The Network Topology of the Hungarian Short-Term Foreign Exchange Swap Market

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Abstract

Several studies have analyzed interbank networks, but to the best of our knowledge, foreign exchange swap (FX swap) markets have not been examined with the tools of network theory. We have made an empirical analysis of the network structure of the Hungarian FX swap market. The network of the FX swap market is a small-world type graph, which also means that the market is sensitive to the behavior of the big players. A continuous change was identified in centrality measures after 2010 until the end of our observation period (September 2012), which implies that those players that remain in the market can have a greater influence on the stability of the network. We have also found that preferential trading activity is more typical of foreign banks than of resident banks.

JEL classification codes: G01, G15, C45
Keywords: financial networks, FX swap, financial crisis, emerging markets, topology, centrality indices

1. Introduction and Literature Review

The global economic crisis starting in 2007 escalated in Hungary with the breakdown of financial markets after the Lehman Brothers collapse. In October 2008 Hungarian financial markets stopped functioning. The government bond market, the interbank HUF market, and the foreign exchange swap (FX swap) market were paralyzed for some days, which adversely affected the entire banking system. Rolling over of FX swaps is crucial for banks to close their on-balance sheet open FX position. If they had not been able to roll over their maturing FX swaps, they would have to use the spot market to obtain foreign currency to meet their obligations. This would have put a lot of pressure on the HUF exchange rate. Commitment of foreign parent banks to their Hungarian subsidiaries played an important role in managing these problems. Besides this, the introduction of new facilities from the Magyar Nemzeti Bank (MNB, the central bank of Hungary) was also needed. Initially the MNB introduced a two-way overnight EUR/HUF swap tender facility in October 2008, acting as an intermediary between market participants in order to mitigate counterparty risks. Subsequently, thanks to an agreement with the European Central Bank, it introduced overnight, 6– and 3-month EUR/HUF swap instruments for those banks that could not obtain foreign currency on the market or only at a high price. Banks had been demanding for these facilities for a long time.

This chapter of the crisis was a good example of the importance of the FX swap market for Hungarian financial intermediation. Domestic banks partially raise their foreign currency liquidity through FX swap transactions. FX liquidity is essential to closing their on-balance sheet open FX position, which is a result of expansive FX lending. Foreign banks are also active in this market. They can take up forward positions through FX swaps and they can hedge the exchange rate risk of their HUF assets as well. The FX swap market is also important from the point of view of monetary policy. Disturbances in the market may result in a significant decrease of the implied HUF yields, so speculation against the HUF will be cheaper.

Several papers have focused on the functioning of the Hungarian FX swap market and its role in financial intermediation. Páles, Kuti and Csávás (2010) gave a detailed analysis of the market. They highlighted the differences in motive of involved participants (e.g. foreign participants and domestic banks) for trading in this market. Several widely used strategies were presented in their paper. In addition, a descriptive analysis of how the structure and the functioning of the market changed during the crisis was also provided in the study. Due to the turmoil, non-resident banks significantly reduced their counterparty limits vis-à-vis the domestic banking system, and the limits of domestic banks vis-à-vis each other also contracted. The margin call requirements of FX swap transactions heightened, which increased FX swap needs. Banai, Király and Nagy (2010) also dealt with issues in the FX swap market during the crisis. They found that until the escalation of the crisis, local banks (banks without strategic foreign owners) had accumulated a large amount of FX swap stock (and to a lesser extent foreign banks also used FX swaps). During the crisis, rolling over of the FX swap stock and meeting of margin call requirements posed significant challenges to the banks, so the MNB swap facilities had to be used. Most foreign-owned banks relied on the FX swap market to a lesser extent and their parent institutions supported them; even so, they also used central bank facilities from time to time.

Studies of the domestic FX swap market have mainly focused on the size and the maturity of the stock, the implied yields, or the different strategies of different players. However, examination of the network structure of financial markets may give additional information. In the last ten years and especially after the onset of the crisis, the network topology of financial markets and the dynamics of financial networks have become hot research topics. In the Hungarian literature, Lublóy (2006) has provided one of the earliest papers. She focused on the network structure of the VIBER (Large Value Transfer System). According to the study, the observed network characteristics were stable over time. The author could identify the most important players from the point of view of network stability. Surprisingly, the identified institutions differed from the largest banks of the banking system based on balance sheet total.

With respect to our current study, the most important antecedent in the Hungarian literature is the paper by Berlinger et al. (2011), which analyzed the network structure of the interbank HUF deposit market and its dynamics during the crisis. Network characteristics changed significantly with the escalation of the crisis after the Lehman collapse. Changes in some ratios started at the end of 2007, well before the toughest period of the crisis. The average degree of the weekly network decreased from around 9 to 7 in 2007 and it fell further to 4 after the Lehman collapse. Contraction of average betweenness also began at the end of 2007, but it became drastic in the fall of 2008. Finally, from late 2007 the size of the core of the network began to decline. All in all, several network characteristics anticipated changes in the market.

Analyzing financial markets with a network theory approach is more common in international literature. Iazzetta and Manna (2009) focused their research on the characteristics of the Italian interbank market. The dynamics of several network measures were presented in their study. According to their paper, the connectivity of the network was low, which is common in real-world networks. They also found that connectivity was decreasing during the 222 months of observation. It was also important that the network was connected all along; that is, a path could be identified between any pairs of banks. Their third finding was that the average shortest path of the network slightly increased. In addition, they showed that the big players in the market were trading regularly with smaller counterparties. This means that the affinity function was downward sloping. Their final result was that the proportion of big banks in the network declined and an increasing number of banks only had a few counterparts. Iori et al. (2008) dealt with the Italian O/N interbank market in their paper. They also found that based on degree, large banks have many small partners, which raises the risk of contagion in a network with high connectivity.

Wetherilt et al. (2010) also focused on the structure of the unsecured interbank market and the crisis was included in their observation period. They found that increasing partner risk during the crisis had influence on the structure of the network. Before the onset of the crisis, few banks had outstandingly high degrees or a special role in the network. Increasing issues in global financial markets motivated many institutions to diversify their counterparties and to rely less on the core banks of the network. As a result, the role of some banks became more important during the crisis, and they also turned out to be core institutions. Soramäki et al. (2006) analyzed the network characteristics of the Fedwire Funds Service. They found that this network was characterized by all those features which are common in real-world networks – namely, scale-free degree distribution, relatively high clustering coefficients, and "small-world" phenomena (a term which was introduced by Watts and Strogatz (1998) and very common in financial networks). In addition, it was shown that network measures were stable over time.

This short literature review implies that network theory in finance is usually used to examine payment and settlement systems, or unsecured interbank markets (although, for example, Markose et al. (2010) focused on the CDS market). We did not find any paper in the Hungarian or the international literature which analyzed the network structure of the FX swap market. We have attempted this in our paper, since it might be very important from two perspectives. First, most papers explain changes in financial networks' structures with credit risk. Since an FX swap is collateralized, this opinion might imply that the network characteristics of an FX swap market are stable over time. Otherwise, credit risk is not the only important factor behind the dynamics of financial networks. Second, due to the importance of the FX swap market in Hungary, its stability is essential for the banking sector. Different network types have different reactions to shocks, which means that network characteristics are very important from a stability point of view.

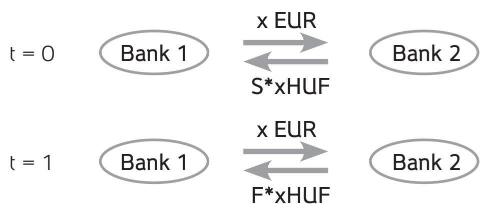
The maturity of FX swap transactions can differ by years, and their functions in banking vary by maturity. For this reason, we have focused our paper on contracts with one– or two-day maturity. This is the most liquid part of the market with most of the transactions. In the second section, we illustrate the main characteristics of the domestic FX swap market and its special role in the Hungarian banking system, which is essential to understanding the importance of this research. The third section presents the dataset and the methodology used. Our results are discussed in the fourth section and our conclusion in the fifth section.

2. The FX Swap Market

2.1. The FX Swap Transaction

A foreign exchange swap, or FX swap, is a derivative financial market instrument with two legs. On the spot leg, the counterparties exchange two types of currencies with each other, and they swap them back on the forward leg. Both the spot and the forward exchange rates are determined at the beginning of the transaction. According to market convention in the case of FX swaps involving the Hungarian forint, the foreign exchange amounts are equal on the spot and forward legs, and the spot and forward forint amounts are equal to the foreign exchange amount multiplied by the spot and forward exchange rates accordingly (Figure 1).

Figure 1. Spot (t=0) and Forward (t=1) Cash Flows of a Forint/Euro FX Swap Transaction with S Spot (S) and Forward (F)Exchange Rates[1]



The pricing of a swap implies a swap spread, which is the difference between the yield differential of the two currencies priced in the forward premium (the difference between the forward and the spot exchange rates) and a reference yield differential:

$$\mathrm{F} = \mathrm{S} \times \frac{1 + i_{HUF} \times t}{1 + i_{EUR} \times t} \approx \mathrm{S} \times \left[1 + (i_{HUF} - i_{EUR}) \times t\right] \qquad (1)$$

$$SWS = (i_{HUF;ref} - i_{EUR;ref}) - (i_{HUF} - i_{EUR}) \qquad (2),$$

[1] The exchange rates are quoted in HUF (1 EUR = S HUF and 1 EUR = F HUF).

where i_{HUF} and i_{EUR} are the implied interest rates, t is the tenor of the transaction, SWS is the swap spread, and $i_{HUF;ref}$ and $i_{EUR;ref}$ are the reference interest rates.[2] Actual exposure (the net present value of the transaction) against an FX swap counterparty is smaller by orders of magnitude than in the case of uncollateralized deposits or loans. Initial exposure of the transaction is zero, unless the discount rates differ from the swap-implied yields. Later movements in interest rates and in the exchange rate influence the net present value of the transaction. Accordingly, at origination, the potential highest future exposure can be calculated, generally by statistical methods (e.g. under certain circumstances, what is the potential highest exposure during the maturity of the transaction with a certain probability; Páles et al., 2010, and BIS, 1998). The limit systems of banks put a bar on the sum of actual and potential highest future exposures against different counterparties. Another risk-mitigating instrument is margining. This reduces exposures using the balance of margin accounts. Margining can cause negative liquidity shock to the obligor, and margining typically occurs in foreign exchange (not in forint).

There are three interpretations of FX swaps:

- a temporary exchange of *liquidity* in different currencies
- a temporary exchange of *funding* in different currencies
- lending against foreign exchange collateral.[3]

FX swaps have a broad range of applications and thus are popular in the money markets.

2.2. The Hungarian Currency Swap Market

Due to data constraints, the only part of the Hungarian currency swap market that is known to us is where at least one of the counterparties is a Hungarian bank. We have anecdotal information that in London there is an off-shore forint/foreign exchange swap market (Balogh-Gábriel, 2003). The currency swap market is a less regulated OTC (over-the-counter) market where trading with forint/foreign exchange transactions typically takes place through London brokers, and direct bilateral communication and quotation are not typical (Csávás et al., 2006). On the other hand, in the segment of maturity of up to one month, Hungarian banks can be used as market makers due to their exclusive access to the central bank's forint market instruments. As the ratio of cross-currency swap turnover (among CHF, EUR, and USD) to the turnover of the HUF/FX market segment is relatively high (41 per cent in the analyzed 2005–September 2012 period) – indicating that there might be free movement among different foreign exchanges through swaps – the swap market of different foreign currencies against forint is taken generally as the HUF/FX swap market hereinafter (and no distinction is made between, for example, the USD/HUF and the EUR/HUF segments).

The turnover of the forint/foreign exchange swap market was 5.6 times the Hungarian GDP in the period analyzed, between 1 January 2005 and 30 September 2012. The Hungarian banking system's gross HUF/FX swap exposure against foreigners was 22 per cent of the total assets of the banking system at the end of the period (which is nearly 80 per cent of the loans granted to households and companies). These two figures indicate the significant role of the swap market in the Hungarian economy, behind which lies not only the broad range of applications of currency swaps, but also macroeconomic factors. Before the global

[2] Linear yield calculus is the convention for maturities of up to one year.

[3] This function is not supported by the sophisticated collateral management instruments used in case of repos (Csávás, Kóczán and Varga, 2006).

financial crisis, which started with the default of Lehman Brothers investment bank on 15 September 2008, the net foreign debt of Hungary, and hence the foreign funding needs of the banking system, increased markedly. Net foreign debt equals the sum of the open long forint positions of the different sectors in the economy (Páles et al., 2010), which means that one of the sectors had to take this open forint position. Foreigners were unwilling to take the position, and that is why the bulk of the position was taken by the domestic private sector through the balance sheet of the banking system, which opened the on-balance sheet foreign exchange position of the banks. According to edict 2000/244, the banking system is subject to a capital requirement after its open foreign exchange position,[4] and that is why it is incentivized to close its open on-balance FX position off-balance. Banks typically close on-balance sheet open FX positions by using FX swaps (together with reverse spot transactions; Páles et al.. 2010). Mainly due to this activity, the FX swap market is considered to be the most important money market in Hungary.

2.3. The Global Financial Crisis and its Effect on the Currency Swap Market

Although financing costs in Hungarian markets had already risen since the summer of 2007, the start of the subprime mortgage crisis, and there was a short period of turbulence in the government bond market in March 2008, the global financial crisis escalated in Hungary mainly after the default of Lehman Brothers on 15 September 2008. The most severe period of the crisis was between autumn 2008 and spring 2009. In autumn 2008 access to foreign exchange and later to forint liquidity suddenly became more expensive, and market participants cut down their counterparty limits. On the currency swap market, total turnover became volatile. Although the maturity of the outstanding swaps had gradually lengthened before, this process came to a halt during the crisis, and new swaps were traded at shorter maturities. Moreover, the euro became the most important foreign currency on the market, substituting for the US dollar (Páles et al., 2010).

The 1–2 days market dried up, and the aggregate liquidity index measuring the liquidity of the market fell to −8 by the end of October 2008 (Figure 2). This means that the liquidity of the market was 8 standard deviations below its long-term average before the crisis.[5] Meanwhile, swap spreads increased markedly. Spreads which were around zero before the crisis jumped to hundreds of basis points (Figure 3). This means that in that period, one could receive forint funding (against foreign exchange collateral) through an FX swap at an interest rate several percentage points below the reference money market interest rate.

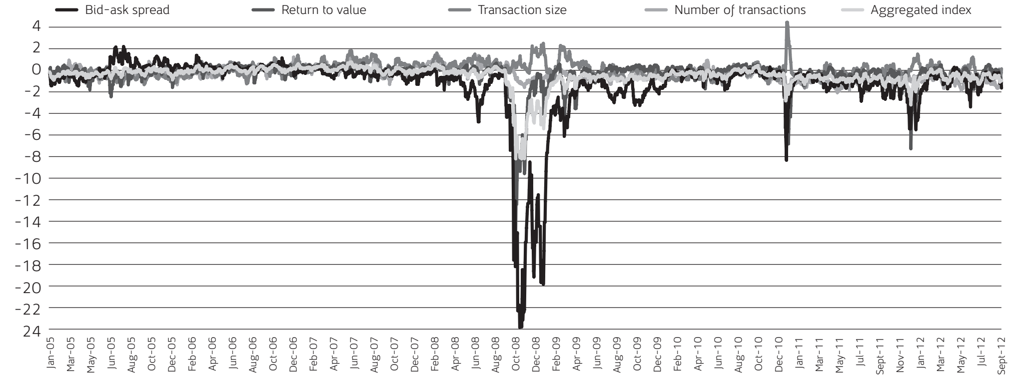
Between September 2008 and March 2009 the forint depreciated against the euro by 30 per cent. Elevated swap spreads and thus profitable reverse carry trade through swaps supported the spot plus swap based synthetic forward short forint positioning of the foreigners, which resulted in significant depreciation. The exchange rate speculation of foreigners increased the net foreign exchange receiving swap stock of the Hungarian banking system, at a time when foreign exchange liquidity was already tight on the swap market. The increase in the exchange rate elevated the net present value (the actual exposure) of the swaps, which entailed margin call requirements against Hungarian credit institutions. As margining took place in foreign exchange, it resulted in an extra shock to foreign exchange liquidity in the banking system.

[4] If the total foreign exchange position exceeds 2% of own funds before the deduction of transgressions, then the capital requirement of foreign exchange risk is 8% of the open foreign exchange position.

[5] For more information on the aggregate liquidity index, see Páles and Varga (2008).

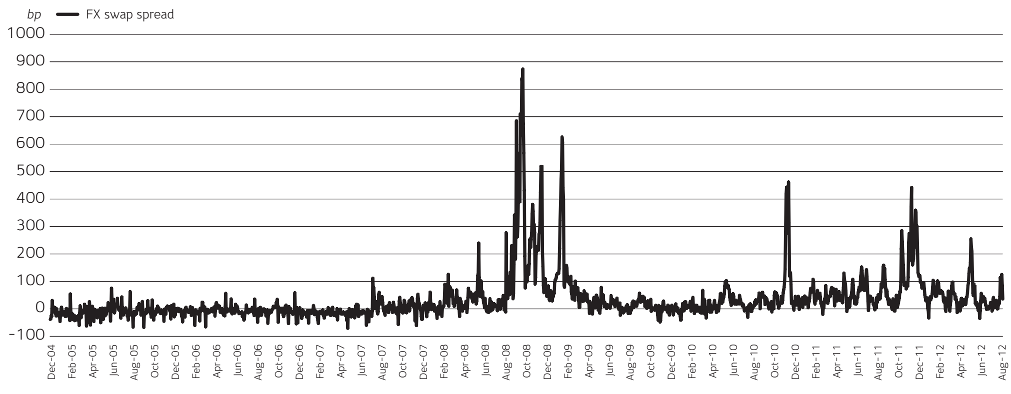
Furthermore, as margining was financed at least in part by new foreign exchange borrowing swaps, it resulted in a liquidity shock in the forint market as well (Páles et al., 2010).

Figure 2. The Liquidity Indices of the 1–2 Days EUR/HUF and USD/HUF FX Swap Markets (Exponential Moving Averages)



Note: The liquidity index of the HUF swap market contains data from the 1–2 days EUR/HUF and USD/HUF segments, where there is a maximum of two business days between the deal date and the maturity date. Higher values indicate better liquidity in every dimension. The sub-indices are standardized by their long-term mean and standard deviation before the crisis.
Source: MNB

Figure 3. The Spread of the 1–2 Days FX Swap Market



Note: HUF, EUR and USD reference interest rates are taken from the following: HUFONIA, EONIA, Fed funds rate.
Source: MNB

In order to manage the liquidity shock to the swap market and to the Hungarian financial markets in general, the MNB introduced new and in part temporary measures. For instance, focusing on the FX swap market, in October 2008 a two-side overnight EUR/HUF instrument was introduced by the MNB as an intermediary. Later a one-side euro liquidity-providing overnight EUR/HUF standing facility was launched. Then in February 2009 came a one-week maturity Swiss franc liquidity-providing CHF/EUR tool, and in March euro liquidity-providing 3– and 6-month EUR/HUF instruments were initiated by the central bank. These central bank instruments contributed to the easing of market tensions and the moderation of swap spreads (Csávás and Szabó, 2010, Fábián and Mátrai, 2012). Today, only the overnight and the 3-month euro liquidity-providing EUR/HUF tools are active, and there is an ad hoc 1– or 2-week euro liquidity-providing EUR/HUF instrument in the potential toolkit of the MNB. Pre-crisis conditions have still not returned to the 1–2 days swap market. Swap spreads have consolidated only in part, and the aggregate market liquidity index is still in negative territory at the end of the period.

3. Our Dataset and Methodology

In this section we present the dataset used and some tools from network theory as a brief introduction. The results for the FX swap market can be seen in the next section.

3.1. The Dataset

The central bank of Hungary obliges Hungarian credit institutions to report all their foreign currency–related transactions, including FX swaps. This database formed the basis of our research. In this paper, we focus on the 1–2 days segment of the FX swap market, that is, overnight, next-day swaps and swaps of two-day maturity with equal deal date and value date. That definition harmonizes with the market segment analyzed by the aggregated liquidity index, but that index is counted only in USD/HUF and EUR/HUF, while in this examination we also take into account CHF/HUF transactions (Table 1).

Table 1. Distribution of 1–2 Days FX Swap Market by Two Dimensions

currency	USD	EUR	CHF	together
	92%	8%	<1%	100%
maturity	overnight	tom-next	two days	together
	42%	55%	3%	100%

Source: Authors' calculation

We have dealt with all the FX swap transactions between 1 January 2005 and 13 September 2012. Both domestic and foreign participants appear as nodes in our graphs, but we excluded the central bank of Hungary (MNB). Our focus was solely on credit institutions; so, for example, non-financial corporations were omitted. Domestic banking groups were consolidated; therefore all the member institutions of a domestic banking group are represented by one node. However, we have not consolidated foreign groups for several reasons. Consolidation would not have been useful, since we wanted to get a detailed picture of relationships with parent banks. In addition, intragroup relationships may differ from one bank to another, and we did not have information to make this distinction. For these reasons, all the foreign banks have their own node in the graph. The boundaries between nodes are based on transactions in the observed period, and not on stocks. We aggregated the transactions of every five workdays to compose the matrices of the graphs. In other words, we took the signed sum of bilateral exposures on five consecutive workdays (for more details, see 3.2).

Signed HUF values on the spot legs are summed between every (i,j) pair of participants; we give a positive value for the transactions where bank j obtains HUF from bank *i* on the spot leg, and a negative value vice versa. Non-business days in the USA, Switzerland, and the Eurozone were omitted, because on these days the trade volume is very low.

3.2. Adjacency Matrices

Let us consider a financial market with N banks and let W be the matrix of bilateral exposures. In other words, $W_{i,j}$ is the net amount of HUF paid on the spot legs to bank j from bank i. The matrix W has only non-negative elements, and it can be asymmetric; furthermore, the main diagonal is all zero. This matrix defines a directed and weighted network without loop edges [6] If $W_{i,j} > 0$ there is a directed link from i to j and naturally the edge weight is $W_{i,j}$.

Usually in network research there is minimal interest in the size or the direction of the transactions. This is because the fact that there is a link between two banks provides enough information, and this makes easier to understand some network measures.

Let A denote the adjacency matrix of an undirected and unweighted network, i.e.

$$A_{i,j} = \begin{cases} 1, \; W_{i,j} + W_{j,i} > 0 \\ 0, \; otherwise \end{cases} \tag{3}$$

For many network measures, the network has to be weakly connected. This means every node can be reached from all other nodes on an undirected path. If the network is disconnected, we consider only the overall weakly connected subgraph.

3.3. Network Measures

After we created the adjacency matrices (using our database), we computed the following measures for each five-day period. Finally, we used these time series data structures for the analysis. These ratios can provide information about the main characteristics of the market. Analyzing the time series gives the opportunity to see the changes in the market regarding its stability and the behavior of banks.

Size

The most fundamental network measure is the size of the graph, i.e. the number of banks which make at least one transaction (lending or borrowing) in a particular period.

Degree

In a directed network, the in (out) degree of a given node is the number of incoming (outgoing) links (Newman, 2010). If the network is undirected, degree is defined as the number of connections to other nodes. In other words, a high degree means many business partners. This implies on the one hand that the bank can easily substitute for its partners, but on the other hand the bank can be a source of serious contagion. More precisely, the degree of a given node I is:

$$f(i) = \sum_{j=1}^{N} A_{i,j} \tag{4}$$

[6] This is an edge that connects a node to itself.

Another important measure of the network is the degree distribution. This shows the frequency of nodes with degree *k*. It is usually divided by the total number of nodes in the network, but we only use the frequencies. Many real-world networks have degree distribution which follows the power law. This means there are many nodes with low k and a few nodes with high degree. In other words, if we denote the frequency of nodes with degree *k* by *p*(*k*), we get:

$$p(k) = ck^{-\gamma} \tag{5}$$

where *c* is a normalization constant, and γ is a positive parameter which usually lies in the [2,3] interval. These type of networks are called scale-free networks (Barabási and Albert, 1999).

Average Path Length, Diameter and Mass Function

The distance between two given nodes *i* and *j* is the minimum number of steps that have to be taken from *i* to *j*. This is the shortest path between two nodes and it is denoted by *d*(*i,j*). Naturally, if the network is undirected, *d*(*i,j*) equals *d*(*j,i*).

The average path length is defined as the average of the shortest paths, and the diameter can be specified as the maximum of all shortest paths. A low average path length means that the institution has relatively close connection with the other players. This characteristic implies the bank has a central role. If the diameter of the banking network is substantially different from that of a random network, it indicates that there could be preferential paths for money flows between banks (Iori et al., 2008).

We now introduce the mass function (Iazzetta et al., 2009), which shows the fraction of distances less than or equal to a specified constant *k* (*k* = 2,3,4,5). Naturally, if k equals the diameter, then the mass function is equal to one, because every shortest path is less than or equal to the diameter. The mass distance function can be considered a summary of the average path length of individual institutions for the whole market.

Closeness

For a given node i, closeness is defined as the multiplicative inverse of the maximum of the shortest paths started from *i* (Berlinger et al., 2011). More precisely, if *c*(*i*) denotes the closeness of node *i*:

$$c(i) = \frac{1}{\max_j d_{(i,j)}} \tag{6}$$

Graphically $\max_j d_{(i,j)}$ hows how many steps must be taken to reach all other nodes from *i*.

Betweenness

Betweenness is defined as the number of shortest paths going through a node (Newman, 2010). Shortest paths that start from or end at *i* are ignored. If we want to compare the betweenness for different graphs with different sizes, we have to normalize with:

$$\frac{(N\text{-}1)(N\text{-}2)}{2} \qquad 7)$$

which is the maximum number of shortest paths going through a node. It shows the position of the bank in the market. It is a good measure for estimating the possible contagious effect of an institution's idiosyncratic turmoil.

Density
The density of a network is defined as the ratio of the number of existing links to the number of possible links (Newman 2010). For a given network with N nodes, the possible number of links is equal to:

$$\frac{N\,(N\text{-}1)}{2} \qquad 8)$$

This is because every node can be connected to N–1 other nodes, and every link is counted twice.

Clustering Coefficient
For a given node i, the clustering coefficient is specified to be the probability that i node's two neighbors are connected to each other (Newman, 2010). In other words, the average clustering coefficient shows the ratio of extant triangles to potential triangles (in this case "triangle" is defined as three nodes which are connected to each other). A high clustering coefficient of a bank means that there is a high probability that its counterparties have interbank connections with each other.

Affinity
The affinity function shows the average degree of nodes which are connected to nodes with degree k (Iori et al., 2008). If the affinity function is decreasing with k, then low-degree nodes are likely to be connected with high-degree nodes. This situation is called disassortative mixing. Similarly, if the affinity is increasing with k, we have an assortative affinity function. In a financial market, an affinity curve with a negative slope suggests that smaller banks tend to do business with larger ones, so large hubs exist in the market.

Participation Ratio
The participation ratio shows how even the distribution of edge weights for a given node is. This measure is very similar to the Herfindahl–Hirschman index (HHI), i.e. this is an HHI index for the nodes. Let us denote by $N(i)$ the set of nodes which can be reached from i in one step and also let $s(i)$ be sum of the weights of outgoing links:

$$s(i) = \Sigma_{j\in N(i)} W_{i,j} \qquad (9)$$

The participation ratio is defined as:

$$R(i) = \Sigma_{j\in N(i)} \left(\frac{W_{i,j}}{s(i)}\right)^2 \qquad 10)$$

Naturally, for incoming links and for undirected networks the definition is the same (Iori et al., 2008). The participation ratio is a good tool to analyze possible preferential trading in the market.

3.4 Random Networks

Now we introduce the Erdős–Rényi network, the most commonly used random model. Let us consider N nodes and create links between all pairs with probability p independent from other links. We use the Erdős–Rényi model to compare the clustering coefficients. If the ratio of the clustering coefficients is close to 1, we say there is no structure in the network.

For a given network G, we create an Erdős–Rényi model with the same number of nodes and p is defined as:

$$p = \frac{\text{averege degree in } G}{\text{number of nodes} - 1} \tag{11}$$

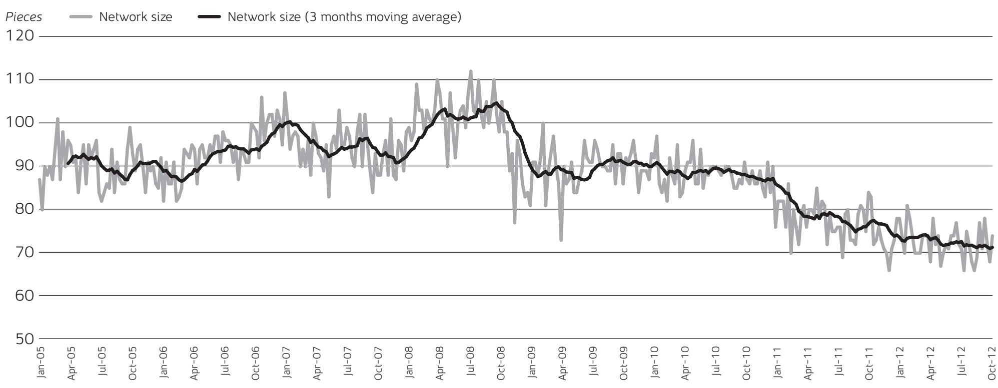
Our database consists only of transactions reported by inland banks; thus the probability of two foreign banks being connected is zero. Hence we have to use another random model. Let us denote by GBB the subgraph of inland banks (inland nodes and links between inland banks). Moreover, we create a bipartite Erdős–Rényi graph where the two disjoint sets are the inland and the foreign banks. This means inland banks can be connected to foreign banks and similarly, foreign banks can be connected to inland banks only. Naturally, we try to create inland–foreign links only with probability p. Finally, we define the modified Erdős–Rényi model as the union of GBB and the bipartite random graph.

The dataset used in our research is unique in the sense that it includes all the interbank FX swap transactions of Hungarian credit institutions with relevant maturity and against the mentioned foreign currencies in the examined eight-year period. Nevertheless, owing to the national attribute of data reporting, the potentially significant off-shore market lies outside our perspective. In addition to commonly used network indicators such as centrality measures, we also take into account some network features which are less frequently used in research of interbank markets, such as affinity, the participation ratio, and random networks.

4. Our Results

In the third section we presented all the mathematical tools we used to map the network structure of the 1–2 days FX swap market. This set of ratios makes it possible to discover the most important characteristics of the network and their dynamics. In addition, it is worth pointing out the differences and similarities with other financial networks. In this section we present our results and explanations.

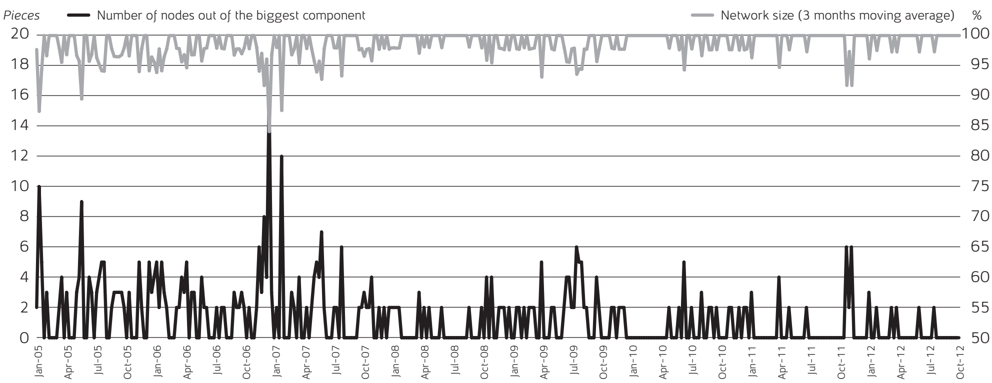
Figure 4. Dynamics of the Size of the Network



Source: Authors' calculation

First of all, we analyzed the size of the network, i.e. the number of banks active on the FX swap market in a week-long period. The number of participants was far from constant. It changed with all the major economic issues. At the start of the observed period the size stagnated, while with the boom in FX lending it increased[7] (Figure 4). After the initial challenges with Bear Stearns and the onset of the Northern Rock crisis in the autumn of 2007 there was some minor decrease, but the next year was a period of continuous increase. Domestic banks' motivation for using the FX swap market was the high FX liquidity need generated by the ongoing expansive FX lending. The pace of lending did not slow until autumn 2008; thus the foreign currency need of domestic banks was continuous, and this ensured foreign currency liquidity was easier and cheaper through the FX swap market. The activity of foreign participants can be explained by the so-called "decoupling theory". Until the Lehman collapse, the financial issues of the developed countries only marginally affected emerging markets. Many (e.g. Dooley and Hutchinson, 2009) thought that emerging markets would not be hit by this crisis; moreover, they would be able to support the recovery of developed economies. For that reason, an increasing number of banks took positions on the Hungarian FX swap market until the Lehman default. Another possible explanation is that due to some disturbances in the interbank deposit market in 2007, some participants may have increased their activity on the FX swap market. In other words, the FX swap market somewhat took over the function of the interbank deposit market. The number of participants (i.e. the number of nodes) fell significantly after October 2008, and fluctuated around the level from 2005. The next breakpoint can be identified at the end of 2010. Although the number of banks declined slightly in autumn 2010, significant change was triggered by the negative decision by Moody's in December. With this step, Hungary was just one notch above junk at two agencies, so Hungarian assets became less attractive for some investors. The average number of banks decreased by about 10. This decreasing trend is observed until the end of our observation period.

Figure 5. Number of Nodes of the Largest Weakly Connected Component (on a 1 Week Frequency)



Source: Authors' calculation

[7] From early 2005 until the end of 2008, the household loan portfolio tripled. While in January 2005 only 15 per cent of the stock was denominated in foreign currency, at the end of 2008 the proportion was more than 70 per cent. About 4100 billion HUF (about 26 billion CHF) in foreign currency loans was disbursed, and most of the new FX loans were denominated in CHF. Two-thirds of the new loans were issued in 2007 and 2008, so the need for foreign currency liquidity became very intensive in this period.

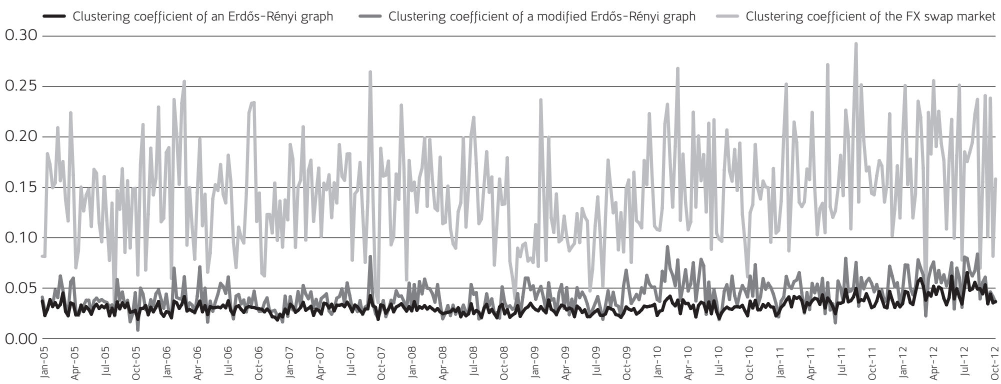
The first interesting characteristic of the network is that the graph is not connected in several cases. Considering the graphs for one trading day, we can see many separate areas. In some cases, daily graphs contain more than ten separate areas. Connected graphs are required for the analysis, because centrality measures cannot be interpreted without them. For this reason, we had to find a frequency which did not hide market movements but was long enough to contain most of the banks in one connected graph. We observed that on a one-week frequency, more than 90 per cent of banks appeared in one connected graph. More than 10 per cent of the banks fell outside of the largest connected component in only 3 of the 370 observed cases. The number of institutions in the residual component(s) did not exceed 4 in most cases (Figure 5).

This lack of integration of the network is an important characteristic. Several examples can be found in the literature where the network of a financial market is not connected (e.g. Berlinger et al., 2011, Bech and Atalay 2008). Increasing the frequency from one day to one week proved to be a good solution, for instance in the first example. At the latter frequency, the authors found only a few instances where two banks did not connect to the main component.

In the Hungarian FX swap market, this phenomenon can be observed many times, leading to two possible explanations. The first is the limits of our dataset. Many participants in the Hungarian FX swap market are foreign institutions, and they do business with each other. Our database includes only contracts where at least one partner is Hungarian. We have no information about contracts between foreign banks, which may connect separate parts. The second probable explanation also stems from the dominance of foreign institutions on the FX swap market. Many foreign banks are mainly doing business with their subsidiaries. When this connection is exclusive on both sides, these banks are separated from other parts of the network. We have checked these cases on an individual bank level. We found that seven banks were outside the main component more than 20 times during the observation period. The second hypothesis was confirmed. In several cases, banks were outside the main component because they were only trading with their parents.

Unlike some of the ratios, centrality measures cannot be counted for an unconnected graph. For this reason, hereafter we focus on the largest weakly connected component.

Figure 6. Clustering Coefficient of the FX Swap Market's Graph and Erd s–Rényi Random Graphs

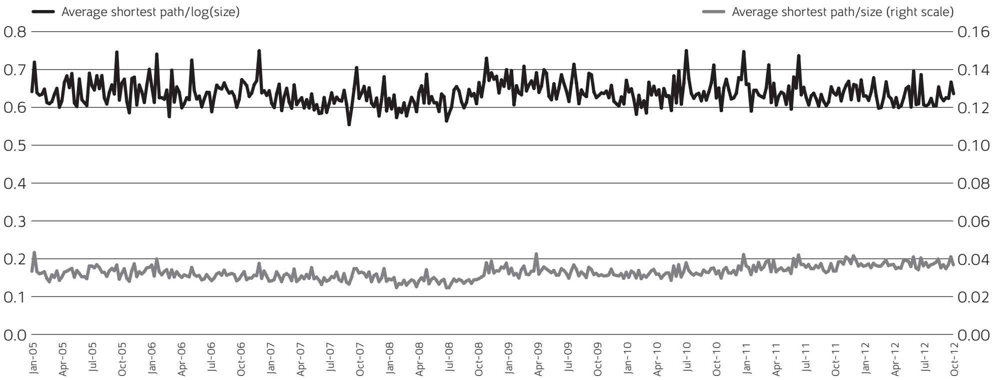


Source: Authors' calculation

We checked whether our network was a random graph. We generated two random graphs to compare with the network of the FX swap market. On the one hand we compared it with an Erdős–Rényi random graph with the same average degree. On the other hand we also used a modified Erdős–Rényi random graph for comparison. In the latter case, we used different probabilities for edges between two domestic participants, two foreign participants, or one domestic and one foreign participant. Of course, due to the special characteristics of our database, the probability of an edge between two foreign players was 0.

The clustering coefficients of all three graphs were counted. The ratio was much higher for the FX swap market than for the random graphs (Figure 6), which confirms our view that it is worthwhile analyzing this network.

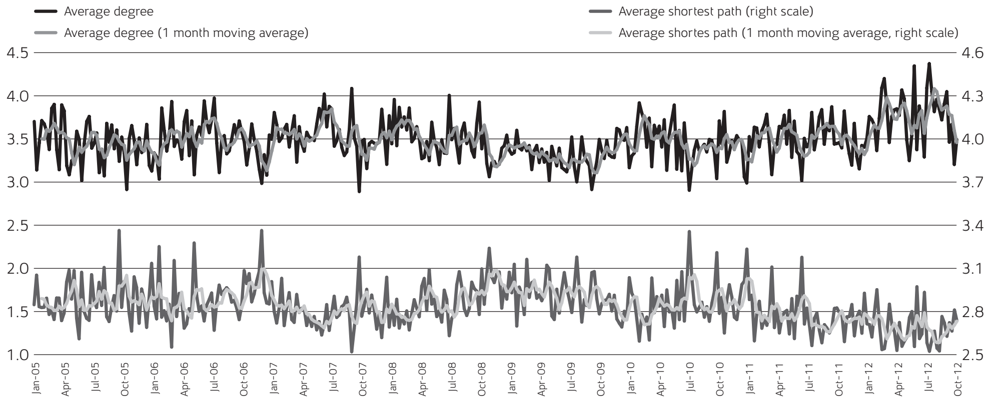
Figure 7. Ratios Confirming the "Small-World" Characteristic of the Graph



Source: Authors' calculation

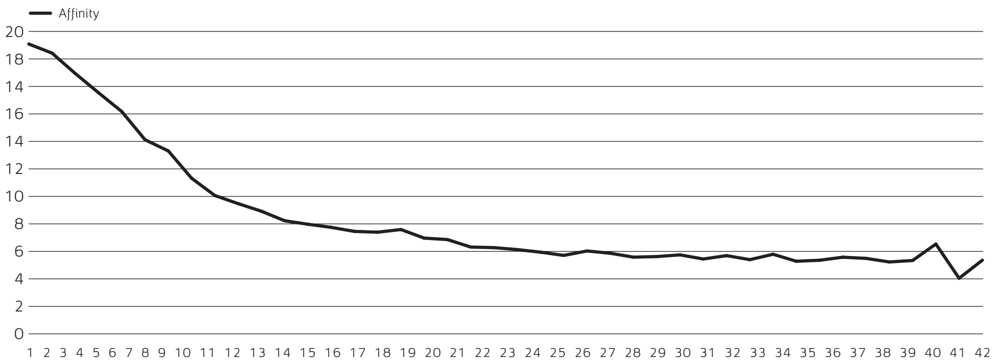
The network is a so-called scale-free graph, and its degree distribution follows the power law accordingly. Using *k* for the degrees, the 53**k*-2 power function is a good approximation of the degree distribution. As a characteristic of power law distribution, few nodes have a high degree and many have a low degree. The few nodes with high degrees connect as a center to the other nodes. This "small-world" characteristic can be proved by the dynamics of the network measures. The high clustering coefficient compared to the random graph implies the small-world characteristic (Figure 6). When the average shortest path is small compared to the size of the network, or the ratio of the average shortest path to the size's logarithm is constant, we may also talk about a small-world network (Newman, 2003, Pető-Békési, 2009). The two latter ratios in Figure 7 confirm that the network of the FX swap market is a small-world network. The average shortest path is about 3 to 4 per cent of the size of the network, which is very low. The ratio of the average shortest path to the size's logarithm can be deemed constant in time, according to Figure 7. The small-world characteristic is a risk from a stability point of view. Small-world networks are stable for a random shock, but they are sensitive to the behavior of the largest players (Albert et al., 1999, Newman, 2003). This means that any crisis of the central nodes enhances and speeds up contagion (Markose et al., 2010). This stems from the fact that in a small-world network, the distance between two given nodes is relatively small.

Figure 8. Dynamics of Average Degree and Average Shortest Path



Source: Authors' calculation

Figure 9. Affinity Function



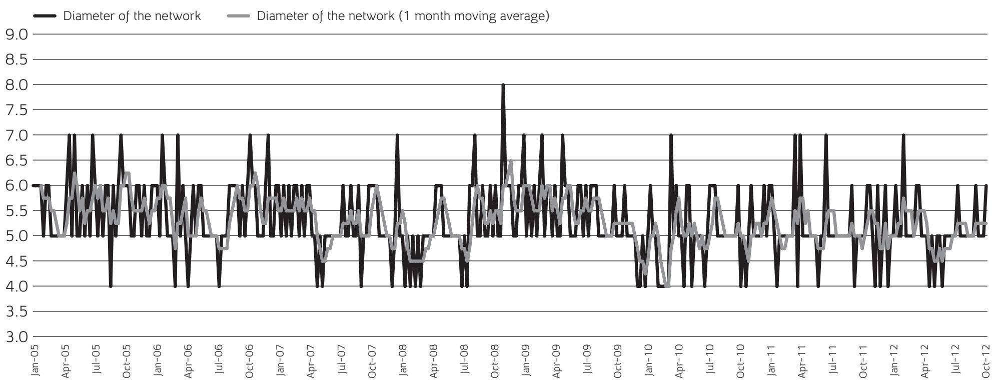
Note: The horizontal axis shows the degree of each node, while the vertical axis shows the average degree of neighboring nodes, e. g. the neighboring nodes of nodes with one degree have degrees around 19.
Source: Authors' calculation

The average degree of the network fluctuated between 2.5–4.5 during the entire observation period (Figure 8). In mid-2007, for a short period the ratio decreased significantly, but after it returned to its former level and until the Lehman collapse, it was around this level. After the Lehman collapse, the average degree was below its ordinary level, but from autumn 2010 a constant increase can be observed. The decline after the Lehman default can be explained by two factors. On the one hand, many banks left the market or reduced their activity, as was shown before. Among these. some institutions were larger players with higher than average degrees. In some cases, leaving the market was not a business decision but the consequence of a default. On the other hand, some banks stayed active in the market but started to trade with only the best partners. From late 2010, the average degree started to increase, although the number of nodes declined again. It seems that the banks that left the market were marginal players with a very limited number of partners. The average degree changed significantly in the unsecured interbank HUF market as well, but a constant decline had already begun in 2007 (Berlinger et al., 2010). It intensified after the Lehman collapse. This implies that the greater risk of the interbank market made banks more cautious, and they reacted to the unexpected turmoil faster.

The average shortest path naturally moved in the opposite direction. When players trade with more and more partners, new shortest paths come into existence with new edges, and vice versa. A lower average number of partners decreases the number of possible paths between two nodes, so the average shortest path increases (Figure 8).

An important characteristic of a network is its affinity function. This shows the relationship between the degree of the nodes and the average degree of their neighboring nodes (Figure 9). In financial networks, it is common that institutions with high degrees trade directly with institutions with low degrees (this phenomenon was illustrated by Iori et al., 2008 and Iazzetta et al., 2009). The same goes for the FX swap market. Since there are many small players (based on degree) in the market, most active banks have to trade with institutions with lower degrees. For this reason, the operation of these institutions with high degrees is essential. Many institutions would lose the connection with the network without these partners. It is important to mention that small players in this network, based on degree, may be large international institutions, that is, from a risk perspective, their role in the network is not necessarily relevant.

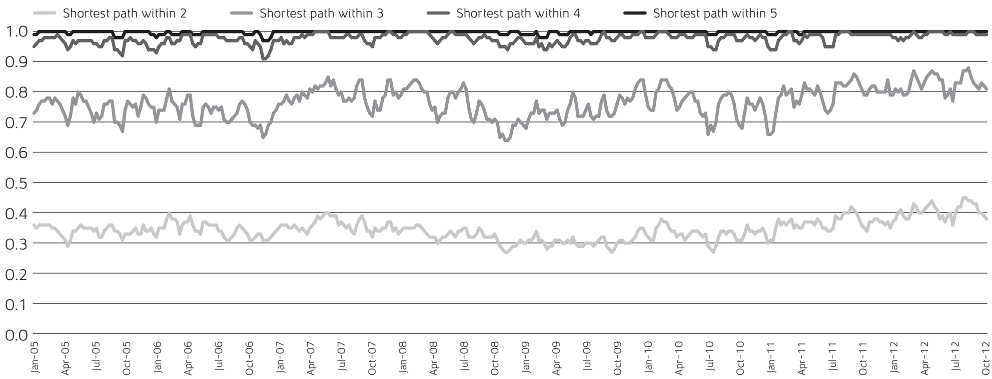
Figure 10. Dynamics of Diameter



Source: Authors' calculation

As a rule of thumb, a social network with small-world characteristics has a diameter with a maximum value of 6 (Newman, 2003). The value of the diameter is important in the identification of possible contagion. A smaller number of steps between two institutions means a higher probability of contagious effects between them. The diameter proved to be very stable over time in the observed market. The average diameter was 5.3. In 314 of the 370 observed weeks, the diameter was 5 or 6. It reached its maximum level of 8 once in October 2008, and it was also rare for the diameter to be as low as 4 or as high as 7. That it reached its maximum during the escalation of the crisis is not a surprise. Since the average degree decreased, reaching one node from another became more difficult than before. Although the ratio is relatively stable, its average level declined somewhat after autumn 2010. This confirms our view that it was mainly marginal players in the market who left the network (Figure 10).

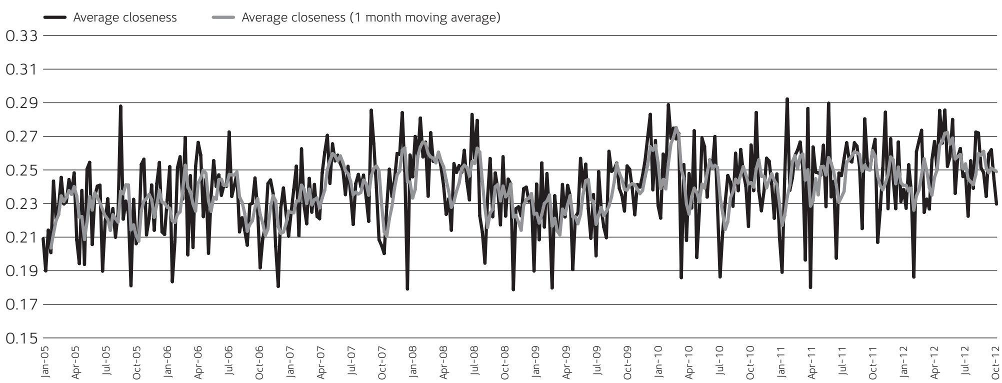
Figure 11. Mass Distance Function



Source: Authors' calculation

The mass distance function also confirms the views above. The small-world characteristic of a network means not only that it has a relatively low diameter, but that the distances between nodes are short as well. According to the mass distance function (Figure 11), 30–40 per cent of pairs of nodes are within two steps, while 70–80 per cent are within three. Less than 10 per cent of node-pairs have more than four steps' distance between them. Pair of nodes further from each other represent a constant proportion in the network, but the role of pairs within two or three steps became more dominant from autumn 2010. This tendency may be explained by the exit of marginal banks. Since they have few partners, it can be difficult for them to reach other marginal players.

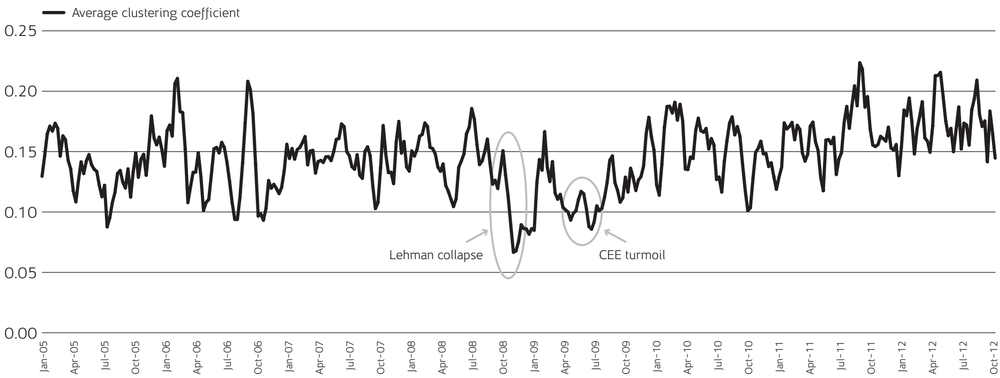
Figure 12. Average Closeness



Source: Authors' calculation

According to Berlinger et al. (2011), in the case of the unsecured interbank market, the average closeness was the first ratio which changed as a reaction to the crisis. Although it had a very high level, above 0.5, it started to decrease in late 2006 and reached the level of 0.4 in 2009. Both the level and the tendency differed in the network of the FX swap market. Along with the problems in developed markets, the ratio changed. From the end of 2007 until the Lehman collapse, average closeness increased. This implies that the growing number of participants were relatively active. Somewhat before the Lehman default, a significant change started. In accordance with the fall in average degree, the decline of average closeness shows that it became harder to find a way between two nodes. The rise of the ratio from autumn 2010 confirms our view about the exit of marginal players (Figure 12).[8]

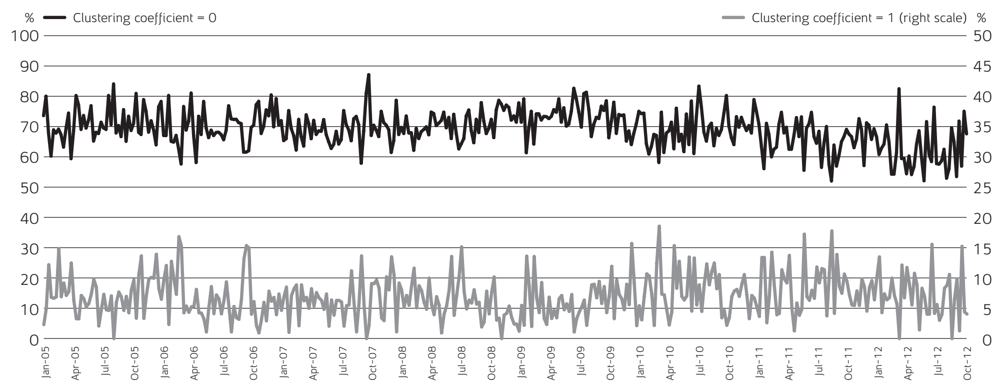
Figure 13. Average Clustering Coefficient



Source: Authors' calculation

From a stability point of view, the clustering coefficient is an important ratio both on a systemic and an individual level. This ratio shows how frequently it is that partners of an institution do business with each other. During the periods of most severe stress (e.g. the aftermath of the Lehman collapse, and the CEE turmoil in 2009), the clustering coefficient decreased significantly. Diminishing clustering in those periods implies the strengthening of distrust between banks. From the end of 2010 the ratio increased constantly, which supports our idea about the exiting players (Figure 13).

Figure 14. Proportion of Nodes in the Network with Clustering Coefficients Equal to 1 or 0

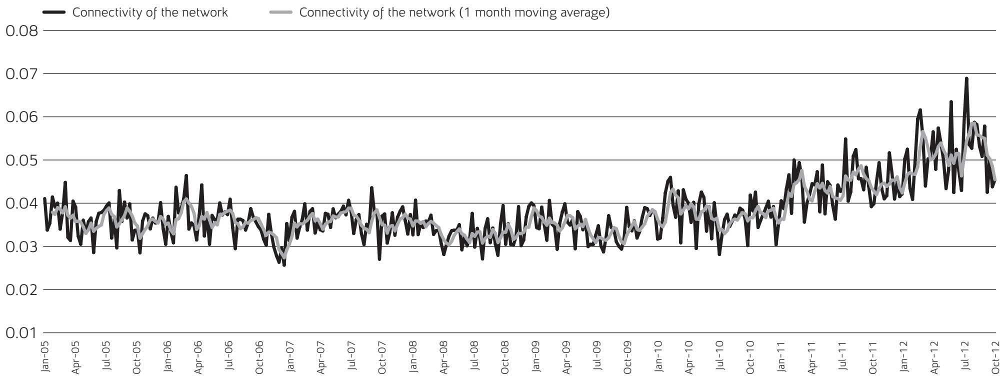


Source: Authors' calculation

[8] We also counted average closeness using another method. Accordingly, we took the reciprocal of the average shortest paths, instead of taking the reciprocal of the maximum shortest path. We found the same tendency in both cases.

Nodes with clustering coefficients totaling 1 or 0 usually have a low degree, according to several papers (e. g. Soramäki et al., 2006). The probability of an existing connection between all the partners of a high degree bank is very low; thus they have clustering coefficients lower than 1. But some partners are usually connected, so the clustering coefficients of high-degree participants are higher than 0. In financial networks, nodes with clustering coefficients that equal 0 or 1 are usually dominant. This is true of our network. The proportion of this kind of node is 80 per cent. The proportion of banks with clustering coefficients that equal 1 fluctuated around 5 to 10 per cent, while nodes with 0 clustering coefficients became more dominant, confirming our big picture (Figure 14).

Figure 15. Connectivity



Source: Authors' calculation

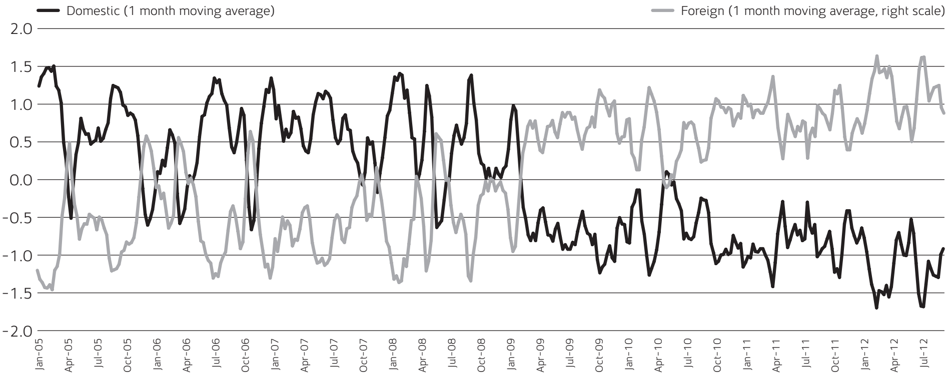
An important characteristic of the network structure is the dynamics of its connectivity. The ratio was relatively stable until the summer of 2010 (except for some minor swings). Parallel with the other measures, the second half of 2010 was a turning point. Connectivity started an increasing trend from that time, mainly due to the dropping out of low-degree nodes (Figure 15). When a marginal player exits, the number of edges in the network (the numerator of the ratio) is almost constant but the number of possible edges (the denominator of the ratio) decreases significantly.

Table 2. Activity of Domestic and Foreign Participants on the Spot Leg of 1–2 Days FX Swap Contracts (Billion HUF)

	Domestic		Foreign	
	Pay HUF	Borrow HUF	Pay HUF	Borrow HUF
2007	63,338	42,056	27,873	49,155
2008	59,400	55,458	40,998	44,940
2009	39,019	62,517	44,633	21,135
2010	36,696	60,216	41,986	18,466
2011	28,083	53,891	39,558	13,749

Source: Authors' calculation

Figure 16. Average Degree of Domestic and Foreign Participants by Netting "in" and "out" Edges



Note: We were netting the number of "out" and "in" edges, i.e. it can be seen which direction is in the majority at each bank. A positive number means that on the spot leg, the bank pays HUF and receives FX.

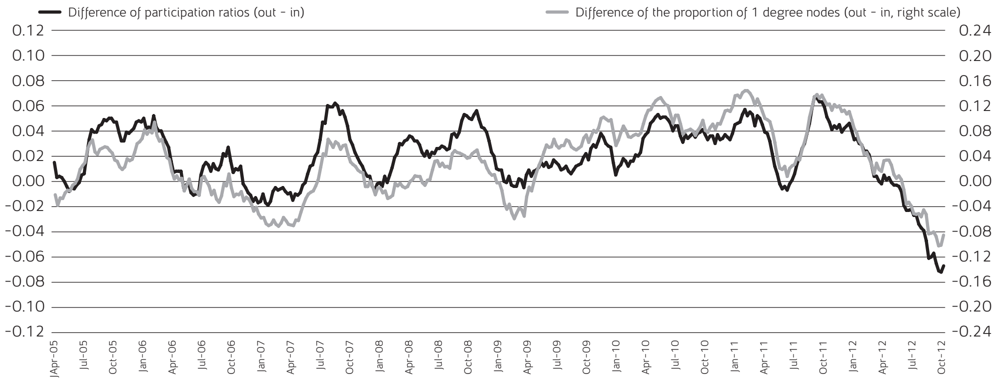
Source: Authors' calculation

So far we have focused only on the connection between banks. In the following section, directions are the focus. It has been shown that before the crisis, very short-term swaps were mainly used by domestic banks for obtaining foreign currency liquidity. After the onset of the crisis, this tendency changed and banks raised more and more foreign currency liquidity in longer term FX swap markets. 1–2 days FX swaps were used to manage their excess foreign currency. According to Table 2, in 2007–08 Hungarian banks mainly paid HUF on the spot leg of FX swaps, while foreign partners received HUF on the spot leg. From 2009 we observed the opposite direction. This idea is supported by examination of the edges' direction. From spring 2009 foreign banks mainly received foreign currency on the spot leg (Figure 16).

As we mentioned above, the participation ratio shows how each bank differs in the size of the contracts between its partners. It is a kind of concentration ratio, which is close to 1 when concentration is high, and close to 0 when the bank has the same-sized contracts with all of its partners. Several papers have found that in the case of interbank deposit markets, concentration can be different for the lender and the borrower. Iori et al. (2008) showed that the participation ratio is higher for lenders than for borrowers. According to their explanation, lenders choose their partner because they are running a credit risk. This difference may disappear when the partner itself becomes less important for liquidity management reasons. In the Portuguese interbank market, when the liquidity of the system decreased, lenders distinguished more between their partners (Cocco et al., 2003).

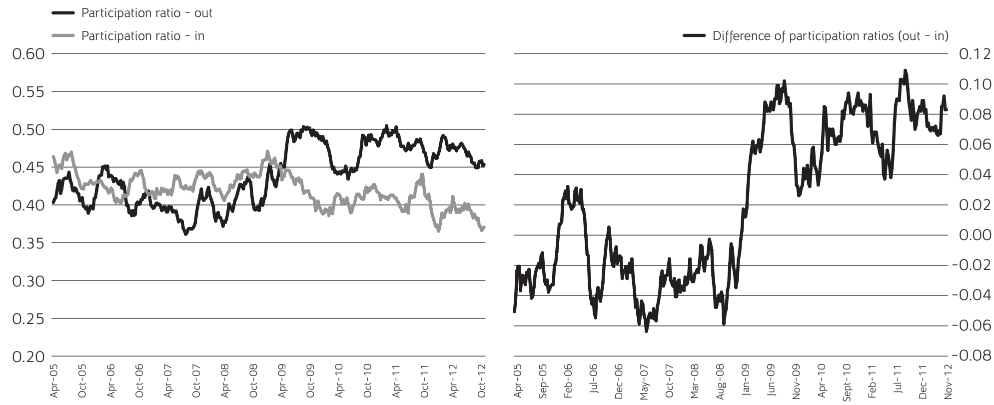
Participants in the swap market run a relatively low credit risk, which would imply that there is no significant difference between the participation ratio of those who pay HUF on the spot leg and those who receive HUF. Simply counting the ratio, we can see that the participation ratio is mostly higher on the paying side (i.e. the "out" edges). This difference is the result of the counting method. According to our observations, many banks only have one partner. Of course their participation ratio is 1, although many of them do not have low limits compared with other participants in the market. The average participation ratio depends on the proportion of 1 degree nodes (Figure 17).

Figure 17. Differences of Participation Ratios and Proportions of 1 Degree Nodes



Source: Authors' calculation

Figure 18. Dynamics of Participation Ratios and their Difference



Source: Authors' calculation

We have also counted this ratio, excluding the one-degree nodes to eliminate this distortion. The "in" and "out" sides (or in other words the "receiver" and "payer") differed significantly before and after 2009. While before 2009 the receiver side was usually higher, from 2009 the payer side exceeded the receiver side significantly. In addition, the difference in absolute terms became much greater. As we have seen, parallel with this change, domestic banks became dominant on the receiver side. All this implies that the foreign banks' behavior is characterized by preferential trading. After 2009 the foreign banks became more rigorous in their selection of partners (Figure 18).

5. Conclusions

Since the onset of the crisis in 2007, some major disturbances could be observed in the financial markets. Some markets dried up, and central bank interventions were needed to mitigate the negative effects on the banking system. As a result of this crisis, severe turmoil was experienced, even in the FX swap markets (which are secured) around the world. For this reason, central banks concluded several bilateral swap line agreements, and played the role of "FX lender of last resort". This was true of Hungary as well. The operation of the government bond market, the interbank deposit market, and the FX swap market was stalled in some periods of the crisis. Issues can be identified not only in the dynamics of ordinary market measures (e.g. implied yield, liquidity indices, turnover) but in the change in the market's network structure.

We did not find any paper that focuses on the network structure of the FX swap market, even in the international literature. In our paper, we have illustrated the main characteristics of the FX swap market's network structure. We have seen that the network is not always connected based on a one– or two-week frequency. This may be explained by the fact that in many cases, some banks do business only with their parent institutions. Our analysis of the largest connected component has shown that the usual characteristics of financial networks also apply to the FX swap market. The network's degree distribution follows the power law. Most participants have few connections, and the number of high-degree nodes is very low. The core of the network is composed of these high-degree nodes, which work as intermediaries between other nodes. This result corresponds to our knowledge that some Hungarian banks are market makers. The market is a so-called "small-world" network, i.e. every node can be reached from any other node in a relatively small number of steps. The small-world characteristic can be considered a risk factor from a stability point of view. It means that the market is very sensitive to shocks to the central institutions. For this reason, the central bank has to have a special focus on these banks.

Some of the ratios were constant during the observed period, so these characteristics did not change significantly (e.g. average closeness, diameter). However, some other characteristics varied over time, although the credit risk of FX swaps is marginal. The dynamics of the participation ratio show that preferential trading existed in this market – although an FX swap transaction is secured – and that selection at foreign banks is stricter than at their Hungarian counterparties. This selection among partners has become more evident since 2009. These results mean that credit risk is not only the reason behind significant changes in network structures. This implies that roll-over risk can have the same importance, especially at crisis times. The size of the network changed significantly. From summer 2007 it increased, which can be explained by decoupling theory. It is also possible that the FX swap market was used instead of the interbank deposit market. After the Lehman collapse, the size of the network suddenly fell significantly, then from autumn 2010 a decreasing trend started. It is unknown what kind of institutions left the market or decreased their activity in autumn 2008, since the network measures did not change significantly. But the dynamics of the ratios from the second half of 2010 implies that the decrease in size was the result of marginal players' exit (e.g. this is shown by the mass distance function, the clustering coefficient, and connectivity).[9] Decreasing activity is a negative phenomenon, since the small number of participants increase the risk of drying up. The existence of a stable core of the market is still a key issue for the Hungarian economy.

[9] We did not analyze in detail the trends for longer FX swap markets, but their size decreased slightly, so the dynamics of the 1–2 days FX swap market cannot be explained by higher activity in longer term markets.

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