ceiling and a floor to the overnight interbank rate, the European OverNight Index Average ("EONIA"). The relationship between the level of the interbank rate within the corridor and the level of liquidity is documented in Bech and Monnet (2015) or Garcia de Andoain *et al.* (2015).

[2]The secured interbank rate is measured using the overnight "Stoxx GC Pooling" (averaged over reserve re-

Second, between May 2011 and September 2011, the ECB increased its rates by 25 basis points, while the interbank rate actually dropped by 29 basis points over the same period. Third, between December 2012 and June 2014, the ECB cut its main interest rate by a total of 50 basis points, while the market rate increased by 23 basis points. These fluctuations went beyond the interbank market and were reflected in other crucial short-term interest rates and in longer term interest rates (see appendix I). Thus, fluctuations of the interbank rate have pushed the interest rates faced by all agents in the Economy away from the level set by the central bank. These movements in liquidity and interest rates therefore represent a significant disruption of monetary policy transmission, which have concerned policy makers and analysts.[3]

Figure 2: The ECB key interest rates and the interbank rate since 2005



Source: ECB

Note: The "interbank rate" on this figure is the overnight unsecured interbank rate (EONIA) averaged over the maintenance period of reserve requirements.

The contribution of this paper is to explain jointly the fluctuations of the money supply and the movements of interest rates. It shows that in order to understand these phenomena, it is crucial to take into account the fragmentation of the interbank market. Fragmentation is the fact that banks located in some countries (the "peripheral banks") are considered *ceteris paribus* to have a higher probability of default than other banks (the "core banks"). This follows

quirements maintenance periods). It is a better proxy for the risk-free interbank rate than the EONIA. The EONIA is available for a longer time span and is therefore used on Figure 2. The two rates are in any case extremely close to each other (see appendix I).

[3]For instance, when interbank rates where creeping upward in 2014, while the ECB was cutting its interest rates, an ECB top official declared: "We may have situations where the level of excess liquidity may not be appropriate for our monetary policy stance" (WSJ (2014)). Similarly, in 2011, when rates where also increasing one could read market analysis: "Excess liquidity is gone, and we have recently seen how this affects money markets. EONIA volatility increased significantly and money markets have become much less predictable [...] Clearly this is problematic for the ECB, but it is currently very difficult for the European Central Bank to do much about." (FXStreet (2011))

from country specific risks such as sovereign risk and fears of Euro-Area break up. Such risks have been a major cause of disturbance of financial markets in recent years and in particular of interbank markets. The existence of a country-specific credit risk for Euro-Area banks has been documented empirically for instance in Gilchrist and Mojon (forthcoming) and Garcia-de Andoain *et al.* (2014).

The paper build on models of monetary policy implementation (such as Bech and Keister (2013)) and adds two important dimensions. First, the supply of central bank liquidity is endogenous, thus accounting for a crucial aspect of Euro-Area post-crisis monetary policy: the central bank supplies liquidity on demand at a fixed-price (the so called "fixed-rate full allotment"). It implies that the quantity of liquidity depends on the demand of banks. Second, the interbank market is allowed to be fragmented. Due to fragmentation, peripheral banks can only borrow on the interbank market (secured or unsecured) at a premium. Contrary to the market, the central bank does not discriminate banks according to their country of origin. It will imply that at equilibrium, peripheral banks will turn to the central bank for liquidity and will not rely on the interbank market.

This is equivalent to a capital flight from the periphery to the core. Hence, in times of fragmentation, peripheral banks will have to borrow more than in normal times from the central bank. Core banks will not borrow at all from the central bank and will have a surplus of liquidity. The model predicts that on aggregate, there will be more liquidity than in normal times because the increase in the demand for liquidity from peripheral banks is not matched by a decrease from core banks, as they do not borrow anything. Hence, excess liquidity arises endogenously in the model. Due to this surplus, the interbank rate (which reflects only the price of transactions between core banks) is lower than the central bank main rate. *In fine*, the amount of liquidity and the interbank interest rate will fluctuate according to the size of the capital flight, which the central bank does not control.

This mechanism explains the two stylized facts already discussed as well as additional phenomena such as the low level of "core countries" government bond yields and the so-called "TARGET2 imbalances" observed in the Euro-Area since 2008. The model allows to relate these developments to the "Euro-Area sovereign debt crisis", which can be seen as an increase of fragmentation (as more and more banks are perceived to be risky).

The paper then tests the predictions of the model. Using data on cross-border financial flows and central bank liquidity, the empirical analysis shows that indeed fragmentation has driven liquidity movements since 2008. Then, it is shown that equilibrium conditions derived in the theoretical section are able to match closely the observed movements in the interbank rate.

The model allows to draw several policy implications. First, by providing large amounts of liquidity at favorable conditions the central bank can avoid divergence in financing costs across the monetary union. However, by doing so it also hampers the functioning of the interbank market. Second, there are ways to control the interbank rate even when the banking system is fragmented. The central bank can purchase a large amount of assets to increase the reserves of banks, pushing down the interbank rate and anchoring it at the deposit facility rate. An alternative solution to keep the interbank rate under control would be to absorb excess liquidity. The model shows that in case of fragmentation, contrary to normal times, the central bank can withdraw liquidity from the banking system, even if banks can borrow as much as they wish from the central bank. Third, the paper proposes a new scheme to address fragmentation itself. Instead of lending liquidity on demand to some banks, and thus triggering an excess of liquidity for other banks, the central bank could lend collateral to peripheral banks. This collateral could then be used to borrow on the secured interbank market. Hence no injection of liquidity would be required and no excess liquidity would arise.

The topic of this paper is related to the literature on excess liquidity in the Euro-Area. Bech and Monnet (2015) in a "directed search" model replicate the increase of liquidity and the decline of the interbank rate in the Euro-Area, as well as other stylized facts. However, their model does not account for the interbank rate deviating from the central bank main interest rate and for monetary policy transmission being disrupted. In their model, aggregate liquidity is always controlled by the central bank, which changes the level of its main interest rate within the corridor in order to stimulate borrowings of banks and lower the interbank rate. Heider *et al.* (2015) model banks hoarding liquidity because of counterparty risk and the possibility of a breakdown of the interbank market. While liquidity hoarding can play a role in the increase of liquidity (as it would in the present model), it cannot explain the decline of the interbank rate below the central bank main rate. Rather, liquidity hoarding should results in an increase of the interbank rate as also shown in Acharya and Merrouche (2013).[4] In terms of modeling, this paper is related to the literature on monetary policy implementation, in the tradition of Poole (1968). Later contributions to this literature notably include Nautz (1998), Bindseil

[4] Hauck and Neyer (2010) also explain the increase of central bank liquidity with higher counterparty risk. In their model, higher liquidity is associated with higher interest rates, contrary to the present model.

et al. (2004), Whitesell (2006) and Bech and Keister (2013). The framework presented in this paper is closest to Bech and Keister (2013). The main characteristic of these models is that banks are subject to some regular shocks (positive or negative) on their deposits, that they cannot mitigate by using the interbank market, and which forces them to go to the central bank. Alternative models of monetary policy implementation featuring search frictions on the interbank market exist (e.g. Afonso and Lagos (2015), Bianchi and Bigio (2014) or Bech and Monnet (2015)). The fragmentation of the interbank market would have the same consequences in these specifications, but it would be significantly more demanding mathematically without adding much additional insight.

The rest of the paper is organized as follows. Section 2 presents the theoretical model. Section 3 discusses policy implications. Section 4 presents empirical evidence and section 5 concludes.

2 The model

This section develops the theoretical model that allows to understand fluctuations of liquidity and interbank rates.

First, a model of monetary policy implementation where central bank liquidity is endogenous (as in the Euro-Area) is introduced. Second, using the model, it is shown that traditional explanations for the increase of liquidity such as liquidity hoarding by banks, liquidity regulation or the so called "fixed-rate full allotment" cannot replicate the decline of the interbank rate. In the third subsection, fragmentation is therefore introduced and it is shown it can explain convincingly both the fluctuations of liquidity and of the interbank rate.

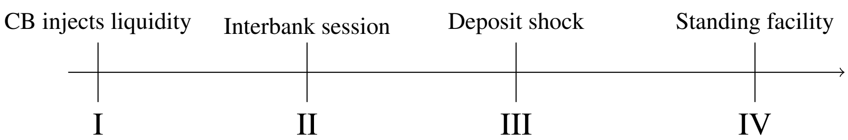
2.1 Monetary policy implementation when liquidity is endogenous

The model draws from Bech and Keister (2013) which is in the tradition of models of Poole (1968). Readers familiar with Poole-type of models can go directly to subsection 2.1.4. These models show how banks subject to minimum reserve requirements maximize their expected profits by choosing the amount of interbank loans they make, depending on how much liquidity is created by the central bank. Contrary to most models of monetary policy implementation where the central bank injects liquidity by buying assets from banks (as done in the US), the model presented below features a central bank that makes loans to banks (as done in the Euro-

Area). How much liquidity is injected in the system depends on the decisions of banks. Central bank liquidity contrary to other models is therefore endogenous.

The timing of the model is the following: first, the central bank refinancing operation is conducted, which injects liquidity (bank reserves) in the banking system. Second, the trading session for interbank loans occurs. Third, once the interbank market is closed, banks experience a "late" deposit shock. Fourth, banks go to the central bank standing facilities.[5] These standing facilities are either the marginal lending facility (the US equivalent is the "Discount Window") at which the banks can borrow overnight unlimited amount of funds at a penalty rate, or the deposit facility at which banks can deposit funds on an interest bearing account.[6]

Diagram 1: Timing of the model



The game is now solved backward, period per period.

2.1.1 Recourse to central bank standing facilities

The central bank marginal lending facility refers to a facility that is accessible after the interbank session is closed, and enables banks to borrow overnight without limit. During this phase the central bank is passive and the banks take the decision to access or not the facility depending on their needs. The funds borrowed at the standing facility are meant to address liquidity shocks and cannot be lent to other banks. The funds are credited to the account of the bank that access the facility after the interbank session and taken out before the next session starts.

In this model, the central bank imposes minimum reserve requirements to its banks, as is the case for instance in the Euro-Area, in the US and in over 90% of central banks in the world (Gray (2011)). These reserves requirements take the form of the following constraint for bank

[5] Indeed, in the Euro-Area, standing facilities are made accessible only when the payment system closes and all interbank transactions have been processed (at 18:30). Since, an interbank loan takes some time to be set up, no interbank loans are initiated after 17:00. Any unexpected payment arising between 17:00 and 18:30 can only be accommodated by using the Eurosystem standing facilities (see Bindseil *et al.* (2004)).

[6] Banks borrowing from the central bank have to provide adequate collateral against the funds, at least in the case of major central banks (Cheun *et al.* (2009)). In the present paper, it is assumed that banks always have sufficient collateral to accommodate their borrowing needs.

"i":

$$R^i + B^i - \epsilon^i + X^i \geq K^i \tag{1}$$

where K^i is set by the central bank and corresponds to the amount of liquidity that bank "i" must keep on its account at the central bank.[7] R^i is the amount of reserves held by bank "i" at the central bank at the end of period I (so it excludes borrowing from the central bank standing facility, interbank borrowings or any deposit shock). B^i are interbank borrowings (negative values are interbank loans). ϵ^i is a shock on the deposits collected by the bank. X^i are overnight borrowing from the central bank' standing facility. This facility is automatically activated by the central bank, whenever (1) is not respected. Therefore:

$$X^i = max\{K^i - (R^i + B^i - \epsilon^i); 0\} \tag{2}$$

It means that banks have to go to the central bank in case a reserve deficiency appears after the interbank market has closed (when they cannot change B^i).

Funds deposited at the end of the business day at the central bank in excess of reserve requirements (so called "excess reserves") are remunerated at r_r. r_r is the interest on excess reserves, also called the deposit facility rate.

2.1.2 Deposit shock

ϵ^i is some random deposit shock that occurs after the interbank market has closed ($\epsilon^i > 0$ is an unexpected net withdrawal of funds from bank "i" and $\epsilon^i < 0$ an unexpected net inflow of funds). These shocks on the liquidity positions of banks can push them to use the central bank standing facilities, to avoid a minimum reserves deficiency. By an abuse of notation ϵ^i denotes both the random variable and its realization. $g(.)$ is the density function of the random variable. ϵ^i's are independently distributed across banks and $E(\epsilon^i) = 0$. Further, $G(.)$, the cumulative distribution function of ϵ^i is symmetric around 0 ($G(E(\epsilon^i)) = G(0) = 0.5$).[8]

[7] Reserve requirements are usually set by the central bank to stabilize the demand of liquidity from banks and by the same token market rates (see Ennis and Keister (2008)). To do so central banks allow commercial banks to average the fulfillment of reserve requirements over some period. In this model, K^i is interpreted as the reserve requirements over this period *i.e.* the bank within the game has to meet (1) at all time, not on average. The same interpretation is made in Bech and Keister (2013).

[8] Economically, these shocks can be interpreted as all liquidity shocks that hit banks and that cannot be mitigated by borrowing/lending on the interbank market. Depositors withdrawing more/less from cash machines than expected produce the same kind of shocks, as the cash withdrawn from one bank does not go back immediately to

$\hat{\epsilon}^i$ is defined such that for given R^i, B^i and K^i:
$\epsilon^i > \hat{\epsilon}^i \Rightarrow X^i > 0$. $\hat{\epsilon}^i$ is a threshold, which defines the amount of deposit withdrawals above which bank "i" has to borrow from the central bank standing facility ($X^i > 0$). Therefore:

$$\hat{\epsilon}^i = R^i + B^i - K^i \tag{3}$$

2.1.3 The interbank market

The profit function of bank "i" writes:

$$\Pi^i = -r_X X^i - r_B B^i - r_D(D^i - \epsilon^i) - r_M M^i + r_r(R^i + B^i - \epsilon^i + X^i - K^i) \tag{4}$$

Reserves held at the end of the day (end of period IV) in excess of minimum reserves (excess reserves) yield r_r while minimum reserves yield some rate that is assumed to be zero to avoid cumbersome notations.[9] Deposits (D^i) from non-banks and the overnight central bank borrowings (X^i) cost to the bank interests r_D and r_X to the bank respectively. r_M is the interest paid on money borrowed from the central bank refinancing operation (M^i).

This profit function is very general. One could easily add additional items such as loans and securities but this should not change anything to the problem studied here (see appendix II).

Rearranging, substituting (2) into (4) and taking expectations yields:

$$\begin{aligned} E[\Pi^i] = {} & -r_B B^i - r_D D^i - r_M M^i + r_r(R^i + B^i - K^i) \\ & - (r_X - r_r) E[\max\{K^i - (R^i + B^i - \epsilon^i); 0\}] \end{aligned} \tag{5}$$

$g(.)$ is the density function of ϵ^i (it is the same for all ϵ^i's) and $\hat{\epsilon}^i$ is the threshold above which a deposit shock is large enough to force the bank to borrow from the central bank standing

the banking system. The fact that $G(E(\epsilon^i)) = G(0) = 0.5$ just means that the forecast of banks regarding this type of liquidity needs is unbiased. In practice, forecasts of total cash to be withdrawn are published by the Eurosystem every week. This forecast is unbiased and symmetric (Gonzalez-Paramo (2007)).

[9] In reality, central banks tend to remunerate minimum reserves (Gray (2011)). It does not change anything in this model to assume that minimum reserves are remunerated or not as long as one assumes a large financial penalty in case of non-compliance with minimum reserve requirements. To see when this has an impact see Kashyap and Stein (2012) or Whitesell (2006).

facility. Therefore:

$$E[\Pi^i] = -r_B B^i - r_D D^i - r_M M^i + r_r(R^i + B^i - K^i) \\ - (r_X - r_r) \int_{\hat{\epsilon^i}}^{\infty} g(\epsilon^i)(K^i - (R^i + B^i - \epsilon^i))\mathrm{d}\epsilon^i \quad (6)$$

Bank "i" chooses B^i to maximize its profit. If G(.) is the strictly increasing cumulative distribution function of ϵ^i's, it means that:

$$\frac{\partial E[\Pi^i]}{\partial B^i} = 0 \quad (7)$$

$$\Rightarrow r_B = r_r G(\hat{\epsilon^i}) + r_X(1 - G(\hat{\epsilon^i})) \quad (8)$$

Banks will price their loans to other banks such that the revenue they receive from the transaction is equal to the expected value of not lending one more unit of fund. This expected value is equal to the probability of being long in cash $G(\hat{\epsilon^i})$ times the remuneration of excess reserves (r_r) plus the probability of being short in cash $1 - G(\hat{\epsilon^i})$ times the cost of borrowing from the central bank facility (r_X).

Aggregating over the mass 1 of banks, it must be the case that:

$$\int_0^1 B^i di = 0 \quad (9)$$

Combining (3), (33) and (8) yields:

$$r_B^\star = r_r + (r_X - r_r)(1 - G(R - K)) \quad (10)$$

A starred variable denotes the market equilibrium level of this variable. $R \equiv \int_0^1 R^i di$ are the aggregate reserves and $K \equiv \int_0^1 K^i di$ is the aggregate reserve requirements of the banking system. $R - K$ is the amount of reserves in excess of minimum reserve requirements, also called the "excess liquidity". Equation (10) shows that the level of excess liquidity directly impacts the level of the interbank rate. The higher (*resp.* lower) the level of excess liquidity the closer the interbank rate from the deposit (*resp.* marginal lending) facility rate.

2.1.4 Central bank refinancing operation

If the central bank controls R, (10) shows that it can steer the interest rate in the interbank market toward a target (r_M) using the rates on the deposit and the marginal lending facility, the reserve requirements and the total quantity of reserves in the banking system.

One can invert (10) to find:

$$R^{cb} = K + G^{-1}\left(\frac{r_X - r_M}{r_X - r_r}\right) \tag{11}$$

A variable with superscript "*cb*" denotes the level of this variable that in normal time allows the central bank to reach its target (r_M) for the interbank rate, also called the operational target of the central bank.[10] r_M can be anywhere between the interest rates of the two standing facilities. For ease of presentation, it is assumed that it is at equal distance of the two rates, also called the middle of the "corridor". It does not change anything for the problem studied here that the target is closer from one facility rate, a situation referred as asymmetric corridor, studied in appendix III. Thus:

$$r_M = \frac{r_r + r_X}{2} \tag{12}$$

Equation (11) can be rewritten:

$$R^{cb} = K + G^{-1}(1/2) \tag{13}$$

Since $G(0) = 0.5$, it follows that:

$$R^{cb} = K \tag{14}$$

If the interbank rate is to be in the middle of the corridor, the central has to make sure there is just enough reserves on aggregate to satisfy reserve requirements.

R is the total amount of reserves in the banking system excluding deposit shocks and the amount borrowed via the marginal lending facility. Prior the interbank market, banks obtain

[10] It is assumed that the central bank uses *R* rather than K for its monetary policy. In reality, some central banks especially in emerging countries use the level of minimum reserves *K* (Glocker and Towbin (2012)). Some developed countries exceptionally use reserve requirements to change the level of excess liquidity in the system but these are extremely rare changes, while R moves on a day-to-day basis. The Eurosystem lowered the level of reserves requirements in February 2012 (ECB (2011)).

central bank liquidity either by borrowing from the central bank (M^i) or from deposits (D^i).

$$R^i = M^i + D^i \tag{15}$$

At the bank level, when the interbank rate is equal to the policy rate, inverting equation (8) and using equations (3) and (15) implies:

$$M^{i\star} + B^{i\star} = K^i - D^i \tag{16}$$

Deposits are to be thought as deposits from non-banks minus loans to non-banks, denominated in Euros. Therefore D^i can be positive or negative depending on whether the bank is specialized in collecting deposits or in making loans. According to equation (16) the gap between loans and deposits ($-D^i$) and reserve requirements (K^i) is closed by borrowing from the central bank or the interbank market.

The aggregate amount of bank deposits (M3) can only increase if a bank loan is created (in the same bank or in another bank) or if the central bank buys assets from a non-bank agent. Conversely, bank deposits can decrease if bank loans are repaid, if the central bank sells assets or if the demand from currency increases (see appendix II for more details on this accounting identity). Thus,

$$\int_0^1 D^i di = O - C \tag{17}$$

Where "O" is the amount of assets purchased by the central bank and "C" the amount currency in circulation. They are known at the time of the central bank tender. It implies that aggregated reserves are given by:

$$R = M + O - C \tag{18}$$

Using equations (14) and (18) above, yields:

$$M^{cb} = K + C - O \tag{19}$$

At equilibrium, the central bank lends just enough liquidity for banks to be able to satisfy reserve requirements and the demand for currency in circulation, minus how much was already injected via outright purchase of assets. This is the case because the target for the interbank rate is in the middle of the corridor. If the target was strictly lower than the middle of the corridor, the central bank would need to supply more liquidity (see appendix III).

If:

$$K > O - C \tag{20}$$

it means that banks structurally need to borrow from the central bank in order to fulfill their reserve requirements. The Eurosystem does set minimum reserve requirements to make sure that banks need to borrow (ECB (2013a)). Therefore, in what follows it will be assumed that equation (20) holds.

It is crucial to note that this refinancing operation is a borrowing operation exclusively. This means that $M^i \geq 0$ for all i's.

This model is a useful benchmark but it cannot explain excess reserves and deviations of the interbank rate from the central bank main interest rate in the Euro-Area. The remainder of this theoretical section addresses this shortcoming.

2.2 Conventional explanations of the increase in liquidity in the Euro-Area

This subsection discusses several conventional explanations for the large excess liquidity observed in the Euro-Area during the last six years. It shows that none of them can account for the simultaneous decrease of the interbank rate (given that the central bank has not increased unilaterally the supply of liquidity as in the US).

2.2.1 Fixed-rate full allotment

From its creation to October 2008 the Eurosystem was lending some fixed amount of liquidity to banks. In this case, the model developed in the previous subsection applies, and the central bank supplies an amount of loans equal to M^{cb}. However, since October 2008, the Eurosystem operates under a "fixed-rate full allotment" regime where banks individually ask for the quantity of liquidity they want (ECB (2008)) at fixed pre-announced rate (the ECB main interest rate). Hence, the money supply and the excess liquidity in the Euro-Area are endogenous to bank's behavior. How this changes the mechanics of monetary policy implementation is the focus of what follows.

Proposition 1: Under fixed-rate full allotment, in a perfectly integrated banking system, the interbank rate is equal to the policy rate ($r_B = r_M$).

Proof: Assume that there exists a corridor and that the main rate is in its lowest half:[11]

$$\frac{r_X + r_r}{2} \geq r_M > r_r \tag{21}$$

Assume that the expected interbank rate before the refinancing operation is conducted, is strictly greater than the main central bank interest rate ($E[r_B] > r_M$). Then, all banks borrow an infinite amount at the refinancing operation in order to lend it on the interbank market: $R \to +\infty$. Using equation (10), *this would mean that $r_B^\star = r_r < r_M \Rightarrow r_B \neq E[r_B]$, this would not be an equilibrium. Therefore: $E[r_B] \leq r_M$. Assume $E[r_B] < r_M$, then banks prefer to borrow from the interbank market and no bank borrows at the refinancing operation ($M^\star = 0$). Equations* (10), (18) *and* (20) *imply: $r_B > \frac{r_X + r_r}{2} \geq r_M$. Again, this is not an equilibrium. Therefore, a no arbitrage condition is $E[r_B] = r_M$. By definition, this holds only when: $\int_0^1 M^{i\star} di = K + C - O = M^{cb}$.*

In other words, in a perfectly integrated banking system, the fixed-rate full allotment should result in the same quantity of liquidity and the same interbank rate as in the case where the central bank restricts the quantity of liquidity.

2.2.2 The impact of precautionary demand for liquidity and liquidity regulation

If banks want to hold a liquidity buffer for precautionary motive (ECB (2014)) or if they use liquidity to fulfill liquidity regulation (ECB (2013b)), in this model this would translate into:

$$\hat{\epsilon}^i = R^i + B^i - K^i - A^i \tag{22}$$

where $A^i \geq 0$ is the amount of reserves a bank must have to satisfy liquidity regulation. It can also be seen as the expected value of a large deposit withdrawal that could occur after the close

[11] This condition has always been fulfilled in the Euro-Area during the period studied (Figure 2). One could relax $\frac{r_X + r_r}{2} \geq r_M$ and have instead $r_X > r_M$. *Proposition 1* would then still hold if $K + C - O$ is large enough.

of the interbank market.[12]

Proposition 2: In a fixed-rate full allotment regime, ceteris paribus, if banks increase their demand for central bank refinancing for precautionary motives or to fulfill a legal obligation, excess liquidity appears and the interbank rate remains at the central bank main rate.

Proof: Injecting equation (22) *into* (8) *and then aggregating across all banks means that the equilibrium interbank rate in this regime,* $r_B^{\star\prime}$ *is:*

$$r_B^{\star\prime} = r_r + (r_X - r_r)(1 - G(R - K - A)) \tag{23}$$

The quantity of central bank borrowings $M^{\star\prime}$ *necessary to achieve* $r_B^{\star\prime} = r_M = \frac{r_X + r_r}{2}$*, would then be:*

$$M^{\star\prime} = K + C - O + A \tag{24}$$

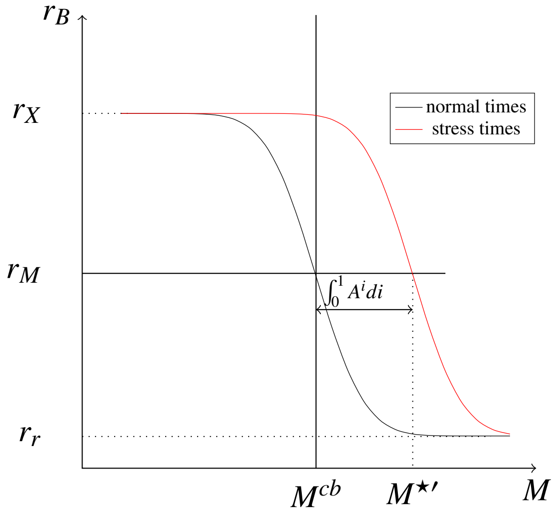
It is equal to what the central bank normally allots (equation (19)*), plus* $A = \int_0^1 A^i di$*. That is* $M^{\star\prime} = M^{cb} + A$

Proposition 1 applies and therefore in a fixed rate full allotment regime, the interbank rate would be in the middle of the corridor. The quantity of central bank borrowing that would prevail would therefore be $M^{\star\prime}$*.*

To the extent that $A^i \geq 0$ is taken as exogenous, it would have the same effect on banks' demand for liquidity as increasing minimum reserve requirements and would consequently increase the take up of banks at the central bank main refinancing operation, as shown on diagram 2 below. If the central bank injects only M^{cb}, the interbank rate increases above the target.

[12] One could alternatively assume that the withdrawal takes place before the interbank market. If the interbank market is operative, this does not change anything compared to the benchmark model. If the interbank market is dysfunctional, the case with fragmentation is more relevant. There is an intermediate case where banks wrongly anticipate a breakdown of the interbank market together with a large withdrawal. Then, as these events do not materialize, it would push the interbank rate down as banks will be willing to trade the surplus of liquidity they have borrowed from the central banks. However if agents are rational, such surprise should not happen on a repeated basis. Such chain of events would make profits lower. Hence, it is not a satisfactory explanation for the persistently low level of the interbank rate.

Diagram 2: Demand for liquidity in times of stress *vs* normal times[13]



To sum up: neither the fixed-rate full allotment nor liquidity hoarding behavior by banks can explain the large increase in liquidity while the interbank rate was declining. As shown now, fragmentation can. It does not necessarily mean that fixed-rate full allotment and liquidity hoarding by banks have played no-role in increasing liquidity on top of the increase due to fragmentation. It just means that they have played no role in the decrease of the interbank rate.

2.3 Introducing fragmentation into the model

Two important assumptions will be introduced in the course of the present subsection, and will change the dynamic of the model.

First, banks located in peripheral countries (peripheral banks) are subject to an exogenous increase of their probability of default on interbank borrowings. Other banks (core banks) are considered safe. The country of origin of the bank is observable on the interbank market. Differences in credit worthiness based solely on the country of location of banks is supported empirically, for instance in Gilchrist and Mojon (forthcoming) and Garcia-de Andoain *et al.* (2014). This systematic difference in credit risk is how fragmentation is defined in these papers and it is also this definition which is adopted here. The difference in credit risk could come from tensions in the local sovereign debt market that devalue the domestic sovereign debt holdings of peripheral banks (as documented by Acharya and Steffen (2015)). Such tensions would also translate into lower capacity of sovereigns to rescue their banks and would thus weaken the implicit guarantee that banks usually enjoy (Lane (2012)). Relatedly, sovereign debt issues would increase the risk that a country will exit the monetary union and that liabilities of banks will be

[13] The shape of the curves come from the Normal cumulative distribution function.

converted in a new currency (Cecchetti *et al.* (2012)) and that the solvency of the banks of such country will be negatively affected.[14] The probability of default is similar on the secured or the unsecured interbank market. The reason is that peripheral banks are assumed to hold mostly illiquid loans or domestic sovereign debt. The value of such assets would also be negatively affected in case of Euro-Area break-up and are thus extremely correlated with the risk of default of peripheral banks. The reasoning extends to longer maturities than the overnight market. As the time horizon increases, so does the risk of default. Appendix I shows that during the period considered the interbank for overnight unsecured transactions behaved similarly to the secured overnight market and to longer-term funding markets.

Second, the monetary union is subject to current account imbalances. Some countries, that will be called "peripheral countries" have had negative current accounts balances for several years and have a negative international investment position. Other countries in the monetary union the "core countries" have experienced current account surpluses and enjoy a positive international investment position. Appendix IV shows that this is indeed the case in the Euro-Area.

These two assumptions might be related. A country with large current account deficits will have higher level of debt and as a result might be seen as more likely to exit the monetary union. These two features are anyway taken as exogenous. Why some countries in monetary unions run large and persistent current account deficits is the topic of a large literature as discussed for instance in Kalemli-Ozcan *et al.* (2010).

There is a mass one of each type of banks and the timing of the model is exactly the same as above.

2.3.1 Recourse to central bank standing facilities

As before banks will use the central bank marginal lending facility to cover a reserve deficiency and the deposit facility to stock their excess reserves. Equation (2) still holds in the two countries. Further, $Z^{i,y}$ is a variable that applies to bank $i \in [0;1]$ in country $y = \{C, P\}$. With

[14] A bank located in a core country but which is part of banking group headquartered in the periphery should be thought as a peripheral bank. This is because, it would be considered as very much exposed to the its headquarter. For the same reason, a bank located in the periphery but which is part of a core banking group, is considered as a core bank. A bank located in the periphery (*resp* core) but affiliated to a banking group headquartered outside the Euro-Area is considered as a peripheral bank (*resp* core). This is because expectations of Euro-Area break-up would reduce (*resp* increase) the ability of this bank to borrow, even from its own banking group (Cecchetti *et al.* (2012)).

$\int_0^1 Z^{i,y} di = Z^y$ and $Z^C + Z^P = Z$. Then:

$$X^{i,C} = max\{K^{i,C} - (R^{i,C} + B^{i,C} - \epsilon^{i,C}); 0\} \tag{25}$$

$$X^{i,P} = max\{K^{i,P} - (R^{i,P} + B^{i,P} - \epsilon^{i,P}); 0\} \tag{26}$$

2.3.2 Deposit shocks

There are now two different expected profit functions:

$$\begin{aligned} E[\Pi^{i,C}] = &-r_D(D^{i,C}) - r_B B^{i,C} - r_M M^{i,C} + r_r(R^{i,C} + B^{i,C} - K^{i,C}) \\ &- (r_X - r_r) \int_{\hat{\epsilon}^{i,C}}^{\infty} g(\epsilon^{i,C})(K^{i,C} - (R^{i,C} + B^{i,C} - \epsilon^{i,C}))\mathrm{d}\epsilon^{i,C} \end{aligned} \tag{27}$$

$$\begin{aligned} E[\Pi^{i,P}] = &-r_D(D^{i,P}) - \tilde{r}_B B^{i,P} - r_M M^{i,P} + r_r(R^{i,P} + B^{i,P} - K^{i,P}) \\ &- (r_X - r_r) \int_{\hat{\epsilon}^{i,P}}^{\infty} g(\epsilon^{i,P})(K^{i,P} - (R^{i,P} + B^{i,P} - \epsilon^{i,P}))\mathrm{d}\epsilon^{i,P} \end{aligned} \tag{28}$$

The risk-free interbank rate is still denoted r_B. $\tilde{r}_B$ is the risk-adjusted rate that peripheral banks have to pay on the interbank market.

2.3.3 Interbank market rate

Let ρ be the expected recovery rate on one Euro lent. It is equal to 1 when the loan is considered risk-free and 0 when there is probability one that the loan will not be reimbursed at all. $\tilde{r}_B$ is the interest rate charged to risky banks. Therefore, a bank lending to a peripheral bank can expect to recover:

$$\rho(1 + \tilde{r}_B) \tag{29}$$

Since lending to a core bank is risk-less, it must be the case that:

$$\rho(1 + \tilde{r}_B) = 1 + r_B \Leftrightarrow 1 + \tilde{r}_B = \frac{1 + r_B}{\rho} \tag{30}$$

In a fixed-rate full allotment regime, if $r_M < \tilde{r}_B$, one can show using equation (28) that peripheral banks make higher profits by relying exclusively on the central bank and not using at all the interbank market. Using previous equation, this happens whenever:

$$\rho < \frac{1+r_B}{1+r_M} \tag{31}$$

Since $r_B \geq r_r$, this will be the case for any value of r_B if:

$$\rho < \frac{1+r_r}{1+r_M} \tag{32}$$

In what follows, it will be assumed that condition (32) holds.[15] Under such circumstances, the risk of default of peripheral banks and the conditions under which the central bank is willing to lend to them, is such that peripheral banks will chose not to borrow on the interbank market.[16]

A question that naturally arises is why the central bank lends at a rate lower than the private market rate? There are several reasons for this. First, it might be the case that the central bank considers itself to be in a better position than the market to assess credit risk. Second, central banks usually have senior status compared to private creditors (Steinkamp and Westermann (2014)) and hence face lower risk than market participants. Third, the central bank might not be able to protect itself from the risk of a country leaving the monetary union, as the private market does. This would imply that two banks of equal credit quality, submitting similar collateral, would pay different interest rates depending on the country in which they are located. The Eurosystem never took such steps as it would probably send a negative signal to market participants and as a result increase fragmentation. This issue is discussed further in section 3.

If equation (32), holds then $B^{i,P} = 0 \ \forall i$. The interbank market clearing condition becomes:

$$\int_0^1 B^{i,C} di = 0 \tag{33}$$

Following the same maximization and aggregating steps as above with core banks, the interbank rate is given by:

$$r_B^\star = r_r + (r_X - r_r)(1 - G(R^C - K^C)) \tag{34}$$

[15] This assumption is extremely realistic in the case of the Eurosystem. On average, between October 2008 and September 2014, $\frac{1+r_r}{1+r_M}$ was over 0.99. The slightest doubt on the credit worthiness of a counterparty is therefore sufficient to drive it out of the interbank market.

[16] Section 4 shows that indeed peripheral banks tend to rely to a large extent on the central bank rather than on the interbank market.

Note that the observed interbank rate will be risk-free, which follows from the fact that peripheral banks are completely excluded from the interbank market.[17] Just as in the case without fragmentation, if $r_B > r_M$, core banks borrow large amounts of liquidity from the central bank which decreases r_B towards r_M (see proposition 1).

Therefore, it must be the case that $r_B \leq r_M$. It is now possible that $r_B < r_M$. Indeed, the second part of *proposition 1* does not apply.[18]

Using (34), for $r_B < r_M$, it must be the case that:

$$R^C > K^C \tag{35}$$

To determine when this happens, one needs to solve for R^C.

2.3.4 Central bank main refinancing operations

By identity, it is still the case that:

$$R^C = M^C + D^C \tag{36}$$

and:

$$R^P = M^P + D^P \tag{37}$$

Except for the interbank market, peripheral banks and core banks differ in another crucial dimension: they do not have the same amount of deposits. The aggregate amount of deposits in the core (D^C) is larger than in the periphery (D^P). Recall that D^P and D^C are the total amount of deposits from non-bank agents minus loans to non-bank agents (both denominated in Euro), in each country.

This difference is due to the macroeconomic imbalances discussed at the beginning of this subsection. It is assumed that banks are the main source of financial intermediation and that foreign trade and financing is done in Euro. Thus, current account imbalances within the monetary union (that is the difference in net savings across countries) map in this model as flows

[17] This is again consistent with empirical evidence, looking at appendix VIII for instance, one can see that the observed interbank rate is very close to the rate of central bank bills (which is credit risk-free). See also the discussion on central bank bills in section 3

[18] This is because even if condition (20) still holds, when the interbank market is dysfunctional, it will not always be sufficient to stimulate the demand for liquidity from core banks.

of deposits from the periphery to the core. Importers will run down their deposit balance in peripheral banks in order to pay for goods, while exporters will see their deposits in core banks increase.

Therefore, it is assumed that aggregate amount of domestic deposits in the core banking system is as before equal to the amount of assets purchased by the central bank (O^C) minus the currency (C^C) in circulation plus the additional deposits accumulated in core banks through current account surpluses (called "F"):

$$D^C = O^C - C^C + F \tag{38}$$

Conversely, the deposit base in the periphery is:

$$D^P = O^P - C^P - F \tag{39}$$

When $r_B = r_M$, the reasoning of the case with no fragmentation applies to the core banking system. One can use condition (16) together with the zero supply on interbank loans to find:

$$M^{C\star} = K^C - D^C \tag{40}$$

This condition together with equation (38) implies:

$$M^{C\star} = K^C + C^C - O^C - F \tag{41}$$

Then, there is no excess liquidity. This solution applies only to the case where F is small.

Proposition 3: If imbalances are sufficiently large (F large), excess liquidity appears and the interbank rate in the core is strictly lower than the rate of the main refinancing operation ($r_B < r_M$).

Proof: when $E(r_B) < r_M$, core banks prefer borrowing on the interbank market rather than from the central bank ($M^C = 0$). It implies that $R^C = F + O^C - C^C$. Injecting this equality into equation (35) yields:

$$r_B < r_M \Leftrightarrow F > K^C + C^C - O^C \tag{42}$$

When the accumulated imbalances are relatively small, if core banks receive additional liquidity, they will lower their borrowings from the central bank. When, F is larger than core banks liquidity needs (reserve requirements plus demand for currency from the public net of central bank outright purchases), core banks will have no interest in going to the central bank. Core banks are then saturated with liquidity. Additional liquidity inflows cannot be compensated by borrowing less at the refinancing operation as they already borrow nothing (see diagram 3 in appendix for a graphical representation). This triggers an excess of liquidity in the core that exerts a downward pressure on rates. Hence, in general:

$$M^{C\star} = max\{0; K^C + C^C - O^C - F\} \tag{43}$$

For high levels of F equation (34) becomes:

$$r_B^\star = r_r + (r_X - r_r)(1 - G(F - C^C - K^C + O^C)) \tag{44}$$

This equation shows that the interbank rate depends negatively on F.

In order to determine the borrowings of peripheral banks from the central bank, one can maximize equation (28) with respect to M^i, aggregate across all banks and make use of the fact that $r_M = \frac{r_X + r_r}{2}$. These steps yield:

$$M^{P\star} = K^P + C^P - O^P + F \tag{45}$$

Hence, peripheral banks borrow just enough to satisfy their liquidity needs. They finance themselves at the central bank main rate, which is strictly higher than the interbank rate, at which core banks can borrow.

Using equation (18), (45) and (43), for high levels of F:

$$R^\star = F + K^P + O^C - C^C \tag{46}$$

This contrasts with equation (14), where the equilibrium amount of reserves in the banking system was always equal to reserve requirements. Now, it increases with the size of imbalances (F), outright purchases (O^C) and decreases with the level of currency in circulation (C^C) in the core. The interbank rate declines accordingly when reserves increase and *vice versa*. When F is large, core banks are saturated with liquidity and cannot compensate movements in currency or central bank purchases by asking more or less liquidity to the central bank (they always borrow zero).

3 Policy Implications

When the interbank market operates (a situation which can be thought as the pre-crisis environment in the Euro-Area), imbalances do not matter for monetary policy transmission. Then, interbank loans are in positive net supply among core banks. Peripheral banks borrow a net amount F from core banks ($B^P = F$ and $B^C = -F$) and the current account surplus of core countries is invested on the interbank market. When some banks become risky, condition (31) applies, and interbank loans between core and periphery stop. This is a sudden stop or a capital flight.[19] This situation depends on market perception of the risk of Euro-Area break-up and might change quickly. If some more countries with current account deficits are seen as likely to leave the monetary union, F increases. If countries in which banks are excluded from the interbank market start running current account surpluses, F decreases. F can be seen as the part of current account deficits that cannot be financed by the interbank market and it can vary. This implies some unpredictable variations of the money supply (see equation (46)) and for the interbank rate (see equation (44)).

In this case, the interbank rate can deviate from the central bank targeted level. Suppose for instance that the central bank sets its main rate (r_M) equal to some targeted level (r^{cb}). In a fixed-rate full allotment regime, when the interbank market is functioning well, the central bank will reach this target (see *proposition 1*). If the interbank market is fragmented but F is small as well. However, if the interbank market is fragmented and F is large, the interbank rate will deviate from the main interest rate (see *proposition 3*). The interbank rate will then settle at some lower level (see equation (44)) that the central bank does not control. The central bank can alternatively set its target at the level of the deposit facility ($r_r = r^{cb}$). This would still be problematic though. Indeed, in case of fragmentation, peripheral banks borrow from the central bank at the main interest rate (r_M). Thus, the target could not be met for these banks. When F is extremely large, the target would be met for core banks. However, in case the access of peripheral banks to the interbank market improves, F would go down and the interbank rate would go up. All in all, it will be harder for the central bank to control the interbank rate.

[19] In the absence of interbank flows, one may then wonder how the balance of payments clears. This is done via the TARGET2 system as explained in section 4.

Moreover, in this set-up, the central bank has to increase its lending compared to normal times, which it might find uncomfortable.[20]

Thus, assuming that the central bank wants i) the rate of financing of banks to be as close as possible from some exogenous targeted level r^{cb} and ii) lending as little as possible to banks, several policy implications can be derived from the model.

The central bank cannot address the fundamental friction of the model which is that it gives equal treatment to banks located in different countries, which in turn have different probabilities to exit the monetary union. Discriminating depending on countries of origin would break equal treatment of member states and signal that the central bank gives credit to fears of monetary union dislocation. This would probably lead to a further deterioration of market sentiment toward some countries. This would cause even more fragmentation (lower ρ and more countries being perceived as risky) and would therefore lead to banks relying to an even greater extent on the central bank. Thus, by trying to protect itself, the central bank could end-up being more exposed to the periphery. In fact, the announcement of the Outright Monetary Transaction (Draghi (2012)) can be seen the exact opposite strategy: by announcing that it was willing to be more exposed to the periphery, the central bank triggered a shift in sentiment that would lead fragmentation to recede and thus the exposure of the central bank to the periphery to decrease (Bacchetta *et al.* (2015)). Other policy options are available.

Whether peripheral banks rely on the central bank depends on condition (32). If ρ is small (high probability of default), then peripheral banks rather borrow from the central bank than from the interbank market and the mechanics described in subsection 2.3 applies. The central bank can affect condition (32) since it sets r_M and r_r. A larger corridor (small $\frac{1+r_r}{1+r_M}$) implies that it will be more likely that the interbank market will function, but this would also mean that peripheral banks finance themselves at an even higher rate ($\tilde{r_B}$) compared to core banks. Therefore, the central bank faces a trade-off between keeping the interbank market active and preventing financing conditions to diverge across the monetary union.

This trade-off is more or less acute depending on the size of ρ. At the height of the crisis, in July 2012, the perceived risk to lend to a peripheral bank was probably so high (very low ρ) that even if the central bank had an extremely large corridor (low $\frac{1+r_r}{1+r_M}$), peripheral banks would still have stayed excluded from the interbank market. At that time, widening the corridor would have only increased financing costs of peripheral banks without improving the functioning of

[20]Indeed, it seems that central banks are reluctant to expand their lending to banks (See for instance Carlson *et al.* (2015)). This has been particularly the case of the Eurosystem (FT (2010)) and Trichet (2011).

the market.

Similarly to increasing the size of the corridor, the central bank can discontinue the fixed-rate full allotment and provide only a limited amount of liquidity at its main rate. Then, condition (32) becomes $\rho < \frac{1+r_r}{1+r_X}$ where $\frac{1+r_r}{1+r_X} < \frac{1+r_r}{1+r_M}$. This new condition would be less stringent and thus peripheral banks would be more likely to be able to access the interbank market (peripheral banks would participate to the interbank market for a larger sets of values of ρ). In case the interbank market still does not function, whatever the quantity of liquidity allotted at the main, most of it would be taken by peripheral banks in order to cover their liquidity needs. For low levels of imbalances (F), what is not borrowed at the central bank by core banks is borrowed by peripheral banks and the interbank rate remains at the level of the main rate. Past the critical threshold discussed in subsection 2.3, core banks would ask zero to the central bank and would still have too much liquidity from the capital flight. Interbank rate would decline accordingly. Peripheral banks, depending on which quantity is allotted would need to top-up what they take at the main refinancing operation with borrowings from the marginal lending facility and finance themselves at a higher rate than core banks. It is an interesting insight of the model that even without the fixed-rate full allotment, there can be an excess of liquidity and a volatile interbank rate.

The remainder of this section explores how fluctuations of the interbank rate can be avoided, in case of fragmentation (*i.e.* assuming equation (32) holds).

The central bank can decide to inject liquidity through asset purchases (increasing "O^C" in equation (34)). This would lower the interbank rate to the deposit facility rate. Peripheral banks would use the liquidity injected in the periphery to lower borrowings from the central bank (equation (45)). Once, their borrowings are zero, the shadow cost of funding of peripheral banks would then also converge to the deposit facility rate. The most relevant rate for monetary policy would then be the deposit facility rate. This is what happened in the UK and to some extent in the US during the crisis (see Bech and Klee (2011)). A massive increase in assets purchased (or "Quantitative Easing") pushed the interbank rate to the "floor". Buying assets allows to inject liquidity beyond what banks demand (Bindseil (2014)) and would place all banks in a situation where they are always saturated with liquidity. A practical problem is that a large, safe and liquid asset market needs to be available to the central bank. The controversy that surrounded the assets purchase programs announced by the ECB in September 2014 suggests that holding large amount of assets might not be an option in the long run.[21] Fragmentation on the other hand could persist in the long run. Other tools to steer the interbank rate might therefore be needed.

If the central bank cannot increase liquidity to anchor the interbank rate at the deposit facility rate, it could try to withdraw liquidity to anchor the interbank rare at the main rate. How a central bank that has committed to lend to banks as much as they wish can withdraw liquidity? In a model with a well integrated banking sector, this would actually be impossible. Absorption operations (equivalent in liquidity terms to the central bank selling assets) would have no effect on aggregate liquidity, as banks compensate one-for-one liquidity absorbed by borrowing more to the central bank. Alternatively, in the presence of fragmentation, these operations are not neutral. This should not come as a surprise as this is economically the opposite operation to buying assets. The basic intuition is the same: core banks are unable to compensate liquidity movements from the central bank because they are overwhelmed with liquidity. There are however some differences, as explained now.

In the Euro-Area, absorption operations take the form of deposits made by banks at the central bank.[22] These deposits are adjudicated according to a sealed bid auction. Bids contain a rate and a quantity. Banks bidding at the lowest rates are chosen first until the quantity of deposits the central bank intends to collect ($\underline{S}$) is reached. Each selected bank receives the rates it bids for. No bid above the main rate (r_M) are considered.

In the model, it means that these funds are deposited before the interbank market opens (contrary to the deposit facility) and then cannot be used for interbank loans. The funds are remunerated at $r_S \leq r_M$.

Denoting the size of absorption operations also called sterilization operations by "S" (with $S > 0$), now it is the case that:[23]

$$M^{C\star} = max\{K^C + C^C - O^C - F + S\,; 0\} \tag{47}$$

[21] Against the possibility of a deflation, the ECB announced in 2015 that it would buy large amounts of assets (ECB (2015)). This resulted in substantial opposition from some members of the ECB Governing Council (Reuters (2014)). Absent the threat of deflation, it is not clear that central banks will be willing to continue to hold large amount of assets.

[22] It is assumed that these operations take the same form as the ones conducted between May 2010 and June 2014. The absorption operations were limited in size because they aimed specifically at absorbing the liquidity injected through assets purchases made under the securities markets program (SMP). In the scheme proposed here, the size of the operations could be unlimited.

[23] Core banks have incentives to participate to sterilization operations as shown in appendix VI.

For low values of F, absorption operations (S) increases the amount borrowed at the refinancing operations and aggregate liquidity does not change (banks compensate).[24] Past a certain threshold, core banks borrow zero anyway, so locally, no compensation can occur and absorption operations are successful in decreasing the amount of liquidity and increasing interbank rates. This threshold is defined below. Using equation (44):

$$F > K^C - O^C + C^C + \underline{S} \Leftrightarrow r_S = r_B < r_M$$

Since lending to another core bank or subscribing to the central bank absorption operations are two risk-less options for core banks, at equilibrium they will have the same remuneration. Appendix VIII shows that this was indeed the case when the Eurosystem was conducting liquidity absorbing operations. Between 2010 and 2014, the rate on sterilization certificates was moving closely with the interbank rate (much more closely than standing facility rates or the main rate). This stresses the importance of sterilization operations in steering the interbank rate when there is excess liquidity due to fragmentation.

Core banks that do not borrow from the central bank, will be able to park their liquidity at a rate strictly below the main policy rate. This is not the case of peripheral banks for whom it would not be profitable since they finance themselves by borrowing from the central bank at the main rate.[25] Therefore, money demand from peripheral bank is unchanged compared to when there is no sterilization. Absorption operations work similarly to assets purchases. A key difference though, is that in the case of absorption operations, banks self-select: only core banks participate.

At last, the central bank could lend directly securities to peripheral banks *via* standard securities lending agreements. Instead of lending liquidity to peripheral banks, the central bank can lend securities from its own portfolio, *e.g.* ESM bonds. It would not be a repo where

[24] Alternatively, one could assume that when excess liquidity is zero banks do not participate to the sterilization operations. The results would be the same: when there is no excess liquidity increasing the size of the sterilization operation is neutral.

[25] The fact that only core banks participate to sterilization operations is confirmed by looking at the balance sheets of the main central banks of the Euro-Area. One can see that at the end of 2011, banks located in Germany, France, Netherlands, Belgium, Austria, Finland and Luxembourg accounted for 97% of all sterilization operations, against 2% for banks located in Spain, Italy, Greece, Ireland, Portugal and Cyprus. At the end of 2012 the picture is even more clear: 100% against 0% (see the financial statement in the annual reports 2011 and 2012 of these central banks). These two groups of countries are made according to a simple criteria: those who benefited from external support (International Monetary Fund, European Financial Stability Facility or European Stability Mechanism programs) since 2008 and the others. This allows to isolate countries that had a sovereign and/or a banking crisis and thus were likely cut-off from the Euro-Area interbank market (the peripheral countries).

the central bank lends a security against funds, but lending a security against potentially a less liquid collateral. By doing so the central bank would provide peripheral banks with a suitable collateral to borrow on the (secured) interbank market. If one thinks that peripheral banks cannot borrow on the secured interbank market because the securities they have are too risky or too correlated with their own risk of default (*e.g.* domestic sovereign bonds), lending them safe collateral could be a solution. This would address the breakdown of the interbank market. This would allow peripheral banks to roll over their loans, avoid any large repayment flows and therefore any kind of excess liquidity and or any undue fluctuations of the interbank rate.

4 Testing the predictions of the model

The model replicates the main stylized facts of monetary policy in the Euro-Area: the endogenous increase in liquidity since the crisis and the simultaneous decline of the interbank rate (without the central bank intending to increase the supply of liquidity). This section intends to shows that the main predictions of the model are fulfilled. Its findings are consistent with the empirical litterature on fragmentation such as Garcia de Andoain *et al.* (2015). The main predictions of the model are:

Prediction 1: There is a stable relationship between excess liquidity (total liquidity minus reserve requirements) and the interbank rate (equations (10) *and* (44)*).*

Prediction 2: Since the crisis, peripheral banks borrow more from the central bank than they keep as reserves. It is the opposite for core banks (equations (45) *and* (43)*).*

Prediction 3: The capital flight increases excess liquidity and consequently decreases interbank rates (equations (46) *and* (44)*).*

Prediction 4: Absorption operations, in the context of fragmentation, can contribute to reduce excess liquidity and increase interbank rates, even with fixed-rate full allotment (equation (48)*).*

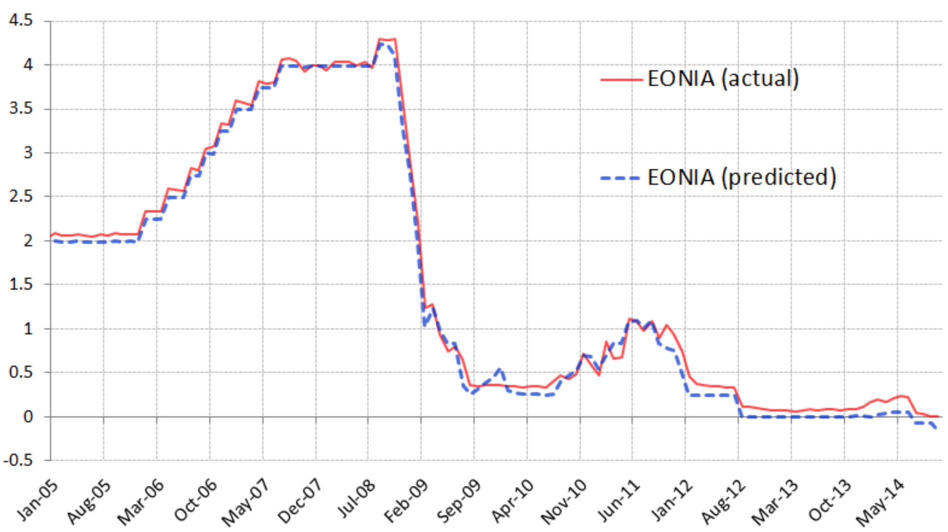
4.1 Prediction 1: the relationship between excess liquidity and the interbank rate

This subsection shows that the simple model developed above is able to capture the relationship between the level of the interbank rate and the amount of liquidity in the banking system.

Note that surprisingly, according to the theoretical model, this relationship should not have changed with the crisis. Looking at equations (10) and (44), which are equilibrium conditions taking into account the maximization process of banks with and without fragmentation, one can see that the interbank rate is a simple function of excess liquidity. Indeed, in the two cases, the interbank rate is equal to the deposit facility rate, plus the corridor times a normal cumulative distribution function that takes as input the level of excess liquidity. Excess liquidity is defined as total bank reserves minus minimum reserve requirements.

The theoretical model predicts that before the crisis, the interbank rate should respond to excess liquidity in the whole monetary union while after the crisis it should respond to excess liquidity in the core (since only core banks transact on the interbank market). However, the model also predicts that in case of fragmentation, excess liquidity should be zero in the periphery and should be positive in the core. Therefore, total excess liquidity is equal to excess liquidity in the core.[26]

Figure 3: Predicted EONIA *vs* actual (Maintenance period average, percentage points)



Source: ECB and author's calculations.

Data on standing facility rates and excess liquidity come from the ECB statistical data

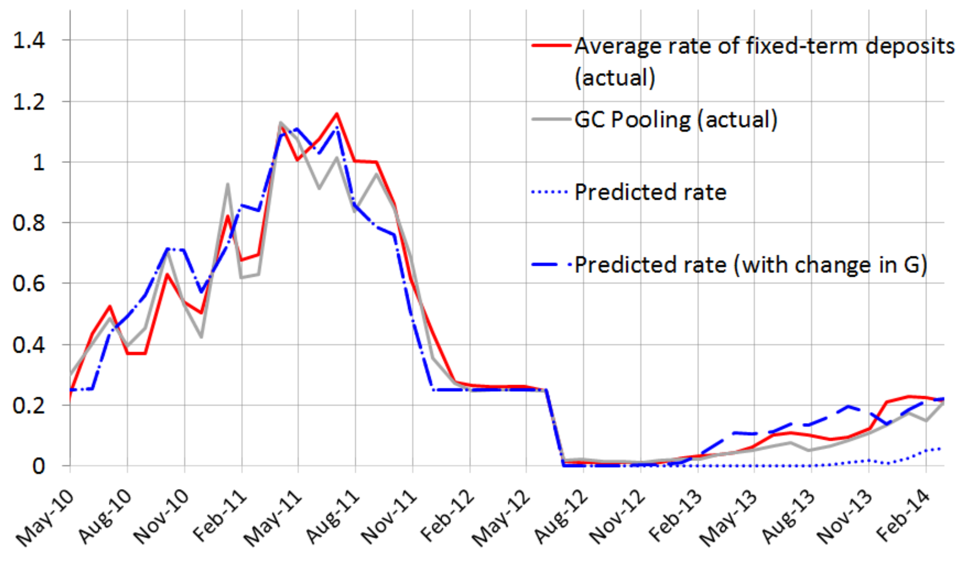
[26]It is shown empirically in section 4.2 that total excess liquidity can indeed be well approximated by excess liquidity in the core.

warehouse. G(.) is the cumulative distribution function of a normal distribution with mean 0. The standard deviation of this distribution, is constant throughout the whole period at EUR 86 bn. It is chosen such that the interbank rate is at the middle point of the corridor before the crisis.

At first, the EONIA is used as the interbank rate. EONIA observations are averaged over the maintenance period, which is the horizon over which banks have to meet their minimum reserve requirements.

The model seems indeed to capture well the relationship between liquidity and the interbank rate. The mean square error is 1.2 basis point. The EONIA deviates more from its predicted value after October 2008 (start of the crisis) compared to before (the mean square error is 1.7 basis point *vs* 0.5 basis point), suggesting that the relationship could have been impacted marginally. This prediction delivers a much better result than a naive guess, that assumes the EONIA equates the main rate (mean square error of 19 basis points over the whole period and 34 basis points after the crisis). After the crisis, the EONIA is more often above its predicted value, which suggests that either banks that have access to the market incur a risk premium or that some banks are keeping some precautionary liquidity buffer that they are not ready to trade. It is also likely that during the crisis the function $G(.)$ has changed and that its variance has increased.

Figure 4: Predicted money market rate *vs* actual (Maintenance period average, percentage points)



Source: ECB and author's calculations.

In order to avoid these issues, other money market rates can be used. Notably, one can use short term money market rates with lower risk-premia compared to the EONIA.[27] Two such rates can be used. The first one is the overnight "Stoxx GC Pooling", the ECB official benchmark for Euro-secured deposits.[28] It is calculated by a private institution from cash transactions processed via Central Counterparties (CCP). The second one, is the rate on Eurosystem one-week, fixed term deposits.[29] These deposits were collected by the Eurosystem on a limited basis according to a variable rate tender. Contrary to the EONIA, lenders on these two markets face virtually no counterparty risk. Unfortunately, these two rates were calculated only from 2010, which limits the number of observations.

Figure 4 shows that the model can replicate even better the dynamic of these rates over the period May 2010 and June 2014, which is the period over which the Eurosystem offered fixed term deposits. The mean square error between the predicted rate and the GC Pooling rate is 1.1 basis point. It stands at 1.2 basis point between the average rate of fixed term deposits and the predicted rate. If one allows for a one-off increase in the variance of G after August 2012 (say because deposits might have been more volatile amid extreme financial market turmoils), the predicted rate is able to replicate the creeping up of actual money market rates. The mean square error is then below one basis point.

This exercise shows that the simple model developed above is able to explain the dynamics of the interbank rate, using data on excess liquidity. It supports the idea according to which the relationship between the two has not really changed with the crisis, contrary to what models of liquidity hoarding predict. [30]

It also shows that in order to fully understand the dynamic of the interbank rate, one needs to understand the dynamics of excess liquidity. This is what next subsections do.

[27]Recall that in the model, at equilibrium, the interbank rate is risk-free.

[28]"Stoxx" is the name of the data provider for this index."GC" stands for "General Collateral" and means that ECB eligible collateral can be used to secure the transaction. "Pooling" is a method to manage the collateral and implies that the borrower can use a pool of securities to secure its borrowings, as opposed to a specific or earmarked security.

[29]These deposits have a slightly longer maturity than the EONIA. However, the contracts were such that no policy rate change could occur between the inception and the maturity. Hence, there should be limited term premia.

[30]Models such as Heider *et al.* (2015) or Hauck and Neyer (2010) predict a radical change in the relationship. Bech and Monnet (2015) does not imply a change in the relationship but as discussed above it could not replicate market rates differing from the central bank main rate. On the other hand, fragmentation is the only explanation able to account for an increase in liquidity, independent of the central bank's action, with the interbank rate falling as a result.

4.2 Prediction 2: the repartition of liquidity within the Euro-Area

Prediction 2 states that liquidity should be distributed in an heterogeneous manner in the Euro-Area, following the inability of the interbank market to redistribute liquidity.

4.2.1 National central banks' balance sheet

The Eurosystem operates in a decentralized manner. Commercial banks have their account and borrow from their home central bank (*i.e.* Deutsche Bank in Germany with the Bundesbank and Unicredit in Italy with the Banca d'Italia). Therefore, one can look at the Balance sheet of national central banks to verify prediction 2. This is exactly what Figures 5, 6, 7 and 8 do with the balance sheet of the central banks of Germany, Netherlands, Spain and Italy. These are the large Euro-Area countries which have an impact on aggregate Euro-Area liquidity.[31]

These data are provided by each central bank on a monthly frequency, following slightly different reporting conventions. It enables to understand separately the amount of funds borrowed and the amount of reserves kept.

Figure 5: Evolution of the Banca d'Italia's Balance sheet (EUR bn)

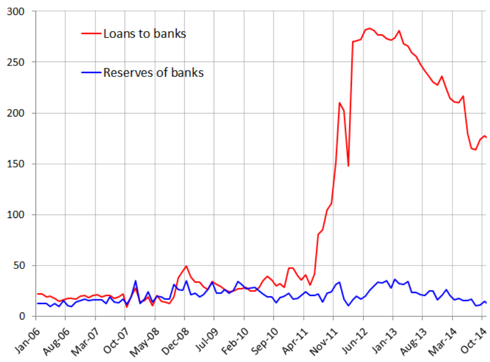
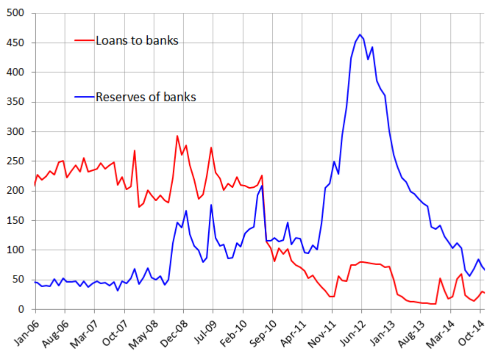


Figure 6: Evolution of the Bundesbank's Balance sheet (EUR bn)



Note: "Loans to banks" includes lending made under the main refinancing and the Longer term refinancing operations. "Reserves" includes the current account of banks, the deposit facility and fixed term deposits. This precise breakdown is only available for Italy and Germany.

Source: National central banks' balance sheet

One can see that countries in which the sovereign debt market underwent severe strains (Spain and Italy), were also the countries where banks borrowed most. Hence, Figures 5 and 7 show that banks located in Spain and Italy borrowed heavily from the Eurosystem. They kept only a small share of this liquidity. Looking at the amount of liquidity they were keeping pre-crisis, it is likely that the liquidity kept during the crisis corresponds to minimum reserve

[31] France is voluntarily excluded from this exercise as its sovereign debt market did not experience major strains. It did not had large current account surpluses before the crisis either.

Figure 7: Evolution of the Banco de Espana Balance sheet(EUR bn)

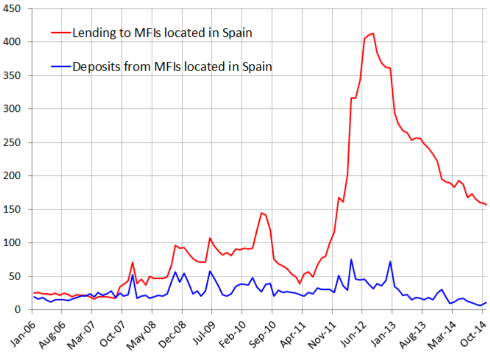
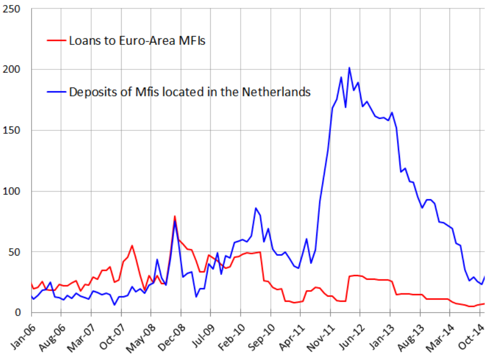


Figure 8: Evolution of the Dutch National bank's Balance sheet (EUR bn)



Note: "MFIs" stands for Monetary Financial institutions and are basically banks and central banks. "Loans to Euro-Area MFIs" excludes claims on other central banks related to TARGET2.

Source: National central banks' balance sheet

requirements, as predicted by the model. Another sign that excess reserves were limited is the quasi absence of fixed-term deposits in Spain and Italy.[32] These deposits which were offered by the Eurosystem from May 2010 to June 2014 had a higher return than the deposit facility. For banks which had structurally a large amount of excess reserves, it made perfect sense to use these fixed-term deposits. Indeed, countries in the Netherlands and Germany made an extensive use of these instruments.

On the other hand, banks located in Germany and the Netherlands have large reserve holdings and almost no central banks' borrowings. Still there are (modest) amount of borrowings in these countries. This can be due to several factors. Banks could have opportunistically borrowed from the 3-year longer-term refinancing operations (LTRO) at the end of 2011. This seems indeed to be the case (on a relatively limited basis) as suggested by the slight increase of borrowings at that date and the decrease at the beginning of 2013, when anticipated repayments of 3-year LTROs became possible (ECB (2011)). Also, some peripheral banking groups could be using their affiliates in core countries to borrow from the central bank, in order to fund their activities in core countries. From a collateral management perspective, it would be more efficient than to borrow from the head office.

These figures show that the explanation according to which banks borrow from the central bank in order to hoard the funds on their own central bank account is not consistent with empirical evidence. Indeed, overall, the banks borrowing from the Eurosystem and the bank deposit-

[32]Spain and Netherlands do not report the amount of fixed term deposits separately, at a monthly frequency. The absence of fixed term deposits in Spain and its presence in the Netherlands can however be observed at the yearly frequency (see footnote 22)

ing at the Eurosystem are not in the same countries. Instead, the thesis advocated in this paper according to which one category of banks borrows and another deposits funds, seems much more consistent with the data. Moreover, the underlying motivation from this phenomenon: the exclusion of peripheral banks from the interbank market seems indeed to be at work. One can see that banks in Spain and Italy finance themselves massively *via* the central bank at a rate strictly higher than the interbank rate. It means that they do not have unlimited access to the interbank market.

4.2.2 TARGET2 imbalances

An alternative way to understand this phenomenon is to look at the "TARGET2 imbalances".

Banks can make payments across the monetary union, transferring Euros on different accounts held at central banks. Transfers between accounts held at two different central banks goes through the Euro-Area payment system, named TARGET2.[33] Transactions on TARGET2 are made via central banks. In the (likely) case where the banks of country A send more money to other countries via the TARGET2 payment system than they receive, a "TARGET2 liability" appears on the balance sheet of the central bank of country A. The country receiving more money than what it is sending, gets a "TARGET2 asset". At first sight, TARGET2 imbalances (measured as the sum of all TARGET2 assets that by identity has to be equal to the sum of all TARGET2 liabilities) just keep track of imbalances in the payment system (ECB (2013c)).

TARGET2 imbalances can also be interpreted in an economic way. In a well integrated monetary union, current account imbalances can build up. Deficit countries buy goods and services to surplus countries thanks to loans granted by surplus countries. Such loans can take the form of interbank market loans or the purchase by surplus countries banks of securities in deficit countries. Therefore, money is sent by deficit countries to surplus countries in exchange of goods. Money goes back from surplus countries to deficit countries in exchange of a liability of the deficit country, clearing the balance of payments.

If a well integrated monetary union becomes suddenly fragmented, deficit countries will not be able to roll-over their loans from core banks. It means that once the loans arrive at maturity, peripheral banks have to pay them off. Such repayments will result in one-way payment flows, *i.e.* TARGET2 imbalances.

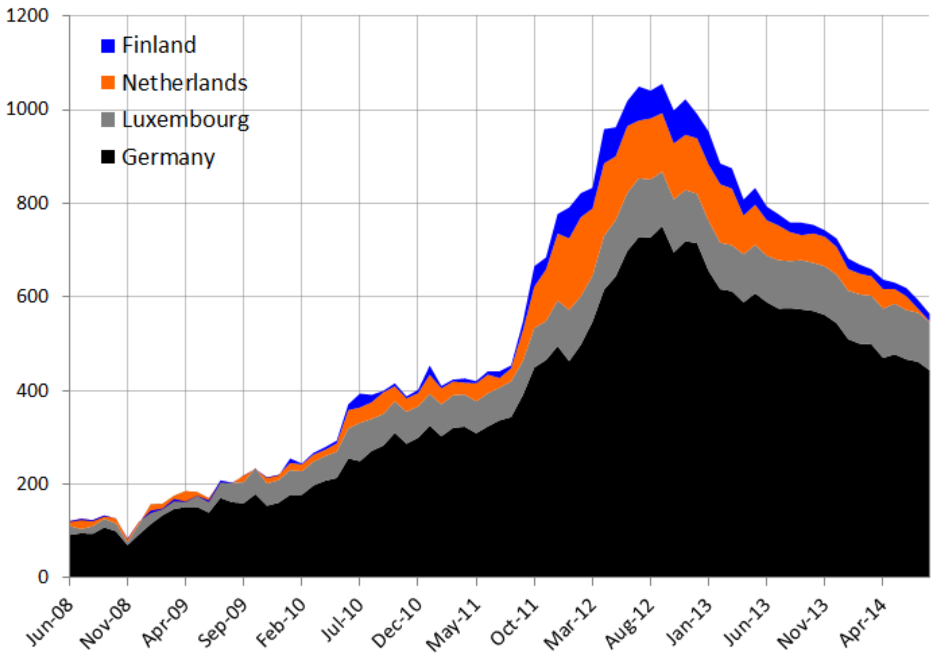
[33] "TARGET2" stands for the second version of the Trans-European Automated Real-time Gross settlement Express Transfer system.

The only way for the loans to be paid-off in the absence of other source of financing would be for deficit countries to manage a current account surplus (by macroeconomic identity). As this is not possible overnight, the banks will need to obtain the liquidity to repay core banks in some other way.

Therefore, banks in deficit countries finance these flows by borrowing more from their central bank. On the contrary, surplus countries banks will accumulate more reserves on their accounts at central banks as repayments flow in. Countries subject to a capital flight, as described above will have their central bank incur a TARGET2 liability. Countries recipients of funds, a TARGET2 asset. TARGET2 assets and liabilities are part of the international investment position of a country. Their variations clear the balance of payments when private flows are not sufficient.

TARGET2 imbalances (as measured by the sum of all TARGET2 assets) are a direct measure of the capital flight, which is itself the cause of the uneven recourse to central banks borrowings in different countries. Therefore, TARGET2 imbalances can be used as a proxy for F.[34]

Figure 9: Evolution of TARGET2 claims during the crisis (EUR bn)



Source: ECB statistical data warehouse.

Figure 9 shows the breakdown of TARGET2 claims during the crisis.[35] They indeed in-

[34]There are some technical differences in practice between TARGET2 and F, as discussed in appendix VII.

[35]TARGET2 liabilities of course follow the mirror pattern. TARGET2 claims are used because they involve much less countries than TARGET2 liabilities and are therefore easier to visualize and calculate.

creased substantially since 2008 (as noted by Auer (2014) for instance). Also, the net recipients of capital (the core countries) are indeed countries perceived as extremely safe and with positive international investment positions. Note that the decrease of TARGET2 imbalances since 2012 is not necessarily a sign of a better integration. It can very well be that deficit countries (peripheral countries) are still cut from the interbank market but run current account surpluses since the crisis. Such current account surpluses, *ceteris paribus*, would generate outflows of funds out of the core into the periphery (F goes down).

It is not easy to compare the size of the TARGET2 imbalances to the liquidity needs of core banks, as done in the model. The reason it that the liquidity needs are not available on a country-per-country basis. In particular minimum reserve requirements are only available on aggregate. What is certain is that TARGET2 imbalances have been larger than the aggregate liquidity needs of the whole Euro-Area (which have varied from EUR 400 bn to EUR 600 bn) from September 2011 to September 2014. A less conservative estimate of core liquidity needs (for instance half of total liquidity needs) would suggest that TARGET2 have been higher than the critical threshold since April 2010, the start of the Greek crisis.

4.3 Predictions 3 and 4: the effect of fragmentation and absorption operations on liquidity

The theoretical part of the model states that as F increases, liquidity should increase. The corresponding policy implication, is that absorption operations, in the context of fragmentation, can be effective in reducing liquidity even if banks can borrow as much as they wish from the central bank. These two assertions are tested now.

4.3.1 Methodology

In order to test predictions 3 and 4, equation (46) is used. Assuming that F is above the critical threshold and taking into account sterilization operations yields:

$$R^{\star} = F + O^{C} - C^{C} + K^{P} - S \tag{48}$$

This condition states that the level of aggregate reserves banks have on their accounts at the central bank depends on the level of the capital flight F, outright purchases made by the central bank in the core, the amount of currency in circulation in the core, minimum reserve requirements in the periphery and the size of sterilization operations. This relationship is an equilibrium condition taken from the model. Recall that without fragmentation, at equilibrium, aggregate reserves R should just be equal to minimum reserve requirements (as in equation (14)) and in this case most right-hand side variables should have no effect on reserves.

The general econometric specification reads as follow:

$$R_t = \alpha + \beta_1 F_t + \beta_2 O_t + \beta_3 C_t + \beta_4 K_t + \beta_5 S_t + \epsilon_t$$

Subscripts t indicate the timing of the variables with respect to each other. The first differences of level variables are used in order to avoid unit roots. The equations are estimated using OLS.

The left-hand side variable, R is the total reserves of banks at the central bank. It is the sum of all Euros that can be used for overnight interbank loans, that are held on accounts of commercial banks at Eurosystem central banks measured after the payment system is closed. It directly depends on how much banks on aggregate borrow from the central bank. The following variables should explain this amount.

As explained above, TARGET2 imbalances (as measured by the sum of all TARGET2 assets) are used as a proxy for F. Recall that TARGET2 imbalances measure the capital flight from the periphery to the core. The capital flight depends on the perceived risk from investors of leaving their money in the periphery and of how much money they left in the periphery in the first place, *i.e.* the net liability position of peripheral countries toward core countries. The net liability position of peripheral countries is by large predetermined at the time the crisis hit. The extent of the flight of this pre-determined invested money depends on fragmentation. Fragmentation itself depends on perceived credit risk on peripheral countries.

Perceived credit risk, independently of TARGET2 is controlled for, using the spread of Spanish and Italian 2-year government bonds *vs* Germany (the unweighted average of the two is used).[36] This intends to check that TARGET2 captures only the capital flight from periphery to the core and not some liquidity hoarding motive resulting from investor's fear of financial markets breakdown. This variable is called "Spreads". For both F_t and "Spreads" a positive sign is expected. The coefficient of F_t should be close to one.

The size of sterilization operations, S_t, is set by the central bank. If the theoretical model is correct, its coefficient will be negative (and close to minus one). If the mechanism described

[36]Using for instance the spread on 10-year government bonds yields similar results.

above is not at work, the coefficient will be zero (*i.e.* liquidity absorbed by the central bank pushes banks to borrow more, resulting in a zero net effect). The total amount sterilized responds to purchases by the central bank (which is controlled for) under the "Securities Markets Programme" (ECB (2010)). As explained in the theoretical part, when excess liquidity is large (which is almost always the case during the period considered) and once the amount purchased by the central bank is controlled for, this variable should be exogenous.

Assets purchases, O_t, if the theory is correct should increase the amount of reserves. If the theory is wrong, it should have no effect (increased purchases injects liquidity pushing banks to borrow less from the central bank resulting in a zero net effect). "O" includes mostly assets purchased under the "Securities Markets Programme" (SMP) and the "Covered Purchases Programmes" (CBPPs).[37] These purchase programmes responded to tensions in financial markets, which is controlled for.

Notably, the 3-month EURIBOR-OIS spread is used to control for financial markets turmoil and to capture possible liquidity hoarding motives. "EURIBOR-OIS" measures the premium that banks charge to each other for a 3-month loans compared to an overnight loan. It should increase as bank loose confidence and as they hoard liquidity (Acharya and Skeie (2011)). Its coefficient should be positive.

The level of reserve requirements, K_t are changed by the Eurosystem once a month for large banks and quarterly for small ones. They are calculated as one percent of the "reserve base" with a 3-month lag.[38] The reserve base represents banks' short term liabilities as of 3 months before. Required reserves are remunerated by the central bank such that it is not profitable to change its reserve base (ECB (2013a)). Overall, K is very stable, there is no incentive for banks to change it depending on the situation. The reserve base is changed with delay and the reserve ratio has been changed only once. Therefore, it can be considered as exogenous. Its coefficient should be positive.

According to the model currency in circulation in the core C_t when going up, should relieve core banks from some excess liquidity and therefore lower aggregate liquidity (negative coefficient). If on the other hand there is no fragmentation, increase in demand for currency is matched by higher recourse to central bank operations. Then the coefficient should be zero. Currency in circulation is seen by central banks as an "autonomous factors", *i.e.* something outside of its control. It is highly dependent on exogenous factors such as holidays and tax

[37]The asset-backed securities purchases programme (ABSPP), started after the period covered by the data.

[38]It was two percents before February 2012.

collection calendar (Gonzalez-Paramo (2007)). Therefore, it can be considered exogenous in the present context. Its coefficient should be negative.

Banks tend to hoard liquidity at the end of the year in order to embellish end-of-year statement to appear cash-rich (see Allen and Saunders (1992) or Bindseil *et al.* (2003)). In order to capture this, "End-of-year" is a dummy variable, equal to one when the maintenance period goes over year-end and 0 otherwise.

Right-hand side variables can be considered exogenous.

Controls are in place and there is no reason to think about reverse causality, except potentially for TARGET2 imbalances.

However, the present paper argues that TARGET2 imbalances arise purely from the capital flight, itself triggered by factors that affect the left-hand side variable through TARGET2 imbalances and other controls. This paper strongly defends the view that TARGET2 imbalances are a sign of the capital flight and trigger the use of central bank operations and not the opposite, *i.e.* TARGET2 imbalances are exogenous in the regressions.

However, if one were to reject this view, and interpret the results of regressions as correlations, it would still be instructive on the validity of theoretical mechanism. The reason is that in a model without fragmentation, TARGET2 imbalances and liquidity should not be correlated (contrary to a case with fragmentation where they should be positively related).

The fact that time series are being used does not change the reasoning. As explained previously, there is no reason to think that right-hand side variables are forward looking. If the capital flight or say the amount currency demanded by the public are expected to increase, banks still have no incentive in increasing or decreasing their liquidity positions ahead these events. Keeping liquidity idle has a cost (the cost of funding of the bank minus the deposit facility rate). Therefore, banks should change their demand for liquidity contemporaneously to change in right-hand side variables.

4.3.2 Data

R, O, S, C, K and TARGET2 imbalances are taken from the ECB statistical data warehouse.

The six first variables involve Eurosystem's passive or active participation. Therefore, they are unlikely to be subject to any kind of measurement errors.

An empirical challenge is that except for TARGET2 these variables are not available on a country per country basis. Theoretically, this does not matter for S or for R as the variations of these series should come from the core exclusively.[39] For O, C and K, this is more problematic because only the share of these variables that applies to core countries should explain the left-hand side variable. If the movements of these variables is positively correlated between core and peripheral countries (*e.g.* demand for currency goes up in the core and the periphery at the same time), this would just results in the coefficients to be driven toward zero, but they should still be significant. If these variables are not correlated, this could result in the coefficients to be insignificant. There is *a priori* no reason to believe these variables to be negatively correlated across the monetary union.

Except from currency in circulation, other items also affect the aggregate liquidity position of the banking system without being directly related to bank's borrowings. These items are called "autonomous factors". Autonomous factors are classified in four categories: Currency in circulation, Net foreign assets of the central bank, government deposits and other autonomous factors (ECB (2002)). For consistency, one may wish to include them all together. However, only currency in circulation and Net foreign assets are included in the regressions (as "C"). Government deposits at the central bank and other autonomous factors are not included because they are likely to affect peripheral countries relatively more than core countries. Indeed, looking at the balance sheet of central banks, it seems that by far the largest and most volatile government deposits are in Italy. Other autonomous factors include notably the Emergency Liquidity Assistance (ELA), which should arguably be granted to distressed banks exclusively.

Sovereign spreads and EURIBOR-OIS are computed using daily end-of-day data from Bloomberg. "Spreads" is the arithmetic unweighted average of Italian and Spanish 2-year generic government bond yield spreads *vs* their German counterpart. Other peripheral government bonds could have been included but this would have been detrimental to the quality of the data as other peripheral countries do not have generic 2-year government bond outstanding from 2008 to 2014.

All these variables are averaged over the maintenance period (roughly a month) using end-of-day values, except for TARGET2 for which only end-of-month data are available.

4.3.3 Results

The Augmented Dickey Fuller test confirms that first differentiated variables have no unit root. It is preferable to run the regressions from October 2008, as central bank liquidity was restricted

[39]This is also empirically verified as shown in section 4.2.

Table 1: Dependent variable: banks' reserves

capital flight (F)	0.69***	0.69***	0.72***	0.77***
	(0.19)	(0.19)	(0.18)	(0.19)
Currency (C)	−0.31	−0.40	−0.17	−0.12
	(0.25)	(0.24)	(0.25)	(0.26)
Sterilization (S)	−1.18***	−1.08***	−0.88**	−0.89**
	(0.41)	(0.40)	(0.39)	(0.39)
Outright purchases (O)	0.88	0.69	0.32	0.37
	(0.65)	(0.63)	(0.62)	(0.62)
Required reserves (K)	0.32	0.30	0.10	0.21
	(0.48)	(0.46)	(0.45)	(0.47)
End-of-year dummy		54,649***	59,910***	56,131***
		(20,326)	(19,660)	(20,182)
EURIBOR-OIS			111,560**	122,806**
			(44,759)	(46,711)
Spreads				−12,472
				(14,474)
R^2	0.28	0.35	0.41	0.42
Adjusted R^2	0.22	0.29	0.34	0.34

Standard deviations in parenthesis
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

before 2008. The sample stops in September 2014.[40] There are 71 observations.

As one can see from table 1 all significant coefficients have the expected sign and expected magnitude. Durbin-Watson and endogeneity tests are conclusive. Capital flight (F) always has the expected sign significant and close to one in absolute value. Sterilization operations (S) are always significant. It is always correctly signed and close to minus one (as theory predicts). Values are stable across regressions.

Currency in circulation in the core (C) and minimum reserve requirements (K), have the expected signs but are not significant. This comes probably from the imperfect proxies used (total value instead of country-per-country).

As expected, there is a significant and large End-of-year effect.

Also, there is a role in the sample for liquidity hoarding or precautionary demand of liquidity to the central bank, as the 3-month EURIBOR-OIS spread is strongly significant and large.

[40] At this date the Eurosystem started Targeted Longer Term Refinancing Operations. These operations contrary to standard longer term refinancing operations had a rate different from the main refinancing operation rate. Participation to these operations have an important expectation component and are harder to account for.

"Spreads" is not significant showing that it is not the stress on financial markets that drives the results, but rather that fragmentation, proxied by TARGET2, is key to understand liquidity in the Euro-Area. In the theoretical model, sovereign risk itself should have no direct effect. It should have an effect only via the capital flight.

Some more robustness checks are conducted. In December 2011 and Mars 2012, the Eurosystem offered two three-year longer term refinancing operations. These operations can be considered as different from other standard operations because of their exceptionally long maturity. Additional considerations could have pushed banks to borrow from these specific operations. Banks were allowed to repay these operations after approximately a year (January 2013 and February 2013 respectively) if they did not wish to keep the funds for three years. Hence, the same regressions as in Table 1 are run, on a period excluding the period from December 2011 to March 2013. There are then 56 observations left. The results of the regressions (not shown in details) are similar from before: TARGET2 and fixed-term deposits are significant. All significant variables are correctly signed. The R-square increase up to 0.54 and adjusted R-square up to 0.46. The beginning of the sample, up to the crisis in April 2010 is then also excluded. They are then only 39 observations left. Still, TARGET2 and fixed term deposits are always significant. All significant variables are correctly signed and the R-square increases up to 0.62 and the adjusted R-square up to 0.51.

These results are all extremely supportive of the theoretical model laid out above.

5 Conclusion

This paper has shown theoretically and empirically how fragmentation causes interest rates and the money supply to fluctuate out of the central bank control. This has allowed to derive some policy implications.

When the credit risk of peripheral banks is elevated, the central bank by providing large amount of liquidity at favorable conditions prevents financing costs to diverge substantially between countries. By doing so, it also discourages interbank market activity and increases the reliance of banks on the central bank. In this sense, it faces a trade-off between preventing financial conditions to diverge across the monetary union and lending to banks.

Assets purchases can help to steer the interbank rate toward the deposit facility rate. For this, the central bank needs to purchase a large amount of assets (larger than the liquidity needs of the banking system), which might not always be possible.

Surprisingly, using absorption operations can be an effective way to reduce excess liquidity and stabilize the interbank rate, even in a context of ample liquidity provision.

At last, in order to avoid fragmentation and restore interbank market functioning, the central bank can lend securities to banks, for them to borrow on the secured interbank market.

Given the very nature of the Euro-Area, fragmentation is probably a long term phenomenon. In the future, some sovereigns will probably be perceived more risky than others and some countries will be perceived as being able to leave the Euro-Area. Thus, it is likely that some banks will be cut from the interbank market and that the mechanism described in the paper will apply.

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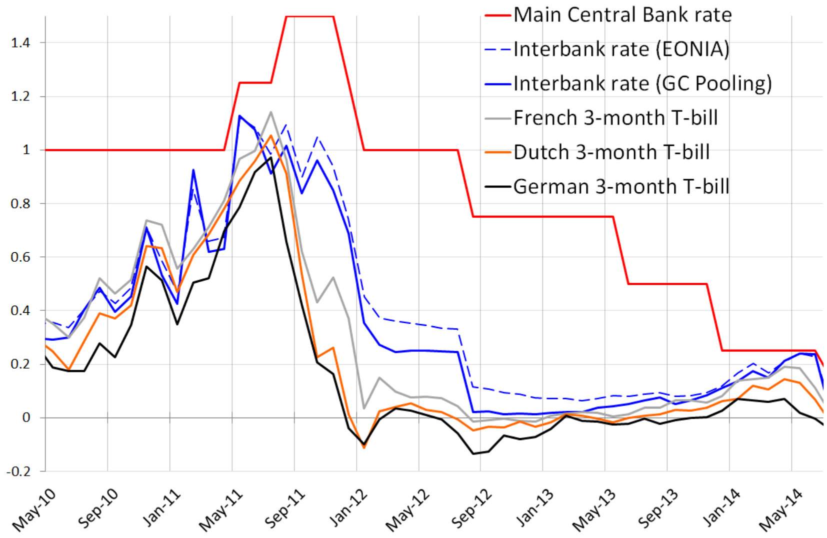
6 Appendix

Appendix I: The overnight interbank rate movements and 3-month Overnight Interest rate Swap (OIS)

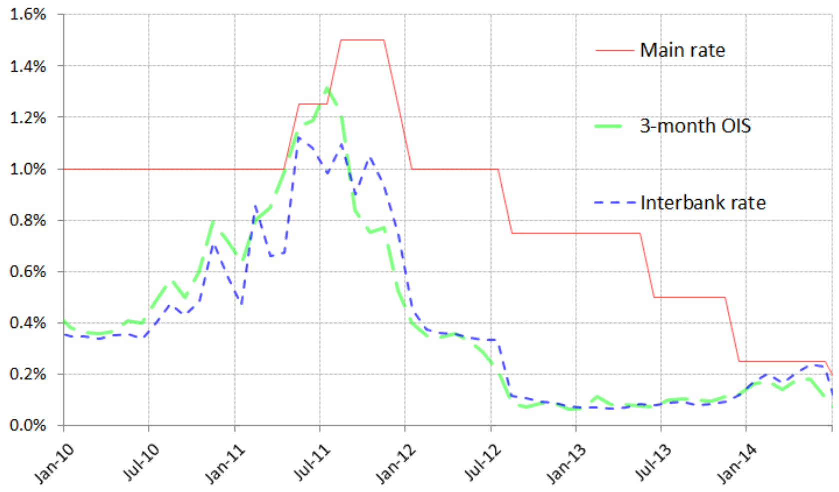
The fluctuations of the unsecured overnight interbank rate, the EONIA spread to other crucial interest rates such as sovereign Treasury bills (Figure 10). "T-bill" are benchmark short term instruments with little if no credit risk, and are in turn used to price bonds of longer maturities and of riskier issuers. The Overnight Interest rate Swaps (OIS), a critical instrument to price longer term loans was also affected (Figure 11).

Figure 10: Evolution of Money market rates and of the central bank rate between 2010 and 2014 (percentage points)



Source: ECB & Bloomberg

Figure 11: The interbank rate movements and the yield curve



Source: ECB, Bloomberg and author's calculations.

Appendix II: Adding loans to the real Economy

The goal of this appendix is to show that the problem studied in this paper is independent of the provision of loans to the real economy made by banks.[41]

The assets of bank "i", are the reserves held at the central bank "R^i" and the amount of loans granted to non-bank agents, including holdings of securities issued by non-bank agents "L^i".

Liabilities of bank "i" are the net interbank borrowings B^i, borrowings from the central bank "M^i" and the liability of bank "i" to the public (including its equity) "d^i".

"net deposits", D^i can be defined as $D^i = d^i - L^i$. This item is of interest because it appears in the profit function of banks. It represents the liquidity surplus (*resp.* shortage) of a bank toward, non-bank agents.

Recall that the assets of the central bank are the assets purchased outright ("O"), and the amount of loans provided to banks ("M"). The liabilities are the amount of reserves ("R") and the currency in circulation ("C"). Using the fact that all assets must equal liabilities means that:

$$L + R + M + O = d + M + R + C \tag{49}$$

It implies that:

$$O - C = D \tag{50}$$

[41]This appendix consider the implication of loans in terms of liquidity. However, it is likely that the ability of banks to expand loans is anyway limited in the short run by capital regulations.

This shows that D, which represent the net amount of deposits from the non-banking sector "net"of the loans made, is fixed and determined by the central bank as it can adjust the amount of outright purchases if it sees an increase in currency (which is completely determined by the demand of the public). The gross amounts of loans and deposits is not addressed in the model but it should have no impact on the liquidity position of the banking sector or on any item of interest in this model.

It can seem surprising that deposits are fixed. When a bank grants a loan, it credits the funds on the account of the borrower, which are usually held at the same bank. Therefore, a bank granting a loan usually gains the required deposits at the same time (no change in "D^i"). If the funds are spent by the borrower and assuming the recipients of the funds have not an account with the bank originally granting the loan, the banks will see its net deposits go down (lower D^i). If the funds are withdrawn from the bank in exchange for currency, the central bank will need to provide the banking sector with more funds (increase in M^i and C^i). If they are not exchanged for currency, it means that another bank "j" will experience an inflow of funds (and thus an increase in "D^j" and R^j above required reserves). Hence, the aggregate amount of deposits does not change if the amount of currency does not change.

To the extent that the interbank market functions well, the bank that has suffered from an outflow will be able to recover this liquidity via the interbank market, given that at least another bank has a liquidity surplus.

In a symmetric equilibrium this would never happen and either borrowers deposits all the funds at the bank from which they borrow or they exchange it for currency.

What can have an effect on the equilibrium is asymmetry. This happens when $D^i \neq D^j$. In the case of a symmetric equilibrium, it had to be the case that all variables for a given banks were all equal to the average (since there is a mass one of banks, the average is equal to the sum): $D^i = D$, $M^i = M$ and $B^i = B = 0$. However, it would be reasonable to assume that banks differ in the size if their net deposit base. It is still the case that, $K^i - D^i = M^i + B^i$. One can assume that the central bank allocates an equal amount of loans to each bank. Then $K^i - D^i = M + B^i$. Idiosyncratic changes (expected or unexpected) in D^i can occur, if the interbank market remains competitive, this should not change anything to the interbank rate or liquidity that are the two main object of interest of this paper.[42] This would just be a reallocation. For instance,

[42]Several papers address the case where large lenders/borrowers of funds have market power in the interbank market, for instance Bech and Klee (2011) or Afonso and Lagos (2015). Such frictions would not change the results of the present paper.

a bank that is structurally taking more deposits than its peers ($D^i > D$) would be a structural lender on the interbank market ($B^i < B$). If it remunerates these deposits at the same rate as interbank loans, this should not be a first order change to profits either and would therefore not enter into the maximization problem of a risk-neutral bank.

The fact that the deposit bases are not symmetric really matters when the interbank market is unable to relocate efficiently liquidity. This case is already addressed in the paper when the banking sector is fragmented.

Bianchi and Bigio (2014) assume that granting a loan (and taking the resulting deposit) increases liquidity risk (the probability of losing deposits). This case is beyond the scope of this paper, but it would not change the results, if the interbank market remains competitive in the core and if peripheral banks have unlimited access to central bank funding.

Appendix III: Asymmetric corridor

Proposition 4: An asymmetric corridor triggers excess liquidity.

Proof: Let r_M be anywhere within in the lowest half of the corridor:

$$r_M = \alpha r_r + (1 - \alpha) r_X \tag{51}$$

Where $1 > \alpha > 0.5$. *Then,* (11) *can be rewritten:*

$$R^{cb} = K + G^{-1}(\alpha) \tag{52}$$

In a fixed rate full allotment regime, Proposition 1 would apply ($r_B^\star = r_M$) the quantity of liquidity that would emerge would therefore be the same as the one the central bank would choose.

In any case, excess liquidity is given by:

$$R - K = G^{-1}(\alpha) \tag{53}$$

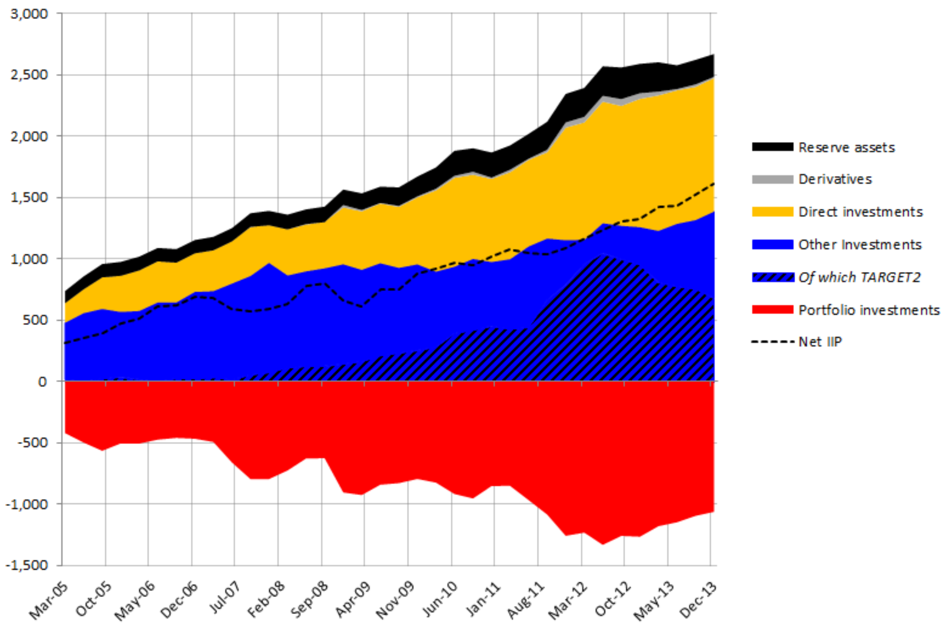
It must be strictly positive whenever the main rate is strictly closer from the deposit facility rate than the marginal lending facility rate ($\alpha > 0.5$).

Since its creation, the ECB has left its main interest rate most of the time in the middle of the corridor ($\alpha = 0.5$). In this case, assuming that $G(.)$ is the cumulative distribution function of a symmetric distribution around zero, excess liquidity should be zero. However, from November 2013 to June 2014 for instance, the corridor was asymmetric, with $r_r = 0$, $r_M = 0.25\%$ and $r_X = 0.75\%$. (53) implies that during this period the ECB triggered some excess liquidity because of its asymmetric corridor. This phenomenon is independent of fragmentation.

Appendix IV: International Investment Positions and Fragmentation

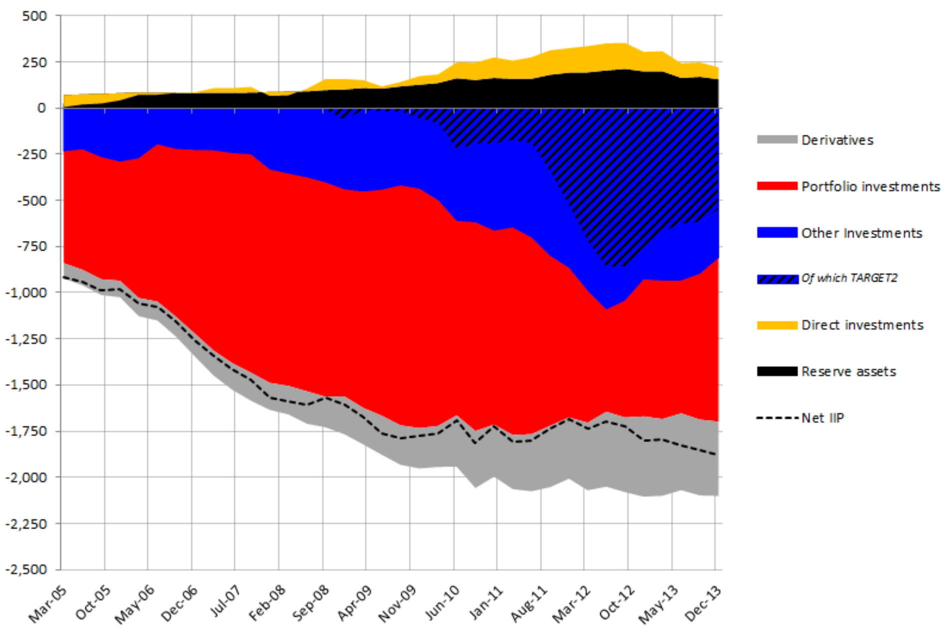
If a well-integrated monetary union becomes suddenly fragmented, deficit countries will not be able to roll-over their loans from core banks. It means that once the loans arrive at maturity, peripheral banks have to pay them off, *i.e.* they have to send a certain amount of liquidity ("F") back to core banks. The only way for the loans to be paid-off in the absence of other sources of financing would be for deficit countries to manage a current account surplus (by macroeconomic identity). As this is not possible overnight, the banks will need to obtain the liquidity to repay core banks in some other way. Deficit countries' banks borrow from the central bank to repay surplus countries' banks. The fact that the interbank market became inaccessible for peripheral banks at a time when they had a large net liability toward core banks is further documented in this appendix. Figures 12 and 13 below display the net International Investment Position (IIP) of core and peripheral countries. Each category of financial flow (direct investment, portfolios investment, *etc.*) is netted. A negative position represents a liability and is equivalent to past inflows.

Figure 12: IIP of TARGET2 surplus countries (Germany, Netherlands, Luxembourg and Finland), broken down by category (EUR bn).



Source: IMF BOPS, ECB, "Euro crisis monitor" and author's calculations.

Figure 13: IIP of TARGET2 deficit countries (Portugal, Italy, Greece and Spain), broken down by category (EUR bn).



Note:Ireland is excluded due data unavailability.

Source: IMF BOPS, ECB, "Euro crisis monitor" and author's calculations.

It shows that indeed core countries (Germany, Netherlands, Luxembourg and Finland) had a substantial net creditor position (positive net IIP) toward the rest of the world. Except for portfolios investment, they have a creditor position in all types of investments. Peripheral countries (Portugal, Italy, Greece and Spain) on the other hand had accumulated a net external liability before the outbreak of the crisis. This is the result of past accumulated current account imbalances. Interbank loans appear in the category "other investments".[43] "Other investments" from core banks indeed, seem to have stopped with the crisis (Graph 1). Most of the money lent abroad by banks before the crisis seems to have returned, as suggested by the substantial increase of TARGET2 imbalances, which is also classified as "other investments".[44]

In both core and periphery, net "other investments" excluding TARGET2 balances almost completely vanished (Figures 12 and 13). Portfolio investments also probably played a role in the capital reversal between core and periphery. Indeed, TARGET2 deficits rose in the periphery also at the expense of its portfolio investments liability. As a mirror image, the TARGET2 surplus of core countries seems to be related to the decrease of "other investments" positions but also to the increase of the liability in portfolios investments. This should not come as a complete surprise, since short term bank securities and interbank borrowings are close substitutes. The former appears in "portfolio investment" and the latter in "other investments". Still "other investments" seems to have played a larger role.

Recall that a TARGET2 liability means that there is more money transferred out of the country than in the country. This is a sign *per se* that banks have difficulties to attract liquidity below the central bank rate (*i.e.* it shows fragmentation). The total international investment liability position of a country gives the limit to how much TARGET2 liabilities can rise.

Appendix V: Graphical representation of the demand for liquidity at the central bank

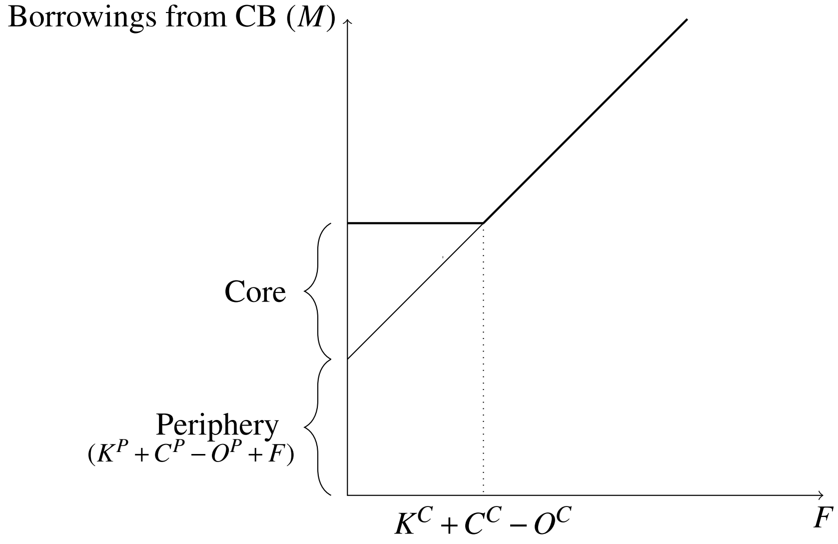
Diagram 3 below is a graphical representation of the theoretical mechanism described in the paper. When F is small, peripheral and core banks ask just enough liquidity to fulfill their liquidity needs (reserve requirements, *etc.*). As F increases peripheral banks ask more and more

[43] See IMF Balance of payments manual 6.

[44] Similar conclusions are reached by Auer (2014) using accumulated current account and financial flows. This appendix rather uses international investment positions, because the relevant concept is the total liability positions and not recent borrowings. Moreover, IIP statistics offer some advantages over international flow Figures (see for instance Curcuru *et al.* (2008) for the US case).

liquidity, and if F is small (below the critical level $K^C + C^C - O^C$) core banks ask less and less. At some point (when F is higher than the critical level) core banks ask zero to the central bank and the increase in F triggers excess liquidity because the increase in the demand of peripheral banks (vertical distance between the zero line and the upward slopping line) is not matched by a decrease in the demand by core banks.

Diagram 3: The demand of refinancing of core and peripheral banks.



Appendix VI: Sterilization operations

Proposition 5: When the capital flight (F) is large enough, increasing the size of the sterilization operations, decreases excess liquidity in the core, even when banks can borrow as much as they wish from the central bank.

Proof: When the central bank conducts sterilization operations it offers a deposit to banks remunerated at rate r_S. This rate is the result of a bidding process by banks. Assuming perfect competition, banks bid their marginal valuation and therefore $r_S = r_B^\star$. Given sterilization operations, the excess of liquidity (if any) will be $F + O^C - C^C - K^C - S$ and therefore level of the interbank rate: $r_B^\star = r_r + (r_X - r_r)(1 - G(F + O^C - C^C - K^C - S))$.

The profit function of core banks is then:

$$E[\Pi^{i,C}] = -r_D(D^{i,C}) - r_B B^{i,C} + r_S S + r_r(R^{i,C} + B^{i,C} - K^{i,C} - S) \\ - (r_X - r_r)\int_{\hat{\epsilon}^{i,C}}^{\infty} g(\epsilon^{i,C})(K^{i,C} - (R^{i,C} + B^{i,C} - \epsilon^{i,C} - S)\mathrm{d}\epsilon^{i,C} \quad (54)$$

Maximizing with respect to the amount of funds deposited at sterilization operations:

$$\frac{\partial E[\Pi^{i,C}]}{\partial S} = S\frac{r_S}{\partial S} + r_S - r_r - (r_X - r_r)(1 - G(R^{i,C} + B^{i,C} - K^{i,C} - S)) \quad (55)$$

Since $r_S = r_B^\star = r_r + (r_X - r_r)(1 - G(F + O^C - C^C - K^C - S))$, the last three terms in (55) *cancel out. Hence:*

$$\frac{\partial E[\Pi^{i,C}]}{\partial S} = S\frac{r_S}{\partial S} = S\frac{r_B^\star}{\partial S} = (r_X - r_r)g(F + O^C - C^C - K^C - S) > 0 \quad (56)$$

Therefore, in case of excess liquidity, profits of core banks are increasing in the amount of sterilization deposits. As long as we are in the case where F is large, this has no impact on core banks borrowings (as it remains at zero). These operations have no impact on periphery banks borrowing as there marginal valuation for fund is $r_M > r_B^\star$. Therefore, these operations are able to decrease excess liquidity and increase the interbank rate.

Appendix VII: TARGET2 technical appendix

There are two things that differentiate F from TARGET2 imbalances.

First, some capital movements from one country to the other are not recorded in TARGET2. Indeed some capital movements can occur through the use of banknotes. Such movements can be substantial and turn countries with apparent capital flight into capital recipients (see Handig *et al.* (2012)).

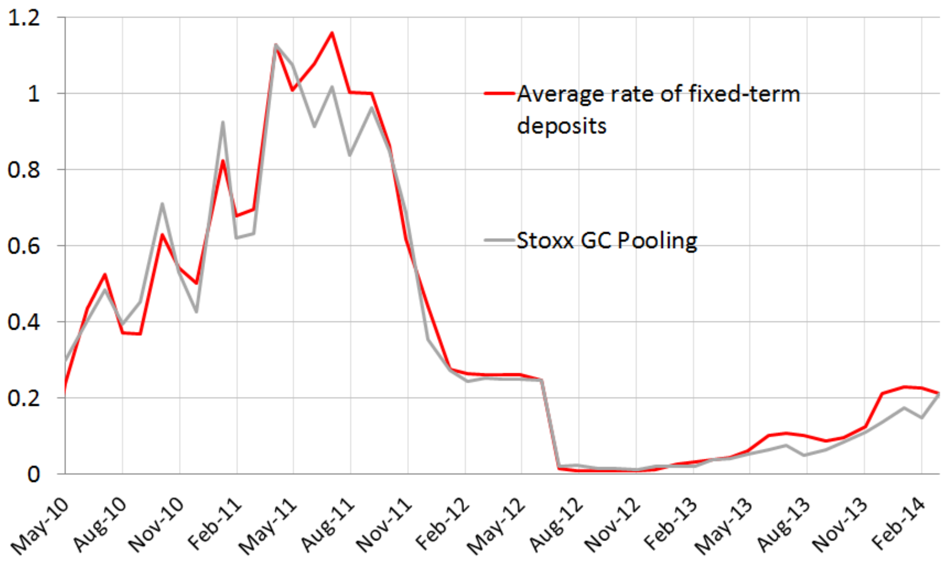
Also, there are some transactions in the TARGET2 payment system that do not correspond to capital movements in Euro. This second point has not been noted in the literature. For instance, the use of swap lines with foreign central banks triggers accounting transactions between central banks and will appear in TARGET2 while actually not a euro has moved within the monetary union. The Eurosystem lent US Dollars to its banks during the crisis. In order to finance such loans, it has made swaps with the Fed, swapping Dollars against Euros. The

ECB was receiving the Dollars while it was national central banks lending Dollars to their banks. Therefore, the ECB lent Dollars to national central banks against a TARGET2 claim. National central banks would then see a TARGET2 liability appear on their balance sheets. This probably deteriorated the TARGET2 position of some national central banks during the crisis, in particular those that extensively lent Dollars to their banks. Ideally, one should correct for these two data issues before using TARGET2 imbalances. Unfortunately, the data series needed to make such adjustment are not publicly available.

Appendix VIII: Liquidity absorbing operations in the Euro-Area between 2010 and 2014

Figure 14 plots the interbank rate and the average rate at which the Eurosystem was able to absorb liquidity between 2010 and 2014.

Figure 14: Stoxx GC Repo *vs* rate one fixed-term deposits (Maintenance period average, percentage points)



Source: ECB and author's calculations.

There are some modest wedges between the two rates at several points in time. This can come from the difference in maturity (one week *vs* overnight) at times of elevated market volatility.