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FRICTIONS IN CREDIT MARKETS

by

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CENTRAL EUROPEAN UNIVERSITY
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DISCLOSURE OF CO-AUTHORS CONTRIBUTION

Title of paper: In Lands of Foreign Currency Credit, Bank Lending Channels Run Through?

Co-authors: Steven Ongena and Ibolya Schindele

The nature of the cooperation and the roles of the individual co-authors and approximate share of each co-author in the joint work: The paper was developed in cooperation with Steven Ongena and Ibolya Schindele. Steven invented the identification strategy and worked mostly on writing, he worked out the structure and the logic of the paper. Ibolya participated in writing, programming and regressions analysis. My main contribution is in data management, programming and regressions analysis.

10.14754/CEU.2016.04

Abstract

This thesis consists of one co-authored and two single-authored chapters; each investigates some friction in the credit market. The first chapter is an empirical one; it isolates the effect of the foreign currency on the loan performance of firms borrowing in different currencies in crisis time. I use a novel micro-level dataset from Hungary to decompose the factors contributing to the higher loan deterioration of foreign currency borrowers compared to local currency debtors. The results suggest that foreign currency denomination can increase the default probability considerably (even by 7 percentage points). Hence regulators should pay more attention to loans denominated in safe haven currencies, since they harm particularly in bad times.

The second chapter is also empirical and is co-authored with Steven Ongena and Ibolya Schindele. It studies the impact of monetary policy on the supply of bank credit when bank lending is also denominated in foreign currencies. Accessing a comprehensive supervisory dataset from Hungary, we find that the supply of bank credit in a foreign currency is less sensitive to changes in domestic monetary conditions than the equivalent supply in the domestic currency. Changes in foreign monetary conditions similarly affect bank lending more in the foreign than in the domestic currency. Hence when banks lend in multiple currencies the domestic bank lending channel is weakened and international bank lending channels become operational.

The third chapter is a theoretical piece. It extends the standard global games framework by introducing an addition target on which agents can coordinate on. Global games are appropriate to model economic situations where agents have incentive to coordinate on some action, but due to incomplete information perfect coordination fails. I compare the multidimensional case to the standard global games problem. Furthermore, I investigate the effects of consolidating the multiple targets. I find that introducing an additional option generates a negative strategic correlation between the options and thus weakens the coordination. However, unifying the options eliminates the endogenous correlation and

thus restores the coordination. I also show two potential applications to be modeled by the multidimensional global games framework.

Chapter 1: Why Do Firms Default on Their Foreign Currency Loans? The Case of Hungary

Chapter 1 analyzes the factors contributing to the decline in loan quality of firms borrowing in different currencies during the 2008 crisis. I study a micro level dataset covering all firms with bank loan in Hungary. I assess what part of the change in the default rate is due to foreign currency denomination and to other effects of the crisis.

I find that the foreign currency denomination can increase the default probability considerably. For firms borrowing in Swiss Franc the currency effect varies between 0.7 percentage points and 7 percentage points, thus it accounts for 22%-42% of the overall default change. In case of firms with Euro loan the effect varies between -0.2 and 1.7 percentage points and thus run to -9%-18% of the overall default change. A large part of this effect is attributed the exchange rate volatility, and indeed, the Hungarian Forint depreciated more against the Swiss Franc than against the Euro.

The comparison of the currency borrower groups shows that not only the currency effect, but also the other crisis effects are the highest for firms with Swiss Franc loan. Hence loans denominated in foreign currency afflicted exactly those companies the most who were also hit the hardest by the crisis. These correlated shocks caused the salient decline in loan quality of the Swiss Franc borrowers.

These results highlight the importance of regulating the borrowing in safe haven currencies. In emerging countries the loans denominated in safe haven currencies are often popular during credit boom periods, since they are typically cheaper than credit denominated in local currencies. However, in a crisis the safe haven currencies appreciate to the local currency and thus the debt burden of their borrowers increases. Thus, these loans are advantageous in good times and harmful in bad times.

Chapter 2: In Lands of Foreign Currency Credit, Bank Lending Channels Run Through?

Chapter 2 analyzes the differential impact of domestic and foreign monetary policy on the local supply of bank credit in domestic and foreign currencies. We analyze a novel, supervisory dataset from Hungary that records all bank lending to firms including its currency denomination. This chapter therefore takes the next obvious step in the empirical literature that identifies - with micro-data - the impact of monetary policy on the provision of credit.

Accounting for time-varying firm-specific heterogeneity in loan demand, we find that a lower domestic interest rate expands the supply of credit in the domestic but not in the foreign currency. A lower foreign interest rate on the other hand expands lending by lowly versus highly capitalized banks relatively more in the foreign than in the domestic currency.

The implications of our findings for monetary policy making are straightforward but salient. Local bank lending in foreign currencies limits the flow of the transmission of domestic monetary policy through a bank lending channel in the domestic currency only. Lending in foreign currencies is seemingly mostly unaffected by domestic monetary policy. On the other hand, monetary policies pursued by central banks abroad may affect local bank lending in these foreign currencies. Changes in foreign monetary policy, therefore, also seems to transmit to local lending, through an international bank-lending channel that changes the currency composition of the local bank loan supply. Overall, these findings suggest that calls for global monetary policy coordination even during normal times are well-founded (though difficult and unlikely given current institutional mandates).

Chapter 3: Multidimensional Global Games and Some Applications

Chapter 3 investigates the coordination aspect of multidimensional global games. Global games are coordination games with incomplete information; they have been applied to several economic situations, such as bank runs, currency crisis, and technology adoption. I extend the standard global games framework by introducing and additional coordination target.

Multidimensionality has an important consequence for the power of coordination. When there are multiple options, coordination weakens. This is due to strategic motives of agents. Agents have incentives to make mutually consistent actions. Since there are a fixed number of agents, when there are multiple options, their power is split. The more people coordinate on one option the less people there are who can potentially coordinate on the other. This generates a negative correlation between the two options which I call strategic correlation.

The key element of the model is the interaction of the coordination motives of agents to move together and the substitutability of the options. When there are multiple options,

10.14754/CEU.2016.04

each potential object of coordination, they are in fact substitutes. Thus, with multiple options the coordination disperses. However, unifying the options eliminates the coordination split and thus strengthens the power of coordination.

I show two applications which can be modeled by the multidimensional global games framework. The first application is the choice of invoicing currency of oil. In the oil market the historically established currency is the US Dollar. I show that there are situations when an agent would switch to the usage of a new currency if there were one new currency besides the US Dollar, however, would not switch if there were two other currencies. The second application is the introduction of common European bond. A common argument for joint issuance is that it smooths out idiosyncratic risk. While this argument is present in my model, there is an extra layer: joint bond issuance can make participating countries more vulnerable to speculative attacks.

10.14754/CEU.2016.04

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10.14754/CEU.2016.04

Contents

10.14754/CEU.2016.04

10.14754/CEU.2016.04

List of Tables

10.14754/CEU.2016.04

List of Figures

10.14754/CEU.2016.04

10.14754/CEU.2016.04

Chapter 1

Why Do Firms Default on Their Foreign Currency Loans? The Case of Hungary

1.1 Introduction

Excessive credit growth periods are potential threats to the financial stability. Credit booms followed by recession periods may turn into financial crises. In emerging market countries, due to the interest rate gap between the local and the major currencies, credit boom periods are often accompanied by significant foreign currency indebtedness, which potentially aggravates the crisis. This was the case during the Latin American debt crises in the 1980s, the Asian crisis in 1997-98 and the 2008 financial crisis in Central and Eastern Europe.

In this paper I isolate the effect of the foreign currency on loan performance in the example of the 2008 Hungarian episode. The basic identification challenge is that those who are selfselected to these loans might not be identical to other borrowers. My main contribution is that I decompose the higher decrease in loan quality of foreign currency borrowers into the effect of the currency and into the heterogeneity stemmed from the selection. I find that foreign currency denomination can increase the default probability considerably (even by 7 percentage points). However, the selection also contributes significantly to the default differences (by 1.4 percentage points the most).

I analyze firms in Hungary during the 2008 financial crisis and the following recession. Hungary entered the crises with more that half of the total private sector loans denominated in foreign currency. Mainly two currencies - the Euro and the Swiss Franc - were used for foreign currency lending. During the crisis Euro borrowers performed much better than firms with Swiss Franc loan. In particular, the raise in non-performing loan ratio of Swiss Franc denominated loans in the corporate sector was more than twice as big as the raise of Hungarian Forint loans. Meanwhile, the loan performance of Euro and Hungarian Forint borrowers have changed quite similarly. I investigate why there is such a big difference among currency borrower groups.

The loan performance depends on some observable characteristics which depend on the earlier currency choice of the firms. There are unobserved factors affecting both the firms' currency decision and their loan performance. I use the currency supply of the related bank as an instrument for the firms' foreign currency indebtedness. The motivation of the instrument is based on the observation that the currency denomination of loans are affected by the supply side. However, currency lending also influences the bank-firm matching process. Because of that, instruments building on the current bank-firm relationships might be correlated to the unobserved factors affecting the denomination preference of firms. Hence, I restrict the sample to firms who already have been with their banks before the foreign currency lending boom.

Overall, I find that foreign currency lending deteriorated the situation. The direct effect of the foreign currency worsen significantly the loan performance of borrowers. What is more, it afflicted exactly those companies who have performed worse even before the crisis and were also hit anyway harder by the crisis. These correlated shocks caused the salient bad loan performance of Swiss Franc borrowers.

This is the first paper which isolates the effect of the foreign currency on loan performance based on micro data. It contributes to the literature on foreign currency lending. This literature mostly focuses on the determinants of the phenomenon,[1] meanwhile also points out that risk is often involved. Regarding the demand side unhedged borrowers also take on such loans, typically because of the lower interest rates[2] and in turn run the exchange rate risk.[3] Regarding the supply side the literature shows that banks might lend more in foreign currency than would be optimal for example in case of competition for

[1]For a detail overview see Nagy et al. (2011).

[2]See, among others, Basso et al. (2011), Brown et al. (2011) and Rosenberg and Tirpák (2009) on the role of the interest rate gap in foreign currency borrowing.

[3]See for instance Barajas and Morales (2003), Luca and Petrova (2008) and Brown et al. (2011).

market shares,[4] in case of incomplete markets[5] or when banks would like to match their net open foreign currency positions.[6] The risk involved can be large,[7] though the literature mostly neglects to quantify its impact. I calculate the effect of the currency denomination and I find that the materialization of the risk is substantial.

My paper is also related to the literature which analyzes credit cycles and systematic risk. Aggregate studies show that episodes of excessive credit growth are good predictors of financial crises.[8] The literature distinguishes demand and supply driven credit expansions. The former follows the change in quality of demand.[9] The latter is caused by some malfunction in the credit supply process.[10] Foreign currency lending is often associated with credit growth periods.[11] I analyze an experience of a crisis episode following a credit growth period characterized by significant foreign currency lending. I isolate the impact of the foreign currency from the effects of the crisis. My results suggest that the currency mismatch can magnify considerable the following crisis.

This paper is also related to the literature assessing the macro-level[12] determinants of loan performance. Papers in this stream typically analyze how the macroeconomic factors (such as GDP growth, inflation, unemployment, monetary conditions or degree of loan concentration in vulnerable sectors) influence the evolution of non-performing loans. There are papers also considering the degree of foreign currency indebtedness as one of the factors. For example Beck et al. (2013) analyzing the evolution of the non-performing loan ratios of 75 countries point out that in countries with a high share of unhedged foreign currency loans, the exchange rate depreciation is related to an increase in the non-performing loan ratio. While papers in this literature build on bank or country level data, I use firm level

[4]See for example Steiner (2012).

[5]For example Brown et al. (2014a) analyze the lending behavior of a Bulgarian bank and find that the bank is unwilling to provide long-term loans denominated in the local currency.

[6]For instance this can be the case if cheap foreign funding is available (either through the market or through its parent bank) as in Bakker and Gulde (2010), Brown and De Haas (2012) and Brown et al. (2014a).

[7]Yeşin (2013) assesses the systemic risk arising from foreign currency loans in Europe and find that it is significant in the non-euro area.

[8]See for example Mendoza and Terrones (2012), Schularick and Taylor (2012) and Jordà et al. (2011).

[9]For example better net worth as in Bernanke and Gertler (1989) or better collateral as in Kiyotaki and Moore (1997).

[10]For instance bank managers with short horizons as in Rajan (1994) or banks' agency frictions as in Holmstrom and Tirole (1997) or Diamond and Rajan (2006).

[11]Mendoza and Terrones (2008) demonstrate that before the peak of the credit boom there is a raise in capital inflows which thus increases foreign currency lending as shown by Magud et al. (2014).

[12]See for example Louzis et al. (2012), Goodhart et al. (2006), Nkusu (2011) and Cifter et al. (2009).

data and analyze the example of a country with large share of foreign currency loans. My results confirm the findings of Beck et al. (2013) as I also find that foreign currency indebtedness affect significantly the loan performance.

The paper also adds to the academic literature on safe haven currencies, currencies that are expected to keep their value compared to other currencies in times of market turbulence. The literature is mostly about the origin of such currencies[13] and about determining which currencies exhibit safe haven characteristics.[14] My paper is about the consequences of borrowing in such currencies. In boom period credit denominated in safe haven currencies are typically cheaper than credit denominated in other currencies, however, they harm - through the exchange rate change - exactly when borrowers anyway have to face many difficulties.

The remainder of the paper proceeds as follows. In Section 1.2 I present the economic situation and the data. In Section 1.3 I show a general model of default and describe the empirical strategy. In Section 1.4 I discuss the results. Section 1.5 concludes.

1.2 Background and Data

In this section, first, I describe the economic situation. In particular, I briefly discuss foreign currency lending in general, then I present some related stylized facts in Hungary. Second, I describe the data. I present the sources of data that I used to compile the dataset, then I describe the sample.

1.2.1 Background

In the lead up to the 2008 financial crisis, many European transition countries experienced a credit boom accompanied by high foreign currency lending shares. Figure 1.1 shows the

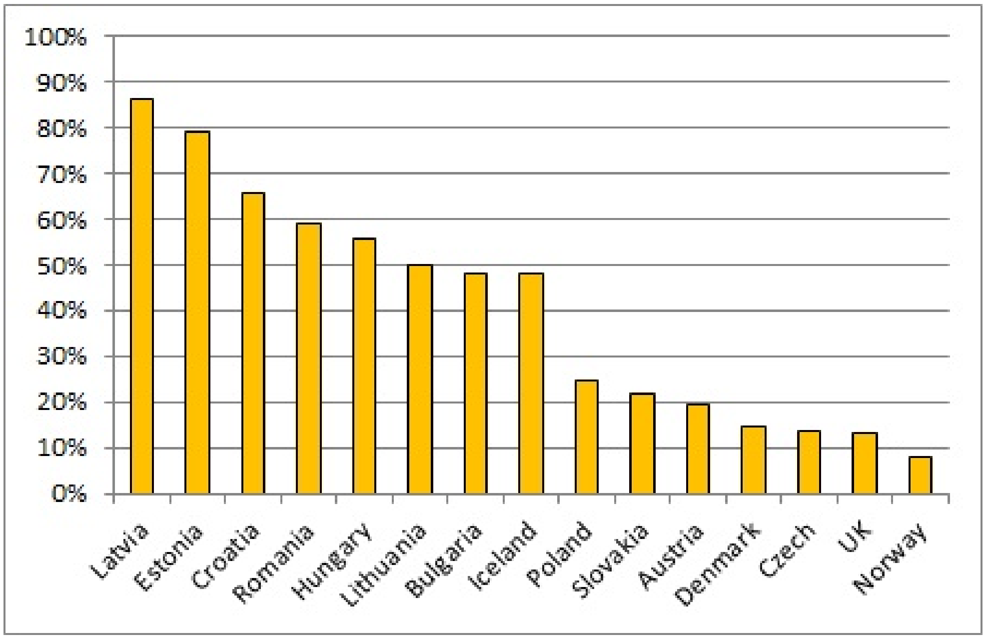
[13] One body of the literature (see for instance Clarida et al. (2009), Lustig et al. (2011) and Menkhoff et al. (2012)) argues that carry trading makes low-yield currencies appreciating during market downturns and thus they become safe haven assets. However, according to Habib and Stracca (2012) not the interest rate spread, but the net foreign asset position (an indicator of country risk and external vulnerability) determines the safe heaven status of a currency.

[14] For instance the gold, the US dollar, the Euro, the Swiss Franc and the Japanese yen are considered to be safe heavens (Baur and Lucey (2010), Coudert (2011), Kaul and Sapp (2006), Grisse and Nitschka (2015), Christiansen et al. (2011)), however, the safe haven status also changes over time (Ranaldo and Söderlind (2010)).

10.14754/CEU.2016.04

share of foreign currency loans from financial institutions to the non-bank sector in some European countries in 2007.

Figure 1.1: Share of Foreign Currency Loans in Some European Countries, 2007



NOTE. – Source: Brown et al. (2009)

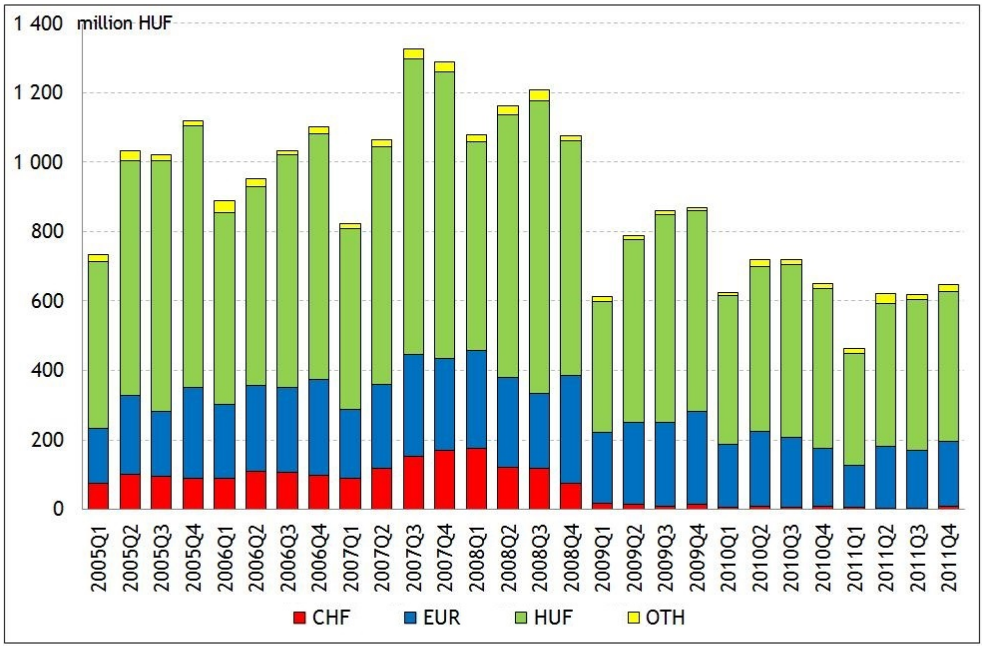
In most of the concerned countries the high foreign currency loan shares have deepened the serious economic downturn following the 2008 financial crisis.[15] The phenomenon is not new; previously we have seen similar situations in many other emerging countries. Famous examples are the Latin American debt crises in the 1980s, the Mexican financial crisis in 1994-1995 and the Asian financial crises in 1997-1998.

Hungary is also among the countries where a significant proportion of companies raised debt in foreign currency. Figure 1.2 presents the currency decomposition of new corporate loans in Hungary between 2005 and 2011. It shows that the two leading foreign currencies are the Euro and the Swiss Franc. Bank credit denominated in Euro represents the same magnitude during the observed period, while Swiss Franc lending after peaking in 2008Q1, collapsed in 2009.

[15]For example Beck et al. (2013) study the determinants of non-performing loans in 75 countries around the 2007-2008 crisis and find that the extent of foreign exchange lending is an important factor in explaining loan performance.

10.14754/CEU.2016.04

Figure 1.2: Annual Amount of New Lending to Corporations in Hungary by Currency, 2005-2011



NOTE. – The figure presents quarterly data between 2005 and 2011 on the amount of new loans (measured in million HUF) issued by banks in Hungary broken down by currency denomination.

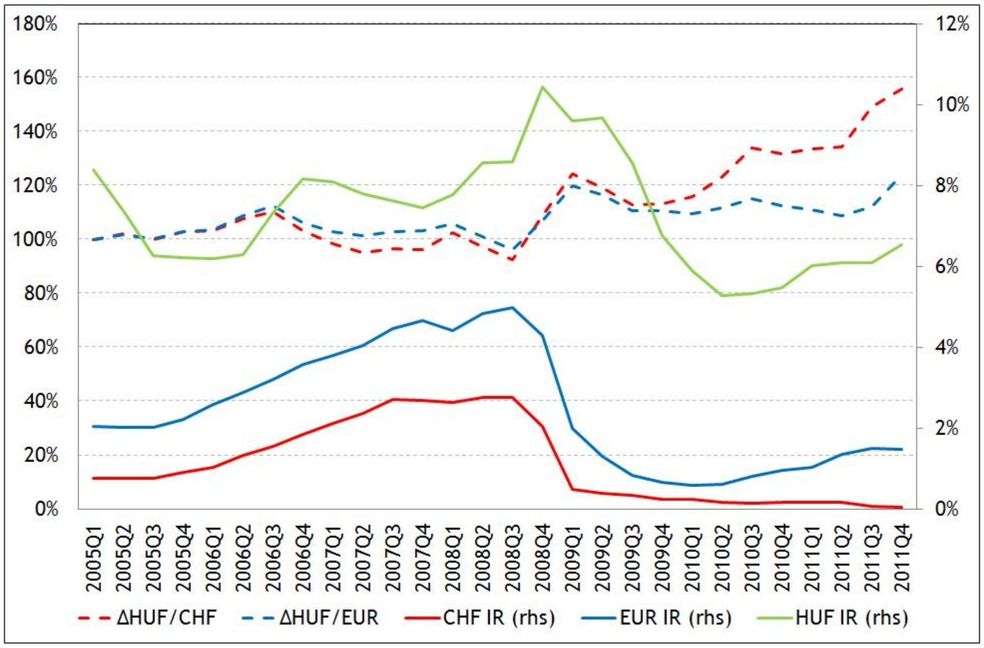
There are several factors which contributed to the popularity of the Euro and Swiss Franc denominations in Hungary.[16] On the one hand, there are demand side factors to be considered. The Euro and the Swiss Franc interest rates were lower than the Hungarian Forint interest rate and the exchange rates were rather stable (see Figure 1.3). Both of these factors increased the willingness of borrowers to choose both foreign currency denominations. Moreover, the Euro also looks a natural choice in countries willing to join the euro-zone,[17] such as Hungary. Furthermore, most of the Hungarian exports go to the Euro-zone. Thus income of exporters are mainly denominated in Euro, hence for them Euro loans are good hedging tools.

On the other hand, there are also explanations pointing to supply side factors. The majority of the banks in Hungary was foreign owned that first promoted foreign currency loans.[18] Additionally, the banking sector was concentrated and foreign currency loans

[16]For a detailed description, see Banai et al. (2011).
[17]See for instance Fidrmuc et al. (2013) or Neanidis (2010).
[18]There is evidence (see for example Beer et al. (2010), Tzanninis (2005), Waschiczek (2002)) that Swiss

became gradually the key products in the competition for market shares.

Figure 1.3: Interest Rates and Exchange Rates



NOTE. – The figure shows quarterly changes in CHF/HUF and EUR/HUF exchange rates compared to 2005Q1 (measured on the left-hand side axis) and 3-month money market HUF, CHF and EUR interest rate levels (measured on the right-hand side axis).

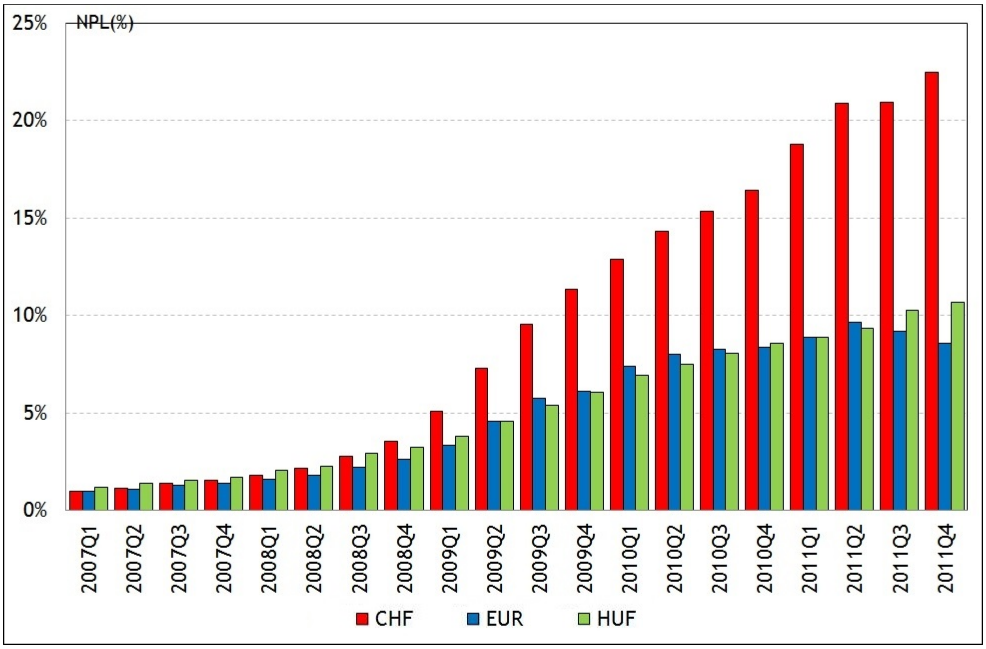
During the crisis the loan performance of Euro and Swiss Franc borrowers changed differently. Figure 1.4 shows the non-performing loan ratios for loans denominated in different currencies between 2007 and 2011. The performance of Euro loans changed rather similar to the performance of the Hungarian Forint denominated loans, while the non-performing loan ratio of Swiss Franc borrowers rose much more steeply.

1.2.2 Data

I use several data sources to compile my database. The first one is the database of the Hungarian National Tax and Customs Administration (APEH) containing the financial report (balance sheet and income statement) of all Hungarian companies with double-

Franc lending has its roots in areas of Austria close to the Swiss border. First the Swiss Franc lending practice dispersed over Austria, then multinational banks transmitted across the borders what local banks quickly adopted.

Figure 1.4: The Ratio of Non-performing Corporate Loans in Hungary by Currency, 2007-2011



NOTE. – The figure shows quarterly data between 2007 and 2011 for non-performing loan ratios (the share of the number of loans with more than 90-day delinquencies in the total loan portfolio) of banks in Hungary.

entry bookkeeping.[19] Then, data on loans is available from the Hungarian credit registry, called Central Credit Information System (KHR). It contains contract level data on all outstanding credit loans in the Hungarian banking sector. Both KHR and APEH contain the tax number of the firms through which I match the two databases. However, KHR does not contain the identity of the lender. Instead, I use the Complex firm register database to construct the firm-bank relationships. This database contains the bank account numbers of each company from which I can identify the set of banks related to each firm in any time period.[20] Finally, I complete my database with bank variables available from bank

[19]According to the Hungarian accounting rules, businesses above a certain threshold have to use double-entry bookkeeping.

[20]The first three digits of the bank account number is the GIRO code. The GIRO code is initially a unique identifier for each bank. However, in case of mergers and acquisitions the successor institution inherits the GIRO code, thus a bank might have more GIRO codes and a GIRO code might belong to different banks in different times. The Verification Table issued monthly by the Central Bank of Hungary contains the actual GIRO code-bank matches. Using the historical versions of the Verification Table I track the GIRO code-bank matches through time and thus identify in each period the bank associated with a bank account number.

regulatory reports. Figure A.1 in the Appendix sums up how the data is compiled.

My sample includes non-financial corporations with bank loan at the end of 2007 of which I have data on bank relationship and firm characteristics. I exclude firms borrowing in foreign currency other than Euro or Swiss Franc[21] in order to avoid capturing the effect of other foreign currencies. Only a minority of the firms have both Euro and Swiss Franc; I exclude them as well from the analysis.[22] The final sample consists of 51 954 individual firms and 32 banks.[23] Table 1.1 shows the composition of borrowers broken down by currency denomination of their credit.

Table 1.1: Composition of Borrowers in 2007 Broken Down by Currency Denomination of Their Loans

Group 1	Group 2		Group 3		Excluded		
HUF	CHF	CHF,HUF	EUR	EUR,HUF	CHF,EUR	CHF,EUR, HUF	Total
37 651	4 163	3 998	2 736	3 406	374	863	53 191

NOTE. – The table reports the composition of 2007-year borrowers based on the currency denomination of their loan.

I categorize the borrowing firms into three groups according to the denomination of their loans. Firms with only Hungarian Forint loans belong to the first group. The second group contains firms with any Swiss Franc loan, that is those firms who have only Swiss Franc loans or have both Swiss Franc and Hungarian Forint loans. The third category consists of Euro borrowers, that is firms with only Euro or with both Euro and Hungarian Forint loans. I refer to the three groups as Hungarian Forint, Swiss Franc and Euro borrowers, respectively. Table 1.2 shows the 2007 end-of-year summary statistics of the borrower firms and of their banks by currency group.[24]

Firms with Euro loan export more on average, are owned by foreigners with higher probability, bigger than their peers both in terms of total assets and number of employees,

[21]Only 0.6% of all borrower firms have loan denominated in other foreign currency. The results are robust to their inclusion.

[22]Neither duplicating the observations, then assigning them both to the group of Euro borrowers and to the group of Swiss Franc borrowers, nor randomly assigning them to either the Euro or the Swiss Franc borrowers alter my findings.

[23]I use the label bank both for commercial banks and branch offices of foreign banks. Although these two groups have different legal status, they operate alike in terms of lending. Note, however, that my sample does not cover saving cooperatives since they differ in many relevant aspects. Saving cooperatives are typically rural institutions with special clientele and more limited range of services. They give only 3-4% of corporate lending and less than 1% of foreign currency corporate lending.

[24]The definition of the variables is found in Table A.1 in the Appendix.

Table 1.2: Summary Statistics

	Group 1 (HUF)			Group 2 (CHF)			Group 3 (EUR)		
Variable	Mean	Std.	Median	Mean	Std.	Median	Mean	Std.	Median
Export Sales Ratio	0.04	0.16	0.00	0.02	0.11	0.00	0.20	0.32	0.00
Foreign Ownership	0.05	0.23	0.00	0.03	0.17	0.00	0.27	0.44	0.00
Capital Ratio	0.40	0.29	0.37	0.29	0.24	0.25	0.32	0.25	0.29
Liquidity Ratio	0.63	0.30	0.69	0.50	0.30	0.49	0.49	0.30	0.48
Ln(Total Assets)	10.53	1.91	10.48	11.19	1.65	11.20	12.70	1.69	12.83
ROA	-0.04	0.69	0.02	-0.02	0.41	0.02	-0.01	0.47	0.01
Ln(Num.of Employees)	1.52	1.25	1.39	1.69	1.24	1.61	2.54	1.58	2.64
Ln(Age)	2.02	0.60	2.08	2.05	0.58	2.08	2.22	0.59	2.40
Switcher	1.32	0.60	1.00	1.36	0.58	1.00	1.84	0.91	2.00
Number of Banks	1.64	0.89	1.00	1.85	0.99	2.00	2.03	1.22	2.00
Bank Foreign Ownership	0.86	0.28	1.00	0.78	0.33	1.00	0.83	0.29	1.00
Ln(Bank Total Assets)	14.42	0.79	14.59	14.38	0.73	14.56	14.19	0.83	14.52
Bank Capital Ratio	0.09	0.04	0.08	0.08	0.02	0.08	0.08	0.04	0.08
Bank Liquidity Ratio	0.13	0.05	0.12	0.13	0.04	0.12	0.14	0.06	0.12
Bank ROA	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01
Bank Doubtful Loans	0.29	0.03	0.29	0.29	0.03	0.29	0.28	0.02	0.28

NOTE. – The table reports summary statistics of firms with only Hungarian Forint, with Swiss Franc and with Euro loan in 2007. The statistics are based on the 2007 end-of-year financial statement data. The definition of the variables is found in Table A.1 in the Appendix. The number of banks in our sample is 32. The number of firms in our sample is 51 954.

more profitable, elder, less liquid and have more bank relationships than their peers. Swiss Franc borrowers export less, are owned by foreigners with smaller probability and are less capitalized than other firms. Hungarian Forint borrowers are more capitalized, more liquid, less profitable, smaller, younger and have fewer bank relationships than their peers.

I analyze how the loan performance of firms with bank credit at the end of 2007[25] changes in the subsequent 4 years. My indicator of loan performance is the so called default. A firm is defined to be in default or to be non-performing if it has loan with more than 90-day delinquency. I am interested in how the ratio of firms in default for each currency borrower group changes between 2008 and 2011. Table 1.3 shows the default ratios of 2007-year borrowers from 2007 to 2011 by currency groups. In each year the Swiss Franc borrower group has the highest default ratio and the Hungarian Forint borrowers have the lowest.

[25] I choose 2007/2008 as the turning point since in Hungary the crisis started to escalate in the fall of 2008, thus the 2008 variables might have been already affected by the crisis.

Table 1.3: The Default Ratios of 2007-year Borrowers, 2007-2011

	HUF	CHF	EUR
2007	0.87%	1.18%	0.94%
2008	2.64%	4.63%	3.39%
2009	5.20%	10.16%	6.78%
2010	7.74%	14.50%	9.85%
2011	9.66%	17.59%	11.73%

NOTE. – The table reports from 2007 to 2011 the default ratio of firms with only Hungarian Forint, with Swiss Franc and with Euro loan in 2007

1.3 Empirical Strategy

1.3.1 General Model of Default

In this section I present a 2-period default model.[26] The first period ($t = 1$) represents normal times, the second period ($t = 2$) stands for crisis times. There are N number of firms denoted by i. Some of the firms borrow only in the local currency, while others also borrow in foreign currency.

Consider the following model of default by firm i at period t:

$$def_{it} = \beta_t X_{it} + \varepsilon_{it} \tag{1.1}$$

where def_{it} is an indicator variable for weather firm i is in default at time t. On the right hand side X_{it} is a vector of firm characteristics for firm i in period t. The time-series behavior of the firm-characteristics can be characterized by the following equation:

$$X_{i2} = \mu X_{i1} + \delta FX_i + \epsilon_i \tag{1.2}$$

where FX_i is an indicator variable for firm i having a foreign currency loan. That is, the default does not depend directly on the foreign currency indebtedness, only on other firm characteristics. However, the firm characteristics at a given period depend on their previous period realization and also on the firm's currency indebtedness.[27] Hence the second period

[26] The model can be generalized to multiple periods which I show in Appendix B.2.

[27] A straightforward example is that due to the exchange rate changes the leverage ratio of a firm changes differently if its loan is denominated in foreign currency.

default can also be characterized by the first period firm characteristics and the firm's currency indebtedness. This can be seen if we plug in equation (1.2) into equation (1.1) at $t = 2$:

$$def_{i2} = \beta_2 \mu X_{i1} + \beta_2 \delta FX_i + (\beta_2 \epsilon_i + \varepsilon_{i2}) \tag{1.3}$$

I focus on the change in default from the first to the second period:

$$\Delta def_i \equiv def_{i2} - def_{i1} = (\beta_2 \mu - \beta_1) X_{i1} + \beta_2 \delta FX_i + (\beta_2 \epsilon_i + \varepsilon_{i2} - \varepsilon_{i1}) \tag{1.4}$$

I am primarily interested in the $\beta_2 \delta$ term which is the part attributed directly to the loan denomination. The characteristics of foreign currency borrower firms change differently (this effect is given by δ), which then affect their default probability in the consecutive period (which is represented by β_2). I label this factor as the direct effect of foreign currency. The remaining part of the change in group default ratio can be attributed to other effects of the crisis. Based on the Blinder-Oaxaca decomposition[28] it can be broken down into two parts, on the one hand the financials (X_{it}) are altered by factors other than the foreign currency, on the other hand the valuation of the financials (β_{it}) changes as well. The first would be given by $\beta_2(\mu - 1)X_{i1}$, the second by $(\beta_2 - \beta_1)X_{i1}$.

I assume that in the initial period the set of firm characteristics, X_{i1}, are exogenous to the default probability def_{i1}. However, there might be unobserved heterogeneity across currency borrower groups, both in terms of default and in terms of the evolution of firm characteristics. That is, the error terms ϵ_i and ε_i are potentially correlated with FX_i and therefore with X_{i2}. Hence estimating the direct effect of the foreign currency from equation (1.3) or (1.4) would give biased estimates.

I address this problem by applying an instrumental variable approach. I estimate equation (1.3) using a measure of currency supply of the bank related to firm i as an instrument for the foreign currency indebtedness of firm i. The motivation of the instrument is based on the observation that the currency denomination of loans is affected by the supply side. However, currency lending also affects the bank-firm matching process. Because of that, instrument building on the current bank-firm relationships might be correlated to the unobserved factors affecting the denomination preference of firms. Hence, I restrict the sample to firms who have already been with their banks before the foreign currency lending boom,

[28]See the works of Blinder (1973) and Oaxaca (1973).

10.14754/CEU.2016.04

in particular, I include only firms that have not established new bank relationships since 2005.

In the following subsections I discuss in more detail the choice of instrument. In Subsection 1.3.2 I investigate whether foreign currency lending affected the bank-affiliation of firms. Then in Subsection 1.3.3 I motivate the instrument by presenting the potential demand and supply side explanations of foreign currency lending then I present some evidence on the validity of the chosen instrument.

1.3.2 Bank-Firm Relationship

In this subsection I investigate whether foreign currency lending had effect on the bank-affiliation of firms. If firms go to banks where they can borrow easily in foreign currency, then we should see that those who would like to borrow in foreign currency switches banks with higher probability and thus the currency demand of new and old clients should be different. However, banks handle new clients differently (e.g. due to information asymmetry), which would confound the comparison of new and old clients. Thus, instead I compare new clients who decide to go to the bank and new clients who get to the bank involuntarily.

I study a bank acquisition, which took place at the end of 2007. In 2007 the acquirer bank lent more both in Swiss Franc and in Euro (16.3% and 36.7% of its extended credit was denominated in Swiss Franc and in Euro, respectively) than an average bank (10.6% Swiss Franc and 29.8% Euro share) or the acquired bank (5.1% Swiss Franc and 30.4% Euro share). This suggests that the clients of the acquirer bank get a loan denominated in foreign currency with higher probability. I analyze the currency choice[29] of the clients of the acquirer bank in 2008, the year right after the acquisition. I differentiate old clients, new clients who decide to go to the bank and clients inherited from the acquired bank. I apply a multinomial logit estimator to model their denomination choice. The potential outcomes are the three denomination based categories, that is $J \in \{HUF, EUR, CHF\}$. The probability that firm i borrows in currency J is given by the following multinomial logit regression:

[29] I separate the choice of borrowing from the choice of currency denomination. Therefore, I concentrate on companies taking loan in 2008 and thus exclude firms not borrowing in that year from the sample.

$$\Pr(y_i = J) = \frac{\exp(\theta_1^J \mathit{Self\text{-}Newcomer}_i + \theta_2^J \mathit{Acquired}_i + \beta^J X_i)}{\sum_{K \in \{HUF,EUR,CHF\}} \exp(\theta_1^K \mathit{Self\text{-}Newcomer}_i + \theta_2^K \mathit{Acquired}_i + \beta^K X_i)} \tag{1.5}$$

where y_i is the currency group where firm i belongs to, based on the currency structure of its 2008-year new loans. The $\mathit{Self\text{-}Newcomer}$ dummy indicates companies deciding to go to the bank of their own accord in 2008. The *Acquired* dummy represents the clients inherited from the acquired bank. X_i is a set of firm characteristics corresponding to firm i at the end of 2007, in particular firm sector dummies, export sales ratio, foreign ownership, size, capital ratio, liquidity, profitability and age.

Table A.2 in the Appendix presents the results. I report the marginal effects of each covariate evaluated at the mean of the explanatory variables. The marginal effects show the change in the probability of observing a given outcome resulted from a small change in a covariate (a change from 0 to 1 for dummy variables), holding all other explanatory variables constant, in this case at their mean. Compared to old clients, self-newcomers borrow in Swiss Franc with a higher relative probability, while acquired clients do not borrow significantly more in Swiss Franc. This suggests that firms go to the bank with the intention of getting Swiss Franc denominated loans, which proves that the bank-firm matching is indeed affected by foreign currency lending.

1.3.3 Supply Effect

The instrument builds on the assumption that the banking sector also encouraged foreign currency loans. In this section I investigate this assumption. In particular, I test whether the lending practice of the banks influences the denomination choice of their clients. I compare two otherwise identical firms who are related to different banks. I show that the currency lending practice of the affiliated bank predicts the currency choice of the firm.

I apply a multinomial logit estimator to model the possible denomination outcomes. The potential outcomes are the three denomination based categories, that is $J \in \{HUF, EUR, CHF\}$. The probability that the currency structure of the outstanding loans of firm i in year t falls into category J is given by the multinomial logit regression as follows:

$$\Pr(y_{i,t}=J)=\frac{\exp(\theta^J_{CHF} Bank\ CHF_{i,t-1}+\theta^J_{EUR} Bank\ EUR_{i,t-1}+\beta^J X_{i,t-1})}{\sum_{K\in\{HUF,EUR,CHF\}}\exp(\theta^K_{CHF} Bank\ CHF_{i,t-1}+\theta^K_{EUR} Bank\ EUR_{i,t-1}+\beta^K X_{i,t-1})} \tag{1.6}$$

where $y_{i,t}$ is the currency group where firm i belongs to in year t based on the currency structure of its outstanding loans. The $Bank\ CHF_{i,t}$ and the $Bank\ EUR_{i,t}$ variables are the share of the Swiss Franc and the share of the Euro in the credit portfolio of the bank of firm i in year t.[30] Then $X_{i,t}$ includes a set of firm characteristics corresponding to firm i at the end of year t, in particular, I include the following firm specific variables: sector dummies, firm export sales ratio, foreign ownership, size, capital ratio, liquidity, profitability and age. I also include year fixed effects.

If bank-firm relationships were exogenous, the coefficients of $Bank\ CHF$ and $Bank\ EUR$ would purely capture supply side effects. However, Subsection 1.3.2 showed that foreign currency lending affects the evolution of bank-firm relationships. A company which is more willing to lend in foreign currency is more willing to choose a bank who lends more in foreign currency. If there are unobserved factors affecting both the currency and the bank choice of firms, the parameter estimates will be biased. In order to get around this problem, instead of the current relationships, I use bank-firm connections established not later than 2003.[31] The variables are thus the share of currency in the credit portfolio of the bank that had already been related to the firm before 2003.

Table A.3 in the Appendix presents the results. I report the marginal effects of each covariate evaluated at the mean of the explanatory variables. The higher share of a foreign currency in the credit portfolio of a bank makes the clients of the bank more likely to borrow in that currency. This suggests a supply side push of foreign currency loans, hence the currency choice decomposition of banks are different not only because banks have different clientele, but also because banks provide foreign currency denominated loans with different intensity. An interesting observation is that when a firm is related to a bank which is lending more in Swiss Franc, then the firm borrows in Euro with higher

[30]If a firm has multiple bank relationships I use the average characteristics of the related banks.

[31]The results are robust to using earlier years. However, there is a trade-off: using earlier bank-firm connections on the one hand reduces the likelihood of endogenous bank-firm relationships, on the other hand increases the probability of selection bias by eliminating firms younger than the chosen time lag.

probability, while the reverse is not true.

1.4 Results

1.4.1 Direct Effect of the Foreign Currency

In this section I concentrate on the direct effect of foreign currency loan to the change of the default ratio. I use an instrumental variable approach to estimate this effect.

Based on equation (1.3) I estimate the following model for $t = \{2008, 2009, 2010, 2011\}$

$$def_{it} = \beta_t \mu X_{i2007} + \lambda_{EUR,t} EUR\ ratio_{i2007} + \lambda_{CHF,t} CHF\ ratio_{i2007} + \eta_{it} \tag{1.7}$$

where def_{it} is a dummy for default in year t. X_{i2007} is a set of firm variables for firm i at the end of year 2007 (in particular, firm sector dummies, export sales ratio, foreign ownership, size, capital ratio, liquidity, profitability, age, indicator for a new bank relationship). Then $EUR\ ratio_{i2007}$ and $CHF\ ratio_{i2007}$ are the share of loans denominated in Euro and in Swiss Franc, respectively. After estimating the model the average direct foreign currency effects can be calculated by multiplying the estimated $\lambda_{EUR,t}$ and $\lambda_{CHF,t}$ coefficients with the average $EUR\ ratio_{i2007}$ and $CHF\ ratio_{i2007}$ ratios, respectively.

However, as I have already pointed out earlier, there are unobserved factors affecting both the riskiness of firms and their currency choice. For example, firms with financially less qualified management are expected to borrow more[32] in foreign currency and also to be per se riskier. Thus, I apply an instrumental variable approach to address this endogeneity problem. In particular, I instrument the foreign currency share of borrowers ($EUR\ ratio_{i2007}$ and $CHF\ ratio_{i2007}$) with bank fixed effects interacted with the year-of-borrowing. The motivation of the instrument is based on the observation that the currency denomination of loans is affected by the supply side as shown in Subsection 1.3.3. However, currency lending also affects the bank-firm matching process as shown in Subsection 1.3.2. Because of that, instruments building on the current bank-firm relationships might be correlated to the unobserved factors affecting the denomination preference of firms. Hence, I restrict the sample to firms who have already been with their banks before the foreign currency lending boom, in particular, I include only firms that have not established new bank relationships since 2005.

[32]See for example Beckmann and Stix (2015).

Table 1.4 reports the estimated $\lambda_{CHF,t}$ and $\lambda_{EUR,t}$ parameters from the IV estimation of equation (1.3). The estimates of $\lambda_{CHF,t}$ for $t = \{2009, 2010, 2011\}$ are positive and significant. Among the estimates of $\lambda_{EUR,t}$ only $\lambda_{EUR,2009}$ is significant.

Table 1.4: Estimated Coefficients from the IV Estimation

	2008	2009	2010	2011
$CHF\ ratio_{i2007}$	0.011	0.048***	0.073***	0.100***
	(1.63)	(4.61)	(3.59)	(4.13)
$EUR\ ratio_{i2007}$	-0.004	0.015***	0.014	0.024
	(-0.81)	(4.28)	(1.20)	(1.68)

NOTE. – The table reports estimates from IV estimation of equation (1.7) for years $t = \{2008, 2009, 2010, 2011\}$. Table A.1 lists the definition of the variables. Coefficients are listed in the first row, t-statistics based on heteroskedasticity-robust standard errors are reported in the row below in parentheses, and the corresponding significance levels are in the adjacent column. *** Significant at 1%, ** significant at 5%, * significant at 10%.

Then the average direct foreign currency effects can be calculated by multiplying the estimated $\lambda_{EUR,t}$ and $\lambda_{CHF,t}$ coefficients with the average $EUR\ ratio_{i2007}$ and $CHF\ ratio_{i2007}$ ratios, respectively. In 2007 on average Euro borrowers had 70.2%, while Swiss Franc borrowers had 70.0% of their loans denominated in foreign currency. The calculated effects are reported in Table 1.5.

Table 1.5: Direct Effect of FX (in Percentage Points)

	2008	2009	2010	2011
CHF	0.742	3.337	5.101	6.969
EUR	-0.211	1.062	0.964	1.667

NOTE. – The table reports the calculated average direct effect of foreign currency on the default in percentage points.

For Swiss Franc borrowers the effect in 2008 is 0.7 percentage points (22% of the overall default change) and increases gradually to 7 percentage points (42% of the overall default change) by 2011, thus it accounts for 22%-42% of the overall default change. In case of firms with Euro loan the effect varies between -0.2 and 1.7 percentage points (-9% and 18% of the overall default change). It is expected that a large part of this effect is coming from the foreign exchange rate fluctuation. The yearly average exchange rates are reported in Table 1.6. Indeed, the results reflect the movements in the exchange rate. For instance, the Hungarian Forint depreciated more against the Swiss Franc than against the Euro and indeed the effects are much stronger for the Swiss Franc in each year. The CHF/HUF exchange rate increased gradually, which is echoed by the trend of the direct Swiss Franc effects. Meanwhile, the average EUR/HUF exchange rate in 2008 was around its average in 2007, and the depreciation started only from 2009. The effect in the case of the Euro was in fact negative in 2008 and became positive from 2009.

Table 1.6: Yearly Average Exchange Rates

	CHF/HUF	EUR/HUF
2005	160.20	248.05
2006	168.02	264.27
2007	153.03	251.31
2008	158.45	251.25
2009	185.82	280.58
2010	199.94	275.41
2011	226.90	279.21

NOTE. – The table reports the yearly average EUR/HUF and CHF/HUF exchange rates from 2005 to 2011.

1.4.2 Other Crisis Effects

In the previous subsection I calculated the average direct foreign currency effects. The remaining part of the change in the group default ratios is attributed to other effects of the crisis. The pure crisis effect arises from changes in financials (X_{it}) caused by factors other than the foreign currency and from changes in the valuation of the financials (β_{it}). The composition of the change in the default rate is summarized in Table 1.7 and is shown in Figure 1.5.

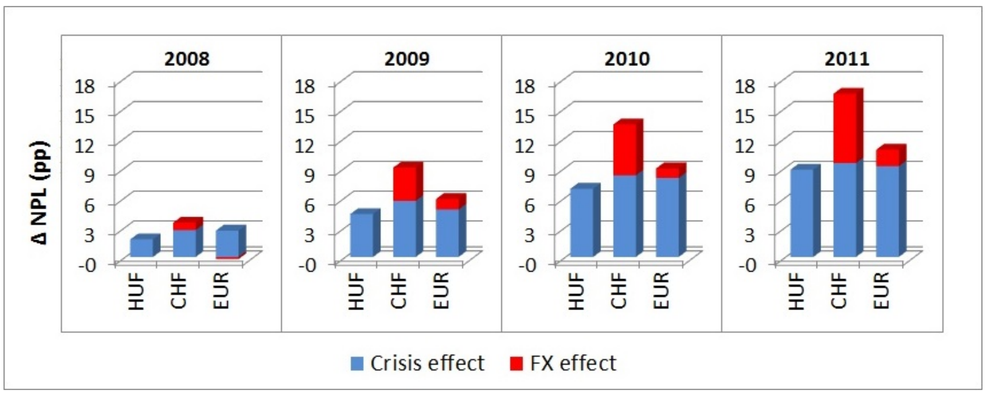
The direct effect of the crisis for firms with only Hungarian Forint is 1.8 percentage points in 2008 and rise to 8.8 percentage points by 2011, for Swiss Franc borrowers it changes from 2.7 percentage points to 9.4 percentage points, while for Euro borrowers the effect increases from 2.7 percentage points to 9.1 percentage points. Although the larger part of the higher run-up in nonperforming loans of Swiss Franc borrowers is attributed to the effect of the foreign currency, the direct effect of the crisis is also the highest for this group in each year. So the foreign currency denomination afflicted exactly those companies who were worse hit by other effects of the crisis.

Table 1.7: Decomposition of the Changes in Default Rate (in Percentage Points)

	FX effect		Crisis effect		
	CHF	EUR	HUF	CHF	EUR
2008	0.742	-0.211	1.770	2.707	2.659
2009	3.337	1.062	4.323	5.646	4.773
2010	5.101	0.964	6.866	8.220	7.946
2011	6.969	1.667	8.789	9.442	9.122

NOTE. – The table reports the components of the default change in percentage points.

Figure 1.5: Decomposition of the Changes in Default Rate



NOTE. – The figure presents the decomposition of the gap between the default ratio of Swiss Franc or Euro borrowers and the default ratio of Hungarian Forint borrowers between 2008 and 2011. The components are the ex-ante default gap, the pure effect of the crisis and the direct effect of the foreign currency.

Note, however, that the pure crisis effect is not the same as the default change would have been without FX lending. First, the composition of the borrowers would be different. There might be firms who borrowed in foreign currency, but would not in local currency. For example, a company may not afford a loan at the higher local interest rate or the bank would not consider the firm to be creditworthy with the higher interest rate. There might also be firms who are crowded out of the market, but would get a loan if there have been only local currency loans. Second, loans denominated in local currency had different conditions, thus their borrowers face a different situation. Most of the loans denominated in Hungarian Forint were variable interest rate loans. These types of loans are exposed to domestic interest rate risk and the materialization of the interest rate risk would have also influenced the loan performance. Unfortunately the data I have access to is not sufficient[33]

[33]For example, one would need data on interest rate on the loan level (which I have not) in order to

10.14754/CEU.2016.04

to calculate the counterfactual default rates if there were no foreign currency loans.

1.5 Conclusions

I analyze the factors contributing to the decline in loan quality of firms borrowing in different currencies during the 2008 crisis. I study a micro level dataset covering all firms with bank loan in Hungary. I assess what part of the change in the default rate is due to foreign currency denomination and to other effects of the crisis.

I find that the foreign currency denomination can increase the default probability considerably. For firms borrowing in Swiss Franc the currency effect varies between 0.7 percentage points and 7 percentage points, thus it accounts for 22%-42% of the overall default change. In case of firms with Euro loan the effect varies between -0.2 and 1.7 percentage points and thus run to -9%-18% of the overall default change. A large part of this effect is attributed the exchange rate volatility, and indeed, the Hungarian Forint depreciated more against the Swiss Franc than against the Euro.

The comparison of the currency borrower groups shows that not only the currency effect, but also the other crisis effects are the highest for firms with Swiss Franc loan. Hence loans denominated in foreign currency afflicted exactly those companies the most who were also hit the hardest by the crisis. These correlated shocks caused the salient decline in loan quality of the Swiss Franc borrowers.

My results highlight the importance of regulating the borrowing in safe haven currencies. In emerging countries the loans denominated in safe haven currencies are often popular during credit boom periods, since they are typically cheaper than credit denominated in local currencies. However, in a crisis the safe haven currencies appreciate to the local currency and thus the debt burden of their borrowers increases. Thus, these loans are advantageous in good times and harmful in bad times.

estimate the interest rate risk sensitivity of the firms.

10.14754/CEU.2016.04

Chapter 2

In Lands of Foreign Currency Credit, Bank Lending Channels Run Through?

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2.1 Introduction

Bank lending in a foreign currency to local businesses and households has been a widely observed phenomenon in many "dollarized" (or "euroized") countries around the world, in South-America, East Asia, and more recently in Eastern Europe.[1] And in those countries with large credit exposures denominated in foreign currencies policy makers never fail to point out the adverse effects of foreign currency lending on the effectiveness of the domestic monetary policy transmission.[2]

[1]Even in the Euro area around ten percent of credit by resident financial institutions to the non-financial sector is granted in a foreign currency (European Central Bank and Brown et al. (2009)).

[2]The 2005 Annual Report of the National Bank of Romania for example states that "[y]et another challenge to monetary policy implementation was to maintain the upward trend in financial intermediation by increasing the share of RON [Romanian New Leu] denominated loans in non-government credit, which would entail an improvement of the transmission mechanism [...]." For similar exhortations see also the Annual Reports of the National Bank of Romania in 2001, 2005, 2011, 2012, and 2013, the Minutes of the Monetary Policy Council Meetings at the National Bank of Poland, in January and February 2008, and the 2012 Report on Monetary Policy Implementation by the Monetary Policy Council of the National Bank of Poland.

Yet, despite the prevalence of foreign currency lending and its widely noted effect on monetary policy effectiveness there is little or no empirical work actually identifying the impact of monetary conditions on the local supply of credit in the domestic versus the foreign currency and equally important there is no work identifying the impact of the monetary policy set by the relevant central bank abroad (that issues the foreign currency) on the local supply of credit (in the different currencies). Given the increased calls for tighter international monetary co-operation in the aftermath of the financial crisis this is a particularly acute policy issue for emerging economies.[3]

To fill this gap in the literature, this chapter investigates the impact of monetary policy on the supply of bank loans in the presence of widespread foreign currency lending. First, we examine whether foreign currency lending hampers the effectiveness of the bank lending channel of domestic monetary policy by testing whether changes in domestic monetary conditions have a differential impact on the supply of bank loans in the domestic and foreign currencies. Second, we investigate whether foreign currency lending introduces international transmission channels through which foreign monetary policies also (differentially) affect the local supply of bank loans in the domestic and foreign currencies. To the best of our knowledge, our paper is the first to assess the existence of an international bank-lending channel that transmits the impact of foreign monetary policy through altering the currency composition of the local loan supply.[4]

In particular, we test two key hypotheses. First, we hypothesize that a monetary

[3]For example, Financial Times, January 30, 2014, "India's Raghuram Rajan hits out at uncoordinated global policy." Similarly Fischer (2015) argues that changes in US monetary conditions may create substantial international spillovers and that as European banks are global players European monetary policy may also play an important role.

[4]Ioannidou et al. (2015) assess if changes in the US federal funds rate have compositional effects on the supply of US Dollar denominated credit granted in Bolivia, an almost entirely dollarized country, while Morais et al. (2015) assess the impact of foreign monetary policies on lending by foreign versus domestic banks in Mexico. However neither paper does assess – as we do – the differential potencies of the bank lending channels in both the domestic and foreign currencies. More similar in this respect is recent work by Acharya et al. (2013) who examine the difference between US and foreign banks in their response to the freeze in the US asset-backed commercial paper market (for which US banks had immediate alternatives but foreign banks did not) when lending in US Dollars, Euros or Pounds to corporations through the syndicated loan market. Recent work also investigates the determinants and effects of global liquidity at the aggregate level. Cerutti et al. (2014) for example use country-to-country level data on cross-border bank flows to study the non-price determinants of the cross-border supply of credit. They find that global liquidity is driven primarily by uncertainty (VIX), US monetary policy (term premia but not federal funds rate per se), and UK and Euro Area bank conditions (proxied by leverage and TED spreads). Dinger and te Kaat (2015) study the impact of country-level current account balances on individual bank risk-taking. See also He and McCauley (2013), Duca et al. (2014), McCauley et al. (2015), and Temesvary et al. (2015).

10.14754/CEU.2016.04

expansion by the domestic central bank decreases the local banks' cost of funding in the domestic currency but not (at least to the same extent) in the foreign currency, generating a differential impact on banks' loan supply decisions in the different currencies.[5] Second, we hypothesize that a monetary expansion by the foreign central bank lowers the domestic (but potentially foreign owned) banks' cost of funding in the foreign currency but not in the domestic currency and examine, again, the local banks' consequent lending decisions in the domestic and foreign currencies.

Hungary provides an almost ideal setting to identify this currency compositional effect. Although the Hungarian economy is not "dollarized" or "euroized",[6] many local loans are denominated in Euro or in Swiss Franc (in some sample years more than a third of the bank lending was). The comprehensive credit register at the Central Bank of Hungary (Magyar Nemzeti Bank) contains granular information on all loans extended by all credit institutions operating in Hungary, including and – essential for our purposes – their currency denomination. And with an economic system dominated by banks,[7] we can identify the causal impact of monetary policy on the supply of bank credit by exploiting theoretically-motivated interactions between changes in monetary conditions on the one hand and a key bank balance-sheet strength variable, i.e., the bank capital-to-total-assets ratio, on the other hand (Bernanke et al. (1996), Kashyap and Stein (2000)). The definition of the bank capital-to-total-assets ratio we employ closely follows the theoretical literature that attributes a prominent role to net worth in determining the ability of banks to obtain financing from their own financiers (Holmstrom and Tirole (1997), Holmstrom and Tirole (1998), Bernanke et al. (1999), Gertler et al. (2010)).

[5]Currencies are unlikely to be perfectly substitutable for most banks. Acharya et al. (2013) show this to be the case even for global banks that lend in the US syndicate loan market. Hungarian banks are no exception. Hungarian banks did rely on foreign currency funding to finance lending in foreign currencies, but at times also used domestic currency funds while hedging some of the resultant on-balance sheet open positions with foreign exchange swap transactions (Mak and Pales (2009)). Analyzing information on the requested and granted loan currency for all loans granted by one Bulgarian bank, Brown et al. (2014a) examine how bank funding affects the currency denomination of business loans. They document that foreign currency lending is at least partially driven by the bank's eagerness to match the currency structure of assets with that of its liabilities.

[6]The amount of foreign cash held in the form of Dollars and Euros has traditionally been very low in Hungary. Based on survey data from the Austrian National Bank, Feige (2003) for example estimates that the fraction of total currency held as foreign currency was only 6 percent in Hungary in 2001.

[7]Bank financing has traditionally been the most important source of funding for corporations in Hungary. Between 2005 and 2011, the ratio of bank credit to non-financial firms to GDP varied between 25 and 31 percent, corporate bond issues were below 2 percent, and the value of IPOs was about 0.1 percent of the country's GDP (Bijlsma and Zwart (2013)).

In this way our identification strategy closely follows the most recent empirical literature assessing the effects of monetary policy on the provision of bank credit. Jiménez and Ongena (2012) and Jiménez et al. (2014a) for example explore a dataset of firms' loan applications to multiple banks and control for firm-level time-varying heterogeneity in credit demand by including borrower-time fixed effects.[8] Their identification of the impact of monetary policy on the volume and composition of credit supply, respectively, rests à la Kashyap and Stein (2000) on the differential responses (to changes in the monetary policy rate) by banks of different balance-sheet strengths. In this paper, we similarly account for all firm-level time-varying heterogeneity in credit demand by including borrower-time fixed effects and also identify supply effects from the differential responses to changes in monetary conditions by banks with different capitalization ratios.

In sum, we will focus on the set of loans in various currencies granted in the same month to the same borrower by one or more banks of varying balance-sheet strengths. Within this set of loans, for which the (observed and unobserved) quality of potential borrowers is constant, we study how monetary conditions affect the granting of loans in different currencies depending on bank capital. Consequently, what we require for the identification of supply effects is that the changes in the domestic (or foreign) interest rate do not affect firms' demand for domestic versus foreign currency loans in a way that is somehow correlated with banks' capitalization ratios.[9]

As common in the literature, we account for the stance of monetary policy with changes in representative short-term interest rates. We further comprehensively account for changes in domestic GDP growth and inflation (Taylor (1993)), at all levels of interaction where the domestic interest rate is also featured. To identify the currency compositional effect, we focus on corporate rather than household bank loan supply. Focusing on corporate loans is likely to generate conservative estimates of the currency compositional effect, since

[8] Using fixed effects is a standard way to control for demand side heterogeneity also in other strands of the literature. Bijlsma and Zwart (2013) for example analyze the effect of credit supply on trade and also include various sets of fixed effects to account for all non-credit determinants.

[9] This condition seems more readily satisfied than the one in Khwaja and Mian (2008). They estimate the impact of bank-specific liquidity shocks on bank lending for a sample of firms with multiple banking relationships. They include firm fixed effects and in their case identification requires that concurrent changes in firm credit demand are not bank-specific. Khwaja and Mian (2008) analyze business cycle fluctuations in bank lending using a sample of firms raising new debt financing, either by taking a bank loan or issuing public debt. In their context, demand explanations are properly ruled out by the use of firm-time fixed effects since their sample is conditioned on firms' issuing new debt. Finally, recall that Kashyap and Stein (2000) use bank-level data that does not allow controlling for heterogeneity in credit demand, making disentangling credit supply from demand a steep challenge.

10.14754/CEU.2016.04

the volume of foreign currency lending was larger in the household than in the corporate sector in Hungary. Furthermore, firms are naturally hedged and most do not actively seek to carry trade (Brown et al. (2011)),[10] a risky activity that could be associated with borrowing from banks with low capital or liquidity ratios.

Given these ingredients we can identify the impact of the monetary conditions set by both domestic and foreign central banks on the supply of credit by local banks in both domestic and foreign currencies. We find that expansionary domestic monetary conditions substantially increase lending from banks with lower capital ratios in the domestic currency but not in the foreign currency. Expansionary foreign monetary conditions on the other hand spur lending in the foreign currency but less so in the domestic currency.[11] These estimated differences in potency of the bank lending channels in domestic and foreign currency are not only statistically significant but also economically relevant (as our detailed discussion in the paper demonstrates). So when credit is also granted in foreign currencies, domestic monetary policy drives only part of the local supply of credit, and foreign monetary policies will also matter. In that case "multiple bank lending channels of various strengths may run through a country."

Our paper relates to the academic and policy debate on the spillover effects of monetary policy. It has been shown that the monetary policies set in large economies considerably impact the rest of the world, and that this impact mostly operates through asset prices and capital flows (BIS (2015) and Chen et al. (2014)). In our paper we analyze the cross-border impact through the bank-lending channel. This channel also consists of international capital flows, however the spillover effects through this particular channel have not been identified before.

Our paper fits in the recent literature that identifies the impact of banks' funding shocks on the provision of credit. Khwaja and Mian (2008) for example provide evidence that bank-specific liquidity shocks contract corporate loan supply in Pakistan. The impact of monetary policy shocks on the supply of credit has also been widely analyzed, by the early literature using credit aggregates (Bernanke and Blinder (1992), Kashyap and Stein (2000))

[10] Their paper analyzes firm level data and documents that foreign currency borrowing by small firms is related to (firm-level) foreign currency revenues suggesting that the macroeconomic and institutional environment may not be the only determinant of financial dollarization. Consequently their paper also suggests that firm-level controls are essential to identify the effects of monetary conditions on bank lending in various currencies.

[11] I.e., we find that the differences in the response of highly versus lowly capitalized banks to changes in the Euro and Swiss monetary rates are larger when banks lend in a foreign currency.

and by recent papers using micro-level data (Jiménez and Ongena (2012), Becker and Ivashina (2014)). Research on the impact of the monetary policy rate on the composition of the supply of credit has so far focused on direct credit risk taken (Jiménez et al. (2014a), Ioannidou et al. (2015), and references therein). In this paper we focus on monetary policy and analyze its impact on the supply of credit along currency denomination and we do so for both the domestic and the foreign monetary policies.

Our paper fits in a specific literature assessing the potency of a domestic bank lending channel in Central and Eastern Europe. Matousek and Sarantis (2009) for example use bank-level data from eight countries in the region and find evidence for the channel's existence – though with varying strength – in each country. Benkovskis (2008) and Kujundzic and Otaševic (2012) use credit aggregates from Latvia and Serbia to show that interest rate changes may affect credit in the domestic currency but seem to have limited impact on credit granted in the foreign currency.[12] Although, in line with our approach, these papers focus on the effects of domestic monetary policy on the provision of credit, analyzing aggregate information they are unable to disentangle supply from demand effects. Our paper is the first to consider the differential effects of domestic (and foreign) monetary policy on the supply of credit by individual banks to individual firms in local and foreign currencies, directly accounting for time-varying firm-level loan demand (at a monthly frequency).

In addition, our paper relates to the large empirical literature on financial dollarization that studies the determinants of banks' domestic lending in foreign currency in Latin American and transition economies (Nagy et al. (2011)). This literature finds that in general the lack of macroeconomic policy credibility, inflation volatility, low institutional quality, interest rate differentials, financial market development, and foreign funding of bank credit all contribute to a high level of foreign currency bank loans in these economies (e.g., Barajas and Morales (2003), De Nicoló et al. (2003), Rajan and Tokatlidis (2005), Rosenberg and Tirpák (2009), Basso et al. (2011), Neanidis et al. (2015)). In contrast to this literature that focuses on macro-level money, credit and output aggregates, and often highlights carry-trade on the demand side, we employ micro-level data to identify the

[12] In addition, few recent papers consider the effectiveness of macroeconomic policies in the presence of financial dollarization (e.g. Brown et al. (2015)). Using credit aggregates from four Central and Eastern European economies Brzoza-Brzezina et al. (2010) find that restrictive monetary policy may lead to a substitution in the demand for domestic to foreign currency loans. Mora (2013) analyzes a sample of 56 banks in Mexico and documents that banks with a low amount of foreign currency deposits are more (less) sensitive to domestic (foreign) monetary policy shocks than banks with a substantial amount of foreign currency deposits.

impact of changes in monetary conditions on the supply of bank credit across currencies.

The rest of the paper is organized as follows. Section 2.2 describes foreign currency lending in Hungary, the country's credit register, and the resultant sample. Section 2.3 discusses the identification strategy. Section 2.4 introduces the methodology and the variables. Section 2.5 contains the results assessing the potency of the bank lending channels in both domestic and foreign currency. Section 2.6 concludes.

2.2 Foreign Currency Lending in Hungary and Data Sources

2.2.1 Foreign Currency Lending in Hungary

Hungary's transition from a centrally planned to a market economy started at the end of the 1980s and was accompanied by a major inflow of foreign bank capital into the financial sector. By the end of the 1990s the majority of the banks in the country were foreign owned. Since capital markets were still underdeveloped, during the transition period, bank loans provided the major funding source for economic growth.

In early 2000s, a credit expansion started fueled by an intense competition in the banking sector. In parallel, the share of foreign currency denominated loans increased significantly both in the household and the corporate sector. While the most popular denominations were the Euro and the Swiss Franc (see Figures 2.1 and 2.2), other currencies like the US Dollar and even the Japanese Yen were also not uncommon for corporations. From 2004 onwards, with the disappearance of state-subsidized domestic currency mortgages, foreign currency loans became a major retail bank product. By the end of 2007, 56 percent of total outstanding loans to non-bank clients were denominated in foreign currency (Brown et al. (2009)).

On the supply side, the foreign ownership of banks and the intense competition in the banking sector both contributed significantly to the spread of foreign currency loans. On the demand side, the major reason for borrowing in a foreign currency was the lower interest rate accompanied by borrowers' low awareness of exchange rate risks.[13] In particular large corporations with revenues in Euro started to borrow in Euro to hedge their exchange rate

[13] The prospect of the introduction of the Euro as the national currency may also have been a contributing factor to the assessment of the foreign exchange risks involved (Fidrmuc et al. (2013)).

Figure 2.1: Annual Amount of New Lending to Corporations in Hungary by Currency, 2005-2011

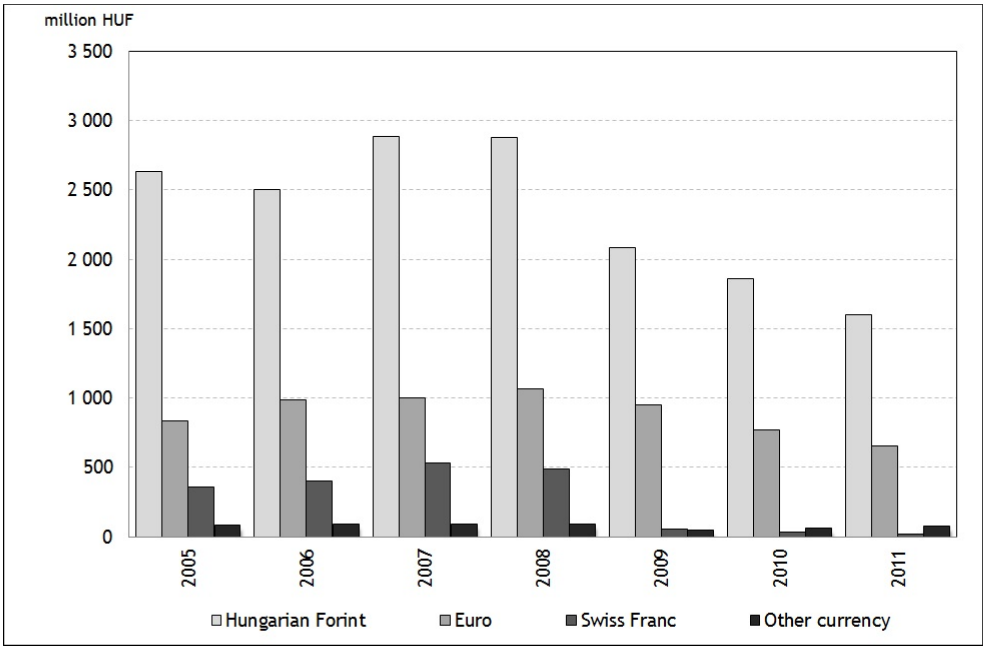
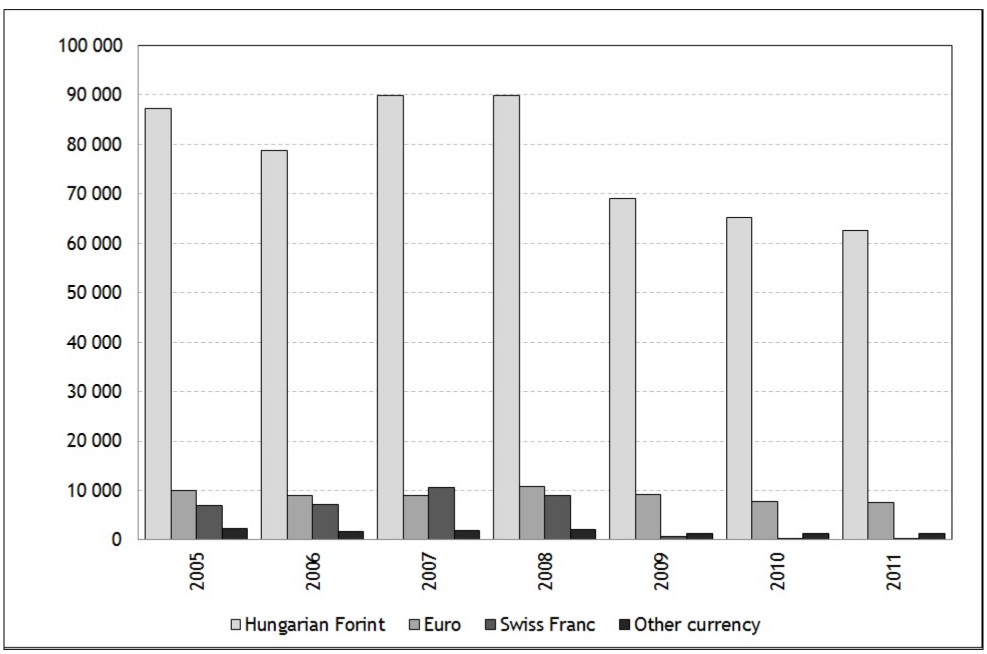


Figure 2.2: Annual Number of New Loans to Corporations in Hungary by Currency, 2005-2011



exposures. The popularity of Swiss Franc loans is attributed to even lower interest rates and low Euro/Swiss Franc exchange rate volatility during the period. When the financial crisis hit Hungary in the Fall of 2008, the Hungarian Forint depreciated significantly against the major currencies. The unprecedented collapse of USD liquidity and the drying up of foreign exchange swap markets curbed Hungarian banks' possibilities to continue lending in Euro and Swiss Franc without foreign currency open positions on their balance sheets. In subsequent years, therefore, the share of foreign currency lending substantially decreased. Swiss Franc lending essentially vanished, but lending in Euro preserved its importance both in the household and corporate sectors.

2.2.2 The Hungarian Central Credit Information System (KHR)

The Hungarian Central Credit Information System (KHR) contains information on all outstanding loans extended by all credit institutions operating in Hungary. As such this credit register contains loans from commercial banks, branch offices of foreign banks, saving cooperatives, credit unions, specialized credit institutions and other financial enterprises. We restrict our sample to corporate loans granted by commercial banks and branch offices of foreign banks and we focus on commercial and industrial loans that represent 66 percent of total corporate loans registered in the credit register (Endrész et al. (2012)).

We observe all outstanding loans denominated in the domestic as well as foreign currency, between 2005 and 2011, at a monthly frequency.[14] We aggregate the data to the firm-month-currency level that will be the focal unit of observation in our analysis. Our dataset includes credit lines but the results we present in subsequent sections are however robust to the exclusion of credit lines from the sample.

We match the thus-organized loan data to firm and bank characteristics. Firms' financial statement data are available from the Hungarian National Tax and Custom Administration (APEH) database that contains the balance sheet and income statement of all Hungarian firms with double-entry book-keeping. Banks' financial and ownership data are available from bank regulatory reports accessible at the Central Bank of Hungary. Because the credit register provides information only about the type of the lender (bank, branch office, savings cooperative, leasing company, or other type) but not the individual lender's identity, we obtain information on the extant bank-firm relationships from a firm register

[14]This time period looks favorable in length compared to those used in recent papers that analyze the effects on the provision of credit of monetary and financial shocks. Aforementioned papers by Jiménez and Ongena (2012) and Jiménez et al. (2014a) cover 2002 to 2008, Ioannidou et al. (2015) analyze data ranging from 1999 to 2003, while Khwaja and Mian (2008) study data from 1996 to 2000.

called Complex that contains each firm's bank account numbers. The first three digits of the bank account number (called GIRO code) uniquely identify the bank belonging to a particular account number. For the majority of firms, this information unambiguously identifies the lender since three quarters of the firms in our dataset borrow from one bank only. A quarter of the firms have multiple bank relationships (and 2.36 banks on average). For these firms, we are not able to uniquely identify the bank-firm relationship (and consequently have to take averages across the reported banks when constructing the relevant bank characteristics).

2.3 Identification Strategy

Do low monetary policy rates at home and/or abroad spur changes in the currency denomination of the credit that is supplied by banks? To address this question one needs to disentangle the impact of the changes in the interest rate on the currency denomination of the supply of credit from changes in the volume of the supply and changes in the quality and the volume of the demand – while accounting for the impact of other key macro variables. This bank supply channel involves compositional changes in the supply of credit at the *bank-firm-currency denomination* level.

Our identification strategy consists of two crucial ingredients: (1) Interacting the change in the interest rate with bank capital and currency denomination, while saturating with firm-time fixed effects; (2) horseracing the interest rate, in its interaction with bank capital and currency denomination, with the corresponding triple interactions of other key macro variables, in particular GDP growth and inflation.

In essence, our identification scheme follows standard state-of-the-art methodology in the most recent literature (Jiménez and Ongena (2012), Jiménez et al. (2014a)) that builds on, but goes well beyond, the path-setting methodology to identify the effect of monetary policy shocks on banks' loan supply decisions first employed by Kashyap and Stein (2000).

As we are assessing the within-firm credit composition (along currency), first-stage firm-level loan application information as in Puri et al. (2011), Jiménez and Ongena (2012), Berg and Kirschenmann (2015) and Jiménez et al. (2014a), for example, would be potentially less informative for our purposes. Given that we focus on the currency denomination of credit granted to a firm in a certain month knowing the currency requested by the firm would be helpful. However, and as far as we are aware, no credit register in the world records this type of information (Miller (2003)) and only one study so far employs information on the

10.14754/CEU.2016.04

currency requested from loan applications made to one bank (Brown et al. (2014a)).

We now discuss the two aforementioned strategy components in more detail, along with our measures of credit granting.

2.3.1 Estimated Model

Our benchmark specification is a model that explains the extensive margin of the granting of loans in a currency given the firm had no precedent loan in the currency before. We also investigate the ending of lending across currencies and the increase in the amount of different currency lending.

Saturation with Fixed Effects and Triple Interactions

- Firm-Time Fixed Effects

Given the prominent role of net worth in determining the borrowing by banks from their financiers, and given that the majority of banks may have little capital at stake, expansionary monetary policy by the central bank managing one currency may spur banks into lending in this respective currency but given imperfect hedging opportunities for either the bank and/or its financiers not necessarily (or at least not to an equal degree) in other currencies.[15]

However, this testable prediction can also be consistent with demand channels, in particular with the firm balance sheet and the interest rate channels of monetary policy (Bernanke and Gertler (1995)). Therefore, to suppress concurrent changes in the type (along balance sheet strength or export opportunities, for example) and volume of the firm demand for credit, we saturate our benchmark specifications with firm-time fixed effects. Observed and unobserved time-varying firm characteristics that are accounted for in this way include the net present value of firm projects, export and investment opportunities, agency problems, risk, pledgeable income and collateral. Our saturated specifications also account for the endogeneity of bank loan supply when changes in macroeconomic conditions affect banks' lending decisions indirectly, by altering the performance and profitability of borrowing firms. In our saturated specifications, identification comes from comparing changes

[15]According to Hungarian regulation, banks' reserve requirements do not differ for deposits in different currencies. Nor does foreign currency lending require banks to maintain different bank capital levels as long as the position is hedged through foreign currency funding (on-balance) or through the foreign exchange swap market (off-balance sheet).

in lending by one or more banks (that are different with respect to their capital-to-asset ratios) in the same month to the same firm in different currencies.[16] Only a quarter of the firms deal with multiple banks,[17] so in robustness we break out the single-bank firms for which we know the exact bank-firm exposure.

- Triple Interaction of Interest Rate, Bank Capital Ratio, and Currency Denomination

Given the set of fixed effects, identification of a bank lending channel comes from exploiting the testable prediction that when the monetary policy rate decreases for one particular currency, banks with lower net worth will react more by lending more in this currency than banks with higher net worth. Therefore, it is essential to have a sharp measure for the intensity of the agency conflict that besets banks' own borrowing from their financiers. The bank capital-to-assets ratio is such a measure (Holmstrom and Tirole (1997)). The ratio is also particularly meaningful in Hungary because off-balance sheet activity by banks has been almost non-existent.[18]

To identify the "currency composition channel" of monetary policy we interact the change in the interest rate with the lagged bank capital ratio (in the spirit of Kashyap and Stein (2000)) and a dummy variable indicating the currency of the bank-firm exposure. When explaining new credit granted or credit growth we expect a negative sign for the estimated coefficient on this triple interaction term: When the domestic interest rate decreases, banks with a lower capital ratio are less likely to grant more credit in the foreign currency.[19] However if the different currencies are substitutable for banks (through e.g. hedging), this estimated coefficient should be close to zero, while if lending in a foreign currency is perceived to facilitate extra risk taking the estimated coefficient may even be

[16]Note that our third panel dimension (that we need for the inclusion of firm-time fixed effects) is the currency dimension. Unlike recent research analyzing loan applications made by firms to different banks (Jiménez and Ongena (2012)), Jiménez et al. (2014a)), we do not observe multiplicity in the firm-bank relationship dimension.

[17]Hence multiple firm-bank relationships are much less commonly observed in Hungary than in Spain and Italy for example. In Ongena and Smith (2000) the mean number of relationships for (large) firms in Hungary equals 4, while in Spain and Italy it equals 10 and 15, respectively.

[18]Banks in Hungary did not develop conduits or Structured Investment Vehicles (SIVs). Total bank assets therefore cover most of the banks' business. Securitization is also not practiced and therefore cannot be a significant motive for lending in the foreign currency.

[19]Highly and lowly capitalized banks have similar loan portfolios in our sample, i.e., the distribution of firms with respect to capitalization and profitability is similar in the two groups of borrowers granted loans by highly versus lowly capitalized banks. Therefore, firms with certain characteristics do not seem to select to certain types of banks.

positive (or at least less negative).[20]

As bank capital may be correlated with other bank characteristics, we also add in corresponding triple interactions (i.e., in which bank capital is featured) of various bank characteristics. In accordance with the focus of our analysis, we cluster standard errors at the firm level.[21]

Horseracing Triple Interactions

- Interest Rate

Banks are mostly funded by short-term debt, the interest rates of which will likely respond to changes in the monetary policy rate. As in Angeloni et al. (2003), we employ the yearly change in a three-month interest rate, for Hungarian Forint exposures on a Hungarian government bond, and for Euro lending on a generic government bond. For Swiss Franc lending we use the annual change in the Swiss 3-month LIBOR interest rate.[22] For all three interest rates our sample period spans a full yet (across-interest-rates) distinct cycle and corresponding changes in the foreign exchange rate (see Figure 2.3).

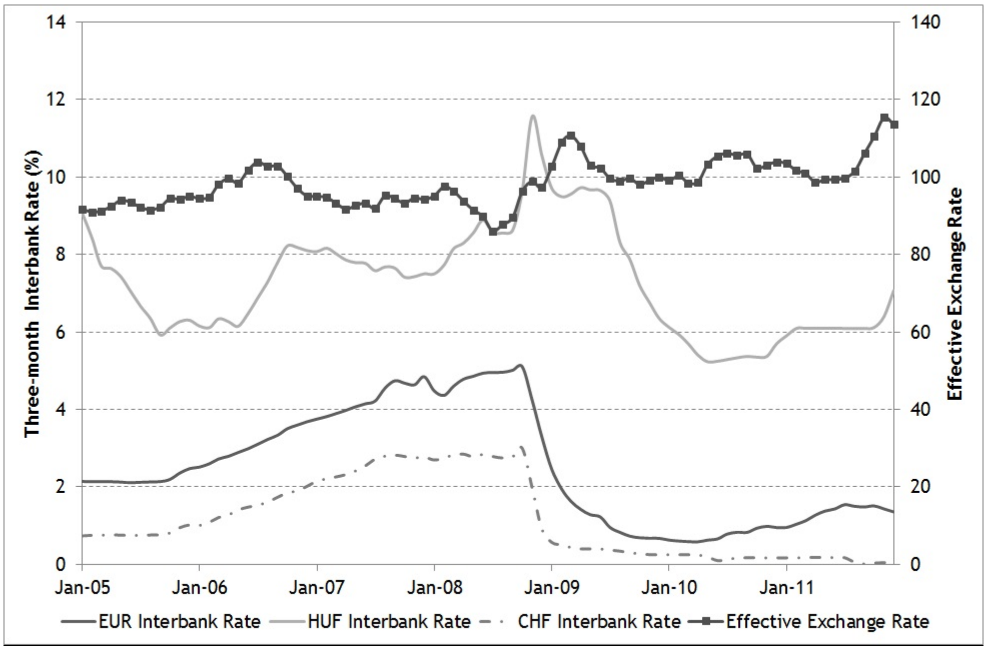
Assuaging concerns of reverse causality (e.g., future foreign currency lending by banks may imply current domestic monetary contraction) and omitted variables (variables correlated with the stance of monetary policy that can also influence bank lending) are the comprehensive sets of firm-time fixed effects which absorb any observed and unobserved time-varying heterogeneity across all included firms (comprising, for all practical purposes,

[20] In this case the bank's lower net worth (or "skin in the game") could lead to more foreign currency lending. Indeed, analyzing banks' lending patterns in Hungary, we find that domestic, lowly capitalized, less liquid and less profitable banks lend with higher relative probability in foreign currencies, especially Swiss Franc. Relatedly, Ongena et al. (2013) provide evidence that foreign banks may engage in risky lending in domestic markets, especially when entry barriers and restrictions on non-core bank activities in domestic markets are low. Notice that banks' engagement in risky foreign currency lending may coincide with more risky lending in the domestic currency and that lending in a foreign currency not necessarily involves more risk-taking (Dell'Ariccia et al. (2011)).

[21] Banks may prefer to lend in a currency in which the firm has revenues for example (even though revenue currency denomination may not always be fully observable, potentially leading to more foreign currency credit as in Brown et al. (2014b)). Due to the high frequency of most variables' series clustering at the firm and time (i.e., year-month) level robs all estimated coefficients of their statistical significance. Clustering at the main bank level (as in e.g. Jiménez et al. (2014b)) throughout the analysis is impossible as we do not know the respective bank shares of the credit exposures.

[22] We use a three-month interbank rate because there is no three-month Swiss Treasury bill or government bond. We rerun all key exercises with the relevant three-month interbank rate from the three currency areas but results are unaffected.

Figure 2.3: Interest Rates and Effective Exchange Rates in Hungarian Forint (HUF), Euro (EUR) and Swiss Francs (CHF)



the entire economy). For monetary conditions set in the Euro area and Switzerland these concerns weigh considerably less.

- Other Key Macro Variables

Despite the predominance of banks' short-term funding, their lending could also be affected by other key macro variables. Hence, the third crucial component in our identification strategy is to concurrently account for the effects of changes in GDP growth and prices as the main determinants of the monetary policy rate (but which may also capture firm investment opportunities and pledgeable income) and other aggregate variables including changes in exchange rate and foreign direct investment. We therefore horserace the triple interaction of changes in GDP growth, prices and other macro variables, with bank capital and currency denomination, with the equivalent triple interactions with the monetary policy rate.[23]

[23]We also run specifications dropping GDP growth and inflation as well as the corresponding double and triple interaction terms of these variables from the regression. Coefficients of the interest rate variable and its interaction terms remain both statistically and economically significant.

Given their correlation with the interest rate, these macro variables in triples also feature as controls, to the extent that the firm-time fixed effects did not already soak up relevant macroeconomic variation.

Given our comprehensive data, sample period, identification strategy, and saturated specifications, we are confident that it is possible to make well-founded inferences on whether short-term monetary policy rates affect banks' lending in different currencies, and in general on whether macroeconomic shocks result in changes in the composition of the supply of credit.

2.4 Methodology and Variables

2.4.1 Model Line-Up

This Section presents and discusses our estimates. We estimate models with as dependent variables new credit granted (extensive margin), and also ending credit (extensive margin) and increase in the credit amount granted (intensive margin). To stepwise saturate with fixed effects and make robust inferences, we employ linear probability models.[24]

The sample period goes from January 2005 to December 2011. The total number of observations (i.e., total firm - credit in currency - year:month) equals 36 661 233, but given computing constraints the less saturated regressions[25] employ a 10 percent random sample of firms.[26] Table 2.1 presents the summary statistics. Summary statistics for banks (firms) are based on the average values of the bank (firm) characteristics over the sample period. The number of banks in our sample is 39. The number of firms in our sample is 318 411.

[24] Given the extensive sets of fixed effects we include and as we are primarily interested in the estimated coefficients on the triple interactions (as the next sections explain), we employ linear probability models (Ai and Norton (2003); Norton et al. (2004)). In further unreported robustness exercises we also run probit models at the quarterly level that only include time (i.e., year:quarter) fixed effects. The higher level of aggregation and the exclusion of firm fixed effects is necessary for estimations to be technically feasible. Results are similar however.

[25] Regressions with only firm or with firm and time fixed effects (in particular model Models 1 to 5 in Tables 2.2, Models 1 to 5 in Tables 2.5 and Models 1, 2, 5 and 6 in Tables 2.6).

[26] Our 10 percent random sample does not suffer from the problem of overrepresentation of short-lived firms. The mean life span of firms in the population and our random sample, in any given month, is approximately the same.

2.4.2 Specification and Dependent Variables

The complete model after saturation with firm-time fixed effects, which is e.g., Model 6 in Table 2.2, equals (in abridged form):

$$\begin{aligned} CREDIT_{ikt} = &\alpha_{it} + \beta IN\ FX_k + \delta \Delta INTEREST\ RATE_{t-1} * IN\ FX_k + \\ &\gamma \Delta INTEREST\ RATE_{t-1} * BANK\ CAPITAL_{bt-1} * IN\ FX_k + Controls + \varepsilon_{ikt} \end{aligned} \tag{2.1}$$

The dependent variable is a measure of the $CREDIT_{ikt}$ granted to firm i in currency k in month t.[27] For each firm for each year we know the set of banks the firm is having an account with but do not know the individual bank-firm credit exposure, except when the firm maintains only one bank which ("fortunately" in a sense) happens in 74 percent of the cases.

We first focus on the extensive margin of new credit, i.e., *New Granting of Credit*, which equals one if firm i receives credit in currency k in month t, conditional on having no debt in currency k in month t-1, and equals zero otherwise. Later we assess the ending of credit and growth in amount with two additional dependent variables: *Ending Credit* which equals one if firm i receives no more credit in currency k in month t, conditional on having received some credit in currency k in month t-1, and equals zero otherwise;[28] and *Increasing the Amount of Credit* which equals one if the nominal amount of credit firm i holds in currency k in month t exceeds the nominal amount of credit in currency k in month t-1, and equals zero otherwise.[29]

The main independent variables are $IN\ FX_k$, the abridged label for *Credit Is Granted in Foreign Currency*, which equals one if the credit to firm i in month t is in currency k which is a foreign currency, and equals zero otherwise, $\Delta INTEREST\ RATE_{t-1}$ is the annual

[27] We also run specifications on a quarterly sample and find that the effect of the interest rate change on the likelihood of credit granting per quarter is four times the monthly effect, confirming the results we obtain from the analysis of monthly data.

[28] For most firms, the variable is equal to one when the firm repays all of its debt and does not take a new loan.

[29] Analyzing the extensive margin of new credit (in a binary manner) has many advantages. Such an analysis is comprehensive, comparable and directly interpretable across all loan types and conditions, it avoids having to adjust for exchange rate changes (which could create spurious correlations in our estimations), and it is least affected by the continuous decrease in firm-bank exposures according to their contracted repayment schedules. We will therefore also investigate in robustness the extensive margin of ending credit and the intensive margin of increasing credit in a binary manner.

change in the relevant three month interest rate at t-1,[30] and $BANK\ CAPITAL_{bt-1}$ is the capital ratio at time t-1 defined as the ratio of bank equity and retained earnings over total assets of the set of banks b granting the credit. These latter two variables are discussed more at length in the next section.

We are interested in the three coefficients, i.e., β, δ and γ, the coefficients on currency denomination[31] and its double and triple interactions with the interest rate, and the interest rate and bank capital. The specification further loads in firm-time fixed effects (represented by α_{it}), and as controls include the following sets of variables: (1) the triple interactions of the change in GDP and inflation, respectively, with bank capital, and currency denomination; (2) in specifications with no firm-time fixed effects bank capital ratio, size, liquidity, profitability and non-performing loans; (3) in specifications with no firm-time fixed effects firm capital ratio, size, liquidity, profitability and export sales ratio and (4) in specifications with no time fixed effects the changes in the exchange rate, foreign direct investment, sovereign credit default swap spread and yield curve.

An alternative model representation is to express foreign currency credit relative to local currency credit:

$$\begin{aligned} RELATIVE\ CREDIT_{ikt} =& \beta + \delta \Delta INTEREST\ RATE_{t-1} + \\ & \gamma \Delta INTEREST\ RATE_{t-1} * BANK\ CAPITAL_{bt-1} + Controls + \epsilon_{ikt} \end{aligned} \tag{2.2}$$

The dependent variable, $RELATIVE\ CREDIT_{ikt}$, is the relative provision of foreign currency credit to Hungarian Forint credit, that is $RELATIVE\ CREDIT_{ikt} \equiv CREDIT_{ikt} - CREDIT_{iHUFt}$. So in fact we implement a within currency transformation. The model in this respect shows what drives the relative supply of foreign currency credit to Hungarian Forint credit. The coefficients of main interest, δ and γ, shows how the interest rate and its interaction with the bank capital, respectively, affects the relative

[30] We also run specifications replacing the one-month lag of the interest rate with its two-, three-, four-, five-, or six-month lags. Results are similar. Furthermore, we run specifications including up to four lags of the interest rate variable as well as interactions between each lag, bank capitalization, and currency denomination of the loan. We find that the sum of the coefficients on the double and triple interaction terms are both statistically and economically significant, and their sum similar in magnitude to those we report on the first lag.

[31] An alternative notation would be to use α_k instead of $\beta IN\ FX_k$ and interpret it as a currency dummy or currency fixed effect.

supply of foreign currency loans.

Given that the sample is fully balanced in terms of currencies, this model is equivalent to the one in equation (1). Since this version is computationally less taxing and results the same estimates, we calculate this version instead of the models saturated with firm-time fixed effects.[32] However, following the practice in the related literature[33], we refer to the fixed effects interpretation.

2.4.3 Main Independent Variables

- Short-Term Interest Rate

The main variable of interest in our analysis is the yearly change in the three-month Forint interest rate that we measure by the yield on the three-month Hungarian government bond rate. The average change in the three-month interest rate during the sample period is -0.73 percentage points and it varies between -5.29 percentage points and 4.25 percentage points. To proxy for monetary policies from the other central banks that issue the currencies that are employed often, we also use the yearly change in three-month interest rates from the Eurozone and Switzerland. The Euro interest rate is based on the average yield on the three-month Euro benchmark government bonds while the Swiss interest rate is the three-month Swiss interbank rate. The average Euro and Swiss three-month interest rates in the sample period are -0.19 percentage points and -0.05 percentage points, respectively. The former varies between -3.91 percentage points and 1.25 percentage points, the latter between -2.73 percentage points and 1.19 percentage points. Definitions and summary statistics of all variables are in Table 2.1.

To comprehensively account for changes in domestic GDP growth and inflation (Taylor (1993)), we include both variables at all levels of interaction where the domestic interest rate is also featured.[34] The average GDP growth rate in Hungary during the sample period

[32]For the less saturated models we cannot use this specification, thus we employ the fixed effect estimation for those models (and use the 10 percent random sample because of computing constraints).

[33]See for example Schnabl (2012), Iyer et al. (2014), Jiménez and Ongena (2012) and Jiménez et al. (2014a) using firm-time fixed effects to absorb firm-level time-varying heterogeneity in credit demand, and identify the impact of changes in monetary policy on the volume or the composition of the supply of credit from the differential responses by banks with different balance-sheet strengths to changes in the monetary policy rate.

[34]Alternatively, we run the interest rate first on GDP growth and inflation and employ the residuals of this regression rather than the interest rate itself. Results are very similar (and obviously independent of whether we then also feature in the second step GDP growth and inflation as independent variables). These results hold for both three-month government bond and interbank interest rates.

Table 2.1: Summary Statistics

Variable	Units	Definition	Mean	Std	Min	Median	Max
Dependent variables							
Euro and Swiss Franc Exposures Aggregated							
New Granting of Credit_{ikt}	0/1	=1 if firm i receives credit in currency k in month t, conditional on having received no credit in currency k in month t-1, =0 otherwise	0.0023	0.0481	0	0	1
Ending Credit_{ikt}	0/1	=1 if firm i receives no more credit in currency k in month t, conditional on having received some credit in currency k in month t-1, =0 otherwise	0.0018	0.0422	0	0	1
Increasing the Amount of Credit_{ikt}	0/1	=1 if the nominal amount of credit firm i holds in currency k in month t exceeds the nominal amount of credit in currency k in month t-1, =0 otherwise	0.0076	0.0871	0	0	1
Euro and Swiss Franc Exposures Disaggregated							
New Granting of Credit_{ikt}	0/1	=1 if firm i receives credit in currency k in month t, conditional on having received no credit in currency k in month t-1, =0 otherwise	0.0016	0.0399	0	0	1
Ending Credit_{ikt}	0/1	=1 if firm i receives no more credit in currency k in month t, conditional on having received some credit in currency k in month t-1, =0 otherwise	0.0012	0.0351	0	0	1
Increasing the Amount of Credit_{ikt}	0/1	=1 if the nominal amount of credit firm i holds in currency k in month t exceeds the nominal amount of credit in currency k in month t-1, =0 otherwise	0.0051	0.0713	0	0	1
Independent variables							
Macroeconomic variables							
Δ Interest $\text{Rate}_{t\text{-}1m}$	-	Annual change in the Hungarian 3-month government bond rate	-0.007	0.024	-0.053	0.001	0.043
Δ Interest Rate in Euro $\text{Area}_{t\text{-}1m}$	-	Annual change in the Euro area 3-month generic government bond rate	-0.002	0.013	-0.039	0.001	0.013
Δ Interest Rate in $\text{Switzerland}_{t\text{-}1m}$	-	Annual change in the Swiss 3-month LIBOR interest rate	0.000	0.010	-0.027	0.001	0.012
Δ Interbank Interest $\text{Rate}_{t\text{-}1m}$	-	Annual change in the Hungarian 3-month interbank rate	-0.008	0.024	-0.051	-0.002	0.041
Δ Interbank Interest Rate in Euro $\text{Area}_{t\text{-}1m}$	-	Annual change in the Euro area 3-month interbank rate	-0.001	0.015	-0.044	0.004	0.014
Δ Taylor Rule Residuals Government $\text{Bonds}_{t\text{-}1m}$	-	Annual change in the residuals of a regression of the Hungarian 3-month government bond rate on GDP growth and the inflation rate	-0.006	0.024	-0.060	-0.005	0.055
Δ Taylor Rule Residuals $\text{Interbank}_{t\text{-}1m}$	-	Annual change of in the residuals of a regression of the Hungarian 3-month interbank rate on GDP growth and the inflation rate	-0.006	0.024	-0.053	-0.006	0.054
Δ $\text{GDP}_{t\text{-}1q}$	-	Annual growth rate in Hungarian gross domestic product	0.008	0.036	-0.080	0.017	0.047
Δ $\text{CPI}_{t\text{-}1m}$	-	Annual change in the Hungarian consumer price index	-0.004	0.027	-0.041	-0.010	0.067
Δ Exchange $\text{Rate}_{t\text{-}1m}$	-	Annual change in the nominal effective exchange rate index of the Forint	0.017	0.067	-0.115	0.018	0.158
Δ Exchange Rate Hungarian Forint to $\text{Euro}_{t\text{-}1m}$	-	Annual change in the HUF/EUR exchange rate	0.017	0.070	-0.128	0.017	0.173
Δ Exchange Rate Hungarian Forint to $\text{CHF}_{t\text{-}1m}$	-	Annual change in the HUF/CHF exchange rate	0.052	0.104	-0.158	0.042	0.249
Δ Foreign Direct $\text{Investment}_{t\text{-}1m}$	-	Annual change in the stock of Hungarian foreign direct investment	0.218	0.210	-0.047	0.162	0.758
Δ Credit Default Swap $\text{Spread}_{t\text{-}1q}$	-	Annual change in the Hungarian 5-year sovereign CDS spreads	0.516	1.424	-3.532	0.187	4.189
Δ Yield $\text{Curve}_{t\text{-}1m}$	-	Annual change in the difference between 10-year and 1-year government bond yields	0.000	0.010	-0.009	-0.004	0.027
Bank characteristics							
Bank Capital $\text{Ratio}_{bt\text{-}1m}$	-	Ratio of bank equity to total bank assets	0.13	0.15	-0.25	0.09	1.00
Bank Total $\text{Assets}_{bt\text{-}1m}$	000 000 Forint	Total bank assets	735 640	1 192 191	173	210 224	7 010 201
Ln(Bank Total $\text{Asset})_{bt\text{-}1m}$	-	Natural logarithm of total bank assets	12.18	1.81	5.15	12.26	15.76
Bank Liquidity $\text{Ratio}_{bt\text{-}1m}$	-	Ratio of liquid assets to total bank assets	0.19	0.17	0.00	0.14	0.99
Bank Return On $\text{Assets}_{bt\text{-}1m}$	-	Ratio of pretax profits to total bank assets	0.00	0.05	-2.29	0.00	0.29
Doubtful Loan $\text{Ratio}_{bt\text{-}1m}$	-	Bank doubtful loan ratio	0.06	0.05	0.00	0.06	0.37
Foreign Owned $\text{Bank}_{bt\text{-}1m}$	0/1	=1 if bank is at least 50% foreign owned, =0 otherwise	0.93	0.25	0	1	1
Firm characteristics							
Firm Capital $\text{Ratio}_{it\text{-}1y}$	-	Ratio of firm equity to total firm assets	0.40	0.35	0.00	0.34	1.00
Firm Total $\text{Assets}_{it\text{-}1y}$	000 Forint	Total assets of the firm	122 737	587 597	18	9 593	7 275 757
Ln(Firm Total $\text{Assets})_{it\text{-}1y}$	-	Natural logarithm of firm total assets	9.17	2.30	2.89	9.17	15.80
Firm Liquidity $\text{Ratio}_{it\text{-}1y}$	-	Ratio of current assets to total firm assets	0.72	0.30	0.00	0.83	1.00
Firm $\text{ROA}_{it\text{-}1y}$	-	Ratio of net income to total firm assets	-0.28	1.31	-9.41	0.00	0.92
Firm Export Sales $\text{Ratio}_{it\text{-}1y}$	-	Ratio of export sales over total firm sales	0.05	0.18	0.00	0.00	1.00

NOTE. – The number of observations in the sample equals 43 724 229. The sample period is January 2005 to December 2011. Summary statistics for banks (firms) are based on the average values of the bank (firm) characteristics over the sample period. The time index on each variable indicates the timing of the variable in the main regressions with t-1 indicating a one-period lag of a month (m), quarter (q) or year (y), respectively. Given the frequency of reporting for GDP and CDS the values of the preceding quarter and for firm characteristics the values of the preceding year are used. The number of banks in our sample is 39. The number of firms in our sample is 318 411.

10.14754/CEU.2016.04

was 0.80 percent ranging between -8.00 percent and 4.70 percent, while average inflation was -0.40 percent, ranging between -1.05 and 6.73 percent. Additional macro controls are the annual change in the nominal effective exchange rate index of the Forint, foreign direct investment captured by the annual change in the amount of currency reserves at the Central Bank of Hungary, the annual change in the CDS rate on 5-year Hungarian sovereign bonds, and the annual change in the difference between 10-year and 1-year government bond yields.[35] The macro variables are available monthly, except for GDP growth and currency reserves, which are measured quarterly. For interim months, we use the end-of-quarter GDP growth rate and currency reserve values.

- Bank Capital Ratio

Our key bank balance-sheet variable is the *Bank Capital Ratio* defined as the ratio of bank equity over total assets.[36] This ratio is a proxy for the bank's ability to obtain funding from its own financiers (Holmstrom and Tirole (1997)) and lend in the currency of the interest rate change ("bank balance sheet channel") but at the same time also for bank moral hazard (i.e., more "skin in the game" may deter 'other' currency lending if that is riskier). The average bank capital ratio during the sample period is 12.76 percent.[37]

We include as control variables a number of bank characteristics that capture the time-variation in banks' loan supply.[38] In particular, we use the natural logarithm of total assets (*Bank Total Assets*) to proxy for bank size and the ratio of liquid to total assets (*Bank Liquidity Ratio*) to measure bank liquidity. We also include the *Bank Return on Assets* to measure profitability and the *Bank Doubtful Loan Ratio* to proxy for the current non-performance and riskiness of the bank's portfolio. We note that the firm fixed effects we include also control for the average time-invariant characteristics of the banks the firms maintain.

[35] In unreported regressions, we also include the annual change in the one-year forward exchange rate as a control variable. Results are robust to controlling for the EUR/HUF and/or CHF/HUF forward exchange rates.

[36] Consistent with the literature, for bank subsidiaries we use local subsidiary rather than bank-group-level capital ratios (see, for example, Kashyap and Stein (2000)). Nevertheless, we test the robustness of our findings to a redefinition of the bank-capital variable and estimate our main specifications using group-level capital ratios. Results do not change.

[37] For a few branch offices of foreign banks, the bank capital ratio takes negative values. In our final sample, observations with negative bank-capital ratio represent less than 0.03 percent of the total number of observations, and removing these few observations does not alter our main findings.

[38] As noted before our data does not allow us to identify the individual bank-firm exposures when firms maintain multiple banks. Multiplicity occurs in around a quarter of the observations. We then simply average bank characteristics across the firms' banks.

10.14754/CEU.2016.04

All bank balance-sheet and income statement variables are available at the monthly frequency. Balance-sheet variables for month t are proxied by their values at the end of month t-1, while bank performance variables for month t are the annualized values of their values measured over month t-1.

2.4.4 Control Variables Including Fixed Effects

To control for the variation in the amount and quality of loan demand faced by the banks, we also include a set of firm characteristics, as well as firm and firm-time fixed effects in our specifications (with time equal to year:month).[39] In particular, in all regressions without firm-time fixed effects, we include the *Firm Capital Ratio* measured by the ratio of the firm's equity capital to total assets, the natural logarithm of the firm's total assets (*Firm Total Assets*), the *Firm Liquidity Ratio* measured by the ratio of current to total assets, the *Firm Return On Assets* that equals to the firm's net income over total assets, as control variables. To capture foreign linkages, we also use the *Firm Export Sales Ratio* calculated as the ratio of export sales to total sales.

Firm characteristics are available at yearly frequency. For each month in a given year, our firm-level balance-sheet variables are proxied by their values taken at the end of the preceding year, while income statement variables are proxied by their values measured over year t-1.

2.5 Results

2.5.1 Effect of Domestic Monetary Policy on the Composition of Loan Supply

- Domestic versus Foreign Currency Credit

We start analysing the effect of domestic monetary policy on banks' loan supply decisions focusing on domestic vis-à-vis foreign currency loans, without distinguishing between firms' exposures in Euro and Swiss Franc. We focus on the extensive margin of lending by examining the effect of monetary policy on changes in the likelihood of banks' first-time

[39]When the sample includes only single-bank firms, the firm-time fixed effects also account for all observed and unobserved heterogeneity at the bank-time level, e.g., changes over time in technology and business model in each individual bank.

credit granting in a certain currency (i.e., the extensive margin of new credit, henceforth abridged as "credit initiation").

Tables 2.2.a and 2.2.b (or in short Tables 2.2) present our first results. Table 2.2.a highlight the coefficients of main interest in an abridged form, while Table 2.2.b include all relevant coefficient, t-statistics and calculated economic effects. Models 1 to 4 provide a step-by-step development towards the base specification which is Model 4 and which includes all relevant interaction terms for the interest rate, GDP growth, and inflation. The estimated coefficients of the domestic interest rate variable are highly significant in all models and have the expected negative sign suggesting that an interest rate decrease expands credit. In addition, Model 2 shows that the coefficient of the interaction of the interest rate with the bank capital ratio is statistically significant and takes a positive sign implying that a lower interest rate boosts credit granting especially by banks with low capital-to-asset ratios. This estimate is consistent with the existence of a bank-lending channel in Hungary, similar to the U.S. (e.g. Kashyap and Stein (2000)) and Spain (Jiménez and Ongena (2012)).

The bottom panel in Table 2.2.b presents the economic relevance of the estimated coefficients. A 25 basis point decrease in the domestic interest rate increases the likelihood of initiating credit by a lowly capitalized bank 0.019 percentage point more than by a highly capitalized bank (if we take the difference between low and high capitalization to be equal to two standard deviations of the sample capitalization ratio). The estimated effect is thus economically significant, taking into account that the sample probability of new credit for any firm is 0.23 percent implying a semi-elasticity of the difference in loan granting between lowly and highly capitalized banks of 8 percent.[40] Notice that this estimated elasticity is more than five times larger than the roughly one percent differential effect of a 25 basis point change in the interest rate on the likelihood of loan granting between lowly and highly capitalized banks documented by Jiménez and Ongena (2012).[41] This difference in estimated elasticity suggests that, when banks grant loans in different currencies, the supply of credit in each currency (so defined) reacts most vigorously to

[40] In robustness we will assess if the low probabilities involved make inference problematic (à la King and Zeng (2001) and King and Zeng (2006)).

[41] Jiménez and Ongena (2012) find that a 100-basis point decrease in the interest rate increases loan granting by lowly capitalized banks by 3.9 percent more than by highly capitalized banks, where the difference in bank capitalization is defined as the difference between the tenth and ninetieth percentiles of the distribution. Other differences between their and our setup include the sample (i.e., they study loan applications) and method of identification (i.e., they rely on loan fixed effects).

changes in monetary conditions.

We next study the compositional effect of monetary policy on banks' loan supply decisions in Models 4 to 7. The estimates in Model 4 show that the differential impact of an interest rate change between lowly and highly capitalized banks is magnified when lending occurs in the domestic currency and minimized when lending occurs in a foreign currency. The same result is obtained in Model 5, which includes time – i.e., year:month – fixed effects, in addition to the firm fixed effects that were present in Models 1 to 4. Model 4 shows that a 25 basis point decrease in the domestic interest rate generates a 0.029 percentage point higher likelihood of credit initiation by a lowly- than by a highly capitalized bank when credit is granted in the domestic currency (Hungarian Forint). This differential impact represents 13 percent of the probability of credit initiation in the sample and is thus economically relevant. Model 5 indicates that the estimated economic effect is even higher – 14 percent of the sample probability of granting first-time credit – when, besides firm fixed effects, we also include time fixed effects in the regression. Coefficients on triple interaction terms including the interest rate variable in Models 4 and 5 show, however, that when lending takes place in a foreign currency, the economic impact of bank capitalization on the likelihood of first-time credit granting is almost insignificant. According to Model 4 (Model 5), a 25 basis point decrease in the domestic interest rate generates a differential impact between low and high capitalization banks that equals only 4 percent (5 percent) of the unconditional probability of initiating credit in the sample.

Models 6 and 7 saturate the empirical specification with firm-time fixed effects that account for all time-varying firm-specific heterogeneity in loan demand (volume and quality). The estimated coefficients on the triple interactions of the interest rate, bank capitalization, and currency denomination, indicate that the differential impact of interest rate changes along capitalization on credit initiation in domestic and foreign currency is robust to accounting for all time-varying firm heterogeneity in loan demand. The bottom panel in Table 2.2.b shows that the size of the difference in the economic impact between the domestic and foreign currencies equals 8 and 6 percent, respectively. The two models differ in the sample employed: Model 7 restricts the sample to firms with only one bank relationship (making the bank singularly identifiable), which represent 74 percent of all firms in our sample. Model 7 reveals that our results on the currency compositional effect of monetary policy are robust to the restriction of our analysis to one-bank firms.

Concerning the effects of other key macro variables, Tables 2.2 confirms the economic relevance of GDP growth and CPI inflation in banks' loan supply decisions. Model 1 shows

10.14754/CEU.2016.04

Table 2.2.a: The Granting of Credit in Domestic or Foreign Currency to Borrowers Currently Without Credit in Domestic or Foreign Currency (Extensive Margin) - Abridged Form

				Credit Is Granted in Foreign Currency	
		-	Bank Capital Ratio	-	Bank Capital Ratio
Δ Interest Rate	(1)	-0.0101***			
	(2)	-0.0343***	0.2554***		
	(3)	-0.0134***		0.0067**	
	(4)	-0.0506***	0.3914***	0.0327***	-0.2721***
	(5)		0.4411***	0.0327***	-0.2721***
	(6)			0.0335***	-0.2516***
	(7)			0.0215***	-0.1762***
Δ GDP	(1)	0.0021			
	(2)	0.0095**	-0.0817***		
	(3)	0.0130***		-0.0216***	
	(4)	0.0249***	-0.1291***	-0.0308***	0.0948**
	(5)		-0.0791*	-0.0308***	0.0948**
	(6)			-0.0231***	0.0565***
	(7)			-0.0195***	0.0702***
Δ CPI	(1)	0.0031			
	(2)	-0.0075*	0.1136***		
	(3)	0.0024		0.0015	
	(4)	-0.0203***	0.2421***	0.0255***	-0.2569***
	(5)		0.2414***	0.0255***	-0.2569***
	(6)			0.0105***	-0.1026***
	(7)			0.0062***	-0.0656***

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable is a dummy that equals one if the firm is granted credit in domestic (foreign) currency in a particular year:month conditional on having received no credit in this currency in the month before and equals zero otherwise. All independent variables are either lagged one month or calculated over the preceding month. Table 2.1 lists the definition of all variables. Coefficients with significance levels corresponding to t-statistics based on robust standard errors clustered at the firm level are reported in the table. *** Significant at 1%, ** significant at 5%, * significant at 10%. Models (1)-(4) include firm fixed effects, model (5) includes both firm and time fixed effects, models (6)-(7) include firm-time fixed effects.

10.14754/CEU.2016.04

Table 2.2.b: The Granting of Credit in Domestic or Foreign Currency to Borrowers Currently Without Credit in Domestic or Foreign Currency (Extensive Margin)

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sample	*All Firms*	*All Firms*	*All Firms*	*All Firms*	*All Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*
Δ Interest Rate	-0.0101***	-0.0343***	-0.0134***	-0.0506***			
	(-3.37)	(-6.64)	(-3.62)	(-6.43)			
Δ Interest Rate * Bank Capital Ratio		0.2554***		0.3914***	0.4411***		
		(6.13)		(5.58)	(6.25)		
Δ Interest Rate * Credit Is Granted in Foreign Currency			0.0067**	0.0327***	0.0327***	0.0335***	0.0215***
			(2.36)	(4.24)	(4.24)	(16.79)	(11.45)
Δ Interest Rate * Bank Capital Ratio * Credit Is Granted in Foreign Currency				-0.2721***	-0.2721***	-0.2516***	-0.1762***
				(-3.80)	(-3.80)	(-13.55)	(-10.13)
Δ GDP	0.0021	0.0095**	0.0130***	0.0249***			
	(0.53)	(2.05)	(3.07)	(4.41)			
Δ GDP * Bank Capital Ratio		-0.0817***		-0.1291***	-0.0791*		
		(-3.19)		(-3.11)	(-1.91)		
Δ GDP * Credit Granted in Foreign Currency			-0.0216***	-0.0308***	-0.0308***	-0.0231***	-0.0195***
			(-13.07)	(-7.02)	(-7.02)	(-19.88)	(-18.10)
Δ GDP * Bank Capital Ratio * Credit Is Granted in Foreign Currency				0.0948**	0.0948**	0.0565***	0.0702***
				(2.19)	(2.19)	(4.94)	(6.64)
Δ CPI	0.0031	-0.0075*	0.0024	-0.0203***			
	(1.26)	(-1.74)	(0.76)	(-2.99)			
Δ CPI * Bank Capital Ratio		0.1136***		0.2421***	0.2414***		
		(3.23)		(3.85)	(3.81)		
Δ CPI * Credit Is Granted in Foreign Currency			0.0015	0.0255***	0.0255***	0.0105***	0.0062***
			(0.56)	(3.64)	(3.64)	(6.43)	(4.21)
Δ CPI * Bank Capital Ratio * Credit Is Granted in Foreign Currency				-0.2569***	-0.2569***	-0.1026***	-0.0656***
				(-3.80)	(-3.80)	(-6.95)	(-5.08)
Δ Exchange Rate	-0.0007	-0.0008	-0.0007	-0.0008			
	(-0.63)	(-0.76)	(-0.63)	(-0.76)			
Δ Foreign Direct Investment	-0.0012***	-0.0012***	-0.0012***	-0.0012***			
	(-2.87)	(-2.75)	(-2.87)	(-2.75)			
Δ Credit Default Swap Spread	0.0001**	0.0002***	0.0001**	0.0002***			
	(2.30)	(2.59)	(2.30)	(2.59)			
Δ Yield Curve	-0.0093	-0.0098	-0.0093	-0.0098			
	(-0.81)	(-0.85)	(-0.81)	(-0.85)			
Bank Capital Ratio	-0.0022	-0.0005	-0.0022	-0.0026	-0.0087***		
	(-1.13)	(-0.25)	(-1.13)	(-1.15)	(-3.73)		
Bank Total Assets	-0.0010***	-0.0009***	-0.0010***	-0.0009***	-0.0001		
	(-6.93)	(-6.74)	(-6.93)	(-6.74)	(-0.44)		
Bank Liquidity Ratio	-0.0079***	-0.0078***	-0.0079***	-0.0078***	-0.0027***		
	(-10.36)	(-10.16)	(-10.36)	(-10.16)	(-3.11)		
Bank Return On Assets	0.0009	0.0021	0.0009	0.0021	0.0030		
	(0.47)	(1.07)	(0.47)	(1.07)	(1.48)		
Bank Doubtful Loan Ratio	-0.0174***	-0.0178***	-0.0174***	-0.0178***	0.0148***		
	(-10.12)	(-10.02)	(-10.12)	(-10.02)	(5.98)		
Credit Is Granted in Foreign Currency	-0.0029***	-0.0029***	-0.0027***	-0.0031***	-0.0031***	-0.0026***	-0.0019***
	(-41.80)	(-41.80)	(-37.49)	(-17.15)	(-17.15)	(-60.29)	(-46.20)
Bank Capital Ratio * Credit Is Granted in Foreign Currency				0.0043***	0.0043***	0.0032***	0.0012***
				(2.59)	(2.59)	(8.10)	(3.37)
Firm Capital Ratio	0.0022***	0.0022***	0.0022***	0.0022***	0.0024***		
	(10.09)	(10.13)	(10.09)	(10.13)	(10.68)		
Firm Total Assets	-0.0003***	-0.0003***	-0.0003***	-0.0003***	-0.0002**		
	(-3.97)	(-3.97)	(-3.97)	(-3.97)	(-2.18)		
Firm Liquidity Ratio	0.0012***	0.0012***	0.0012***	0.0012***	0.0012***		
	(4.43)	(4.41)	(4.43)	(4.41)	(4.37)		
Firm Return On Assets	0.0002***	0.0002***	0.0002***	0.0002***	0.0002***		
	(8.45)	(8.43)	(8.45)	(8.43)	(6.20)		
Firm Export Sales Ratio	-0.0005	-0.0005	-0.0005	-0.0005	-0.0004		
	(-1.20)	(-1.15)	(-1.20)	(-1.15)	(-0.96)		
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes	–	–
Time Fixed Effects	No	No	No	No	Yes	–	–
Firm - Time Fixed Effects	No	No	No	No	No	Yes	Yes
Number of Observations	2 075 500	2 075 500	2 075 500	2 075 500	2 075 500	11 952 459	8 827 525
Percentage Point Difference in Impact of a Decrease in Interest Rate by 25 bps on the Likelihood of Granting of First-Time Credit by Lower versus Higher Capitalized Banks (Δ=2 Standard Deviations)							
in Hungarian Forint or in Foreign Currency	-	*0.0189*	-	-	-	-	-
in Hungarian Forint	-	-	-	*0.0290*	*0.0326*	-	-
in Foreign Currency	-	-	-	*0.0088*	*0.0125*	-	-
Diff. in Impact Between Foreign Currency and Hungarian Forint	-	-	-	*-0.0201*	*-0.0201*	*-0.0186*	*-0.0130*
Difference in Impact of a Decrease in Interest Rate by 25 bps on the Likelihood of Granting of First-Time Credit by Lower versus Higher Capitalized Banks (Δ=2 Standard Deviations) as Percent of Unconditional Probability of Granting First-Time Credit in Sample (= 0.23%)							
in Hungarian Forint or in Foreign Currency	-	*8%*	-	-	-	-	-
in Hungarian Forint	-	-	-	*13%*	*14%*	-	-
in Foreign Currency	-	-	-	*4%*	*5%*	-	-
Diff. in Impact Between Foreign Currency and Hungarian Forint	-	-	-	*-9%*	*-9%*	*-8%*	*-6%*

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable is a dummy that equals one if the firm is granted credit in domestic (foreign) currency in a particular year:month conditional on having received no credit in this currency in the month before and equals zero otherwise. All independent variables are either lagged one month or calculated over the preceding month. Table 2.1 lists the definition of all variables. Coefficients are listed in the first row, t-statistics based on robust standard errors clustered at the firm level are reported in the row below in parentheses, and the corresponding significance levels are in the adjacent column. "Yes" indicates that the set of fixed effects is included. "No" indicates that the set of fixed effects is not included. "–" indicates that the indicated set of fixed effects are comprised in the wider included set of fixed effects. Time Fixed Effects include an effect for every year:month. *** Significant at 1%, ** significant at 5%, * significant at 10%.

that both GDP growth and inflation have negligible aggregate effect on credit granting. Model 2, however, indicates that there is heterogeneity in how banks respond to changes in these macroeconomic variables. High GDP growth and low inflation boost credit granting by lowly capitalized banks, while reduce lending by highly capitalized banks. This finding corresponds to results in Jiménez and Ongena (2012) suggesting that GDP growth increases the probability of loan granting by Spanish banks. Estimates on the triple interactions of the GDP growth or inflation variables, bank capital, and the foreign currency dummy in Model 4 suggest that the differential impacts of changes in GDP growth and inflation between lowly and highly capitalized banks are magnified when lending occurs in the domestic currency and minimized when lending occurs in a foreign currency. Models 5 to 7 show that these results are robust to the inclusion of time fixed effects or firm-time fixed effects.

Overall, the results of Models 4 to 7 suggest that there is also a compositional effect in banks' loan supply decisions when responding to a change in the domestic interest rate: Expansionary monetary policy increases the likelihood of credit initiation in the domestic currency but banks' foreign currency lending is essentially unaffected. Put differently, the bank lending channel of the domestic monetary policy loses its potency when it comes to the supply of credit in the foreign currency.

- Robustness: Other Macroeconomic Conditions, Asymmetric and Non-linear Effects, Bank Characteristics and Sample Splits

In this robustness section we first examine whether, besides GDP growth and inflation, banks' loan supply decisions are sensitive to shocks in other macroeconomic variables. In particular, we horserace triple interactions of bank capital, currency denomination, and various macroeconomic variables, including, besides GDP growth and inflation, the nominal effective exchange rate, the amount of foreign direct investment, and the credit default swap spread in the country.

The estimates in Models 1 and 2 in Tables 2.3 (2.3.a and 2.3.b) suggest that neither changes in the exchange rate nor changes in foreign direct investment affect the currency composition of credit granting.[42] Inclusion of triple interactions of the three macro vari-

[42]To conserve space in the tables we focus on firms' aggregate foreign currency exposures without distinguishing between Euro and Swiss Franc loans (as we will do in the next section) and we present only the most saturated specification that includes firm-time fixed effects. Results are unaffected when splitting up by currency as the next section will show. To conserve space we henceforth also only report the estimated semi-elasticities.

ables with bank capital and currency denomination does not alter our findings regarding the differential supply effects of monetary policy. The difference in the economic impact between the domestic and foreign currencies is 16 and 11 percent, similar in magnitude to the differential impact obtained in our baseline specifications (see Models 6 and 7 in Tables 2.2).

To test the sensitivity of our results to changes in the macroeconomic shock variable, in unreported regressions we also include either one of two regulatory dummies. The first dummy equals one after 2008:01, the introduction of Basle II, and equals zero before. The second dummy equals one after 2008:09, when Swiss Francs lending by banks to households was no longer allowed, and equals zero before. These dummies are introduced at all levels, including the triple interactions with bank capital and the currency of exposure. But results on the triple interactions with the interest rate are unaffected in both cases.

To test for the asymmetric impact of the interest rate, we replace the change in the interest rate with relevant interactive terms,[43] i.e., the interactions of the change of interest rate with (1) a dummy variable that equals one if the change in the interest rate during the previous month was larger than or equal to zero (and equals zero otherwise) and (2) a dummy variable that equals one if the change in the interest rate during the previous month was smaller than zero (and equals zero otherwise). The estimated coefficients on the resultant quadruples remain qualitatively similar, but it is especially the lowering of the domestic interest rate that has the most pronounced differential impact on domestic versus foreign currency lending. We also include squared terms (of the changes in the interest rate in all relevant interactions) but find no significant second order terms. To conserve space we choose not to report these specifications (that load in these extra terms and become somewhat unwieldy to present).

So far we have focused on bank equity to total bank assets as the only bank balance-sheet characteristic that may affect changes in banks' lending decisions following monetary shocks (Holmstrom and Tirole (1997)). We now alter the measurement of bank capital and also follow the previous literature by examining whether bank size (the natural logarithm of bank assets) and bank liquidity (the ratio of liquid to total bank assets) also affect the impact of interest rate changes on banks' loan supply. Furthermore, we examine whether bank foreign ownership matters.

In Models 3 and 4 we employ as an alternative to the Bank Capital Ratio the (one-

[43]Our methodology is standard and similar to e.g. Thoma (1994) and Weise (1999). They find no asymmetric effects of monetary shocks on prices or output.

10.14754/CEU.2016.04

Table 2.3.a: The Granting of Credit in Domestic or Foreign Currency to Borrowers Currently Without Credit in Domestic or Foreign Currency (Extensive Margin), Interactions with Macroeconomic Variables, Bank Regulatory Capital, Size and Liquidity, and Foreign Ownership - Abridged Form

		Credit Is Granted in Foreign Currency		
		-	Bank Capital Ratio	Bank Characteristic
Δ Interest Rate	(1)	0.0645***	-0.5073***	
	(2)	0.0439***	-0.3354***	
	(3)	0.0404***		-0.0202***
	(4)	0.0264***		-0.0142***
	(5)	0.0313***		-0.0015**
	(6)	-0.0117		0.0011*
	(7)	0.0593***	-0.2567***	-0.0018***
	(8)	0.0059	-0.1799***	0.0011*
	(9)	0.0323***		-0.1250***
	(10)	0.0150***		-0.0503***
	(11)	0.0664***	-0.3402***	-0.1335***
	(12)	0.0394***	-0.2376***	-0.0586***
	(13)	0.0373***	-0.2524***	-0.0038
	(14)	0.0081	-0.1850***	0.0146***
Δ GDP	(1)	-0.0363***	0.1166***	
	(2)	-0.0290***	0.1370***	
	(3)	-0.0161***		0.0001
	(4)	-0.0121***		0.0003
	(5)	-0.0694***		0.0036***
	(6)	-0.0372***		0.0017***
	(7)	-0.0759***	0.0572***	0.0037***
	(8)	-0.0436***	0.0678***	0.0017***
	(9)	-0.0223***		0.0497***
	(10)	-0.0149***		0.0258***
	(11)	-0.0249***	0.0403***	0.0434***
	(12)	-0.0198***	0.0570***	0.0247***
	(13)	-0.0176***	0.0593***	-0.0060**
	(14)	-0.0137***	0.0729***	-0.0063**
Δ CPI	(1)	-0.0190***	0.0733***	
	(2)	-0.0153***	0.0767***	
	(3)	-0.0034**		0.0016**
	(4)	-0.0038***		0.0015***
	(5)	-0.0080		0.0006
	(6)	-0.0044		0.0003
	(7)	0.0083	-0.0997***	0.0001
	(8)	0.0048	-0.0643***	0.0001
	(9)	-0.0050***		0.0177*
	(10)	-0.0070***		0.0345***
	(11)	-0.0000	-0.0954***	0.0447***
	(12)	-0.0032	-0.0680***	0.0530***
	(13)	0.0218***	-0.0959***	-0.0123**
	(14)	0.0110**	-0.0617***	-0.0053
Δ Exchange Rate	(1)	0.0142***	-0.1037***	
	(2)	0.0131***	-0.1158***	
Δ FDI	(1)	-0.0034***	0.0146***	
	(2)	-0.0029***	0.0228***	
Δ CDS	(1)	-0.0012***	0.0085***	
	(2)	-0.0010***	0.0075***	

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable is a dummy that equals one if the firm is granted credit in domestic (foreign) currency in a particular year:month conditional on having received no credit in this currency in the month before and equals zero otherwise. All independent variables are either lagged one month or calculated over the preceding month. Bank Regulatory Capital is the ratio of regulatory capital over risk-weighted assets. Table 2.1 lists the definition of all other variables. Coefficients with significance levels corresponding to t-statistics based on robust standard errors clustered at the firm level are reported in the table. *** Significant at 1%, ** significant at 5%, * significant at 10%. Models (1)-(14) include firm-time fixed effects.

Table 2.3.b: The Granting of Credit in Domestic or Foreign Currency to Borrowers Currently Without Credit in Domestic or Foreign Currency (Extensive Margin), Interactions with Macroeconomic Variables, Bank Regulatory Capital, Size and Liquidity, and Foreign Ownership

multicolumn1rModel	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
In Models (3) to (14): Other Bank Characteristic	Additional,Macroeconomic Variables in Interactions		*Bank,Regulatory Capital Ratio*			*Bank,Total Assets*				*Bank,Liquidity Ratio*			*Foreign,Owned Bank*	
Sample	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*
Δ Interest Rate * Credit Is Granted in Foreign Currency	0.0645***	0.0439***	0.0404***	0.0264***	0.0313***	-0.0117	0.0593***	0.0059	0.0323***	0.0150***	0.0664***	0.0394***	0.0373***	0.0081
	(16.52)	(12.66)	(19.57)	(14.24)	(3.13)	(-1.28)	(5.72)	(0.62)	(17.05)	(8.56)	(22.29)	(14.00)	(7.01)	(1.62)
Δ Interest Rate * Bank Capital Ratio * Credit Is Granted in Foreign Currency	-0.5073***	-0.3354***					-0.2567***	-0.1799***			-0.3402***	-0.2376***	-0.2524***	-0.1850***
	(-13.56)	(-10.37)					(-13.80)	(-10.37)			(-17.35)	(-12.84)	(-13.54)	(-10.58)
Δ Interest Rate * Bank Characteristic * Credit Is Granted in Foreign Currency			-0.0202***	-0.0142***	-0.0015**	0.0011*	-0.0018***	0.0011*	-0.1250***	-0.0503***	-0.1335***	-0.0586***	-0.0038	0.0146***
			(-17.14)	(-13.70)	(-2.25)	(1.80)	(-2.65)	(1.74)	(-12.70)	(-5.42)	(-12.82)	(-5.96)	(-0.73)	(2.95)
Δ GDP * Credit Is Granted in Foreign Currency	-0.0363***	-0.0290***	-0.0161***	-0.0121***	-0.0694***	-0.0372***	-0.0759***	-0.0436***	-0.0223***	-0.0149***	-0.0249***	-0.0198***	-0.0176***	-0.0137***
	(-17.09)	(-15.12)	(-15.97)	(-13.57)	(-12.21)	(-7.29)	(-12.94)	(-8.22)	(-21.27)	(-15.21)	(-14.65)	(-12.54)	(-5.92)	(-4.70)
Δ GDP * Bank Capital Ratio * Credit Is Granted in Foreign Currency	0.1166***	0.1370***					0.0572***	0.0678***			0.0403***	0.0570***	0.0593***	0.0729***
	(5.77)	(7.79)					(5.00)	(6.45)			(3.40)	(5.21)	(5.17)	(6.89)
Δ GDP * Bank Characteristic * Credit Is Granted in Foreign Currency			0.0001	0.0003	0.0036***	0.0017***	0.0037***	0.0017***	0.0497***	0.0258***	0.0434***	0.0247***	-0.0060**	-0.0063**
			(0.13)	(0.69)	(9.36)	(4.80)	(9.54)	(4.86)	(9.83)	(5.43)	(8.31)	(5.03)	(-2.04)	(-2.21)
Δ CPI * Credit Is Granted in Foreign Currency	-0.0190***	-0.0153***	-0.0034**	-0.0038***	-0.0080	-0.0044	0.0083	0.0048	-0.0050***	-0.0070***	-0.0000	-0.0032	0.0218***	0.0110**
	(-7.23)	(-6.46)	(-2.57)	(-3.43)	(-0.91)	(-0.56)	(0.90)	(0.57)	(-2.71)	(-4.02)	(-0.01)	(-1.60)	(4.39)	(2.31)
Δ CPI * Bank Capital Ratio * Credit Is Granted in Foreign Currency	0.0733***	0.0767***					-0.0997***	-0.0643***			-0.0954***	-0.0680***	-0.0959***	-0.0617***
	(3.18)	(3.81)					(-6.69)	(-4.95)			(-6.25)	(-5.06)	(-6.47)	(-4.76)
Δ CPI * Bank Characteristic * Credit Is Granted in Foreign Currency			0.0016**	0.0015***	0.0006	0.0003	0.0001	0.0001	0.0177*	0.0345***	0.0447***	0.0530***	-0.0123**	-0.0053
			(2.39)	(3.04)	(0.93)	(0.52)	(0.16)	(0.17)	(1.67)	(3.44)	(4.03)	(5.06)	(-2.46)	(-1.11)
Δ Exchange Rate * Credit Is Granted in Foreign Currency	0.0142***	0.0131***												
	(11.65)	(11.57)												
Δ Exchange Rate * Bank Capital Ratio * Credit Is Granted in Foreign Currency	-0.1037***	-0.1158***												
	(-9.20)	(-11.03)												
Δ FDI * Credit Is Granted in Foreign Currency	-0.0034***	-0.0029***												
	(-7.15)	(-6.71)												
Δ FDI * Bank Capital Ratio * Credit Is Granted in Foreign Currency	0.0146***	0.0228***												
	(3.15)	(5.65)												
Δ CDS Spread * Credit Is Granted in Foreign Currency	-0.0012***	-0.0010***												
	(-17.39)	(-14.92)												
Δ CDS Spread * Bank Capital Ratio * Credit Is Granted in Foreign Currency	0.0085***	0.0075***												
	(13.08)	(12.35)												
Credit Is Granted in Foreign Currency	-0.0012***	-0.0008***	-0.0029***	-0.0021***	-0.0052***	-0.0027***	-0.0054***	-0.0028***	-0.0032***	-0.0024***	-0.0036***	-0.0027***	-0.0018***	-0.0012***
	(-11.08)	(-7.54)	(-76.83)	(-62.93)	(-20.52)	(-11.32)	(-20.90)	(-11.26)	(-75.37)	(-60.96)	(-60.95)	(-47.54)	(-15.78)	(-10.85)
Bank Bank Capital Ratio * Credit Is Granted in Foreign Currency	-0.0046***	-0.0069***					0.0032***	0.0011***			0.0038***	0.0019***	0.0035***	0.0015***
	(-4.43)	(-7.23)					(7.89)	(3.09)			(9.20)	(5.13)	(8.90)	(4.14)
Bank Characteristic * Credit Is Granted in Foreign Currency			0.0003***	0.0002***	0.0002***	0.0001***	0.0002***	0.0001***	0.0050***	0.0041***	0.0056***	0.0044***	-0.0009***	-0.0008***
			(17.43)	(14.68)	(11.62)	(4.16)	(11.29)	(3.94)	(23.60)	(20.48)	(25.28)	(21.41)	(-8.59)	(-7.22)
Firm - Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	11 952 459	8 827 525	11 535 244	8 493 060	11 952 459	8 827 525	11 952 459	8 827 525	11 952 459	8 827 525	11 952 459	8 827 525	11 952 459	8 827 525

Difference in Impact of a Decrease in Interest Rate by 25 bps on the Likelihood of Granting of First-Time Credit by Lower versus Larger/Higher Regulatory Capitalized, Sized, Liquid, Foreign-Owned and/or Capitalized Banks (Δ=2 Standard Deviations) as Percent of Unconditional Probability of Granting First-Time Credit in Sample (= 0.23%)

Difference in Impact Between Foreign Currency and Hungarian Forint due to	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Bank Capital Ratio	*-16%*	*-11%*	-	-	-	-	*-8%*	*-6%*	-	-	*-11%*	*-8%*	*-11%*	*-8%*
Regulatory Bank Capital Ratio	-	-	*-9%*	*-6%*	-	-	-	-	-	-	-	-	-	-
Bank Total Assets	-	-	-	-	*-1%*	*0%*	*-1%*	*0%*	-	-	-	-	-	-
Bank Liquidity Ratio	-	-	-	-	-	-	-	-	*-5%*	*-2%*	*-5%*	*-2%*	-	-
Foreign Owned Bank	-	-	-	-	-	-	-	-	-	-	-	-	*-5%*	*-2%*

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable is a dummy that equals one if the firm is granted credit in domestic (foreign) currency in a particular year:month conditional on having received no credit in this currency in the month before and equals zero otherwise. All independent variables are either lagged one month or calculated over the preceding month. Bank Regulatory Capital is the ratio of regulatory capital over risk-weighted assets. Table 2.1 lists the definition of all other variables. Coefficients are listed in the first row, t-statistics based on robust standard errors clustered at the firm level are reported in the row below in parentheses, and the corresponding significance levels are in the adjacent column. "Yes" indicates that the set of fixed effects is included. Time Fixed Effects include an effect for every year:month. *** Significant at 1%, ** significant at 5%, * significant at 10%.

10.14754/CEU.2016.04

month lagged) Bank Regulatory Capital Ratio which is defined as regulatory capital over risk-weighted assets. The reasons for this replacement are twofold. First, bank capital is the outcome of strategic choices made by the bank, and even when pre-determined in time endogeneity concerns may linger. Regulatory capital suffers (somewhat less) on this account. Second, Popov and Udell (2012) for example document that especially regulatory capital constraints determine bank lending. Our results remain robust however to the choice of bank capital measure. Alternatively in further unreported regressions we also instrument the Bank Capital Ratio with for example one and two-quarter lags of the Bank Regulatory Capital Ratio (and/or lags of the bank capital ratio itself). Again results are very similar.

In Models 5 and 6 we follow Kashyap and Stein (1995) and focus on the impact of monetary shocks on the supply of loans by banks of different size, measuring bank size by total assets. The estimated coefficients of triple interactions of the interest rate change, bank size, and currency denomination are all insignificant suggesting that following monetary shocks there is no currency compositional effect in the supply of loans identifiable from the adjustment of banks of different size. In Models 7 and 8 we add the Bank Capital Ratio and its interactions and observe that the estimated coefficient on the triple interaction term that includes the bank capital ratio is statistically significant and economically large, while the triple term that includes Bank Total Assets is at best marginally significant and is always economically very small.

In Models 9 and 10, inspired by Kashyap and Stein (2000)) or Jiménez and Ongena (2012), we examine the impact of monetary shocks on the supply of credit by banks with different liquidity ratios. The estimates suggest a differential impact of interest rate changes along the bank liquidity characteristic. Estimates of Model 9, for example, indicate that when credit is granted in the domestic currency a 25 basis point decrease in the domestic interest rate generates a 5 percent larger difference (measured by the semi-elasticity of the coefficient) in the impact on the likelihood of credit granting between banks with low and high liquidity ratios, than when credit is granted in the foreign currency. In Models 11 and 12 we horserace the bank capital ratio with liquidity. The estimates indicate it is especially the bank capital ratio that drives adjustments in banks' loan supply decisions following monetary changes.

Because foreign ownership may affect banks' own funding across currencies differentially we horse race the bank capital ratio with foreign ownership in Models 13 and 14.[44]

[44]Global banks manage liquidity on a global scale actively using cross-border internal funding in response

10.14754/CEU.2016.04

The estimated coefficients on foreign ownership are not statistically significant while the estimated coefficients on the triple interaction term with bank capital ratio again imply that when credit is granted in the domestic currency, a 25 basis point decrease in the domestic interest rate generates a 8 and 6 percent larger difference (again, measured by the semi-elasticity of the coefficients), respectively, in the impact on the likelihood of credit granting between banks with low and high capital ratios, than when credit is granted in a foreign currency.[45] In Model 1 in Tables 2.4 (2.4.a and 2.4.b) we further split the sample by foreign ownership of banks and find similar estimated coefficients on these triple interactions of interest.

Next we study the period before and after the filing for bankruptcy by Lehman Brothers in 2008:09, which is now commonly considered as the start of the most acute phase of the global financial crisis that eventually also spread to Hungary. Models 3 and 4 contain the estimated coefficients from the period before Lehman. The difference in potency between the lending channels in domestic and foreign currency is larger than for the entire period. For the short period after Lehman none of the estimated coefficients are statistically significant (further unreported).[46]

to local shocks (Cetorelli and Goldberg (2012)). Having global operations therefore insulates banks from changes in local monetary policy, while banks without global operations are more affected by monetary policy. Another issue may arise if foreign owned banks have more foreign currency-denominated liabilities on their balance sheets. A decrease in the Forint interest rate may then affect their capital-to-assets ratio through its effect on the exchange rate with the Forint. The Forint depreciation will increase the Forint equivalent of the value of foreign currency denominated liabilities on the banks' balance sheets and may concurrently decrease the capital-to-assets ratios of these banks. However all our specifications employ a one-month lagged capital ratio and in previous models this ratio was replaced or instrumented with one- and two- quarter lags of the regulatory capital ratio. In general foreign banks may follow a different business model (e.g., Giannetti and Ongena (2009), Gormley (2010), Beck et al. (2012), Giannetti and Ongena (2012)) than domestic banks which may change their sensitivity to changes in monetary conditions (see similarly Zaheer et al. (2013) on Islamic banks and Morck et al. (2013) on state-owned banks).

[45] The estimated coefficients on foreign ownership are also not statistically significant when the bank capital ratio is not included. As an alternative for foreign ownership we also impute from the Swiss Franc Lending Monitor dataset (also used in e.g. Krogstrup and Tille (2014)) and from Hungarian bank regulatory reports the quarterly varying currency composition of the balance sheet of the average bank from Austria, Germany, France, Italy, or Hungary, and assign these values to the banks in our dataset that are headquartered in these countries. But we find no statistical significance on the terms of interest, which may be due to the likely substantial measurement error involved.

[46] There are a number of potential explanations for this lack of statistical significance: (1) Banks may have substantially changed their lending policies if not voluntarily (e.g., Cetorelli and Goldberg (2011), de Haas and Lelyveld (2014)) then various regulatory limits may have become binding (Rosenberg and Tirpák (2009)); (2) due to unconventional monetary policies changes in short-term interest rates may have become less representative of changes in monetary conditions; and/or (3) the subsample period may be simply too short to yield statistically significant estimates.

Table 2.4.a: The Granting of Credit in Domestic or Foreign Currency to Borrowers Currently Without Credit in Domestic or Foreign Currency (Extensive Margin), By Sample - Abridged Form

		Credit Is Granted in Foreign Currency	
		-	Bank Capital Ratio
Δ Interest Rate	(1)	0.0424***	-0.2915***
	(2)	0.0328***	-0.2492***
	(3)	0.1337***	-0.9363***
	(4)	0.0980***	-0.7321***
	(5)	0.0458***	-0.3315***
	(6)	0.0326***	-0.2559***

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable is a dummy that equals one if the firm is granted credit in domestic (foreign) currency in a particular year:month conditional on having received no credit in this currency in the month before and equals zero otherwise. All independent variables are either lagged one month or calculated over the preceding month. Table 2.1 lists the definition of all variables. Coefficients with significance levels corresponding to t-statistics based on robust standard errors clustered at the firm level are reported in the table. *** Significant at 1%, ** significant at 5%, * significant at 10%. Models (1)-(6) include firm-time fixed effects.

Finally, in Models 5 and 6 in Tables 2.4 we focus our analysis on the 50 percent largest firms by total assets (the 50 largest percent by number of employees yields similar results). We are interested if the economic relevancy of the difference in potency between the two channels also pertains to these large firms.[47] It does, making the observed phenomenon also relevant in an aggregate sense.

- Domestic versus Euro and Swiss Franc Credit

We continue analysing the effect of domestic monetary policy on banks' loan supply

[47]We also assess results across EU and various other firm-size categorization schemes. Results are similar except for some largest-size classes. However, given the continuous financing needs of the largest firms, changes on their extensive margins of borrowing are also less frequent (potentially leading to less statistical significance). Notice that some small business owners in Hungary are thought to have personal bank accounts in Switzerland or the Euro area, making their (for us un-observable) personal financial situation potentially an omitted variable. We expect this effect to play less of a role for large firms.

Table 2.4.b: The Granting of Credit in Domestic or Foreign Currency to Borrowers Currently Without Credit in Domestic or Foreign Currency (Extensive Margin), By Sample

Model	(1)	(2)	(3)	(4)	(5)	(6)
Overall Sample	*Only,Foreign Owned Banks*		*2005:01-2008:09*		*Only Firms Above Median in Total Assets*	
Sample	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*
Δ Interest Rate * Credit Is Granted in Foreign Currency	0.0424***	0.0328***	0.1337***	0.0980***	0.0458***	0.0326***
	(18.22)	(14.57)	(26.24)	(19.97)	(15.07)	(10.52)
Δ Interest Rate * Bank Capital Ratio * Credit Is Granted	-0.2915***	-0.2492***	-0.9363***	-0.7321***	-0.3315***	-0.2559***
in Foreign Currency	(-13.77)	(-12.05)	(-21.00)	(-17.22)	(-11.75)	(-9.12)
Δ GDP * Credit Is Granted in Foreign Currency	-0.0278***	-0.0218***	0.0148***	0.0195***	-0.0272***	-0.0266***
	(-21.36)	(-17.48)	(3.08)	(4.44)	(-14.81)	(-14.48)
Δ GDP * Bank Capital Ratio * Credit Is Granted	0.1318***	0.1063***	-0.2119***	-0.1539***	0.0278	0.0721***
in Foreign Currency	(10.54)	(8.77)	(-4.90)	(-4.12)	(1.53)	(4.06)
Δ CPI * Credit Is Granted in Foreign Currency	0.0212***	0.0159***	-0.0313***	-0.0228***	0.0094***	0.0047**
	(11.77)	(9.32)	(-10.01)	(-7.86)	(4.02)	(2.03)
Δ CPI * Bank Capital Ratio * Credit Is Granted	-0.1490***	-0.1266***	0.1543***	0.1486***	-0.0983***	-0.0577***
in Foreign Currency	(-9.34)	(-8.33)	(5.69)	(6.07)	(-4.78)	(-3.05)
Credit Is Granted in Foreign Currency	-0.0024***	-0.0017***	-0.0037***	-0.0031***	-0.0038***	-0.0031***
	(-50.83)	(-37.75)	(-28.00)	(-23.80)	(-57.84)	(-46.34)
Bank Bank Capital Ratio * Credit Is Granted	0.0037***	0.0012***	0.0093***	0.0070***	0.0054***	0.0036***
in Foreign Currency	(8.99)	(2.97)	(8.31)	(6.65)	(9.26)	(6.28)
Firm - Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	8 069 180	6 669 450	5 799 489	4 219 655	7 084 576	4 641 868
Difference in Impact of a Decrease in Interest Rate by 25 bps on the Likelihood of Granting of First-Time Credit by Lower versus Higher Capitalized Banks (Δ=2 Standard Deviations) as Percent of Unconditional Probability of Granting First-Time Credit in Sample (= 0.23%)						
Difference in Impact Between Foreign Currency and Hungarian Forint	*-9%*	*-8%*	*-30%*	*-23%*	*-11%*	*-8%*

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable is a dummy that equals one if the firm is granted credit in domestic (foreign) currency in a particular year:month conditional on having received no credit in this currency in the month before and equals zero otherwise. All independent variables are either lagged one month or calculated over the preceding month. Table 2.1 lists the definition of all variables. Coefficients are listed in the first row, t-statistics based on robust standard errors clustered at the firm level are reported in the row below in parentheses, and the corresponding significance levels are in the adjacent column. "Yes" indicates that the set of fixed effects is included. Time Fixed Effects include an effect for every year:month. *** Significant at 1%, ** significant at 5%, * significant at 10%.

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10.14754/CEU.2016.04

Table 2.5.a: The Granting of Credit in Hungarian Forint, Euro, or Swiss Franc to Borrowers Currently Without Credit in Those Currencies (Extensive Margin) - Abridged Form

				Credit Is Granted in Euro		Credit Is Granted in Swiss Franc	
		-	Bank Capital Ratio	-	Bank Capital Ratio	-	Bank Capital Ratio
Δ Interest Rate	(1)	-0.0059***					
	(2)	-0.0216***	0.1657***				
	(3)	-0.0104***		0.0066**		0.0068**	
	(4)	-0.0461***	0.3752***	0.0369***	-0.3176***	0.0365***	-0.3108***
	(5)		0.4099***	0.0369***	-0.3176***	0.0365***	-0.3108***
	(6)			0.0377***	-0.2926***	0.0356***	-0.2629***
	(7)			0.0235***	-0.2022***	0.0222***	-0.1795***

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable is a dummy that equals one if the firm is granted credit in Hungarian Forint / Euro / Swiss Franc in a particular year:month conditional on having received no credit in this currency in the month before and equals zero otherwise. All independent variables are either lagged one month or calculated over the preceding month. Table 2.1 lists the definition of all variables. Coefficients with significance levels corresponding to t-statistics based on robust standard errors clustered at the firm level are reported in the table. *** Significant at 1%, ** significant at 5%, * significant at 10%. Models (1)-(4) include firm fixed effects, model (5) includes both firm and time fixed effects, models (6)-(7) include firm-time fixed effects.

decisions now distinguishing between Euro and Swiss Franc loans. Again, we focus on the extensive margin of lending and analyse banks' first-time credit granting decisions.

Tables 2.5 (2.5.a and 2.5.b) presents our estimates. Models 1 to 7 in Tables 2.5 are equivalent to the similarly numbered models in Tables 2.2, except that in the specifications of Tables 2.5, the dummy variable *"Credit is Granted in Foreign Currency"* is decomposed into two distinctive dummy variables, *"Credit is granted in Euro"* and *"Credit is granted in Swiss Franc"*. This decomposition allows us to investigate whether the impact of monetary policy on the supply of credit depends on a specific foreign currency denomination or not.

The results confirm the evidence presented in Tables 2.2. The estimates of Model 2 in Tables 2.5 for example again imply that a 25 basis point decrease in the domestic interest rate generates a statistically significant and an economically relevant difference (of 8 percent) between lowly and highly capitalized banks in the likelihood of initiating credit, confirming our earlier evidence of the existence of a domestic bank-lending channel.

Furthermore, the coefficients of Models 4 to 7 again indicate that an interest rate decrease affects credit initiation by banks to a greater extent when credit is granted in the domestic currency than when lending occurs in Euro or Swiss Franc. According to Model 5 that incorporates both firm and time fixed effects, a 25 basis point decrease in the domestic interest rate results in a 0.03 percentage points higher likelihood of credit initiation by lowly than by highly capitalized banks when credit is granted in the domestic currency. The economic impact accounts for 19 percent of unconditional probability of credit initiation in

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Table 2.5.b: The Granting of Credit in Hungarian Forint, Euro, or Swiss Franc to Borrowers Currently Without Credit in Those Currencies (Extensive Margin)

Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Sample	*All Firms*	*All Firms*	*All Firms*	*All Firms*	*All Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*
Δ Interest Rate	-0.0059***	-0.0216***	-0.0104***	-0.0461***			
	(-2.92)	(-6.19)	(-3.27)	(-6.15)			
Δ Interest Rate * Bank Capital Ratio		0.1657***		0.3752***	0.4099***		
		(5.90)		(5.45)	(5.94)		
Δ Interest Rate * Credit Is Granted in Euro			0.0066**	0.0369***	0.0369***	0.0377***	0.0235***
			(2.40)	(4.92)	(4.92)	(19.31)	(12.80)
Δ Interest Rate * Bank Capital Ratio * Credit Is Granted in Euro				-0.3176***	-0.3176***	-0.2926***	-0.2022***
				(-4.53)	(-4.53)	(-16.09)	(-11.89)
Δ Interest Rate * Credit Is Granted in Swiss Franc			0.0068**	0.0365***	0.0365***	0.0356***	0.0222***
			(2.50)	(4.92)	(4.92)	(18.50)	(12.24)
Δ Interest Rate * Bank Capital Ratio * Credit Is Granted in Swiss Franc				-0.3108***	-0.3108***	-0.2629***	-0.1795***
				(-4.47)	(-4.47)	(-14.59)	(-10.68)
Δ GDP	0.0016	0.0059*	0.0195***	0.0325***			
	(0.59)	(1.85)	(6.33)	(6.76)			
Δ GDP * Bank Capital Ratio		-0.0473***		-0.1391***	-0.1061***		
		(-2.69)		(-3.43)	(-2.63)		
Δ GDP * Credit Is Granted in Euro			-0.0323***	-0.0493***	-0.0493***	-0.0387***	-0.0279***
			(-19.92)	(-11.49)	(-11.49)	(-33.69)	(-26.47)
Δ GDP * Bank Capital Ratio * Credit Is Granted in Euro				0.1811***	0.1811***	0.1327***	0.1172***
				(4.27)	(4.27)	(11.72)	(11.29)
Δ GDP * Credit Is Granted in Swiss Franc			-0.0215***	-0.0308***	-0.0308***	-0.0248***	-0.0207***
			(-13.80)	(-7.33)	(-7.33)	(-22.42)	(-20.21)
Δ GDP * Bank Capital Ratio * Credit Is Granted in Swiss Franc				0.0943**	0.0943**	0.0739***	0.0816***
				(2.26)	(2.26)	(6.73)	(8.06)
Δ CPI	0.0025	-0.0053*	0.0026	-0.0203***			
	(1.47)	(-1.80)	(0.95)	(-3.08)			
Δ CPI * Bank Capital Ratio		0.0825***		0.2436***	0.2414***		
		(3.48)		(3.88)	(3.82)		
Δ CPI * Credit Is Granted in Euro			-0.0028	0.0197***	0.0197***	0.0064***	0.0047***
			(-1.13)	(2.91)	(2.91)	(4.11)	(3.31)
Δ CPI * Bank Capital Ratio * Credit Is Granted in Euro				-0.2382***	-0.2382***	-0.1049***	-0.0717***
				(-3.61)	(-3.61)	(-7.44)	(-5.86)
Δ CPI * Credit Is Granted in Swiss Franc			0.0024	0.0253***	0.0253***	0.0129***	0.0070***
			(0.94)	(3.73)	(3.73)	(8.27)	(4.89)
Δ CPI * Bank Capital Ratio * Credit Is Granted in Swiss Franc				-0.2451***	-0.2451***	-0.1240***	-0.0706***
				(-3.73)	(-3.73)	(-8.88)	(-5.67)
Credit Granted in Euro	-0.0034***	-0.0034***	-0.0031***	-0.0038***	-0.0038***	-0.0033***	-0.0023***
	(-50.65)	(-50.65)	(-45.26)	(-21.65)	(-21.65)	(-77.73)	(-57.42)
Bank Capital Ratio * Credit Is Granted in Euro				0.0072***	0.0072***	0.0056***	0.0026***
				(4.38)	(4.38)	(14.36)	(7.18)
Credit Granted in Swiss Franc	-0.0033***	-0.0033***	-0.0031***	-0.0038***	-0.0038***	-0.0032***	-0.0022***
	(-50.79)	(-50.79)	(-46.17)	(-21.99)	(-21.99)	(-77.72)	(-55.89)
Bank Capital Ratio * Credit Is Granted in Swiss Franc				0.0072***	0.0072***	0.0055***	0.0027***
				(4.43)	(4.43)	(14.38)	(7.52)
Constant	0.0217***	0.0215***	0.0216***	0.0218***	0.0040**		
	(15.29)	(15.16)	(15.19)	(15.24)	(2.14)		
Macroeconomic Variables	Yes	Yes	Yes	Yes	No	No	No
Bank Characteristics	Yes	Yes	Yes	Yes	Yes	No	No
Firm Characteristics	Yes	Yes	Yes	Yes	Yes	No	No
Firm Fixed Effects	Yes	Yes	Yes	Yes	Yes	–	–
Time Fixed Effects	No	No	No	No	Yes	–	–
Firm - Time Fixed Effects	No	No	No	No	No	Yes	Yes
Number of Observations	3 113 250	3 113 250	3 113 250	3 113 250	3 113 250	11 952 459	8 827 525
Difference in Impact of a Decrease in Interest Rate by 25 bps on the Likelihood of Granting of First-Time Credit by Lower versus Higher Capitalized Banks (Δ=2 Standard Deviations) as Percent of Unconditional Probability of Granting First-Time Credit in The Sample (= 0.16%)							
in Hungarian Forint or in Foreign Currency		*8%*	-	-	-	-	-
in Hungarian Forint	-	-	-	*17%*	*19%*	-	-
in Euro	-	-	-	*3%*	*4%*	-	-
in Swiss Franc	-	-	-	*3%*	*5%*	-	-
Difference in Impact Between Euro and Hungarian Forint	-	-	-	*-15%*	*-15%*	*-14%*	*-9%*
Difference in Impact Between Swiss Franc and Hungarian Forint				*-14%*	*-14%*	*-12%*	*-8%*

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable is a dummy that equals one if the firm is granted credit in Hungarian Forint / Euro / Swiss Franc in a particular year:month conditional on having received no credit in this currency in the month before and equals zero otherwise. All independent variables are either lagged one month or calculated over the preceding month. Table 2.1 lists the definition of all variables. Coefficients are listed in the first row, t-statistics based on robust standard errors clustered at the firm level are reported in the row below in parentheses, and the corresponding significance levels are in the adjacent column. "Yes" indicates that the set of fixed effects is included. "No" indicates that the set of fixed effects is not included. "–" indicates that the indicated set of fixed effects are comprised in the wider included set of fixed effects. Time Fixed Effects include an effect for every year:month. *** Significant at 1%, ** significant at 5%, * significant at 10%.

the sample. When credit is granted in Euro or Swiss Franc, the equivalent differential effects are 4 and 5 percent, respectively, again suggesting a difference in the impact of domestic monetary policy on bank lending in the domestic and foreign currencies, but not between the two foreign currencies considered. The magnitudes of the estimated differential effects implied by the coefficients of Models 6 and 7, presented in the bottom panel of Table 2.5.b, confirm this conjecture. Overall, Models 4 to 7 in Tables 2.5 confirm our evidence of a currency compositional effect of domestic monetary policy on bank loan supply for this extensive margin of lending.

- Further Robustness: Other Margins of Lending

So far we have focused on the positive extensive margin of lending by analysing banks' first-time credit granting decisions. To check our results concerning the compositional effects of monetary policy on banks' loan supply decisions, in this section, we consider other margins of lending. In particular, we consider the likelihood of banks' ending credit (negative extensive margin) and the likelihood of banks' increasing credit (intensive margin) in the domestic and foreign currencies.

The regressions of Models 1 to 4 in Tables 2.6 (2.6.a and 2.6.b) focus on the impact of monetary policy on banks' decisions to end credit to borrowing firms. In Model 1, we include firm fixed effects in the regressions to control for firm heterogeneity in loan demand. Model 2 incorporates both firm and time fixed effects, while Models 3 and 4 represent our most saturated specification which includes firm-time (year:month) fixed effects. The sign of the triple interactions of the variables *Interest Rate Change*, *Bank Capital Ratio*, and *Credit is Granted in Euro* (or *Credit is Granted in Swiss Franc*) shows that the currency compositional supply effect is present along the negative extensive margin as well. A domestic monetary expansion decreases the likelihood of banks' ending credit, but only when credit is granted in the local currency (Hungarian Forint). The economic significance of the impact of monetary expansion on ending credit in Euro or Swiss Franc is negligible, as shown by the numbers at the bottom of Tables 2.6. These estimates overall provide evidence for the presence of a compositional effect along this particular extensive margin although the effect is statistically weaker (maybe because banks dither to cut firms off credit).

Models 5 to 8 in Tables 2.6 examine the impact of monetary conditions on the likelihood of banks' increasing the amount of credit to their borrowers. We find a strong compositional effect of monetary policy on bank loan supply along this intensive margin of lending as

Table 2.6.a: The Repayment of Credit by Borrowers With Credit in Hungarian Forint, Euro, or Swiss Franc (Negative Extensive Margin) and the Increase in the Amount of Credit Borrowers Hold in Hungarian Forint, Euro, or Swiss Franc (Intensive Margin) - Abridged Form

				Credit Is Granted in Euro		Credit Is Granted in Swiss Franc	
		-	Bank Capital Ratio	-	Bank Capital Ratio	-	Bank Capital Ratio
Δ Interest Rate	(1)	0.0409**	-0.3213	-0.0456**	0.4262**	-0.0318	0.2994
	(2)		-0.3179	-0.0456**	0.4262**	-0.0318	0.2994
	(3)			-0.0216***	0.1511**	-0.0005	0.0130
	(4)			-0.0184**	0.1190	-0.0045	0.0260
	(5)	-0.0667***	0.5384***	0.0441***	-0.4528***	0.0570***	-0.5242***
	(6)		0.5995***	0.0441***	-0.4528***	0.0570***	-0.5242***
	(7)			0.0426***	-0.4285***	0.0521***	-0.4766***
	(8)			0.0324***	-0.3370***	0.0357***	-0.3478***
	(9)			0.1587***	0.2439***	-2.2176***	-2.7433***
	(10)			0.2626***	0.3204***	-3.2162***	-3.5568***

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable Ending Credit is a dummy that equals one if the firm has no more credit in Hungarian Forint / Euro / Swiss Franc in a particular year:month conditional on having had credit in this currency in the month before and equals zero otherwise. The dependent variable Increasing the Amount of Credit is a dummy that equals one if the firm increases the nominal amount of credit it receives in Hungarian Forint / Euro / Swiss Franc and equals zero otherwise. Active Firms in Columns 9 and 10 are firms that have more than five nonzero values in Increasing the Amount of Credit during the sample period. All independent variables are either lagged one month or calculated over the preceding month. Table 2.1 lists the definition of all variables. Coefficients with significance levels corresponding to t-statistics based on robust standard errors clustered at the firm level are reported in the table. *** Significant at 1%, ** significant at 5%, * significant at 10%. Models (1) and (5) include firm fixed effects, models (2) and (6) includes both firm and time fixed effects, models (3)-(4), (7)-(10) include firm-time fixed effects.

well. According to Model 6, when credit is granted in Hungarian Forint following a 25 basis point decrease in the domestic interest rate the difference in the response between banks with low and high capital ratios is 9 percent of the unconditional probability of increasing credit amount. In contrast, when credit is granted in Euro or Swiss Franc this differential impact does not exceed 2 or 1 percent, respectively, of the unconditional probability of increasing credit amount in the sample. The strong significance of the triple interaction terms in Models 7 and 8 indicates that this compositional effect is robust to saturation with firm-time fixed effects.

Finally, we address the concern that the low probability of credit granting and growth makes inference problematic (*à la* King and Zeng (2001) and King and Zeng (2006)). We therefore revisit the entire population of bank-firm exposures and select those firms that were granted a minimum of five loans during the sample period. This set of firms accounts for roughly four percent of the population. We re-estimate the last two models for this new sample and display the estimates in Columns 9 and 10. If anything the estimated

Table 2.6.b: The Repayment of Credit by Borrowers With Credit in Hungarian Forint, Euro, or Swiss Franc (Negative Extensive Margin) and the Increase in the Amount of Credit Borrowers Hold in Hungarian Forint, Euro, or Swiss Franc (Intensive Margin)

Dependent Variable	ENDING CREDIT (NEGATIVE EXTENSIVE MARGIN)				INCREASING THE AMOUNT OF CREDIT (INTENSIVE MARGIN)					
Model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Sample	*All firms with debt*	*All firms with debt*	*Entire Sample, All firms with debt*	*Entire Sample, Single-Bank firms with debt*	*All Firms*	*All Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*All Active Firms*	*Active Single-Bank Firms*
Δ Interest Rate	0.0409**				-0.0667***					
	(2.03)				(-5.50)					
Δ Interest Rate * Bank Capital Ratio	-0.3213	-0.3179			0.5384***	0.5995***				
	(-1.62)	(-1.61)			(4.96)	(5.51)				
Δ Interest Rate * Credit Is Granted in Euro	-0.0456**	-0.0456**	-0.0216***	-0.0184**	0.0441***	0.0441***	0.0426***	0.0324***	0.1587***	0.2626***
	(-2.17)	(-2.17)	(-3.37)	(-2.38)	(3.58)	(3.58)	(12.40)	(10.68)	(3.73)	(4.59)
Δ Interest Rate * Bank Capital Ratio * Credit Is Granted in Euro	0.4262**	0.4262**	0.1511**	0.1190	-0.4528***	-0.4528***	-0.4285***	-0.3370***	0.2439***	0.3204***
	(2.00)	(2.00)	(2.34)	(1.59)	(-3.99)	(-3.99)	(-13.61)	(-12.07)	(6.13)	(5.91)
Δ Interest Rate * Credit Is Granted in Swiss Franc	-0.0318	-0.0318	-0.0005	-0.0045	0.0570***	0.0570***	0.0521***	0.0357***	-2.2176***	-3.2162***
	(-1.49)	(-1.49)	(-0.08)	(-0.57)	(4.64)	(4.64)	(15.35)	(11.97)	(-5.29)	(-6.38)
Δ Interest Rate * Bank Capital Ratio * Credit Is Granted in Swiss Franc	0.2994	0.2994	0.0130	0.0260	-0.5242***	-0.5242***	-0.4766***	-0.3478***	-2.7433***	-3.5568***
	(1.39)	(1.39)	(0.20)	(0.34)	(-4.61)	(-4.61)	(-15.22)	(-12.59)	(-6.98)	(-7.34)
Δ GDP	0.0317**				0.0668***					
	(2.07)				(7.36)					
Δ GDP * Bank Capital Ratio	-0.1373	-0.1845			-0.5041***	-0.4424***				
	(-0.94)	(-1.26)			(-6.69)	(-5.94)				
Δ GDP * Credit Is Granted in Euro	-0.0266*	-0.0266*	-0.0147***	-0.0105*	-0.1055***	-0.1055***	-0.0875***	-0.0514***	-0.3027***	-0.2516***
	(-1.79)	(-1.79)	(-3.21)	(-1.88)	(-12.13)	(-12.13)	(-37.11)	(-26.30)	(-10.16)	(-6.53)
Δ GDP * Bank Capital Ratio * Credit Is Granted in Euro	0.2063	0.2063	0.0733	0.0571	0.6881***	0.6881***	0.5502***	0.3812***	-0.0315	-0.0067
	(1.33)	(1.33)	(1.53)	(1.03)	(8.18)	(8.18)	(23.79)	(19.64)	(-1.14)	(-0.19)
Δ GDP * Credit Is Granted in Swiss Franc	-0.0429***	-0.0429***	-0.0345***	-0.0300***	-0.0771***	-0.0771***	-0.0644***	-0.0394***	2.1388***	2.3557***
	(-2.81)	(-2.81)	(-7.41)	(-5.20)	(-9.29)	(-9.29)	(-27.92)	(-20.29)	(7.17)	(7.03)
Δ GDP * Bank Capital Ratio * Credit Is Granted in Swiss Franc	0.2228	0.2228	0.1637***	0.1723***	0.5464***	0.5464***	0.4346***	0.3127***	0.3246	0.6876**
	(1.39)	(1.39)	(3.38)	(3.02)	(6.71)	(6.71)	(19.02)	(16.16)	(1.16)	(2.16)
Δ CPI	-0.0868***				-0.0322***					
	(-4.48)				(-3.18)					
Δ CPI * Bank Capital Ratio	0.8733***	0.8453***			0.3603***	0.3608***				
	(4.22)	(4.09)			(3.98)	(3.98)				
Δ CPI * Credit Is Granted in Euro	0.1006***	0.1006***	0.0416***	0.0192***	0.0275***	0.0275***	0.0147***	0.0119***	0.0654*	0.3302***
	(4.82)	(4.82)	(7.93)	(3.26)	(2.58)	(2.58)	(5.48)	(4.92)	(1.85)	(6.59)
Δ CPI * Bank Capital Ratio * Credit Is Granted in Euro	-0.8884***	-0.8884***	-0.3130***	-0.0848	-0.3228***	-0.3228***	-0.1672***	-0.0800***	0.1674***	0.3883***
	(-3.93)	(-3.93)	(-5.77)	(-1.51)	(-3.29)	(-3.29)	(-6.88)	(-3.62)	(4.94)	(7.86)
Δ CPI * Credit Is Granted in Swiss Franc	0.0876***	0.0876***	0.0359***	0.0120**	0.0368***	0.0368***	0.0269***	0.0162***	-1.0738***	-3.5270***
	(4.35)	(4.35)	(7.00)	(2.02)	(3.52)	(3.52)	(10.09)	(6.70)	(-3.01)	(-7.77)
Δ CPI * Bank Capital Ratio * Credit Is Granted in Swiss Franc	-0.9010***	-0.9010***	-0.3214***	-0.0490	-0.3391***	-0.3391***	-0.2191***	-0.0922***	-1.7150***	-3.8727***
	(-4.17)	(-4.17)	(-6.11)	(-0.87)	(-3.53)	(-3.53)	(-9.08)	(-4.16)	(-5.00)	(-8.60)
Credit Granted in Euro	-0.0084***	-0.0084***	-0.0079***	-0.0083***	-0.0123***	-0.0123***	-0.0105***	-0.0043***	-0.0575***	-0.0425***
	(-15.74)	(-15.74)	(-55.09)	(-47.87)	(-22.54)	(-22.53)	(-75.56)	(-36.58)	(-36.19)	(-20.49)
Bank Capital Ratio * Credit Is Granted in Euro	0.0168***	0.0168***	0.0127***	0.0163***	-0.0023	-0.0023	-0.0052***	-0.0227***	-0.1658***	-0.2533***
	(3.05)	(3.05)	(8.64)	(9.80)	(-0.44)	(-0.44)	(-3.95)	(-17.97)	(-11.00)	(-14.46)
Credit Granted in Swiss Franc	-0.0082***	-0.0082***	-0.0076***	-0.0078***	-0.0134***	-0.0134***	-0.0113***	-0.0045***	-0.0724***	-0.0543***
	(-15.70)	(-15.70)	(-53.63)	(-44.55)	(-24.34)	(-24.34)	(-79.31)	(-38.32)	(-50.56)	(-29.14)
Bank Capital Ratio * Credit Is Granted in Swiss Franc	0.0161***	0.0161***	0.0115***	0.0146***	0.0037	0.0037	-0.0017	-0.0210***	-0.0716***	-0.1725***
	(2.98)	(2.98)	(8.06)	(8.70)	(0.71)	(0.71)	(-1.29)	(-16.68)	(-5.31)	(-11.03)
Constant	-0.0097***	0.0001			0.0275***	-0.0072**			0.0864***	0.0758***
	(-3.25)	(0.03)			(9.80)	(-2.00)			(283.35)	(207.65)
Macroeconomic Variables	Yes	No	No	No	Yes	No	No	No	No	No
Bank Characteristics	Yes	Yes	No	No	Yes	Yes	No	No	No	No
Firm Characteristics	Yes	Yes	No	No	Yes	Yes	No	No	No	No
Firm Fixed Effects	Yes	Yes	–	–	Yes	Yes	–	–	–	–
Time Fixed Effects	No	Yes	–	–	No	Yes	–	–	–	–
Firm - Time Fixed Effects	No	No	Yes	Yes	No	No	Yes	Yes	Yes	Yes
Number of Observations	1 117 353	1 117 353	3 879 066	2 077 611	3 113 250	3 113 250	11 952 459	8 827 525	2 940 117	1 157 754
Difference in Impact of a Decrease in Interest Rate by 25 bps on the Likelihood of Ending Credit and Increasing the Amount of Credit by Lower versus Higher Capitalized Banks (Δ=2 Standard Deviations) as Percent of Unconditional Probability of Ending Credit,(=0.12%) and Increasing the Amount of Credit,(=0.51%),in Sample										
in Hungarian Forint	*-19%*	*-19%*	-	-	*8%*	*9%*	-	-	-	-
in Euro	*6%*	*7%*	-	-	*1%*	*2%*	-	-	-	-
in Swiss Franc	*-1%*	*-1%*	-	-	*0%*	*1%*	-	-	-	-
Difference in Impact Between Euro and Hungarian Forint	*26%*	*26%*	*9%*	*7%*	*-7%*	*-7%*	*-6%*	*-5%*	*-4%*	*-5%*
Difference in Impact Between Swiss Franc and Hungarian Forint	*18%*	*18%*	*1%*	*2%*	*-8%*	*-8%*	*-7%*	*-5%*	*-40%*	*-52%*

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable Ending Credit is a dummy that equals one if the firm has no more credit in Hungarian Forint / Euro / Swiss Franc in a particular year:month conditional on having had credit in this currency in the month before and equals zero otherwise. The dependent variable Increasing the Amount of Credit is a dummy that equals one if the firm increases the nominal amount of credit it receives in Hungarian Forint / Euro / Swiss Franc and equals zero otherwise. Active Firms in Columns 9 and 10 are firms that have more than five nonzero values in Increasing the Amount of Credit during the sample period. All independent variables are either lagged one month or calculated over the preceding month. Table 2.1 lists the definition of all variables. Coefficients are listed in the first row, t-statistics based on robust standard errors clustered at the firm level are reported in the row below in parentheses, and the corresponding significance levels are in the adjacent column. "Yes" indicates that the set of fixed effects is included. "No" indicates that the set of fixed effects is not included. "–" indicates that the indicated set of fixed effects are comprised in the wider included set of fixed effects. Time Fixed Effects include an effect for every year:month. *** Significant at 1%, ** significant at 5%, * significant at 10%.

differential impact of interest rate changes are even larger.[48]

Overall, our evidence suggests that, besides affecting banks' first-time credit granting decisions, monetary policy has an impact on the currency composition of loan supply along the negative extensive margin and the (positive) intensive margin as well.

2.5.2 Compositional Effect of Domestic versus Foreign Monetary Policy

Besides analysing the effect of domestic monetary policy on banks' local lending decisions in the domestic and foreign currencies, we also consider the effects of monetary policy set by the central banks abroad issuing the foreign currency. Hence, in Tables 2.7 (2.7.a and 2.7.b) we extend our basic specification by including the annual change in the Euro and Swiss Franc interest rates as well as the corresponding interactions between interest rates, bank capitalization, and currency denomination.[49] Among the macroeconomic variables the change in the nominal effective exchange rate, i.e., Δ *Exchange Rate*, is replaced by two exchange rates, i.e., Δ *Exchange Rate Hungarian Forint to Euro* and Δ *Exchange Rate Hungarian Forint to CHF*.

Models 1 and 2 in Tables 2.7 present our results concerning the impact of changes in the Euro interest rate while Models 3 and 4 show our results on the impact of the Swiss Franc interest rate on banks' loan supply decisions. Models 5 and 6 include changes in both Euro and Swiss Franc interest rates in the specification. Every model in Tables 2.7 includes firm-month fixed effects to control for time-varying heterogeneity in credit demand and thus builds on our (earlier used) most saturated specification.

We present several results concerning the impact of monetary policy on bank loan supply along the extensive margin of lending. First, our earlier findings concerning the effect of *domestic* monetary policy on the composition of domestic loan supply are confirmed by all models.[50] Following a 25 basis point decrease in the domestic interest rate, the

[48]The larger impact on Swiss Franc lending may be due to differential selection. Estimating a first-stage model selecting for firms with minimum five loans and including the resultant firm-level inverse Mills ratio in various specifications (that therefore do not include firm-time fixed effects) yields smaller (in absolute value) estimates of the triple coefficient of interest.

[49]In unreported regressions, we include changes in the Euro area and Swiss GDP growth rates and inflation as well as their full set of double and triple interactions with bank capitalization and currency denomination, to control for effects of other foreign macroeconomic aggregates. Results of the currency compositional effects of domestic and foreign monetary policies are unchanged.

[50]The mandate of the Central Bank of Hungary is to target domestic inflation and its policy could

Table 2.7.a: The Granting of Credit in Hungarian Forint, Euro, or Swiss Franc to Borrowers Currently Without Credit in Those Currencies (Extensive Margin), Effects of Euro and Swiss Franc Interest Rates - Abridged Form

		Credit Is Granted in Euro		Credit Is Granted in Swiss Franc	
		-	Bank Capital Ratio	-	Bank Capital Ratio
Δ Interest Rate	(1)	0.0454***	-0.3283***	-0.3404***	-0.3320***
	(2)	0.0294***	(-17.06)	(-18.20)	(-17.33)
	(3)	0.0483***	0.0398***	0.0430***	0.0391***
	(4)	0.0320***	(19.41)	(21.48)	(19.14)
	(5)	0.0447***	-0.2870***	-0.3007***	-0.2859***
	(6)	0.0286***	(-15.13)	(-16.23)	(-15.14)
Δ Interest Rate in Euro Area	(1)	-0.1339***	0.7378***	-0.0724***	0.4669***
	(2)	-0.0978***	0.4957***	-0.0653***	0.3419***
	(3)				
	(4)				
	(5)	0.0925***	-0.3819***	0.1011***	-0.5191***
	(6)	0.0800***	-0.4598***	0.0814***	-0.5444***
Δ Interest Rate in Switzerland	(1)				
	(2)				
	(3)	-0.3491***	1.6586***	-0.2464***	1.3424***
	(4)	-0.2814***	1.4412***	-0.2220***	1.2662***
	(5)	-0.4054***	1.8979***	-0.3085***	1.6707***
	(6)	-0.3297***	1.7235***	-0.2714***	1.6018***

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable is a dummy that equals one if the firm is granted credit in Hungarian Forint / Euro / Swiss Franc in a particular year:month conditional on having received no credit in this currency in the month before and equals zero otherwise. All independent variables are either lagged one month or calculated over the preceding month. Table 2.1 lists the definition of all variables. Coefficients with significance levels corresponding to t-statistics based on robust standard errors clustered at the firm level are reported in the table. *** Significant at 1%, ** significant at 5%, * significant at 10%. Models (1)-(6) include firm-time fixed effects.

10.14754/CEU.2016.04

Table 2.7.b: The Granting of Credit in Hungarian Forint, Euro, or Swiss Franc to Borrowers Currently Without Credit in Those Currencies (Extensive Margin), Effects of Euro and Swiss Franc Interest Rates

Model	(1)	(2)	(3)	(4)	(5)	(6)
Sample	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*	*Entire Sample, All Firms*	*Entire Sample, Single-Bank Firms*
Δ Interest Rate * Credit Is Granted in Euro	0.0454***	0.0294***	0.0483***	0.0320***	0.0447***	0.0286***
	(21.72)	(14.88)	(23.83)	(16.65)	(21.49)	(14.49)
Δ Interest Rate * Bank Capital Ratio * Credit Is Granted in Euro	-0.3283***	-0.2278***	-0.3404***	-0.2443***	-0.3320***	-0.2273***
	(-17.06)	(-12.67)	(-18.20)	(-13.88)	(-17.33)	(-12.66)
Δ Interest Rate * Credit Is Granted in Swiss Franc	0.0398***	0.0261***	0.0430***	0.0288***	0.0391***	0.0253***
	(19.41)	(13.42)	(21.48)	(15.17)	(19.14)	(13.03)
Δ Interest Rate * Bank Capital Ratio * Credit Is Granted in Swiss Franc	-0.2870***	-0.1975***	-0.3007***	-0.2160***	-0.2859***	-0.1940***
	(-15.13)	(-11.10)	(-16.23)	(-12.40)	(-15.14)	(-10.93)
Δ Interest Rate in Euro Area * Credit Is Granted in Euro	-0.1339***	-0.0978***			0.0925***	0.0800***
	(-13.76)	(-10.96)			(8.21)	(7.56)
Δ Interest Rate in Euro Area * Bank Capital Ratio * Credit Is Granted in Euro	0.7378***	0.4957***			-0.3819***	-0.4598***
	(8.48)	(6.47)			(-3.73)	(-4.78)
Δ Interest Rate in Euro Area * Credit Is Granted in Swiss Franc	-0.0724***	-0.0653***			0.1011***	0.0814***
	(-7.59)	(-7.36)			(9.50)	(8.00)
Δ Interest Rate in Euro Area * Bank Capital Ratio * Credit Is Granted in Swiss Franc	0.4669***	0.3419***			-0.5191***	-0.5444***
	(5.54)	(4.49)			(-5.33)	(-5.83)
Δ Interest Rate in Switzerland * Credit Is Granted in Euro			-0.3491***	-0.2814***	-0.4054***	-0.3297***
			(-31.96)	(-26.91)	(-32.05)	(-26.82)
Δ Interest Rate in Switzerland * Bank Capital Ratio * Credit Is Granted in Euro			1.6586***	1.4412***	1.8979***	1.7235***
			(17.23)	(16.24)	(16.91)	(15.87)
Δ Interest Rate in Switzerland * Credit Is Granted in Swiss Franc			-0.2464***	-0.2220***	-0.3085***	-0.2714***
			(-22.56)	(-20.92)	(-25.03)	(-22.27)
Δ Interest Rate in Switzerland * Bank Capital Ratio * Credit Is Granted in Swiss Franc			1.3424***	1.2662***	1.6707***	1.6018***
			(14.24)	(14.12)	(15.35)	(14.86)
Δ GDP * Credit Is Granted in Euro	0.0052	0.0044	0.0466***	0.0408***	0.0299***	0.0262***
	(1.48)	(1.36)	(16.07)	(15.02)	(8.11)	(7.72)
Δ GDP * Bank Capital Ratio * Credit Is Granted in Euro	-0.1082***	-0.0468*	-0.2711***	-0.2346***	-0.2039***	-0.1514***
	(-3.38)	(-1.68)	(-10.33)	(-9.93)	(-6.10)	(-5.18)
Δ GDP * Credit Is Granted in Swiss Franc	-0.0012	0.0008	0.0352***	0.0334***	0.0172***	0.0186***
	(-0.33)	(0.26)	(12.10)	(12.14)	(4.66)	(5.43)
Δ GDP * Bank Capital Ratio * Credit Is Granted in Swiss Franc	-0.0780**	-0.0315	-0.2510***	-0.2265***	-0.1608***	-0.1286***
	(-2.48)	(-1.13)	(-9.69)	(-9.51)	(-4.90)	(-4.38)
Δ CPI * Credit Is Granted in Euro	0.0307***	0.0222***	0.0604***	0.0481***	0.0523***	0.0412***
	(12.94)	(10.50)	(24.89)	(21.31)	(20.10)	(17.34)
Δ CPI * Bank Capital Ratio * Credit Is Granted in Euro	-0.2416***	-0.1623***	-0.3683***	-0.2989***	-0.3342***	-0.2598***
	(-10.97)	(-8.62)	(-16.67)	(-15.12)	(-13.95)	(-12.42)
Δ CPI * Credit Is Granted in Swiss Franc	0.0260***	0.0187***	0.0511***	0.0413***	0.0423***	0.0343***
	(11.17)	(8.89)	(21.14)	(18.04)	(16.42)	(14.35)
Δ CPI * Bank Capital Ratio * Credit Is Granted in Swiss Franc	-0.2097***	-0.1330***	-0.3359***	-0.2693***	-0.2912***	-0.2238***
	(-9.83)	(-7.11)	(-15.57)	(-13.49)	(-12.52)	(-10.69)
Credit Granted in Euro	-0.0037***	-0.0026***	-0.0038***	-0.0027***	-0.0036***	-0.0025***
	(-72.37)	(-53.17)	(-81.59)	(-60.45)	(-70.61)	(-52.32)
Bank Capital Ratio * Credit Is Granted in Euro	0.0078***	0.0041***	0.0077***	0.0046***	0.0068***	0.0037***
	(17.45)	(9.93)	(18.78)	(12.08)	(15.12)	(8.79)
Credit Granted in Swiss Franc	-0.0034***	-0.0024***	-0.0036***	-0.0025***	-0.0034***	-0.0023***
	(-68.04)	(-49.39)	(-77.64)	(-56.35)	(-67.04)	(-48.81)
Bank Capital Ratio * Credit Is Granted in Swiss Franc	0.0068***	0.0037***	0.0072***	0.0045***	0.0060***	0.0033***
	(15.61)	(9.01)	(17.77)	(11.61)	(13.72)	(8.11)
Firm - Time Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	11 952 459	8 827 525	11 952 459	8 827 525	11 952 459	8 827 525
Percentage Point Difference in Impact of a Decrease in Forint Interest Rate by 25 bps on the Likelihood of Granting of First-Time Credit by Lower versus Higher Capitalized Banks (Δ=2 Standard Deviations) as Percent of Unconditional Probability of Granting First-Time Credit in Sample (= 0.16%)						
Difference in Impact Between Euro and Hungarian Forint	*-15%*	*-11%*	*-16%*	*-11%*	*-15%*	*-11%*
Difference in Impact Between Swiss Franc and Hungarian Forint	*-13%*	*-9%*	*-14%*	*-10%*	*-13%*	*-9%*
Difference in Impact of a Decrease in Euro Area Interest Rate by 25 bps on the Likelihood of Granting of First-Time Credit by Lower versus Higher Capitalized Banks (Δ=2 Standard Deviations) as Percent of Unconditional Probability of Granting First-Time Credit in Sample (= 0.16%)						
Difference in Impact Between Euro and Hungarian Forint	*34%*	*23%*	-	-	*-18%*	*-21%*
Difference in Impact Between Swiss Franc and Hungarian Forint	*22%*	*16%*	-	-	*-24%*	*-25%*
Difference in Impact Between Hungarian Forint and Swiss Franc	*-22%*	*-16%*	-	-	*24%*	*25%*
Difference in Impact Between Euro and Swiss Franc	*-13%*	*-7%*	-	-	*-6%*	*-4%*
Difference in Impact of a Decrease in Swiss Franc Interest Rate by 25 bps on the Likelihood of Granting of First-Time Credit by Lower versus Higher Capitalized Banks (Δ=2 Standard Deviations) as Percent of Unconditional Probability of Granting First-Time Credit in Sample (= 0.16%)						
Difference in Impact Between Euro and Hungarian Forint	-	-	*77%*	*67%*	*88%*	*80%*
Difference in Impact Between Swiss Franc and Hungarian Forint	-	-	*62%*	*59%*	*78%*	*75%*
Difference in Impact Between Hungarian Forint and Swiss Franc	-	-	*-62%*	*-59%*	*-78%*	*-75%*
Difference in Impact Between Euro and Swiss Franc	-	-	*-15%*	*-8%*	*-11%*	*-6%*

NOTE. – The table reports estimates from ordinary least squares regressions. The dependent variable is a dummy that equals one if the firm is granted credit in Hungarian Forint / Euro / Swiss Franc in a particular year:month conditional on having received no credit in this currency in the month before and equals zero otherwise. All independent variables are either lagged one month or calculated over the preceding month. Table 2.1 lists the definition of all variables. Coefficients are listed in the first row, t-statistics based on robust standard errors clustered at the firm level are reported in the row below in parentheses, and the corresponding significance levels are in the adjacent column. "Yes" indicates that the set of fixed effects is included. "No" indicates that the set of fixed effects is not included. "–" indicates that the indicated set of fixed effects are comprised in the wider included set of fixed effects. Time Fixed Effects include an effect for every year:month. *** Significant at 1%, ** significant at 5%, * significant at 10%.

estimated semi-elasticities of the differences, between lowly and highly capitalized banks, in credit initiation in Euro and Swiss Franc are 11 to 16 percent lower than the estimated semi-elasticities of the differences in credit initiation in Hungarian Forint. Therefore the results confirm the existence of differential supply effects across the three currencies: Domestic monetary expansion positively affects credit supply in Hungarian Forint, but has a negligible effect on the supply of credit in Euro and Swiss Franc.

Second, we present evidence that monetary changes in the Euro area and Switzerland influence the currency composition of the local supply of credit in Hungary. In Models 1 to 2 of Tables 2.7, the significance of the coefficients on the triple interaction of the variables *Interest Rate Change in Euro Area*, *Bank Capital Ratio*, and *Credit is Granted in Euro* (or *Credit is Granted in Swiss Franc*) indicate that changes in the Euro area interest rate have differential effects on the local supply of credit in the domestic and foreign currencies. According to Model 1, following a 25 basis point decrease in the Euro interest rate, the differential likelihood of credit initiation, between lowly and highly capitalized banks, is 0.055 (0.035) percentage points higher when credit is granted in Euro (Swiss Franc) than the differential likelihood when credit is granted in Hungarian Forint. This differential effect between the domestic currency and the Euro (Swiss Franc) amounts to 34 (22) percent of the unconditional likelihood of first-time credit granting in the sample.

Furthermore, Models 3 and 4 indicate that changes in the Swiss interest rate also have a significant impact on the currency composition of domestic credit supply. According to Model 3, following a 25 basis point decrease in the Swiss Franc interest rate, the estimated differences in the likelihood of credit initiation between lowly and highly capitalized banks are 0.123 (0.099) percentage point higher when credit is granted in Euro (Swiss Franc) than when credit is granted in Hungarian Forint. The differential effects of changes in the Swiss interest rate on credit granting in the different currencies are also economically significant.

Finally, results in Models 5 and 6 indicate that the significant impact of changes in the Euro area interest rate disappear once we include both foreign interest rates as well as the relevant double and triple interaction terms in the regressions. This is a straightforward consequence of the multicollinearity problem arising from the high correlation between the

have reacted to interest rates set by other relevant central banks. By including changes in Euro and Swiss interest rates we in effect also account for these additional elements that may be present in an open economy monetary policy rule. However our findings suggest that at least with respect to the transmission through bank lending, foreign interest rates do not play a significant role in the observed policy reaction function. We think it is also rather unlikely that the European Central Bank or the Swiss National Bank would react directly to policy rate changes in Hungary.

two foreign interest rates.

Overall, our results in Tables 2.7 show that the differential responses of highly and lowly capitalized banks, to changes in the Euro and Swiss interest rates, differ across the domestic and foreign currencies. Since the economic effects – of a monetary expansion in the Euro area and Switzerland – are negative and more so for the domestic currency,[51] the results indicate that monetary expansions in the Euro area and Switzerland cause a relative contraction in credit supply in Forint and a relative expansion in the supply of Euro and especially Swiss Franc credit. Therefore, for the local supply of credit not only the domestic monetary policy matters, but also the monetary policy set by the central bank abroad issuing the foreign currency. This indicates the existence of an international (or global) bank lending channel that transmits the impact of foreign monetary policy to the local economy through changing the currency composition of banks' loan supply.

2.6 Conclusions

We analyze the differential impact of domestic and foreign monetary policy on the local supply of bank credit in domestic and foreign currencies. We analyze a novel, supervisory dataset from Hungary that records all bank lending to firms including its currency denomination. This chapter therefore takes the next obvious step in the empirical literature that identifies – with micro-data – the impact of monetary policy on the provision of credit.

Accounting for time-varying firm-specific heterogeneity in loan demand, we find that a lower domestic interest rate expands the supply of credit in the domestic but not in the foreign currency. A lower foreign interest rate on the other hand expands lending by lowly versus highly capitalized banks relatively more in the foreign than in the domestic currency.

The implications of our findings for monetary policy making are straightforward but salient. Local bank lending in foreign currencies limits the flow of the transmission of domestic monetary policy through a bank lending channel in the domestic currency only. Lending in foreign currencies is seemingly mostly unaffected by domestic monetary policy. On the other hand, monetary policies pursued by central banks abroad may affect local bank lending in these foreign currencies. Changes in foreign monetary policy, therefore,

[51] In unreported regressions we find that changes in the Euro and Swiss interest rates result in significantly lower likelihood of credit granting by lowly capitalized banks than by highly capitalized banks and that this differential negative effect is higher when credit is granted in the domestic currency.

10.14754/CEU.2016.04

also seems to transmit to local lending, through an international bank-lending channel that changes the currency composition of the local bank loan supply. Overall, these findings suggest that calls for global monetary policy coordination even during normal times are well-founded (though difficult and unlikely given current institutional mandates).

10.14754/CEU.2016.04

Chapter 3

Multidimensional Global Games and Some Applications

3.1 Introduction

Global games are coordination games with incomplete information. This class of game is appropriate to model economic situations where agents have incentive to coordinate on some action, but due to incomplete information perfect coordination fails. Global games have been applied to several economic situations, such as bank runs (Goldstein and Pauzner (2004), Goldstein and Pauzner (2005)), currency crisis (Morris and Shin (1998)), debt crisis (Morris and Shin (2004)), and technology adoption (Chamley (1999), Heidhues and Melissas (2006)).

In this chapter I extend the standard global games framework by introducing an addition target on which agents can coordinate on. I compare this multidimensional case to the standard global games problem. Furthermore, I investigate the effects of consolidating the multiple targets. I find that introducing an additional option generates a negative strategic correlation between the options and thus weakens the coordination. However, unifying the options eliminates the endogenous correlation and thus restores the coordination. I also show two potential applications to be modeled by these kinds of games.

I build a model with two risky options. There is a continuum of agents who can choose between a safe and the two risky options. The payoff of the agents choosing a risky option is increasing with the number of agents choosing the same outcome. This provides an incentive for the agents to take coordinated actions. However, as the agents have imperfect information, perfect coordination is not possible. I investigate two scenarios: One, in which

10.14754/CEU.2016.04

the two risky options are available separately, and another, in which the two are unified.

The unified-risky-options case is formally equivalent to a usual one dimensional global game. Therefore, in the unique equilibrium, agents choose the risky option only if their signal is above some constant threshold. However, in case of separate risky options multidimensionality results an important difference: the threshold is not a constant but a function of the agents' signal about the risky outcome. In the equilibrium agents choose a certain option if their signal on that outcome exceeds the value taken by the cutoff function at their signal on the other option. I prove the existence and the uniqueness of such an equilibrium to a certain range of parameters by using Banach fixed point theorem. I have no closed-form solution for the threshold functions, instead I construct them by using numerical methods.

Multidimensionality has an important consequence for the power of coordination. When there are multiple options, coordination weakens. This is due to strategic motives of agents. Agents have incentives to make mutually consistent actions. Since there are a fixed number of agents, when there are multiple options, their power is split. The more people coordinate on one option the less people there are who can potentially coordinate on the other. This generates a negative correlation between the two options which I call strategic correlation.

The key element of the model is the interaction of the coordination motives of agents to move together and the substitutability of the options. When there are multiple options, each potential object of coordination, they are in fact substitutes. Thus, with multiple options the coordination disperses. However, unifying the options eliminates the coordination split and thus strengthens the power of coordination.

I show two applications which can be modeled by the multidimensional global games framework. The first application is the choice of invoicing currency of oil. In the oil market the historically established currency is the US Dollar. I show that there are situations when an agent would switch to the usage of a new currency if there were one new currency besides the US Dollar, however, would not switch if there were two other currencies. The second application is the introduction of common European bond. A common argument for joint issuance is that it smooths out idiosyncratic risk. While this argument is present in my model, there is an extra layer: joint bond issuance can make participating countries more vulnerable to speculative attacks.

To my knowledge, this is the first paper showing how the consolidation of multiple coordination targets can increase coordination. This chapter belongs to the literature of global games, in particular to those models which extend the dimension of the standard

10.14754/CEU.2016.04

setup. Such early papers are the theoretical models of contagion of self-fulfilling crises (e.g. Goldstein and Pauzner (2004)). These models also employ multidimensional state space, thus let the payoffs be influenced by not only one single, but multiple economic variables. In particular these models show that when two markets have the same group of agents, however independent fundamentals, contagion of crises from one market to the other is likely to occur. However, my model differs from these papers in both the timing and the driving force. In these papers the decisions related to the two markets are sequential. The main mechanism is driven by wealth effect: the crisis in one country influences the wealth of the agents which changes their behavior toward the other country. In contrast, in my model agents have to decide among different options. Because there exist multiple options agents cannot coordinate on the same action, thus the power of their aggregate move is dispersed. Oury (2013) also deals with global games where the state space is multidimensional. She focuses on the sufficient conditions for equilibrium uniqueness in a general class of multidimensional global games. However, her result does not apply to my model as the action space she defines differs from the one I use in my model.

He et al. (2015) use a similar global games model with two risky options to investigate what drives the value of the reserve asset. Their model also builds on the interaction of the strategic complementarity of the agents' action and strategic substitutability of the options. However, there is no outside option in their model and thus coordination is not weakened only splits between the risky options.

The closest paper to mine is Fujimoto (2014). He explores the similar extension of global games as I do, namely the introduction of multiple options. He proves equilibrium uniqueness and existence for such games in a quite general setup and also examines the consequences of multidimensionality. My work differs from his in three important aspects. First, he considers regime change models and thus discrete outcomes, while in my model the aggregate outcome is continuous. Second, because of the different setup his mathematical proofs do not apply directly to my model and thus I provide different proofs to show the existence and uniqueness of the equilibrium in my setup. Third, I concentrate on the coordination issues of multidimensional global games in general, while he focuses on speculative attacks.

The rest of the paper is organized as follows. Section 3.2 introduces the model. Section 3.3 characterizes the equilibrium behaviour of agents in case of separate issuance, Section 3.4 deals with the case of joint issuance. In Section 3.5 I compare the outcomes in the different scenarios. In Section 3.6 I show some comparative statics. Section 3.7 shows two applications. Finally, Section 3.8 concludes.

3.2 The Model

3.2.1 Set up

There are two uncertain economic fundamentals, θ_A and θ_B. There is a continuum of agent with measure one, indexed by $i \in I = [0,1]$. There are two periods. Each agent is born in period 1 with an endowment e. Consumption occurs only in period 2 and each agent obtains utility of $u(c)$, where c is her consumption in period 2. Function u is increasing, implying that in period 2 agents consume all their wealth. In period 1 agents have to decide between the available options. There are two scenarios. In the first scenario there are two risky options each related to one of the uncertain economic fundamentals and a safe outside option. That is the set of available actions for each agent is $\Omega = \{0, A, B\}$, where the two risky options are denoted by A and B, while the safe action is represented by 0. In the second scenario the two economic fundamentals are unified and thus agents can choose either a risky option related to the unification of the fundamentals or a safe outside action. Thus the set of available actions for the agents is $\Omega = \{0, C\}$, where C means the unified risky option and 0 is the outside option. Hereafter the superscripts stand for the agents, while the subscripts take the same values as the actions. I use $a \in \{0, A, B, C\}$ to denote the actions in general. When I consider only the two risky options I use $r \in \{A, B\}$ to represent one of them, while $-r$ denotes the other, i.e. $-r = \{A, B\}/r$.

Settlement takes place in period 2. Agents who chose the safe outside option get a risk free payment o. Agents who chose a risky option $a \in \{A, B, C\}$ realize payoff $p(\theta_a + L_a)$, where $p' > 0$. The fundamental values θ_A and θ_B are independently and randomly drawn from the real line (i.e. the common priors are independent[1] improper uniform over $\mathbb{R}^2$). While θ_C represents the fundamental value of the unified option and is equal to the average[2] of the individual fundamental values, that is $\theta_C = \frac{1}{2}(\theta_A + \theta_B)$. Furthermore L_A, L_B and L_C denote the mass of agents choosing option A, B or C, respectively. The mass of agents taking action $a \in \Omega$ is given by the aggregate actions $L_a = \int_0^1 1_{[a^i = a]} di$, where a^i is the action taken by agent i, while $1_{[a^i=a]}$ is the indicator function which takes the value of one

[1]I relax this assumption and derive the model with correlated fundamentals in the Appendix.
[2]This assumption is not essential for the main result, but simplifies the model.

if $a^i = a$ and zero otherwise. The assumption that θ_a and L_a enters the payoff function in an additive way is not essential for the results but simplifies the model.

Agents have incomplete information about the economic fundamentals. Each of them receives a noisy signal about both fundamentals. The private signal of agent $i \in [0, 1]$ about fundamental $r \in \{A, B\}$ is $x_r^i = \theta_r + \varepsilon_r^i$, where ε_r^i is an idiosyncratic noise. The noise term consists of two parts: $\varepsilon_r^i = e^i + e_r^i$. The first component, e^i, is the systemic part of the noise which is common in both signals received by an agent. The second component, e_r^i, is the fundamental specific part. The components e^i, e_A^i and e_B^i are distributed independently and normally with mean 0 and standard deviation s, s_A and s_B, respectively, and are independent across agents. Thus, by standard properties of the normal distribution, ε_r^i also has a normal distribution with mean 0 and standard deviation $\sigma_r = \sqrt{s^2 + s_r^2}$, furthermore ε_A^i and ε_B^i are correlated with a correlation coefficient $\rho = \frac{s^2}{\sqrt{\left(s^2+s_A^2\right)}\sqrt{\left(s^2+s_B^2\right)}}$. The parameter distribution and the noise technology is common knowledge among the agents.

3.3 Separate Options

3.3.1 Equilibrium

In the first scenario agents can choose among the two risky and one safe option, that is $\Omega = \{0, A, B\}$. I consider symmetric Bayesian Nash Equilibria. A Bayesian pure strategy is a map $s : \mathbb{R}^2 \to \Omega$, where $s(x^i)$ is the action chosen if the agent receives the pair of signals $x^i = (x_A^i, x_B^i)$.

In equilibrium each agent chooses a risky action if the expected payoff from this option given her own pair of signals and others' strategy is higher than both the expected payoff from the other risky action and the payoff from the safe option.

An agent prefers the risky option r to the safe option if $p\left(\theta_r + L_r\right) > o$. As p is strictly increasing, there exists a constant $n \equiv p^{-1}(o)$, such that the latter is equivalent to $\theta_r + L_r > n$. Between the two risky actions agents prefer to choose the one with higher expected payoff, thus, given that p is strictly increasing, agents prefer action A on action B if $\theta_A + L_A > \theta_B + L_B$, and prefer action B otherwise. Given these preference rankings, the equilibrium is such that each agent chooses the risky option r if the expected value of $\theta_r + L_r$ given her own pair of signals (x^i) and others' strategy $(\times_{j \in I/i} s(x^j))$ is higher than both n and the expected value of $\theta_{-r} + L_{-r}$. That is, for each $x^i \in \mathbb{R}^2$

$$s(x^i) = \begin{cases} A & \text{if } E\left[\theta_A + L_A \left| x^i, \times_{j\in I/i} s(x^j)\right.\right] > \max\left\{E\left[\theta_B + L_B \left| x^i, \times_{j\in I/i} s(x^j)\right.\right], n\right\} \\ B & \text{if } E\left[\theta_B + L_B \left| x^i, \times_{j\in I/i} s(x^j)\right.\right] > \max\left\{E\left[\theta_A + L_A \left| x^i, \times_{j\in I/i} s(x^j)\right.\right], n\right\} \\ 0 & \text{otherwise} \end{cases} \tag{3.1}$$

According to the signal generating process, the posterior cumulative distribution function about the fundamental value θ_r is increasing in the agent's related private signal x^i_r and - as the fundamentals are assumed to be uncorrelated - does not change with her other private signal x^i_{-r}. Corollary I consider monotone Bayesian Nash equilibria in which agents' strategies are increasing in own signals and non-increasing in cross signals. Proposition 1 states that such a strategy is coherent with the equilibrium (see the proof in the Appendix).

Proposition 1 *If all agents have monotone strategies increasing in related own signal and non-increasing in cross signal then the best response of any agent is to also have such a strategy.*

There have to be some cutoff values, such that an agent would choose a given strategy if and only if her signal about the underlying value exceeds this cutoff value. In the usual case when the state space is one dimensional the cutoff is given by a constant (see for instance Morris and Shin (2003)). But here each cutoff is conditional on the signal received by the agent about the other fundamental, thus the cutoffs are not constants, but functions.[3] As the action space consists of three elements, I define cutoffs between each possible pair of actions. The cutoff function between actions $r \in \{A, B\}$ and $q \in \Omega \setminus r = \{-r, 0\}$ is a map $k^{rq} : \mathbb{R} \to \mathbb{R}$, where $k^{rq}(x^i_{-r})$ prescribes a private signal about r (i.e. a value for x^i_r)[4] such that an agent with pair of signals $\left(x^i_{-r}, k^{rq}(x^i_{-r})\right)$ is indifferent between choosing option r and q. The monotonicity of the strategies implies that the above defined k^{rq} cutoff functions are indeed functions, i.e. for each element of their domain associate one single

[3]There is an identical formulation of the problem where some function of the two signals is set against a constant cutoff value. This identical formulation is closer to the logic of the standard one dimensional global games, though the solution concept I apply better matches with the formulation I use in the paper.

[4]Note that the superscript of the functions sets out the two actions that the function separates. For example $k^{A0}(x^i_B)$ is the cutoff function between actions A and 0. The first digit of the superscript shows which signal is set as a function of the other signal. That is $k^{A0}(x^i_B)$ gives the value of x^i_A for a given x^i_B making the agent independent between choosing risky option A or choosing 0, the safe outside option.

value. Altogether 4 cutoff functions are defined: k^{A0}, k^{B0}, k^{AB}, k^{BA}, such that they solve the following equations:

$$E\left[\theta_A + L_A \,\middle|\, \left(x_A^i, k^{B0}(x_A^i)\right)\right] = n \tag{3.2}$$

$$E\left[\theta_B + L_B \,\middle|\, \left(k^{A0}(x_B^i), x_B^i\right)\right] = n \tag{3.3}$$

$$E\left[\theta_A + L_A \,\middle|\, \left(k^{AB}(x_B^i), x_B^i\right)\right] = E\left[\theta_B + L_B \,\middle|\, \left(k^{AB}(x_B^i), x_B^i\right)\right] \tag{3.4}$$

$$E\left[\theta_A + L_A \,\middle|\, \left(x_A^i, k^{BA}(x_A^i)\right)\right] = E\left[\theta_B + L_B \,\middle|\, \left(x_A^i, k^{BA}(x_A^i)\right)\right] \tag{3.5}$$

Note that from (3.4) and (3.5) follows that k^{AB} and k^{BA} are inverse functions. Thus a monotone equilibrium is defined by a joint solution $(k^{A0}(x_B^i), k^{B0}(x_A^i), k^{AB}(x_B^i))$ to equations (3.2)-(3.4).

Indeed, agents prefer the risky option $r \in \{A, B\}$ over the other two options, if and only if both $x_r^i > k^{r0}(x_{-r}^i)$ and $x_r^i > k^{r(-r)}(x_{-r}^i)$. This gives the equilibrium strategies:

Proposition 2 *(strategy profile). If strategies are monotone increasing in the related own signal and non-increasing in the cross signal, the strategy for $\forall i \in [0,1]$ is as follows:*

$$s(x^i) = \begin{cases} A & \text{if } x_A^i > K^A(x_B^i) \\ B & \text{if } x_B^i > K^B(x_A^i) \\ 0 & \quad\text{otherwise} \end{cases} \tag{3.6}$$

where $K^A(x_B^i) \equiv max\left\{k^{A0}(x_B^i), k^{AB}(x_B^i)\right\}$, $K^B(x_A^i) \equiv max\left\{k^{B0}(x_A^i), k^{BA}(x_A^i)\right\}$ and $k^{BA}(x_A^i) = inv(k^{AB}(x_B^i))$.

Suppose these functions indeed exist, thus they should be such as Proposition 3 shows (see the proof in the Appendix).

Proposition 3 *(cutoff functions). The cutoff functions can be characterized by the following equations:*

$$k^{A0}\left(x_B^i\right) = n - 1 + \int_{-\infty}^{\infty} \phi(z)\Phi\left(\frac{K^A\left(x_B^i + \sqrt{2}\sigma_B z\right) - k^{A0}\left(x_B^i\right) - \sqrt{2}\sigma_A \rho z}{\sqrt{2}\sigma_A\sqrt{1-\rho^2}}\right) dz \tag{3.7}$$

$$k^{B0}\left(x_A^i\right) = n - 1 + \int_{-\infty}^{\infty} \phi\left(z\right)\Phi\left(\frac{K^B\left(x_A^i + \sqrt{2}\sigma_A z\right) - k^{B0}\left(x_A^i\right) - \sqrt{2}\sigma_B \rho z}{\sqrt{2}\sigma_B\sqrt{1-\rho^2}}\right)dz \qquad (3.8)$$

$$k^{AB}\left(x_B^i\right) = x_B^i + \int_{-\infty}^{\infty} \phi\left(z\right)\left[\begin{array}{c} \Phi\left(\frac{K^A\left(x_B^i+\sqrt{2}\sigma_B z\right)-k^{AB}\left(x_B^i\right)-\sqrt{2}\sigma_A\rho z}{\sqrt{2}\sigma_A\sqrt{1-\rho^2}}\right) \\ -\Phi\left(\frac{K^B\left(k^{AB}\left(x_B^i\right)+\sqrt{2}\sigma_A z\right)-x_B^i-\sqrt{2}\sigma_B\rho z}{\sqrt{2}\sigma_B\sqrt{1-\rho^2}}\right) \end{array}\right]dz \qquad (3.9)$$

where $\phi\left(z\right)$ and $\Phi\left(z\right)$ denote the pdf and the cdf, respectively, of the univariate standard normal distribution.

It can be shown that if there is enough noise in the signal generating process, there exists a unique equilibrium in monotone strategies. This is stated in Proposition 4 (see the proof in the Appendix).

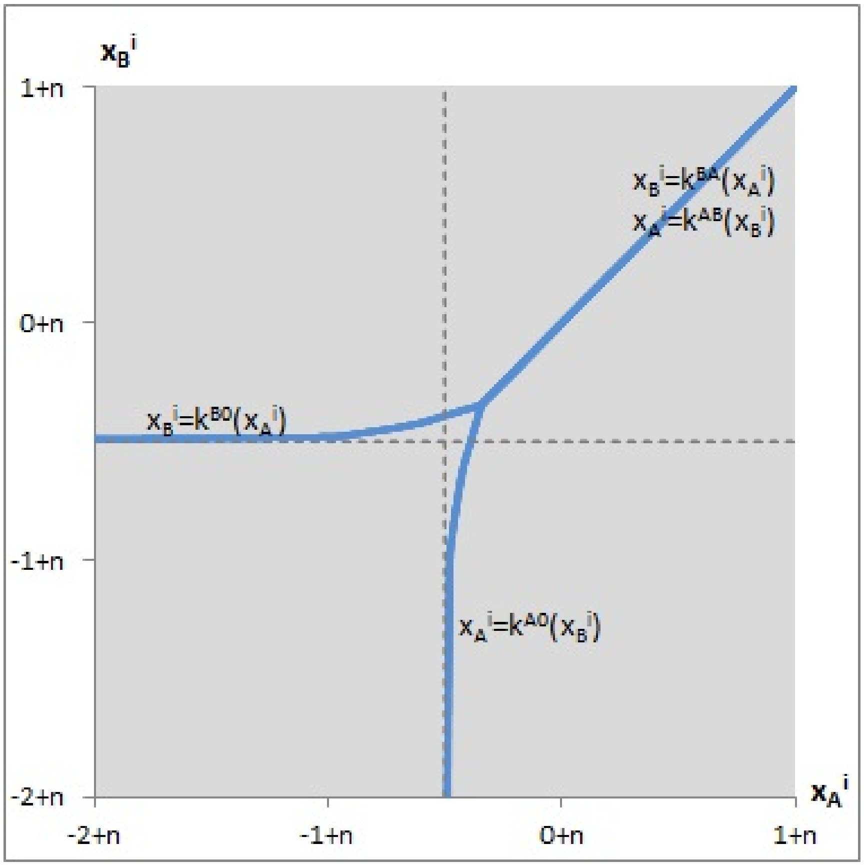
Proposition 4 *(existence, uniqueness). If $\frac{2\sigma_r+\sigma_{-r}}{\sigma_r\sigma_{-r}} < 2\sqrt{\pi}\sqrt{1-\rho^2}$ for all $r \in \{A, B\}$, there exists an essentially[5] unique Bayesian equilibrium described by the cutoff functions given in Proposition 3.*

3.3.2 Implications

Figure 3.1 provides the geometrical representation of the cutoff lines that are characterized by Proposition 3 in the space of private signals. On the figure x_A^i is measured on the horizontal axis, while x_B^i on the vertical axis. If the pair of signals received by an agent falls into the bottom left area enclosed by k^{B0} and k^{A0} she chooses the safe action. In this case her signals about both fundamentals and thus her expected gain from choosing any of the risky options are so low that she rather chooses the outside option. The top left area enclosed by k^{B0} and k^{BA} shows the case when the agent picks action B. In this case her signal on the fundamental value of B is high enough to have an expected gain from choosing action B higher than both from choosing the outside option and from choosing action A. Similarly, the bottom right area enclosed by k^{A0} and k^{BA} shows the case when the agent chooses option A.

[5] The equilibrium is not unique but essentially unique because at the cutoff the agent is indifferent between the concerned actions.

Figure 3.1: Cutoffs for the Separate-risky-option Case in the Space of Private Signals



The mass of agents taking a particular action is given by the share of agents falling in the different domains. Thus the aggregate number of agents choosing risky action r in case of the separate risky options is given by the following equation:

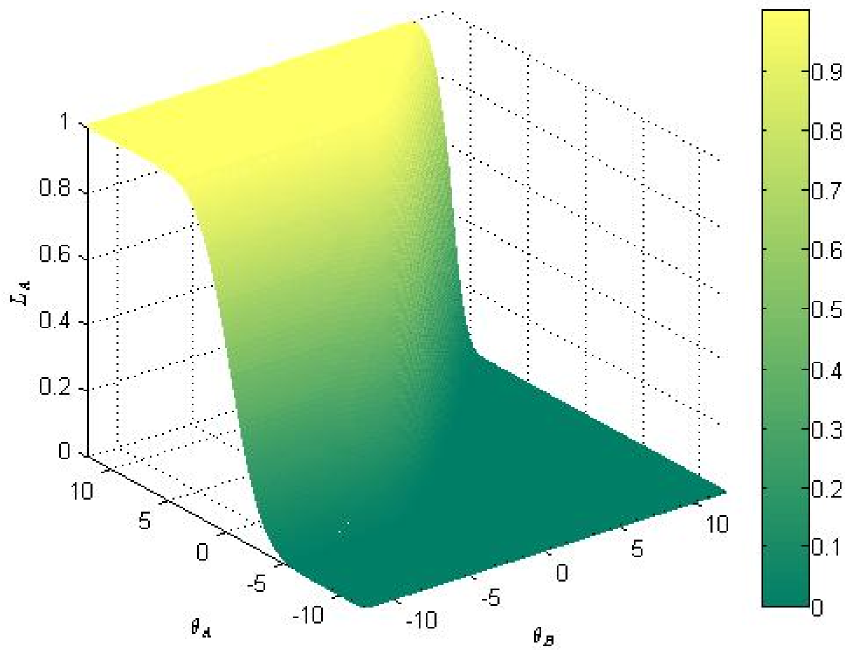
$$E(L_r\,|\theta) = P(x_r^i > K^r(x_{-r}^i)\,|\theta) = \int_{-\infty}^{\infty}\int_{K^r(u_{-r})}^{\infty} f\,(u_A, u_B)\,du_r du_{-r} \qquad (3.10)$$

where $f\,(u_A, u_B)$ is the joint pdf of $x_A^i\,|\theta$ and $x_B^i\,|\theta$. Given the signal generating process, $f\,(u_A, u_B)$ is in fact a bivariate normal distribution with mean vector $[\theta_A\ \theta_B]$ and covariance matrix $\left[\begin{smallmatrix}\sigma_A & \rho \\ \rho & \sigma_B\end{smallmatrix}\right]$.

Figure 3.2 shows the share of agents picking option A. The number of agents choosing action A increases in θ_A and decreases in θ_B. If θ_A increases the distribution of signals on fundamental value A (x_A^i) shifts to the right. Thus the higher θ_A is, the more agents get signal x_A^i high enough (relative to the other signal, x_B^i) to pick action A. While when θ_B

decreases the distribution of signals on fundamental value B (x^i_B) shifts to the left, hence the cutoff for choosing option A decreases and thus more agents opt for action A.

Figure 3.2: Share of Agents Choosing Option A in the Separate-risky-option Case in the Space of Fundamental Values



3.4 Unified Options

3.4.1 Equilibrium

In the second scenario agents either choose the safe option or a risky option depending on the unified fundamentals, that is $\Omega = \{0, C\}$. Again, I consider symmetric Bayesian Nash Equilibria with Bayesian pure strategy $s : \mathbb{R}^2 \to \Omega$, where $s(x^i)$ is the action chosen if the agent receives the pair of signals $x^i = (x^i_A, x^i_B)$. In the equilibrium each agents pick the the risky unified option if its expected payoff given her own pair of signals (x^i) and others' strategy ($\times_{j \in I/i} s(x^j)$) is higher than the payoff from the outside option.

An agent prefers the unified risky option to the safe option if $p\,(\theta_C + L_C) > o$. As p is strictly increasing, there exists a constant $n \equiv p^{-1}(o)$, such that the latter is equivalent to $\theta_C + L_C > n$.

Hence the strategy should be such that an agent opts for the unified option if and only if she expects $\theta_C + L_C$ conditional on her own pair of signals (x^i) and others' strategy ($\times_{j\in I/i}s(x^j)$) to be higher than n. That is, for each $x^i \in \mathbb{R}^2$

$$s(x^i) = \begin{cases} C & \text{if } E\left[\theta_C + L_C \left| x^i, \times_{j\in I/i}s(x^j)\right.\right] > n \\ 0 & \text{otherwise} \end{cases}$$

Let us define $x_C^i \equiv \frac{1}{2}\left(x_A^i + x_B^i\right)$. Given the signal generating processes for x_A^i and x_B^i this can be rearranged to $x_C^i = \frac{1}{2}\left(\theta_A + \varepsilon_A^i + \theta_B + \varepsilon_B^i\right) = \theta_C + \varepsilon_C^i$, with $\varepsilon_C^i = \frac{1}{2}\left(\varepsilon_A^i + \varepsilon_B^i\right) = e^i + \frac{1}{2}\left(e_A^i + e_B^i\right)$. As ε_A^i and ε_B^i are normal random variables ε_C^i is also distributed normally with mean 0 and standard deviation $\sigma_C = \sqrt{\sigma^2 + \frac{1}{4}\sigma_A^2 + \frac{1}{4}\sigma_B^2}$. One can show that the case of unified option is equivalent to the standard one dimensional case with fundamental value θ_C and private signal $x_C^i = \theta_C + \varepsilon_C^i$. This implies[6] that there is always a unique equilibrium in switching strategies, such that agents choose the unified risky option if and only if $x_C^i > n - \frac{1}{2}$.

By using that $x_C^i \equiv \frac{1}{2}\left(x_A^i + x_B^i\right)$, we can express the cutoff in terms of the original signals. Thus we get a cutoff function $k^{C0}\left(x_A^i\right) = -x_A^i + 2n - 1$, implying the strategy

$$s(x^i) = \begin{cases} C & \text{if } x_B^i > k^{C0}(x_A^i) = -x_A^i + 2n - 1 \\ 0 & \text{otherwise} \end{cases} \tag{3.11}$$

3.4.2 Implications

The cutoff line characterized by Equation 3.11 is shown in Figure 3.3. It is in fact a straight line. Agents with a pair of signals falling on the area top right to this line opt for the unified option while others choose the safe option.

The aggregate number of agents choosing the risky joint option is given by the following equation:

$$E(L_C\,|\theta) = P(x_B^i > k^{C0}(x_A^i)\,|\theta) = \int_{-\infty}^{\infty}\int_{k^{C0}(u_A)}^{\infty} f\left(u_A, u_B\right) du_B du_A \tag{3.12}$$

where again, $f\left(u_A, u_B\right)$ is the joint pdf of $x_A^i\,|\theta$ and $x_B^i\,|\theta$.

[6]For a proof see for instance Morris and Shin (2003).

Figure 3.3: Cutoffs for the Unified-risky-option Case in the Space of Private Signals

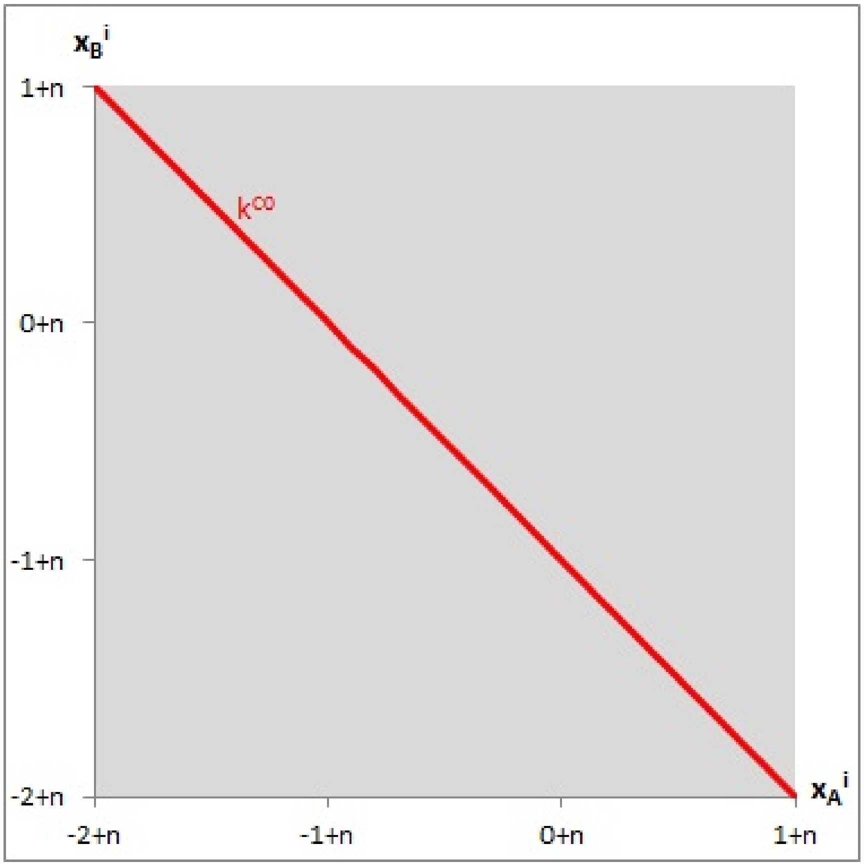
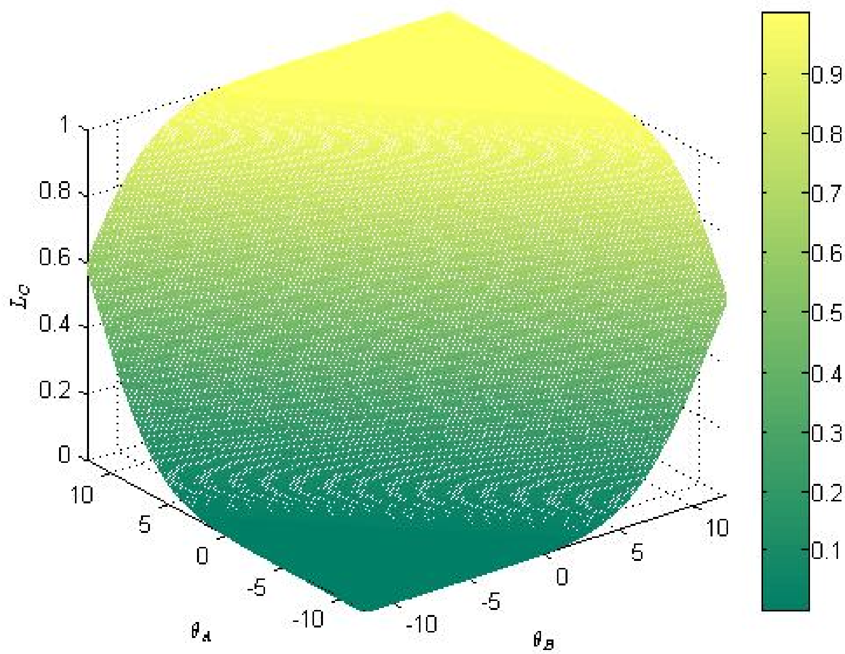


Figure 3.4 shows the share of agents choosing the unified risky option. The share of agents picking the unified option is increasing in both θ_A and θ_B. The higher any of the two fundamental values the more agent gets such signals that their sum is high enough to choose the unified risky option.

3.5 Comparison

In this section I compare different scenarios. In Subchapter 3.5.1 I set the standard benchmark case when there is a single risky option with its own fundamental value against the case of two separate risky options. Then in Subchapter 3.5.2 I compare the two-separate-risky-actions case with the unified-risky-options case, that is when there is one risky action depending on both fundamental values. In both subchapters I first study the difference in the individual decision of agents, then I analyze the aggregate behavior of the agents.

Figure 3.4: Share of Agents Choosing the Unified Risky Option in the Space of Fundamental Values



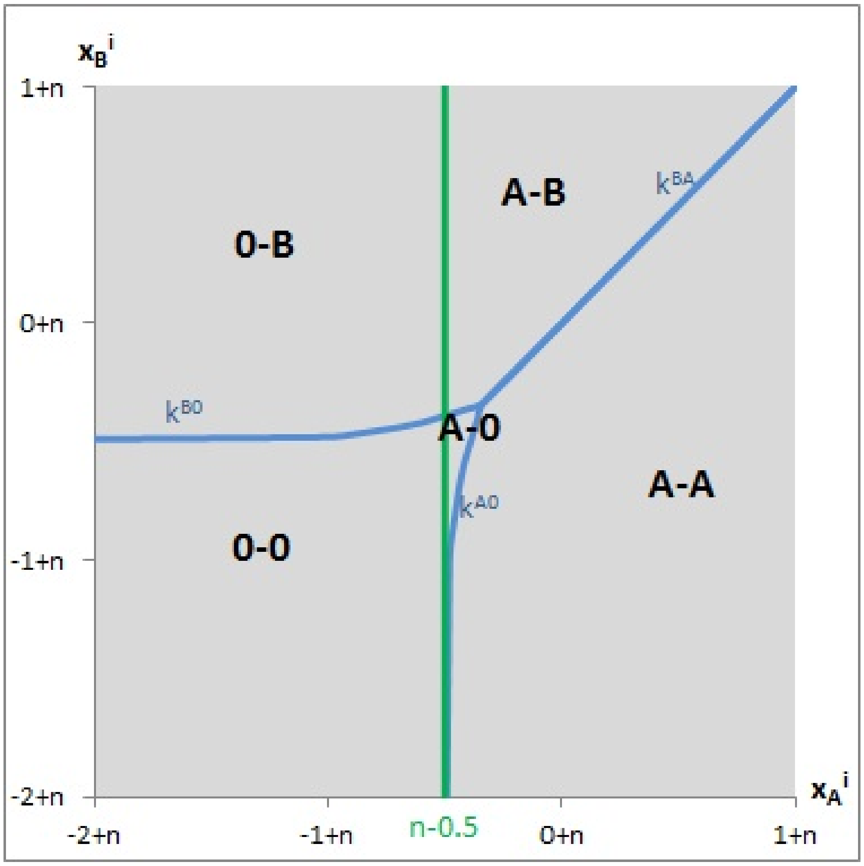
3.5.1 One Single Risky Option Versus Two Separate Risky Options

Suppose there is a single risky option with its own fundamental value. In this case the cutoff is given by a constant, in our setup $k = -0.5 + n$ is the cutoff value (see Morris and Shin (2003)). An agent chooses the safe option if her signal is smaller than the cutoff value and opt for the risky one if higher.

How does the decision of the agent change if instead of a single risky option there are two risky possibilities? Figure 3.5 compares the outcomes regarding action A as a function of the private signals.[7] The lines on the graph are the cutoff functions. The areas determined by the lines are denoted by two letters of which the first indicates the choice in the single-risky-action case, while the second indicates the outcome when there are two risky options.

[7]Note that x_B^i does not influence the decision of the agents when they can only choose action A, still I present the result in the x_A^i-x_B^i space to be comparable with the two-risky-action case.

Figure 3.5: Comparison of the Individual Decisions in the Single-risky-option and Two-separate-risky-option Cases



The vertical line at $n - 0.5$ is the cutoff in the single-risky-option case. With a private signal smaller than $n - 0.5$ (the area left to this line) the agents do not pick the single risky option. Note that this decision is not influenced by the availability of another risky option. Indeed, with such signals she picks risky action A neither in the single-risky-option, nor in the two-separate-risky-option case. The only difference is that when there is a second risky possibility that the agent expects to be attractive enough (her private signal on action B is higher than k^{B0}) she pick that option (see the area denoted by 0-B), which she cannot in the single-risky-option case. Otherwise she keeps choosing the outside option (area 0-0).

When the agent receives a signal above $n - 0.5$ (area right to the line) she picks the single risky option. This action may change when there is another risky possibility. First, she may prefer to take the other risky alternative. With private signals falling on the domain A-B the agent has an expected gain from choosing option B higher than both the outside option and the gain from picking option A. Second, she may also prefer to choose the outside option. Area A-0 shows the pair of signals with which an agent does not choose neither of the two risky options though opt for the single risky option. This domain is enclosed by k^{B0}, k^{A0} and $-0.5+n$ lines. Proposition 5 states that this area indeed exists (see the proof in the Appendix).

Proposition 5 *(inert area). The cutoff functions are above the $-1/2+n$ line, that is $k^{r0}(x^i_{-r}) > -0.5+n$ for $r \in \{A,B\}$ and $x^i_{-r} \in \mathbb{R}$.*

This area reveals that when there is a second option, however, not attractable for an agent, she is less willing to choose the first option. This is because agents have incentives to make mutually consistent actions. Given that the number of agents is fixed, when there are multiple options, their power is split. The more agent coordinates on one option the less people there are who can potentially coordinate on the other. This generates a negative correlation between the two options. I refer to this endogenous correlation as strategic correlation. Given that the fundamentals are uncorrelated, without the strategic correlation the willingness of an agent to pick a risky option should not be influenced by her expectations about the fundamental value of the other risky option that she will not choose for sure. Still, due to the endogenous strategic correlation, the availability of a second option, even when not attractable for an agent, makes the agent less willing to choose the first option.

Let us turn to the aggregates and compare the overall number of agents choosing option A under the two scenarios. Equation (3.10) and Figure 3.2 show the share of agents choosing option A in the two-separate-risky-option case. In the single-risky-option case the share of agents picking the risky option can be simply calculated by using the properties of a one dimensional normal distribution (see Morris and Shin (2003)). For a given θ_A fundamental value the share of agents taking action A is given by the following equation

$$E(L_A\,|\theta_A) = P(x^i_A > -1/2+n) = \frac{1}{\sigma_A}\Phi\left(\frac{\theta_A + 0.5 - n}{\sigma_A}\right) \tag{3.13}$$

where again $\Phi\left(z\right)$ denotes the cdf of the univariate standard normal distribution.

Figure 3.6 compares the share of agents who choose action A if there are two separate risky and a safe option versus if besides the safe option only risky action A is available ($L_A - L$). The outcomes are plotted in the space of fundamentals[8]. The left panel shows

[8]Note that θ_B does not influence the outcome in the single-risky-option case, still I present the result in the θ_A-θ_B space to be comparable with the two-risky-option case.

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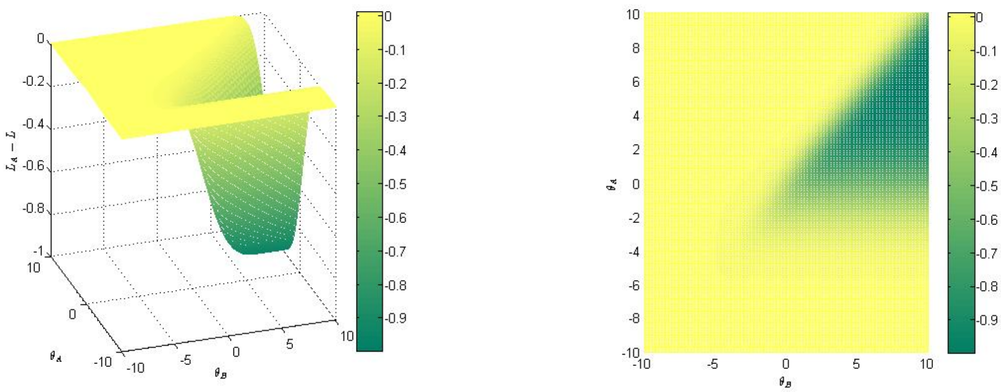
the 3-dimensional surface while the right panel shows its contour projection on the XY plane.

Figure 3.6: Comparison of the Aggregate Number of Agents Choosing the Single Risky Option and Either of the Two Separate Risky Options



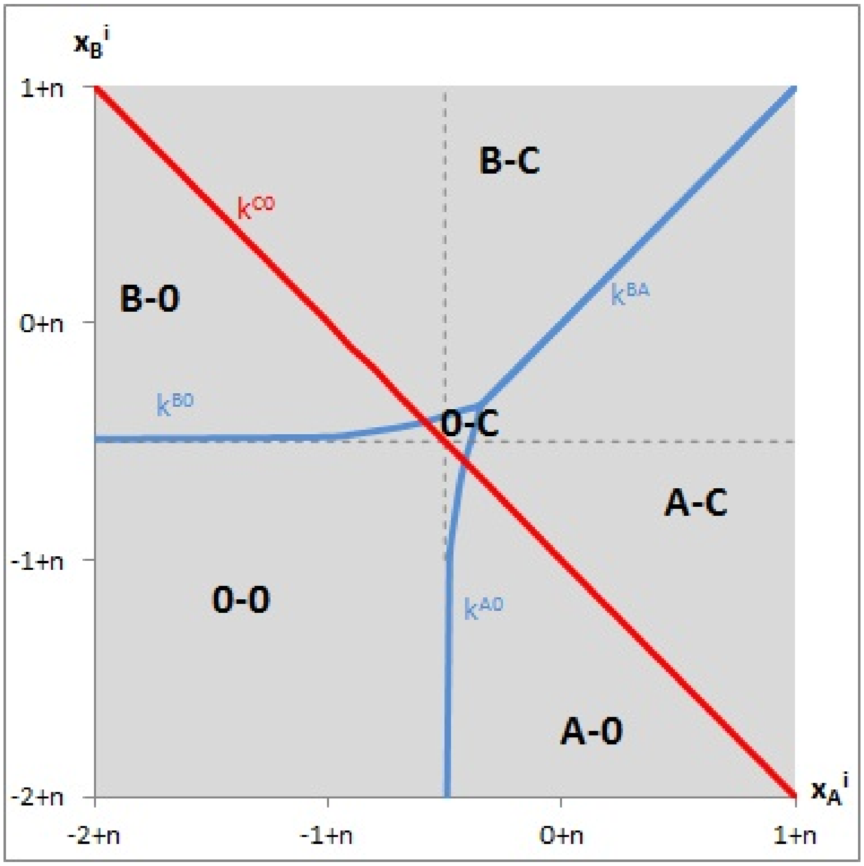
When θ_A is low enough the agents would not pick action A in neither case, thus the presence of the second risky option does not influence the outcome. However, when θ_A is higher the availability of risky option B matters. In particular the higher θ_B is relative to θ_A, the less agents pick option A as they rather choose option B.

3.5.2 Two Separated Versus Two Unified Risky Options

In this subchapter I compare the cases when the two risky options are separated and when they are unified. Figure 3.7 shows the individual decisions as a function of private signals in both cases. The lines on the graph are the cutoff functions. Similarly as before, the k^{A0}, k^{AB} and k^{B0} lines show the cutoff lines in the two-separate-risky-option case. While k^{C0} shows the cutoff line for the unified-risky-option case.

The areas determined by the lines are denoted by two letters of which the first indicates the choice when there are two separated risky possibilities, while the second indicates the outcome when they are unified. Agents with pair of signals falling on the 0-0 domain choose the outside option in both cases. Then, agents in domains A-C and B-C pick one of the separate risky options (at A-C they opt for action A, while at B-C they choose option B) and also the unified risky option. At the same time, agents with pair of signals on area A-0 or B-0 choose the risky option A or B, respectively, but does not choose their union. These areas include agents who receive high signal about one of the fundamentals and low about the other. Hence, these agents expect one of the options to be valuable enough for

Figure 3.7: Comparison of Individual Decisions in the Separate-risky-option and the Unified-risky-option Cases

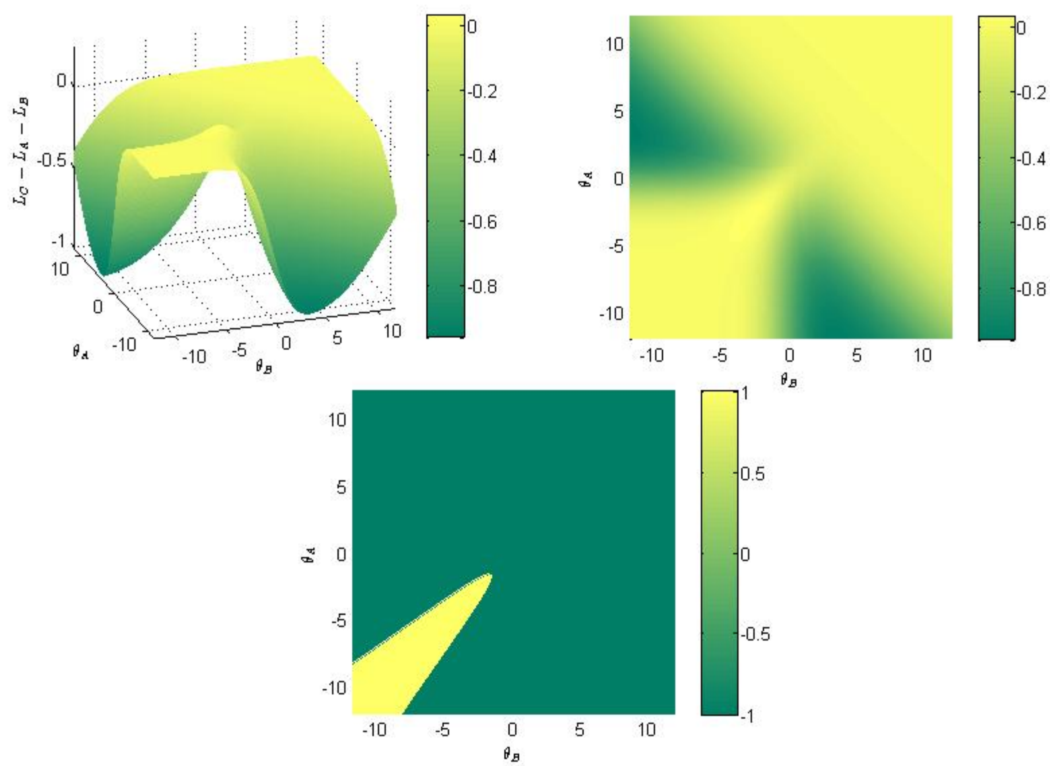


choosing of its own, however the low expected value of the other option makes unattractive the unified option. Finally, agents with private signals on the area 0-C choose neither of the separate risky options but pick their union. This is due to the fact that the negative strategic correlation is present in case of separate options but not in case of unification. Indeed, when there are two separate risky possibilities there are two potential targets to coordinate on, hence the coordination disperses and thus weakens its power. While in case of a unified risky option agents coordinate on a single target, thus the negative strategic correlation does not arise. It is easy to show that the 0-C area indeed exists by using Proposition 5 and the observation that the line k^{C0} crosses the $(n-0.5, n-0.5)$ point.

Let us turn to the aggregate behavior of the agents. Equation (3.10) and Figure 3.2 show L_A, the share of agents choosing option A in the case of two separate risky options. While if the risky options are unified the aggregate number of agents choosing it is shared, that is $L_A = L_B = \frac{L_C}{2}$, where Equation (3.12) and Figure 3.4 show L_C, the share of agents choosing the unified option.

Consider first the overall number of agents choosing any of the risky possibilities. Figure 3.8 shows the difference between the total number of agents choosing a risky option in case of joint and separate risky options ($L_C - L_A - L_B$). The outcomes are shown in the space of the fundamental values of the two options. The top left panel shows the 3-dimensional surface while the top right panel shows its contour projection on the XY plane while the bottom panel shows the sign of the difference.

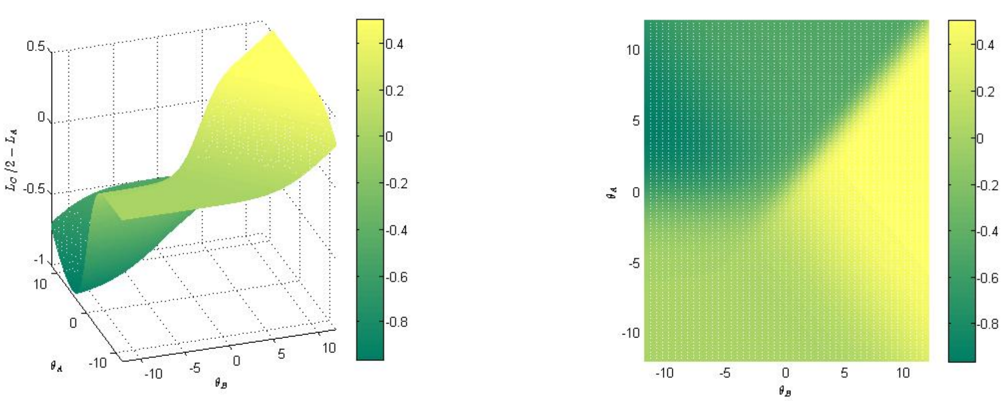
Figure 3.8: Comparison of the Aggregate Number of Agents Choosing the Unified Risky Option and Either of the Risky Options



The sign is positive when more agents pick the unified option than the two separate risky options and negative in the reverse case. The difference is around zero when the unification does not influence the total number of agents choosing them. There are two such typical situations: first, when one of the fundamentals is so high that it outweighs the other fundamental value (see the northeast part on the top right panel); second, when both fundamentals are low (see the southwest part on the top right panel). In the former case, the option with high fundamental value dominates the union, which is thus chosen with similar intensity, while the other option alone is not selected. In the latter case, none of the separate risky options and neither their union is picked. More agents choose either of the independent risky options than their union (see the dark areas on the top right panel) when one of the risky option has high fundamental value and the other has low, but in absolute value the one with low is greater. In this case the option with high fundamental value is chosen, but not the union. However, there are situations when slightly more agents opt for the joint option than in either of the separate risky options (see the light area on the bottom panel). This is the case when the value of the two fundamentals are close to each other and both are low. In this situation, because of the negative strategic correlation, a single target is more attractive than multiple targets, this is why more agents choose the union of the risky options than the distinct options.

Consider next how the form of the risky options affects, say, option A. Figure 3.9 shows the difference between the number of agents assigned to option A in the unified and in the separated case ($L_C/2 - L_A$). The outcomes are shown in the space of fundamentals. The left panel shows the 3-dimensional surface while the right panel shows its contour projection on the XY plane.

Figure 3.9: Comparison of the Aggregate Number of Agents Assigned to Option A in the Separate-risky-option and the Unified-risky-option Cases



The figure reveals that when both θ_A and θ_B are low (see the southwest part on the right panel) the form of the risky options does not make a difference, since neither fundamental A individually, nor the alliance of the two fundamentals is chosen. However, when θ_A is high compared to θ_B (see the north and the northwest part on the right panel) less agent picks the union as fundamental B counteracts the strength of fundamental A, so in these cases option A is less popular individually. Meanwhile, when θ_B is high compared to θ_A (see the east and the southeast part on the right panel) more agents pick option A singly as the lower fundamental value of B makes the union less preferred.

3.6 Information Accuracy

This section shows how the outcomes depend on the information precision. I investigate what happens if the standard deviation, either the systematic part (s) or the fundamental specific parts (s_A and s_B), of the noise term changes. Higher standard deviation means that there is lower information in the signals. The information precision affects the individual decisions when there are separate risky options, but does not affect when they are unified. However, the aggregate behavior of the agents changes in both scenarios.

First, I consider changes in the standard deviation of the systemic part of the noise term (s). Figure 3.10 provides a geometrical representation of how the cutoff lines separating the potential choices of an agent shifts for different s values. The fundamental specific variances are fixed at $s_A = s_B = 0.7$.

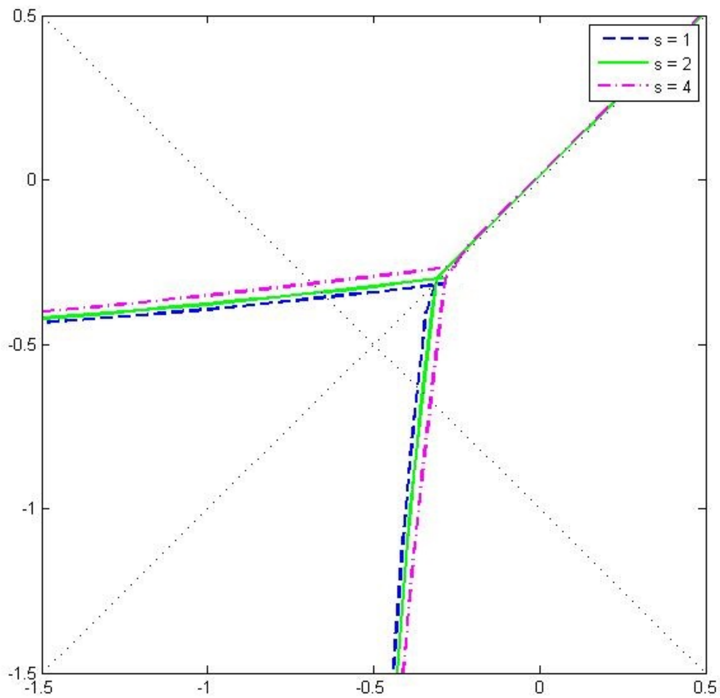
The plot reveals that when s increases, the cutoff lines k^{AO} and k^{BO} shift equally outwards from the -0.5 lines. So the higher the uncertainty, the higher signal on a given option is needed for an agent to choose that option. The intuition is the following: the higher dispersion of the expectation of the fundamentals makes the agents to expect that a larger share of their fellow agents would pick the other risky option. In other worlds, higher uncertainty makes coordination harder, thus strengthens the negative strategic correlation, and therefor enlarges the inert area.

Figure 3.11 shows how the value of s influences the aggregate number of agents choosing option A in the separate-risky-option case (L_A, see the graphs on the left) and in the unified-risky-option case (L_C, see the graphs on the right).

As s increases both curves become flatter, so the higher uncertainty reduces the potency of the fundamentals. This is also reflected in the difference between the aggregate behavior of the agents under the two scenarios, which is plotted on Figure 3.12. Graphs on the left plot the difference between the number of agents choosing option A in case of unified and separate risky options ($L_C/2 - L_A$). The right graphs show the difference between the total number of agents who opt for the unified risky option and who pick either of the separate risky options ($L_C - L_A - L_B$).

Both flatten and drift towards zero as s increases. In other worlds, when the agents'

Figure 3.10: Cutoff Lines in the Two-separate-risky-option Case at Various Standard Deviations of the Systemic Part of the Noise Term ($s = \{1, 2, 4\}$ and $s_A = s_B = 0.7$)



private information is more accurate, the difference between the agents' aggregate behavior under the various scenarios decreases.

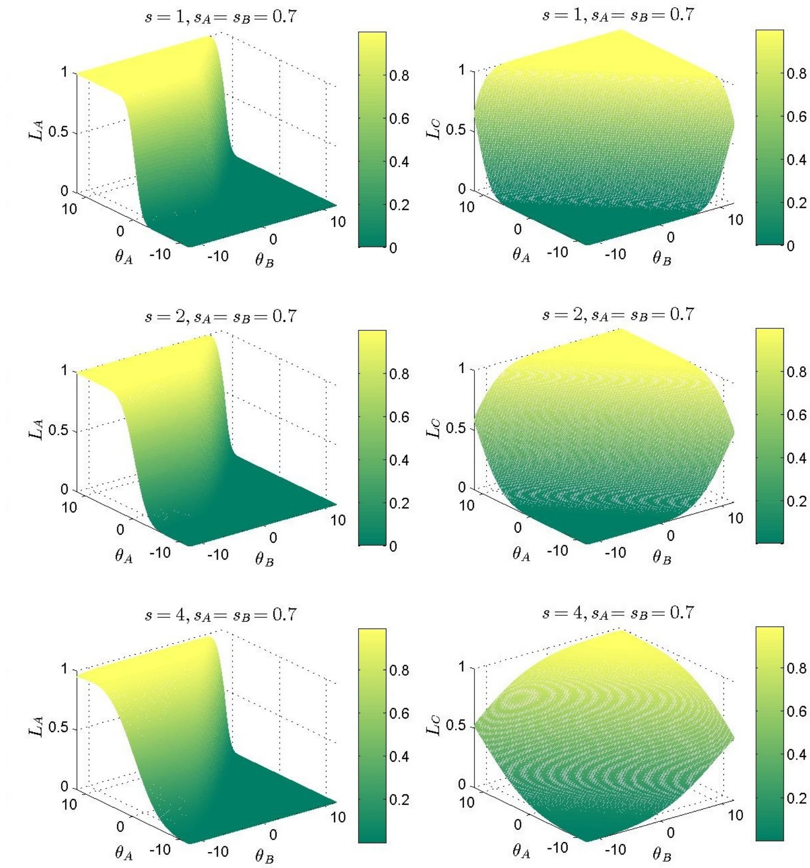
Note that all the effects caused by changes in s are symmetric in the two risky options. Now, I bring in asymmetry and consider variation in the standard deviation of the option specific part of the noise. Figure 3.13 shows how the cutoff lines in the separate-risky-option case vary depending on the value of s_B. The other parameters are fixed at $s_A = 0.7$ and $s = 2$.

When information on option B is less accurate (that is s_B increases), the three cutoff lines move to higher θ_B and lower θ_A values. This is in line with the previous finding that the cutoff lines shifts upward when there is higher uncertainty. Indeed, k^{BO} shifts upward as higher s_B means bigger uncertainty regarding option B. Meanwhile, an increase in s_B decreases the relative (compared to option B) uncertainty about option A, that is why k^{AO} shifts downward.

Figure 3.14 plots the agents aggregate behavior for various s_B values. The graphs on

10.14754/CEU.2016.04

Figure 3.11: Aggregate Number of Agents Choosing Option A (left panel) and the Unified Risky Option (right panel) at Various Standard Deviations of the Systemic Part of the Noise Term ($s = \{1, 2, 4\}$ and $s_A = s_B = 0.7$)

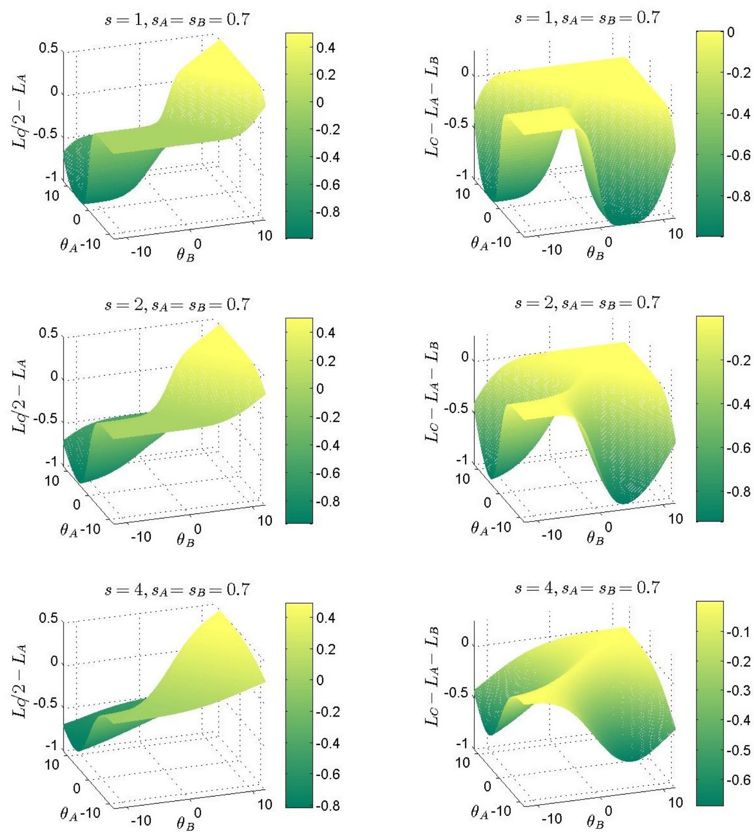


the left show the aggregate number of agents picking option A in the instance of separate risky options (L_A), while the right graphs show the share of agents choosing the unified risky option (L_C).

Changes in s_B twist the L_A surface, but not L_C. This is because due to the unification all effects are divided equally, thus even the option specific changes have symmetric effects and affect only the steepness but not the curvature of L_C.

But, given that L_A rotates, the difference of the share of agents assigned to a risky option under the different scenarios rotates as well. This is shown on Figure 3.15. The left hand side graphs plot the difference between the agents assigned to option A in case of joint and separate options ($\dfrac{L_C}{2} - L_A$). The right column compares the total number of agents who choose the joint risky option and who pick either of the separate risky options

Figure 3.12: Differences Between the Aggregate Number of Agents Under the Two Scenarios at Various Standard Deviations of the Systemic Part of the Noise Term ($s = \{1, 2, 4\}$ and $s_A = s_B = 0.7$)

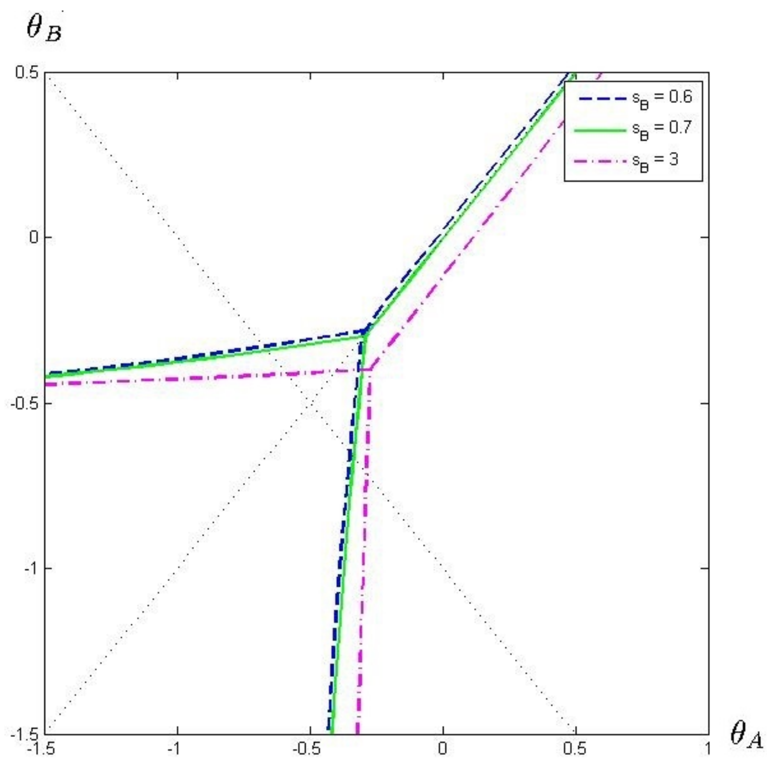


$(L_C - L_A - L_B)$.

3.7 Applications

In this section I show two potential applications of the multidimensional global games model. First, in Subchapter 3.7.1 I describe a model for the choice of oil invoicing currency. Second, in Subchapter 3.7.2 I present a model for the issuance of the European common bond.

Figure 3.13: Cutoff Lines in the Two-separate-risky-option Case at Various Standard Deviations of the Option Specific Part of the Noise Term ($s = 2$, $s_A = 0.7$ and $s_B = \{0.6, 0.7, 3\}$)



3.7.1 Choice of Currency for Oil Invoicing

In this subsection I introduce a model that describes the choice of invoicing currency in the oil market. The model is an extended, but partially simplified version of the model developed by Mileva and Siegfried (2007).[9] There is a continuum of crude oil seller with measure one, indexed by $i \in I = [0, 1]$. Oil sellers have to decide which currency to use for invoicing their oil contracts. Suppose there are three currencies, the US Dollar, the Euro and the British Pound, which can be used, that is $j \in \{UDS, EUR, GBP\}$. Each seller can use only a single currency. In time $t = 1$ sellers decide on the currency, while at time $t = 2$ trade takes place and sellers realize their income. The price of oil is independent of the invoicing currency, however the cost varies depending on the currency.

[9] Their emphasis is on the network effects which arise from the assumption that currency choice of crude oil sellers determine the currency distribution of other goods. I exclude this assumption and rather build on the learning element of the model.

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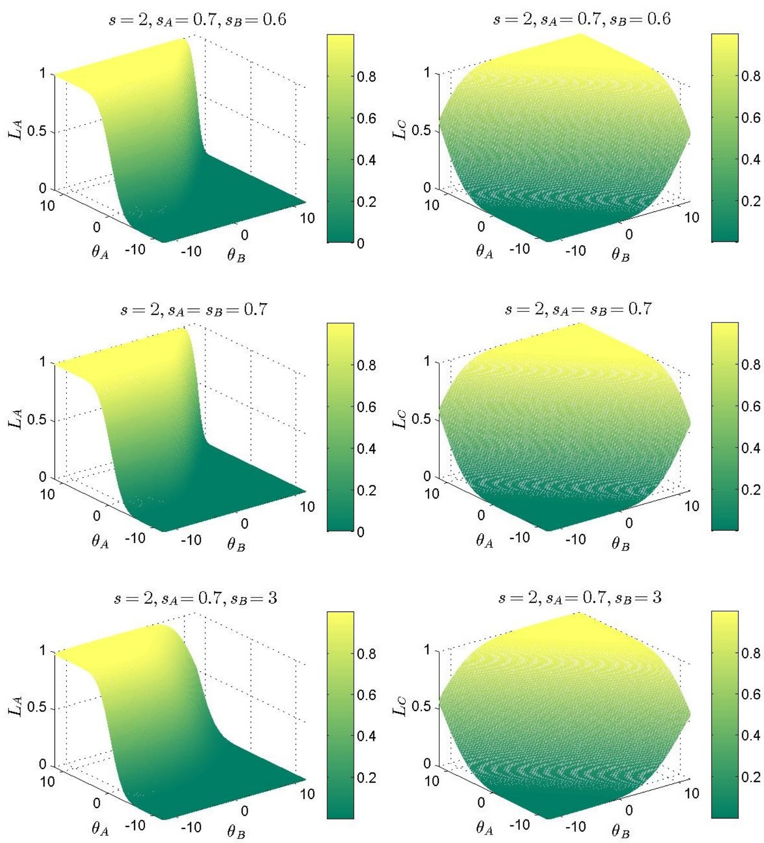
Figure 3.14: Aggregate Number of Agents Choosing Option A (left panel) and the Unified Risky Option (right panel) at Various Standard Deviations of the Option Specific Part of the Noise Term ($s = 2$, $s_A = 0.7$ and $s_B = \{0.6, 0.7, 3\}$)



The cost of using currency j is C_j. It contains the transaction cost, the liquidity cost and the information cost. Information cost arises only for the Euro and for the British Pound. In the oil market the historically established invoicing currency is the US Dollar. However, switching to a different currency have information cost as the traders have to learn the usage of the new unit of account. The more trader uses the new currency the lower the information cost is. I assume that the transaction and the liquidity cost do not depend on the number of traders using the given currency,[10] hence the cost of usage is the function of the number of agents who use the currency for the Euro and for the British

[10]Contrary to the model in Mileva and Siegfried (2007) I suppose that the denomination of oil producers' expenses is not influenced by the composition of the invoicing currency of oil as the oil market is small compared to the non-oil market.

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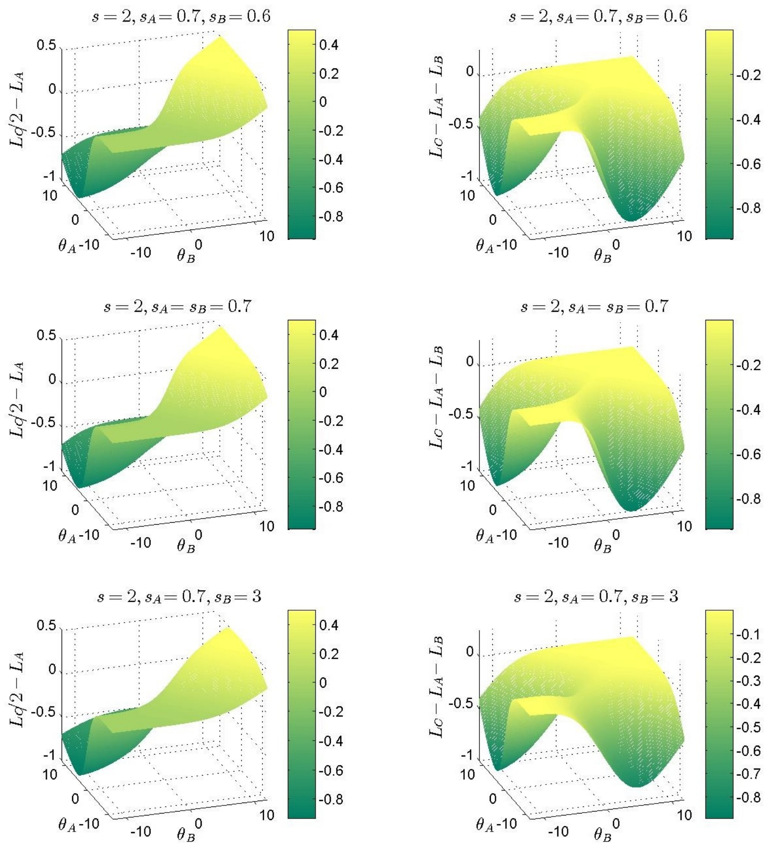
Figure 3.15: Differences Between the Aggregate Number of Agents Under the Two Scenarios at Various Standard Deviations of the Option Specific Part of the Noise Term ($s = 2$, $s_A = 0.7$ and $s_B = \{0.6, 0.7, 3\}$)



Pound but not for the US Dollar. The aggregate number of agents using currency j is denoted by L_j, while c_j is the part of the cost of using currency j which does not depend on the aggregate number of users. For simplicity, I assume that L_j enters the cost function in an additive way. Thus the cost functions are $C_{USD} = c_{USD}$, $C_{EUR} = c_{EUR} - L_{EUR}$ and $C_{GBP} = c_{GBP} - L_{GBP}$.

At $t = 1$ sellers get noisy signals $X_j^i = c_j + \epsilon_j^i$ for each $j \in \{USD, EUR, GBP\}$, where ϵ_j^i are the noise terms which are distributed independently and normally with mean 0 and standard deviation ς_j, and are independent across agents. Given her signal triplet each seller decides on her invoicing currency choice. A seller prefers the Euro over the other two currencies if she expects $c_{EUR} - c_{USD} - L_{EUR}$ to be negative and smaller than $c_{GBP} - c_{USD} - L_{GBP}$. Similarly, a seller prefers the most the British Pound if she expects

$c_{GBP} - c_{USD} - L_{GBP}$ to be negative and smaller than $c_{EUR} - c_{USD} - L_{EUR}$. Otherwise, she prefers the most the US Dollar.

Let me introduce the notations $\theta_r \equiv c_{USD} - c_r$ and $x^i_r \equiv X^i_{USD} - X^i_r$, $\varepsilon^i_r = \epsilon^i_{USD} - \epsilon^i_r$ for $r \in \{EUR, GBP\}$. Such we have the same model as described in Section 3.2. In particular the two risky options are the Euro and the British Pound and the US Dollar is the outside option. The two fundamental values are θ_{EUR} and θ_{GBP} on which oil sellers get signals x^i_{EUR} and x^i_{EUR}, where ϵ^i_{USD} is the systematic part and $-\epsilon^i_r$ is the fundamental specific part of the noise terms. Thus the standard deviations are $\sigma_{EUR} = \sqrt{\varsigma^2_{USD} + \varsigma^2_{EUR}}$ and $\sigma_{GBP} = \sqrt{\varsigma^2_{USD} + \varsigma^2_{GBP}}$, while the correlation coefficient is $\rho = \frac{\varsigma^2_{USD}}{\sqrt{(\varsigma^2_{USD}+\varsigma^2_{EUR})}\sqrt{(\varsigma^2_{USD}+\varsigma^2_{GBP})}}$. Finally, one can get from the payments after some algebra that $n = 0$.

Let me compare the individual decisions when only the Euro and when both the Euro and the British Pound are available besides the US Dollar for invoicing oil contracts. Figure 3.5 is suitable for the comparison. Option 0 represents the US Dollar, option A is the Euro and option C is the British Pound. The line at -0.5 (since $n = 0$, $n - 0.5 = -0.5$) separate the traders decision when only the US Dollar and the Euro are usable. In the three-currency-case the k^{B0}, k^{BA} and k^{A0} lines separate the traders' decisions. A trader with $x^i_r \equiv < -0.5$ (left to the line at -0.5), or equivalently $X^i_{USD} < X^i_r - 0.5$, switches to the Euro, otherwise continues to use the US Dollar in the two-currencies case. How does the availability of another currency (in our example the British Pound) affects the traders' decision on the invoicing currency? Oil sellers using the US Dollar in the two-currencies case either continue to use the US Dollar (0-0 area) or switches to the British Pound (0-B area). Traders who switch to the usage of the Euro when this is the only new currency besides the US Dollar either choose again the Euro (A-A area) or switch to the British Pound (A-B area) or after all use the US Dollar (A-0 area). Hence there are situations when an oil seller would switch to the usage of a new currency if there were one new currency besides the US Dollar, however would not switch if there were two other currencies.

3.7.2 Introduction of the Common European Bond

In this subchapter I present a model to describe the introduction of a joint bond that would replace the national issuance by member states of the Eurozone. Here I concentrate on the case when symmetric countries issue the common bond. For this, the model with uncorrelated fundamentals is suitable. To assess the case of asymmetric countries a model with correlated fundamentals is required, which I sketch in Appendix B.2. The multidimensional global games framework is suitable for evaluating the effect of joint bond issuance on the stability of the participating countries.

A and B are two countries with similar economic strength. Both countries borrow from investors by issuing bonds. There are two scenarios. The first is when the two countries issue bond separately. The second is when the two countries do not issue national bonds, instead they together issue a common bond.[11]

There is a continuum of speculators with measure one, indexed by $i \in I = [0,1]$. There are two periods. In period 1 speculators can decide whether to short some bonds. Because of short-sale constraints, each trader can short sell exactly 1 unit. If countries issue bonds separately speculators can trade any of the two (but because of the short-sale constraints not both at the same time). That is the set of available actions for each speculator is $\Omega = \{0, A, B\}$, where not trading is represented by 0, taking short position in one of the two national bonds are denoted by A and B. If countries issue bonds jointly the set of available actions for the traders is $\Omega = \{0, C\}$, where C means shorting the common bond.

Settlement takes place in period 2. Speculators choosing the outside option get a risk free interest rate r_f, thus their payment is $1 + r_f$. Speculators going short in bond $a \in \{A, B, C\}$ realizes payoff $p\left(\theta_a + L_a\right)$. The fundamental values θ_A and θ_B represent the vulnerability of the two countries, they are independently and randomly drawn from the real line. While $\theta_C = \frac{1}{2}\left(\theta_A + \theta_B\right)$ represents the vulnerability of the alliance of the countries and is equal to the average of the individual fundamental values. Furthermore L_A, L_B and L_C denote the mass of speculators shorting the bond of country A, the bond of country B and the joint bond, respectively.

Each trader receives a noisy signal about both countries' fundamentals. The private signal of investor $i \in [0,1]$ about the fundamental of country $r \in \{A, B\}$ is $x_r^i = \theta_r + \varepsilon_r^i$, where ε_r^i is an idiosyncratic noise. The noise term consists of two parts: $\varepsilon_r^i = e^i + e_r^i$. The first component of the noise term, e^i, is the systemic part of the noise, while the second component, e_r^i, is the country specific part. The components e^i, e_A^i and e_B^i are distributed independently and normally with mean 0 and standard deviation s, s_A and s_B, respectively, and are independent across speculators.

The welfare in country $r \in \{A, B\}$ is a decreasing function of the fundamental vulnerability of the country and the mass of speculators attacking the country: $W_r = w_r\left(\theta_r, L_r\right)$,

[11] Several implementation approaches to common bond issuance have been suggested. Though there are proposals with a mix of national bonds and jointly issued common bonds, in this subchapter I only concentrate on the limiting case when there is a full degree of substitution of joint issuance for national issuance.

where $w_r' < 0$. Similarly, the global welfare is a decreasing function of the sum of the two countries' vulnerability and the overall number of shorting traders: $W = w\left(\theta_A + \theta_A, L_A + L_B\right)$, where $w' < 0$. In case of joint issuance the countries share the cost of attack, that is $L_A = L_B = \frac{L_C}{2}$.

I compare the welfare in the separate and in the joint bond issuance scenarios. The former scenario is equivalent to the separate-risky-options case, while the latter is identical to the unified-risky-options case. Given that the welfare functions w_r and w are decreasing and the value of the fundamental is independent of the type of issuance, the aggregate number of attackers is the key ingredient of the welfare comparison. In particular the one with higher number of attackers results lower welfare. Hence Figure 3.8 and Figure 3.9 capture the results.

Figure 3.8 shows the difference between the total number of speculators attacking in case of joint and separate issuance. The sign is positive when more speculators attack the common bond than the two separate countries and negative in the reverse case. More agents attack either of the independent countries than their alliance (see the dark areas on the top right panel) when one of the countries has high vulnerability and the other has low, but in absolute value the one with low is greater. In this case the country which is vulnerable alone is attacked, but not the common bond. This reveals that the joint issuance can smooth out idiosyncratic risk, which is a common argument for Eurobond. However, when the vulnerability of the two countries are similarly low, slightly more agents speculate in the joint bond than in either of the national bonds (see the light are on the bottom panel). In this case the negative strategic correlation makes the single target more attractive than the multiple targets.

Figure 3.9 shows the difference between the number of speculators impairing country A in case of joint and separate issuance. The figure shows that when the vulnerability of both countries are low (both θ_A and θ_B are low, see the southwest part on the right panel) the form of bond issuance does not make a difference, since neither country A individually, nor the alliance of the two countries is attacked. However, when country A is vulnerable compared to country B (high θ_A compared to θ_B, see the north and the northwest part on the right panel) the joint bond is less attacked since country B counteracts the vulnerability of country A, so in these cases country A is worse off individually. Meanwhile, when the country B is more vulnerable than country A (high θ_B compared to θ_A, see the east and the southeast part on the right panel) country A is better off alone as the vulnerability of country B harms also country A in case of their alliance.

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3.8 Conclusion

In this chapter I analyze the coordination aspect of multidimensional global games. Global games are coordination games with incomplete information, they have been applied to several economic situations, such as bank runs, currency crisis, and technology adoption. I extend the standard global games framework by introducing and additional coordination target.

Multidimensionality has an important consequence for the power of coordination. When there are multiple options, coordination weakens. This is due to strategic motives of agents. Agents have incentives to make mutually consistent actions. Since there are a fixed number of agents, when there are multiple options, their power is split. The more people coordinate on one option the less people there are who can potentially coordinate on the other. This generates a negative correlation between the two options which I call strategic correlation.

The key element of the model is the interaction of the coordination motives of agents to move together and the substitutability of the options. When there are multiple options, each potential object of coordination, they are in fact substitutes. Thus, with multiple options the coordination disperses. However, unifying the options eliminates the coordination split and thus strengthens the power of coordination.

I show two applications which can be modeled by the multidimensional global games framework. The first application is the choice of invoicing currency of oil. In the oil market the historically established currency is the US Dollar. I show that there are situations when an agent would switch to the usage of a new currency if there were one new currency besides the US Dollar, however, would not switch if there were two other currencies. The second application is the introduction of common European bond. A common argument for joint issuance is that it smooths out idiosyncratic risk. While this argument is present in my model, there is an extra layer: joint bond issuance can make participating countries more vulnerable to speculative attacks.

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10.14754/CEU.2016.04

Appendix A

Appendix for Chapter 1

A.1 General Model

There are N number of firms denoted by i. A subgroup of firms borrows in FX, others borrow in HUF.

The general model of default looks as follows

$$def_{i,t} = \beta_t X_{i,t} + \varepsilon_{i,t} \tag{A.1}$$

where

- $def_{i,t}$: indicator variable for default of firm i in period t
- $X_{i,t}$: vector of firm characteristics for firm i in period t

The 1-period time-series behavior of firm characteristics can be characterized by the following equation

$$X_{i,t+1} = \mu_{t+1} X_{i,t} + \delta_{t+1} FX_i + \epsilon_{i,t+1} \tag{A.2}$$

where

- FX_i: indicator variable for firm i having foreign currency loan

That is, the default does not depend directly on the foreign currency indebtedness, only on other firm characteristics. However, the firm characteristics at a given period depend on their previous period realization and also on the firm's currency indebtedness.

By plugging in equation (A.2) at $t+1$ into equation (A.2) at $t+2$ we get $X_{i,t+2}$ as a function of values at t:

$$X_{i,t+2} = \left(\mu_{t+2}\mu_{t+1}\right) X_{i,t} + \left(\mu_{t+2}\delta_{t+1} + \delta_{t+2}\right) FX_i + \left(\mu_{t+2}\epsilon_{i,t+1} + \epsilon_{i,t+2}\right) \tag{A.3}$$

By introducing $\mu_{t+2,2} \equiv \mu_{t+2}\mu_{t+1}$, $\delta_{t+2,2} \equiv \mu_{t+2}\delta_{t+1} + \delta_{t+2}$ and $\epsilon_{i,t+2,2} \equiv \mu_{t+2}\epsilon_{i,t+1} + \epsilon_{i,t+2}$,we can write equation (A.3) as follows:

$$X_{i,t+2} = \mu_{t+2,2}X_{i,t} + \delta_{t+2,2}FX_i + \epsilon_{i,t+2,2} \tag{A.4}$$

By recursion this can be generalized for s period:

$$X_{i,t+s} = \mu_{t+s,s}X_{i,t} + \delta_{t+s,s}FX_i + \epsilon_{i,t+s,s} \tag{A.5}$$

Where

- $\mu_{t+s,s} \equiv \left(\prod_{j=1}^{s-1} \mu_{t+s-j}\right)$
- $\delta_{t+s,s} \equiv \sum_{k=1}^{s} \left[\left(\prod_{j=0}^{k-2} \mu_{t+s-j}\right) \delta_{t+s-k+1}\right]$
- $\epsilon_{i,t+s,s} \equiv \sum_{k=0}^{s-1} \left[\left(\prod_{j=0}^{k-1} \mu_{t+s-j}\right) \epsilon_{i,t+s-k}\right]$

By plugging in equation (A.5) into equation (A.1) we get

$$def_{i,t+s} = \beta_{t+s}\mu_{t+s,s}X_{i,t} + \beta_{t+s}\delta_{t+s,s}FX_i + \beta_{t+s}\epsilon_{i,t+s,s} + \varepsilon_{i,t+s} \tag{A.6}$$

Introducing the following notations $\beta_{t+s,s} \equiv \beta_{t+s}\mu_{t+s,s}$ and $\pi_{t+s,s} \equiv \beta_{t+s}\delta_{t+s,s}$, equation (A.6) can be rewritten as follows:

$$def_{i,t+s} = \beta_{t+s,s}X_{i,t} + \pi_{t+s,s}FX_i + \beta_{t+s}\epsilon_{i,t+s,s} + \varepsilon_{i,t+s} \tag{A.7}$$

The change in the default from period t to period t+s is thus

$$\Delta def_{i,t,s} \equiv def_{i,t+s} - def_{i,t} = (\beta_{t+s,s} - \beta_t)X_{i,t} + \pi_{t+s,s}FX_i + \beta_{t+s}\epsilon_{i,t+s,s} + \varepsilon_{i,t+s} - \varepsilon_{i,t} \tag{A.8}$$

Again, the problem is that the error terms $\varepsilon_{i,t}$ and $\epsilon_{i,t}$ (and thus $\epsilon_{i,t,s}$ which is its function) are potentially correlated with FX_i and therefore with $X_{i,t}$.

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A.2 Tables and Figures

Table A.1: Variable Definitions

variable	**definition**
Default	=1 if firm has loan with more than 90-day delinquency, =0 otherwise
Export Sales Ratio	Ratio of export sales over total firm sales
Foreign Ownership	=1 firm is at least 50% foreign owned, =0 otherwise
Ln(Total Assets)	Natural logarithm of firm total assets
Ln(Num.of Employees)	Natural logarithm firm number of employees
Capital Ratio	Ratio of firm equity to total firm assets
Liquidity Ratio	Ratio of current assets to total firm assets
ROA	Ratio of net income to total firm assets
Ln(Age)	Natural logarithm of one plus firm age
Newcomer	=1 if firm established a new bank relationship in the given year, =0 otherwise
Self-Newcomer	=1 if firm established a new bank relationship not due to acquisition in the given year, =0 otherwise
Acquired	=1 if firm was a client of the acquired bank, =0 otherwise
CHF Ratio	Share of loans denominated in Swiss Franc
EUR Ratio	Share of loans denominated in Euro
Bank Foreign Ownership	=1 if bank is at least 50% foreign owned, =0 otherwise
Ln(Bank Total Assets)	Natural logarithm of total bank assets
Bank Capital Ratio	Ratio of bank equity to total bank assets
Bank Liquidity Ratio	Ratio of liquid assets to total bank assets
Bank ROA	Ratio of pretax profits to total bank assets
Bank Doubtful Loans	Ratio of doubtful loans to total bank loan portfolio
Bank CHF	Share of Swiss Franc in bank credit portfolio
Bank EUR	Share of Euro in bank credit portfolio

NOTE. – Stock variables are measured at the end of the year, flow variables are measured over the year.

Table A.2: Multinomial Logit for the Clients of the Acquirer Bank

Dependent Variable	New loan denomination		
	HUF	CHF	EUR
Export Sales Ratio	-0.005	-0.032**	0.036***
	(-0.52)	(-3.14)	(12.50)
Foreign Ownership	-0.046	-0.041	0.087***
	(-1.51)	(-1.40)	(6.95)
Capital Ratio	0.043***	-0.029**	-0.014*
	(4.07)	(-3.16)	(-2.11)
Liquidity Ratio	0.063***	-0.043***	-0.020***
	(8.39)	(-6.68)	(-3.92)
Ln(Total Assets)	-0.074***	-0.022	0.096***
	(-5.37)	(-1.86)	(10.40)
ROA	-0.022	0.035	-0.012
	(-0.56)	(1.40)	(-0.31)
Ln(Num.of Employee)	0.019*	-0.006	-0.013*
	(2.17)	(-0.81)	(-2.37)
Ln(Age)	-0.023*	0.007	0.016**
	(-2.55)	(0.92)	(2.62)
Self-Newcomer	-0.079***	0.030*	0.049***
	(-5.63)	(2.51)	(5.14)
Acquired	-0.064***	-0.014	0.078***
	(-3.58)	(-0.88)	(6.74)
Sector Dummies	Yes		
Observations	5365		
Pseudo R-squared	0.134		

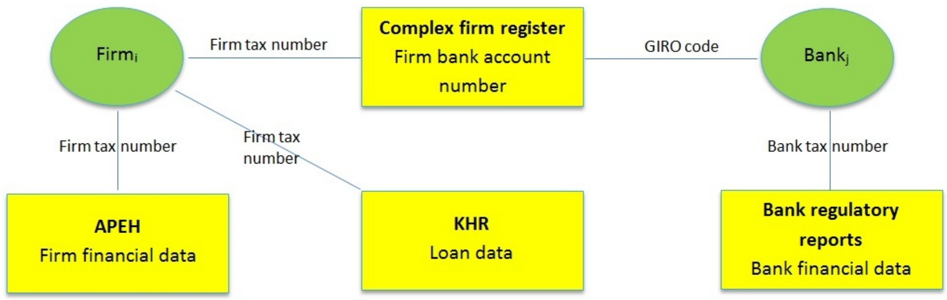
NOTE. – The table reports estimates from multinomial logit regression of firm and bank characteristics on the choice of the currency denomination of the loan for the clients of the acquirer bank in the year subsequent to the acquisition (see equation (1.5)). The table presents the marginal effects evaluated at the mean of all explanatory variables showing the change in the probability of observing each outcome resulted from a small change in a covariate (a change from 0 to 1 for dummy variables), holding all other explanatory variables constant at their mean. Table A.1 lists the definition of the variables. Coefficients are listed in the first row, z-statistics based on heteroskedasticity-robust standard errors are reported in the row below in parentheses, and the corresponding significance levels are in the adjacent column. *** Significant at 1%, ** significant at 5%, * significant at 10%.

Table A.3: Multinomial Logit for Currency Choice

Dependent Variable	Outstanding loan denomination		
	HUF	CHF	EUR
Bank CHF Share	-0.324***	0.178***	0.146***
	(0.04)	(0.03)	(0.03)
Bank EUR Share	-0.145***	-0.057***	0.202***
	(0.02)	(0.02)	(0.02)
Export Sales Ratio	-0.008***	-0.026***	0.034***
	(0.00)	(0.00)	(0.00)
Foreign Ownership	0.080***	-0.124***	0.045***
	(0.01)	(0.01)	(0.01)
Capital Ratio	0.069***	-0.041***	-0.027***
	(0.00)	(0.00)	(0.00)
Liquidity Ratio	0.059***	-0.033***	-0.026***
	(0.00)	(0.00)	(0.00)
Ln(Total Assets)	-0.160***	0.039***	0.121***
	(0.00)	(0.00)	(0.00)
ROA	-0.044***	0.055***	-0.011
	(0.01)	(0.01)	(0.01)
Ln(Num.of employee)	0.022***	-0.004	-0.018***
	(0.00)	(0.00)	(0.00)
Ln(Age)	-0.013***	0.005	0.008**
	(0.00)	(0.00)	(0.00)
Newcomer	-0.041***	0.030***	0.012***
	(0.00)	(0.00)	(0.00)
Sector Dummies	Yes		
Year Fixed Effects	Yes		
Observations	119 511		
Pseudo R-squared	0.157		

NOTE. – The table reports estimates from multinomial logit regression of firm and bank characteristics on the choice of the currency denomination of the loan for the clients of the acquirer bank in the year subsequent to the acquisition (see equation (1.6)). The table presents the marginal effects evaluated at the mean of all explanatory variables showing the change in the probability of observing each outcome resulted from a small change in a covariate (a change from 0 to 1 for dummy variables), holding all other explanatory variables constant at their mean. Table A.1 lists the definition of the variables. Coefficients are listed in the first row, z-statistics based on heteroskedasticity-robust standard errors are reported in the row below in parentheses, and the corresponding significance levels are in the adjacent column. *** Significant at 1%, ** significant at 5%, * significant at 10%.

Figure A.1: Databases



NOTE. – The figure shows which databases are used and how they are matched.

10.14754/CEU.2016.04

Appendix B

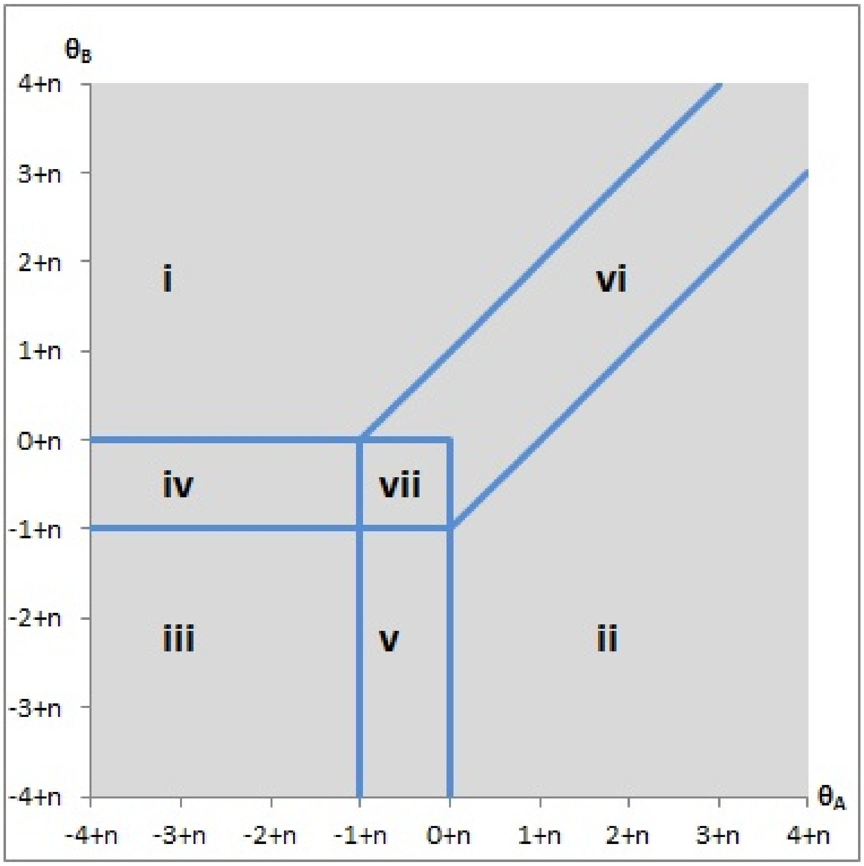
Appendix for Chapter 3

B.1 Complete Information

In case of complete information there are multiple equilibria for a certain range of fundamentals. The following domains can be separated in case of separate risky options (see Figure B.1):

- i) if $\theta_B \geq \max(n, \theta_A + 1)$, each agent has a dominant strategy to choose option B
- ii) if $\theta_A \geq \max(n, \theta_B + 1)$, each agent has a dominant strategy to choose option A
- iii) if $\theta_A < n - 1$ and $\theta_B < n - 1$, each agent has a dominant strategy to choose the outside option
- iv) if $n - 1 \leq \theta_B < n$ and $\theta_A < n - 1$, there are two pure strategy Nash equilibria: either everybody choose option B or everybody choose the outside option
- v) if $n - 1 \leq \theta_A < n$ and $\theta_B < n - 1$, there are two pure strategy Nash equilibria: either everybody choose option A or everybody choose the outside option
- vi) if $\theta_1 - 1 < \theta_B < \theta_A + 1$ and either $n - 1 < \theta_A$ or $n - 1 < \theta_B$, there are two pure strategy Nash equilibria: either everybody choose option A or everybody choose option B
- vii) if $n - 1 \leq \theta_A < n$ and $n - 1 \leq \theta_B < n$, there are three pure strategy Nash equilibria: either everybody choose option A or everybody choose option B or everybody choose the outside option

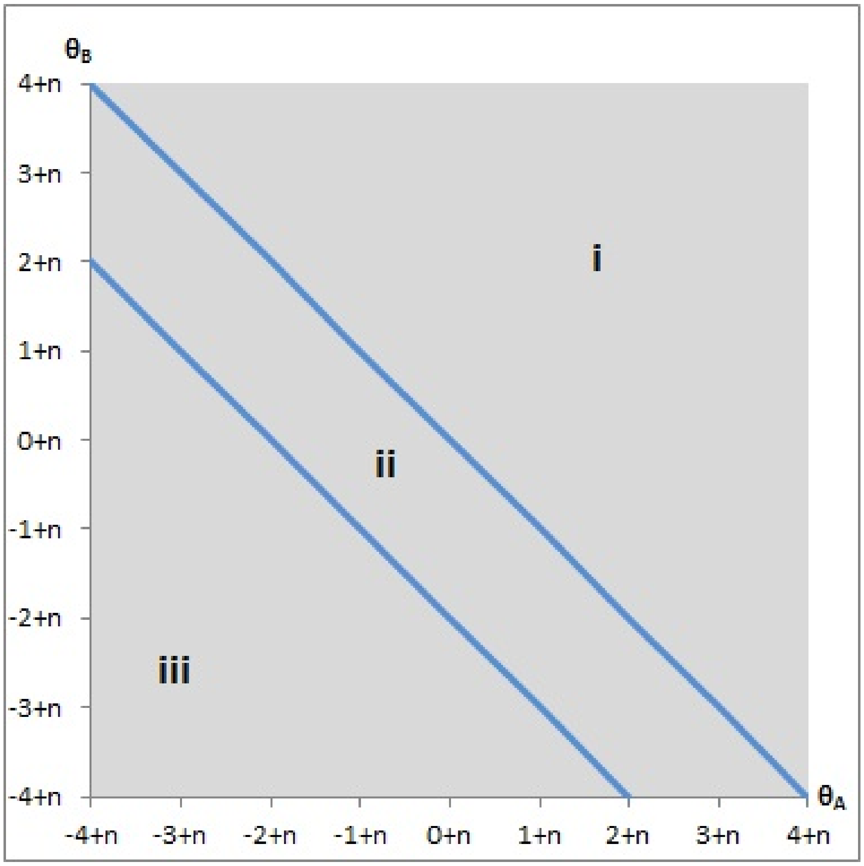
Figure B.1: Equilibria in Case of Complete Information with Two Separate Risky Options in the Space of the Fundamental Values



While in case of join issuance the following domains can be distinguished (see Figure B.2):

- i) if $\theta_B \geq 2n - \theta_A$, each agent has a dominant strategy to choose the unified risky option
- ii) if $2n - \theta_A > \theta_B \geq 2n - \theta_A - 2$, there are two pure strategy Nash equilibria: either everybody choose the unified risky option or everybody choose the outside option
- iii) if $2n - \theta_A - 2 > \theta_B$, each agent has a dominant strategy to choose the outside option

Figure B.2: Equilibria in Case of Complete Information with the Unified Risky Option in the Space of the Fundamental Values



B.2 Correlated Fundamentals

The economic fundamentals, θ_A and θ_B, are correlated with correlation coefficient ρ_θ and follow a bivariate normal distribution such that $\begin{bmatrix}\theta_A \\ \theta_B\end{bmatrix} \sim N\left(\begin{bmatrix}y_A \\ y_B\end{bmatrix}, \begin{bmatrix}\tau_A^2 & \tau_A\tau_B\rho_\theta \\ \tau_A\tau_B\rho_\theta & \tau_B^2\end{bmatrix}\right)$.[1] However, for simplicitiy, I assume that the pair of signals received by and agent are not correlated. For this reason, I set the variance of the systematic part of the individual noise term (e^i) to be 0 (that is $s = 0$), and thus the noise term ε_r^i has mean 0 and standard deviation $s_r = \sigma_r$.

The joint distribution of the fundamentals and the noise terms implies that an agent ob-

[1] An alternative representation is that the fundamentals are independently and randomly drawn from the real line, however each agent observe the pair of noisy public signals $y_A = \theta_A + \varepsilon_A^y$ and $y_B = \theta_B + \varepsilon_B^y$, where $\begin{bmatrix}\varepsilon_A^y \\ \varepsilon_B^y\end{bmatrix} \sim N\left(\begin{bmatrix}0 \\ 0\end{bmatrix}, \begin{bmatrix}\tau_A^2 & \tau_A\tau_B\rho_\theta \\ \tau_A\tau_B\rho_\theta & \tau_B^2\end{bmatrix}\right)$.

serving the vector of signals $x^i = (x^i_A, x^i_B)$ considers the fundamental values and the opponents' signal to be distributed normally such as $\theta\,|x^i \sim N(\overline{\mu}_\theta, \overline{\Sigma}_\theta)$ and $x^j\,|x^i \sim N(\overline{\mu}_{x^j}, \overline{\Sigma}_{x^j})$ for $\forall j \neq i$, where

$$\overline{\mu}_\theta = \overline{\mu}_{x^j} = \begin{pmatrix} H_{AA}x^i_A + (1-H_{AA})y_A + H_{AB}x^i_B + (1-H_{AB})y_B \\ H_{BA}x^i_A + (1-H_{BA})y_A + H_{BB}x^i_B + (1-H_{BB})y_B \end{pmatrix}$$

and

$$\overline{\Sigma}_{x^j} = \overline{\Sigma}_\theta + \begin{pmatrix} \sigma_A^2 & 0 \\ 0 & \sigma_B^2 \end{pmatrix} = \begin{pmatrix} \sigma_A^2(1+H_{AA}) & \sigma_A\sigma_B\sqrt{H_{AB}H_{BA}} \\ \sigma_A\sigma_B\sqrt{H_{AB}H_{BA}} & \sigma_B^2(1+H_{BB}) \end{pmatrix}$$

where the weights are

$$H_{AA} \equiv \frac{(1-\rho^2)(\tau_A\tau_B)^2 + (\tau_A\sigma_B)^2}{(1-\rho^2)(\tau_A\tau_B)^2 + (\tau_A\sigma_B)^2 + (\sigma_A\tau_B)^2 + (\sigma_A\sigma_B)^2} \tag{B.1}$$

$$H_{AB} \equiv \frac{\rho\tau_A\tau_B\sigma_A^2}{(1-\rho^2)(\tau_A\tau_B)^2 + (\tau_A\sigma_B)^2 + (\sigma_A\tau_B)^2 + (\sigma_A\sigma_B)^2} \tag{B.2}$$

$$H_{BA} \equiv \frac{\rho\tau_A\tau_B\sigma_B^2}{(1-\rho^2)(\tau_A\tau_B)^2 + (\tau_A\sigma_B)^2 + (\sigma_A\tau_B)^2 + (\sigma_A\sigma_B)^2} \tag{B.3}$$

$$H_{BB} \equiv \frac{(1-\rho^2)(\tau_A\tau_B)^2 + (\sigma_A\tau_B)^2}{(1-\rho^2)(\tau_A\tau_B)^2 + (\tau_A\sigma_B)^2 + (\sigma_A\tau_B)^2 + (\sigma_A\sigma_B)^2} \tag{B.4}$$

Similarly as in case of uncorrelated fundamentals, the strategy can be characterized by Proposition 2. However the cutoff function characterizing the equilibrium are differ from the uncorrelated case. Proposition 6 describes them.

Proposition 6 *(cutoff functions 2).*

The cutoff functions can be characterized by the following equations:

$$\begin{aligned} k^{A0}(x^i_B) &= \frac{1}{H_{AA}}\Big\{n - 1 - (1-H_{AA})y_A - H_{AB}x^i_B - (1-H_{AB})y_B \\ &+ \int_{-\infty}^{\infty} \phi(z)\Phi\left(D^A\left(z, k^{A0}(x^i_B), x^i_B\right)\right) dz\Big\} \end{aligned} \tag{B.5}$$

$$
\begin{aligned}
k^{B0}(x_A^i) &= \frac{1}{H_{BB}}\Big\{n-1-(1-H_{BB})y_B - H_{BA}x_A^i - (1-H_{BA})y_A \\
&+ \int_{-\infty}^{\infty}\phi(z)\Phi\left(D^B\left(z,k^{B0}(x_A^i),x_A^i\right)\right)dz\Big\}
\end{aligned}
\tag{B.6}
$$

$$
\begin{aligned}
k^{AB}(x_B^i) &= \frac{H_{AB}-H_{BB}}{H_{AA}-H_{BA}}(y_B - x_B^i) + y_A + \frac{1}{H_{AA}-H_{BA}} \\
&\cdot \int_{-\infty}^{\infty}\phi(z)\left[\Phi\left(D^A(z,k^{AB}(x_B^i),x_B^i)\right) - \Phi\left(D^B\left(z,x_B^i,k^{AB}(x_B^i)\right)\right)\right]dz
\end{aligned}
\tag{B.7}
$$

$$
\begin{aligned}
k^{BA}(x_A^i) &= \frac{H_{BA}-H_{AA}}{H_{BB}-H_{AB}}(y_A - x_A^i) + y_B + \frac{1}{H_{BB}-H_{AB}} \\
&\cdot \int_{-\infty}^{\infty}\phi(z)\left[\Phi\left(D^B(z,k^{BA}(x_A^i),x_A^i)\right) - \Phi\left(D^A\left(z,x_A^i,k^{BA}(x_A^i)\right)\right)\right]dz
\end{aligned}
\tag{B.8}
$$

where $\phi(z)$ and $\Phi(z)$ denote the pdf and the cdf, respectively, of the univariate standard normal distribution, H_{AA}, H_{AB}, H_{BA} and H_{BB} as defined in equation (B.1), (B.2),(B.3) and (B.4), respectively and

$$
\begin{aligned}
D^A\left(z,x_A^i,x_B^i\right) &\equiv \frac{\sqrt{1+H_{BB}}}{\sigma_A\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}}\cdot\Big\{K^A\Big(\sigma_B\sqrt{1+H_{BB}}z \\
&+H_{BA}x_A^i + (1-H_{BA})y_A + H_{BB}x_B^i + (1-H_{BB})y_B\Big) - H_{AA}x_A^i \\
&-(1-H_{AA})y_A - H_{AB}x_B^i - (1-H_{AB})y_B - \frac{\sigma_A\sqrt{H_{AB}H_{BA}}z}{\sqrt{1+H_{BB}}}\Big\}
\end{aligned}
$$

$$
\begin{aligned}
D^B\left(z,x_B^i,x_A^i\right) &\equiv \frac{\sqrt{1+H_{AA}}}{\sigma_B\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}}\cdot\Big\{K^B\Big(\sigma_A\sqrt{1+H_{AA}}z \\
&+H_{AB}x_B^i + (1-H_{AB})y_B + H_{AA}x_A^i + (1-H_{AA})y_A\Big) - H_{BB}x_B^i \\
&-(1-H_{BB})y_B - H_{BA}x_A^i - (1-H_{BA})y_A - \frac{\sigma_B\sqrt{H_{BA}H_{AB}}z}{\sqrt{1+H_{AA}}}\Big\}
\end{aligned}
$$

Proposition 7 states that if there is enough noise in the signal generating process, there exists a unique equilibrium in monotone strategies.

Proposition 7 *(existence, uniqueness 2). If ... for all $r \in \{A, B\}$, there exists an essentially unique Bayesian equilibrium described by the cutoff functions given in Proposition 6.*

B.3 Proofs

Proof. (of Proposition 1) The joint distribution of the noise terms implies that an agent observing the vector of signals $x^i = (x^i_A, x^i_B)$ considers the fundamental values and the opponents' signal to be distributed normally as follows: $\theta_r \left| x^i \right. \sim N(x^i_r, \sigma_r)$ and $x^j_r \left| x^i \right. \sim N(x^i_r, \sqrt{2}\sigma_r)$ for $\forall j \neq i$ and $r \in \{A, B\}$. Thus if x^i_r increases ceteris paribus, $E\left(\theta_r \left| x^i \right.\right)$ increases as well.

Moreover the posterior distribution of opponents' signal is also increasing in x^i_r, thus given that agents follow monotone increasing strategies in related signals, and $E\left(L_r \left| x^i \right.\right) = \Pr\left(a^j = r \left| x^i \right.\right)$, an increase in x^i_r rise $E\left(L_r \left| x^i \right.\right)$ as well. This implies that $E\left(\theta_r + L_r \left| x^i \right.\right)$ increases with x^i.

Given that x^i_r is neutral to both $\theta_{-r} \left| x^i \right.$ and $x^j_{-r} \left| x^i \right.$ and opponents follow non-increasing strategy in cross signals, $E\left(\theta_{-r} + L_{-r} \left| x^i \right.\right)$ is non-increasing in x^i.

This makes action r more attractive compared to both action 0 and $-r$. ■

Proof. (of Proposition 3)

Since the noise term is distributed iid., in the symmetric equilibrium, the probability that an agent chooses action r is equal to the aggregate number of agents who chooses that action. Thus given the strategy characterized in Proposition 2 and the conditional distribution $u_r \equiv x^j_r \left| x^i \right. \sim N(x^i_r, \sqrt{2}\sigma_r)$ for $\forall j \neq i$ and $r \in \{A, B\}$, it can be easily shown that

$$E(L_r \left| x^i \right.) = P(x^j_r > K^r(x^j_{-r}) \left| x^i \right.) = \int\limits_{-\infty}^{\infty} \int\limits_{K^r(u_{-r})}^{\infty} f\left(u_A, u_B\right) du_r du_{-r}$$

where $f\left(u_A, u_B\right)$ is the joint pdf of $x^j_A \left| x^i \right.$ and $x^j_B \left| x^i \right.$. Let z_1 and z_2 such that $\begin{bmatrix} z_1 \\ z_2 \end{bmatrix} \sim N\left(\mathbf{0}, \mathbf{I}\right)$, thus by using the Cholesky decomposition $u_A = x^i_A + \sqrt{2}\sigma_A z_A$ and $u_B = x^i_B + \sqrt{2}\sigma_B\left(\rho z_A + \sqrt{1-\rho^2} z_B\right)$ would hold. By introducing $D^r\left(z\right) = \frac{K^r\left(x^i_{-r} + \sqrt{2}\sigma_{-r} z\right) - x^i_r - \sqrt{2}\sigma_r \rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}$, the equations can be rearranged as follows:

$$\begin{aligned}
E\left(L_r\left|x^i\right.\right) &= \int\limits_{-\infty}^{\infty}\int\limits_{K^r(u_{-r})}^{\infty} f\left(u_A,u_B\right)du_r du_{-r} = \int\limits_{-\infty}^{\infty}\int\limits_{D^r(z_{-r})}^{\infty}\phi\left(z_A,z_B\right)dz_r dz_{-r} \\
&= \int_{-\infty}^{\infty}\phi\left(z\right)\left[1-\Phi\left(D^r\left(z\right)\right)\right]dz = 1-\int_{-\infty}^{\infty}\phi\left(z\right)\Phi\left(D^r\left(z\right)\right)dz
\end{aligned}$$

where $\phi\left(z\right)$ and $\Phi\left(z\right)$ denote the pdf and the cdf, respectively, of the univariate standard normal distribution and $\phi(z_A,z_B)$ denotes the pdf of the bivariate standard normal distribution, where z_A and z_B are independent, implying that $\phi\left(z_A,z_B\right)=\phi\left(z_A\right)\phi\left(z_B\right)$. Using that $\theta_r\left|x^i\right.\sim N(x^i_r,\sigma_r)$ for $r\in\{A,B\}$ results in

$$E(\theta_r+L_r\left|x^i\right.)=E(\theta_r\left|x^i\right.)+E(L_r\left|x^i\right.)=x^i_r+1-\int_{-\infty}^{\infty}\phi\left(z\right)\Phi\left(D^r\left(z\right)\right)dz \tag{B.9}$$

The definition of the cutoff function k^{r0} implies that whenever $x^i_r=k^{r0}(x^i_{-r})$, $E(\theta_r+L_r\left|x^i\right.)=n$ has to hold. Substituting this into (B.9) gives

$$k^{r0}(x^i_{-r})+1-\int_{-\infty}^{\infty}\phi\left(z\right)\Phi\left(\frac{K^r\left(x^i_{-r}+\sqrt{2}\sigma_{-r}z\right)-k^{r0}(x^i_{-r})-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)dz=n$$

implying that

$$k^{r0}(x^i_{-r})=n-1+\int_{-\infty}^{\infty}\phi\left(z\right)\Phi\left(\frac{K^r\left(x^i_{-r}+\sqrt{2}\sigma_{-r}z\right)-k^{r0}(x^i_{-r})-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)dz \tag{B.10}$$

The definition of $k^{r(-r)}$ implies that with $x^i_r=k^{r(-r)}\left(x^i_{-r}\right)$, the $E\left(\theta_r+L_r\left|x^i\right.\right)=E\left(\theta_{-r}+L_{-r}\left|x^i\right.\right)$ is satisfied, thus combining this with equation (B.9) gives

$$\begin{aligned}
&k^{r(-r)}\left(x^i_{-r}\right)+1-\int_{-\infty}^{\infty}\phi\left(z\right)\Phi\left(\frac{K^r\left(x^i_{-r}+\sqrt{2}\sigma_{-r}z\right)-k^{r(-r)}\left(x^i_{-r}\right)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)dz \\
=\;& x^i_{-r}+1-\int_{-\infty}^{\infty}\phi\left(z\right)\Phi\left(\frac{K^{-r}\left(k^{r(-r)}\left(x^i_{-r}\right)+\sqrt{2}\sigma_r z\right)-x^i_{-r}-\sqrt{2}\sigma_{-r}\rho z}{\sqrt{2}\sigma_{-r}\sqrt{1-\rho^2}}\right)dz
\end{aligned}$$

which can be rearranged into the following form:

$$k^{r(-r)}\left(x_{-r}^{i}\right)=x_{-r}^{i}+\int_{-\infty}^{\infty}\phi\left(z\right)\left[\begin{array}{c}\Phi\left(\frac{K^{r}\left(x_{-r}^{i}+\sqrt{2}\sigma_{-r}z\right)-k^{r(-r)}\left(x_{-r}^{i}\right)-\sqrt{2}\sigma_{r}\rho z}{\sqrt{2}\sigma_{r}\sqrt{1-\rho^{2}}}\right)\\-\Phi\left(\frac{K^{-r}\left(k^{r(-r)}\left(x_{-r}^{i}\right)+\sqrt{2}\sigma_{r}z\right)-x_{-r}^{i}-\sqrt{2}\sigma_{-r}\rho z}{\sqrt{2}\sigma_{-r}\sqrt{1-\rho^{2}}}\right)\end{array}\right]dz \quad (B.11)$$

■

Proof. (of Proposition 4) By using Banach fixed point theorem, I show that the cutoff function triplet $k=\left\{k^{A0},k^{B0},k^{AB}\right\}$ given by Proposition 3 indeed exists and is unique. For this in Lemma 8 I show that the set of cutoff function triplets $\mathcal{K}$ with some metric d is a complete metric space. In Lemma 9 I prove that the joint best response mapping $B:\mathcal{K}\rightarrow\mathcal{K}$ is a contraction map.

Lemma 8 *(Non-empty Complete Metric Space). The set of cutoff function triplet $\mathcal{K}$ with some metric d is a complete metric space.*

First let me define the metric d for any two sets of functions $F=\{f_1,f_2,\dots f_N\}$ and $G=\{g_1,g_2,\dots g_N\}$ where both contain N number of functions, each with domain $\mathbb{R}$:

$$d\left(F,G\right)\equiv max\left\{\sup_{y\in R}\left|f_1\left(y\right)-g_1\left(y\right)\right|,\sup_{y\in R}\left|f_2\left(y\right)-g_2\left(y\right)\right|,\dots,\sup_{y\in R}\left|f_N\left(y\right)-g_N\left(y\right)\right|\right\}$$

From (B.10) we can establish that $k^{\mathbf{r0}}:\mathbb{R}\rightarrow[-1+n,n]$ is bounded. While from (B.11) follows that $k^{\mathbf{r(-r)}}\left(\mathbf{y}\right)-y:\mathbb{R}\rightarrow[-1,1]$ is bounded. Hence $(\mathcal{K},d)$ is indeed a complete metric space.

Lemma 9 *(Contraction Map). The joint best response mapping $B:\mathcal{C}\rightarrow\mathcal{C}$ is a contraction map.*

Given that everybody has cutoffs $k\equiv\left\{k^{A0},k^{B0},k^{AB}\right\}$, the best response cutoffs of agent i is given by $B(k)=\left\{b^{A0}(k),b^{B0}(k),b^{AB}(k)\right\}$. Where from (B.10) and (B.11) we have for $r\in\{A,B\}$

$$b^{r0}\left(y,k\right)=n-1+\int_{-\infty}^{\infty}\phi\left(z\right)\Phi\left(\frac{K^{r}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0}(y)-\sqrt{2}\sigma_{r}\rho z}{\sqrt{2}\sigma_{r}\sqrt{1-\rho^{2}}}\right)dz \quad (B.12)$$

$$b^{r(-r)}\left(y,k\right)=x_{-r}^{i}+\int_{-\infty}^{\infty}\phi\left(z\right)\left[\begin{array}{c}\Phi\left(\frac{K^{r}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r(-r)}(y)-\sqrt{2}\sigma_{r}\rho z}{\sqrt{2}\sigma_{r}\sqrt{1-\rho^{2}}}\right)\\-\Phi\left(\frac{K^{-r}\left(k^{r(-r)}(y)+\sqrt{2}\sigma_{r}z\right)-y-\sqrt{2}\sigma_{-r}\rho z}{\sqrt{2}\sigma_{-r}\sqrt{1-\rho^{2}}}\right)\end{array}\right]dz \quad (B.13)$$

with $K^r(y) \equiv max\left\{k^{r0}(y), k^{r(-r)}(y)\right\}$*. In order to verify that the map is indeed a contraction map we have to show that* $d(k,k') > d(B(k), B(k'))$*. For this it is enough to show that both* $d(k,k') > \sup_{y\in R}\left|b^{r0}(y,k) - b^{r0}(y,k')\right|$ *and* $d(k,k') > \sup_{y\in R}\left|b^{r(-r)}(y,k) - b^{r(-r)}(y,k')\right|$ *hold if the sufficient conditions are fulfilled.*

First let me concentrate on b^{r0}

$$
\begin{aligned}
& \sup_{y\in R}\left|b^{r0}(y,k) - b^{r0}(y,k')\right| \\
= & \sup_{y\in R}\left| \begin{array}{c} \int_{-\infty}^{\infty}\phi(z)\Phi\left(\frac{K^r\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)dz \\ \int_{-\infty}^{\infty}\phi(z)\Phi\left(\frac{K^{r\prime}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0\prime}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)dz \end{array}\right| \\
= & \sup_{y\in R}\left|\int_{-\infty}^{\infty}\phi(z)\left[\begin{array}{c} \Phi\left(\frac{K^r\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right) \\ -\Phi\left(\frac{K^{r\prime}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0\prime}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)\end{array}\right]dz\right| \qquad \text{(B.14)}
\end{aligned}
$$

According to the mean value theorem there exists ξ *s.t.:*

$$
\phi(\xi) = \frac{\Phi\left(\frac{K^r\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right) - \Phi\left(\frac{K^{r\prime}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0\prime}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)}{\frac{K^r\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}} - \frac{K^{r\prime}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0\prime}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}}
$$

Since $\max_{\xi\in\mathbb{R}}\phi(\xi) = \phi(0) = \frac{1}{\sqrt{2\pi}}$ *we have*

$$
\begin{aligned}
& \phi(0)\frac{K^r\left(y+\sqrt{2}\sigma_{-r}z\right) - K^{r\prime}\left(y+\sqrt{2}\sigma_{-r}z\right) - k^{r0}(y) + k^{r0\prime}(y)}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}} \\
\geq \; & \Phi\left(\frac{K^r\left(y+\sqrt{2}\sigma_{-r}z\right) - k^{r0}(y) - \sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right) \\
& -\Phi\left(\frac{K^{r\prime}\left(y+\sqrt{2}\sigma_{-r}z\right) - k^{r0\prime}(y) - \sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)
\end{aligned}
$$

Moreover for any y *the inequality* $-k^{r0}(y) + k^{r0\prime}(y) \leq \sup_{z\in\mathbb{R}}\left|k^{r0}(y) - k^{r0\prime}(y)\right|$ *has to hold. But from the definition of metric* d *follows that* $\sup_{y\in\mathbb{R}}\left|k^{r0}(y) - k^{r0\prime}(y)\right| \leq d(k,k')$*, which* *implies* $-k^{r0}(y)+k^{r0\prime}(y)\le d(k,k')$. *Similarly holds*

$$\begin{aligned}
& K^{r}\left(y+\sqrt{2}\sigma_{-r}z\right)-K^{r\prime}\left(y+\sqrt{2}\sigma_{-r}z\right)\\
\le\ & \sup_{y\in\mathbb{R}}\left|K^{r}(y)-K^{r\prime}(y)\right|\\
\le\ & \max\left(\sup_{y\in\mathbb{R}}\left|k^{r0}(y)-k^{r0\prime}(y)\right|,\sup_{y\in\mathbb{R}}\left|k^{r(-r)}(y)-k^{r(-r)\prime}(y)\right|\right)\\
\le\ & d(k,k')
\end{aligned}$$

for any y. *These imply that*

$$\begin{aligned}
& \phi(0)\frac{2d(k,k')}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\\
\ge\ & \Phi\left(\frac{K^{r}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)\\
& -\Phi\left(\frac{K^{r\prime}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r0\prime}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)
\end{aligned}$$

Combining this with (B.14) gives:

$$\sup_{y\in\mathbb{R}}\left|b^{r0}(y,k)-b^{r0}(y,k')\right|\le\sup_{y\in\mathbb{R}}\left|\int_{-\infty}^{\infty}\phi(z)\left[\phi(0)\frac{2d\left(k,k^{'}\right)}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right]dz\right|=\frac{d(k,k')}{\sqrt{\pi}\sigma_r\sqrt{1-\rho^2}}.$$

Thus $\sup_{z\in\mathbb{R}}\left|b^{r0}(z,k)-b^{r0}(z,k')\right|<d(k,k')$ *holds if* ρ *and* σ_r *are such that* $\frac{1}{\sigma_r}<\sqrt{\pi}\sqrt{1-\rho^2}$ *(**condition 1**).*

Now let me concentrate on $b^{r(-r)}$. *Equation (B.13) gives*

$$\begin{aligned}
& \sup_{y\in\mathbb{R}}\left|b^{r(-r)}(y,k)-b^{r(-r)}(y,k')\right|\\
=\ & \sup_{y\in\mathbb{R}}\left|\int_{-\infty}^{\infty}\phi(z)\left[\begin{array}{r}\Phi\left(\frac{K^{r}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r(-r)}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)\\ -\Phi\left(\frac{K^{r\prime}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r(-r)\prime}(y)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)\\ -\Phi\left(\frac{K^{-r}\left(k^{r(-r)}(y)+\sqrt{2}\sigma_r z\right)-y-\sqrt{2}\sigma_{-r}\rho z}{\sqrt{2}\sigma_{-r}\sqrt{1-\rho^2}}\right)\\ +\Phi\left(\frac{K^{-r\prime}\left(k^{r(-r)\prime}(y)+\sqrt{2}\sigma_r z\right)-y-\sqrt{2}\sigma_{-r}\rho z}{\sqrt{2}\sigma_{-r}\sqrt{1-\rho^2}}\right)\end{array}\right]dz\right|
\end{aligned}$$

Similarly as above, by using the mean value theorem and the definition of K^r, *one can* *show that*

$$\begin{aligned}
& \phi\left(0\right)\frac{2d\left(k,k'\right)}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}} \\
\geq\ & \Phi\left(\frac{K^r\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r(-r)}\left(y\right)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right) \\
& -\Phi\left(\frac{K^{r\prime}\left(y+\sqrt{2}\sigma_{-r}z\right)-k^{r(-r)\prime}\left(y\right)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right)
\end{aligned}$$

and

$$\begin{aligned}
& \phi\left(0\right)\frac{d\left(k,k'\right)}{\sqrt{2}\sigma_{-r}\sqrt{1-\rho^2}} \\
\geq\ & -\Phi\left(\frac{K^{-r}\left(k^{r(-r)}\left(y\right)+\sqrt{2}\sigma_r z\right)-y-\sqrt{2}\sigma_{-r}\rho z}{\sqrt{2}\sigma_{-r}\sqrt{1-\rho^2}}\right) \\
& +\Phi\left(\frac{K^{-r\prime}\left(k^{r(-r)\prime}\left(y\right)+\sqrt{2}\sigma_r z\right)-y-\sqrt{2}\sigma_{-r}\rho z}{\sqrt{2}\sigma_{-r}\sqrt{1-\rho^2}}\right)
\end{aligned}$$

These imply that

$$\begin{aligned}
& \sup_{z\in\mathbb{R}}\left|b^{r(-r)}\left(y,k\right)-b^{r(-r)}\left(y,k'\right)\right| \\
\leq\ & \int_{-\infty}^{\infty}\phi(z)\left[\phi\left(0\right)\frac{2d\left(k,k'\right)}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}+\phi\left(0\right)\frac{d\left(k,k'\right)}{\sqrt{2}\sigma_{-r}\sqrt{1-\rho^2}}\right]dz \\
=\ & \frac{d\left(k,k'\right)}{\sqrt{\pi}\sqrt{1-\rho^2}}\left(\frac{1}{\sigma_r}+\frac{1}{2\sigma_{-r}}\right)\int_{-\infty}^{\infty}\phi(z)\,dz=\frac{d\left(k,k'\right)}{\sqrt{\pi}\sqrt{1-\rho^2}}\frac{\sigma_r+2\sigma_{-r}}{2\sigma_r\sigma_{-r}}
\end{aligned}$$

Thus if ρ*,* σ_r *and* σ_{-r} *are such that* $\frac{2\sigma_A+\sigma_B}{\sigma_A\sigma_B}<2\sqrt{\pi}\sqrt{1-\rho^2}$ *(**condition 2**), then* $d\left(k,k'\right)>\sup_{y\in\mathbb{R}}\left|b^{r(-r)}\left(y,k\right)-b^{r(-r)}(y,k')\right|$ *holds. Since* $\frac{2}{\sigma_B}<\frac{2\sigma_A+\sigma_B}{\sigma_A\sigma_B}$ ***condition 1** is always satisfied whenever **condition 2** holds. Hence if* $\frac{2\sigma_A+\sigma_B}{\sigma_A\sigma_B}<2\sqrt{\pi}\sqrt{1-\rho^2}$*, for all* $r\in\{A,B\}$*, then*

$$\begin{aligned}
& \left(B\left(k\right),B\left(k'\right)\right) \\
=\ & \max\begin{pmatrix}\sup_{y\in\mathbb{R}}\left|b^{A0}\left(y,k\right)-b^{A0}(y,k')\right|,\sup_{y\in\mathbb{R}}\left|b^{B0}\left(y,k\right)-b^{B0}(y,k')\right|,\\ \sup_{y\in\mathbb{R}}\left|b^{AB}\left(y,k\right)-b^{AB}(y,k')\right|,\sup_{y\in\mathbb{R}}\left|b^{BA}\left(y,k\right)-b^{BA}(y,k')\right|\end{pmatrix} \\
<\ & d\left(k,k^{'}\right)
\end{aligned}$$

is fulfilled. So in this case the mapping is indeed a contraction.

■

Proof. (of Proposition 5) Assume that for some y_0 the inequality $k^{r0}(y_0) > n - 0.5$ does not hold. That is there exists some $\delta_0 \geq 0$ constant such that $k^{r0}(y_0) = n - 0.5 - \delta_0$.

Substituting it into (B.10) gives

$$n - 0.5 - \delta_0 = n - 1 + \int_{-\infty}^{\infty} \phi(z) \Phi\left(\frac{K^r\left(y_0 + \sqrt{2}\sigma_{-r} z\right) - (n - 0.5 - \delta_0) - \sqrt{2}\sigma_r \rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right) dz \tag{B.15}$$

According to the mean value theorem there exists ξ such that

$$\phi(\xi) = \frac{\Phi\left(\frac{K^r\left(y_0+\sqrt{2}\sigma_{-r}z\right)-(n-0.5-\delta_0)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right) - \Phi\left(\frac{-\rho z}{\sqrt{1-\rho^2}}\right)}{\frac{K^r\left(y_0+\sqrt{2}\sigma_{-r}z\right)-(n-0.5-\delta_0)-\sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}} - \frac{-\rho z}{\sqrt{1-\rho^2}}}$$

thus

$$\begin{aligned} &\Phi\left(\frac{K^r\left(y_0 + \sqrt{2}\sigma_{-r}z\right) - (n-0.5-\delta_0) - \sqrt{2}\sigma_r\rho z}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}\right) \\ = \quad &\phi(\xi)\frac{K^r\left(y_0 + \sqrt{2}\sigma_{-r}z\right) - (n-0.5-\delta_0)}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}} + \Phi\left(\frac{-\rho z}{\sqrt{1-\rho^2}}\right) \end{aligned}$$

Combing it with (B.15) gives

$$\int_{-\infty}^{\infty}\phi(z)\left[\phi(\xi)\frac{K^r\left(x^i_{-r} + \sqrt{2}\sigma_{-r}z\right) - (n-0.5-\delta_0)}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}} + \Phi\left(\frac{-\rho z}{\sqrt{1-\rho^2}}\right)\right] dz = 0.5 - \delta_0$$

Using that $\phi(z) = \phi(-z)$ and $\Phi(z) = 1 - \Phi(-z)$ implies that with any constant A: $\int_{-\infty}^{\infty}\phi(z)\Phi(Az)\,dz = \int_{-\infty}^{0}\phi(-z)\left[1-\Phi(-Az)\right] + \int_0^{\infty}\phi(z)\Phi(Az)\,dz = \int_0^{\infty}\phi(z)\,dz$ =0.5. Hence $\int_{-\infty}^{\infty}\phi(z)\Phi\left(\frac{-\rho z}{\sqrt{1-\rho^2}}\right)dz$ =0.5, and thus $\int_{-\infty}^{\infty}\phi(z)\phi(\xi)\frac{K^r\left(y_0+\sqrt{2}\sigma_{-r}z\right)-(n-0.5-\delta_0)}{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}dz = -\delta_0$. Rearrangement gives $\int_{-\infty}^{\infty}\phi(z)K^r\left(y_0+\sqrt{2}\sigma_{-r}z\right)dz = -\delta_0\left(\frac{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}{\phi(\xi)}+1\right) + n - 0.5$, which implies that for some y_1 the following has to hold

$$K^r(y_1) \leq -\delta_0\left(1 + \frac{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}{\phi(\xi)}\right) - 0.5 + n$$

Using condition and that $\max_{\xi \in \mathbb{R}} \phi(\xi) = \phi(0) = \frac{1}{\sqrt{2\pi}}$, the inequality $\frac{\sqrt{2}\sigma_r\sqrt{1-\rho^2}}{\phi(\xi)} < 2$ has to hold. Moreover $K^r(y_A) \equiv max\left\{k^{r0}(y_1)\ \ , k^{r(-r)}(y_1)\right\}$, thus

$$k^{r0}(y_1) < -0.5 + n - 3\delta_0$$

That is there exists some constant $\delta_1 > 3\delta_0 \geq 0$ constant such that $k^{r0}(y_1) = n - 0.5 - \delta_1$. Doing the same transformations as above for y_1 gives that for some y_2 there exists $\delta_2 > 3\delta_1$ such that $k^{r0}(y_2) = n - 0.5 - \delta_2$. Similarly repeating the same steps m times provides $k^{r0}(y_m) = n - 0.5 - \delta_m$ with $\delta_m > 3\delta_{m-1} > 3^{m-1}\delta_1 > 0$. This holds for any m and since δ_1 is a positive constant, $\lim_{m\to-\infty} k^{r0}(y_m) = -\infty$. But given that $k^{r0}(y_m) \in [-1+n, n]$ it is a contradiction. Consequently there cannot be y_0 such that the inequality $k^{r0}(y_0) > n - 0.5$ does not hold. ■

Proof. (of Proposition 6)

Since the noise term is distributed iid., in the symmetric equilibrium, the probability that an agent chooses action r is equal to the aggregate number of agents who chooses that action. Thus given the strategy characterized in Proposition 2 and the conditional distribution $u \equiv x^j\left|x^i\right. \sim N(\overline{\mu}_{x^j}, \overline{\Sigma}_{x^j})$ for $\forall j \neq i$, it can be easily shown that

$$E(L_r\left|x^i\right.) = P(x^j_r > K^r(x^j_{-r})\left|x^i\right.) = \int\limits_{-\infty}^{\infty} \int\limits_{K^r(u_{-r})}^{\infty} f(u_A, u_B)\, du_r du_{-r}$$

where $f(u_A, u_B)$ is the joint pdf of $x^j_A\left|x^i\right.$ and $x^j_B\left|x^i\right.$. Let z_A and z_B such that $\begin{bmatrix} z_A \\ z_B \end{bmatrix} \sim N(\mathbf{0}, \mathbf{I})$, thus by using the Cholesky decomposition z_A and z_B can be set such that $u_B = H_{BA}x^i_A + (1-H_{BA})y_A + H_{BB}x^i_B + (1-H_{BB})y_B + \sigma_B\sqrt{1+H_{BB}}z_B$ and $u_A = H_{AA}x^i_A + (1-H_{AA})y_A + H_{AB}x^i_B + (1-H_{AB})y_B + \frac{\sigma_A}{\sqrt{1+H_{BB}}}(\sqrt{H_{AB}H_{BA}}z_B + \sqrt{(1+H_{AA})(1+H_{BB}) - H_{AB}H_{BA}}z_A)$ would hold. By introducing

$$\begin{aligned} D^A\left(z, x^i_A, x^i_B\right) &= \frac{\sqrt{1+H_{BB}}}{\sigma_A\sqrt{(1+H_{AA})(1+H_{BB}) - H_{AB}H_{BA}}} \cdot \Bigg\{K^A\Bigg(\sigma_B\sqrt{1+H_{BB}}z \\ &\quad + H_{BA}x^i_A + (1-H_{BA})y_A + H_{BB}x^i_B + (1-H_{BB})y_B\Bigg) - H_{AA}x^i_A \\ &\quad - (1-H_{AA})y_A - H_{AB}x^i_B - (1-H_{AB})y_B - \frac{\sigma_A\sqrt{H_{AB}H_{BA}}z}{\sqrt{1+H_{BB}}}\Bigg\} \end{aligned}$$

the equation can be rearranged as follows:

$$
\begin{aligned}
E\left(L_A \left| x^i\right.\right) &= \int\limits_{-\infty}^{\infty}\int\limits_{K^A(u_B)}^{\infty} f\left(u_A, u_B\right) du_A du_B = \int\limits_{-\infty}^{\infty}\int\limits_{D^A(z_B)}^{\infty} \phi\left(z_A, z_B\right) dz_A dz_B \\
&= \int_{-\infty}^{\infty} \phi\left(z\right)\left[1-\Phi\left(D^A\left(z, x_A^i, x_B^i\right)\right)\right] dz = 1-\int_{-\infty}^{\infty} \phi\left(z\right)\Phi\left(D^A\left(z, x_A^i, x_B^i\right)\right) dz
\end{aligned}
$$

where $\phi\left(z\right)$ and $\Phi\left(z\right)$ denote the pdf and the cdf, respectively, of the univariate standard normal distribution and $\phi(z_A, z_B)$ denotes the pdf of the bivariate standard normal distribution, where z_A and z_B are independent, implying that $\phi\left(z_A, z_B\right) = \phi\left(z_A\right)\phi\left(z_B\right)$. Using that $\theta\left|x^i\right. \sim N(\overline{\mu}_\theta, \overline{\Sigma}_\theta)$ results in

$$
\begin{aligned}
E(\theta_A + L_A \left|x^i\right.) &= E(\theta_A \left|x^i\right.) + E(L_A \left|x^i\right.) \\
&= H_{AA}x_A^i + (1-H_{AA})y_A + H_{AB}x_B^i + (1-H_{AB})y_B \\
&+ 1 - \int_{-\infty}^{\infty} \phi\left(z\right)\Phi\left(D^A\left(z, x_A^i, x_B^i\right)\right) dz
\end{aligned} \tag{B.16}
$$

The definition of the cutoff function k^{A0} implies that whenever $x_A^i = k^{A0}(x_B^i)$, $E(\theta_A + L_A\left|x^i\right.) = n$ has to hold. Substituting this into (B.16) gives

$$
\begin{aligned}
H_{AA}k^{A0}(x_B^i) + (1-H_{AA})y_A + H_{AB}x_B^i + (1-H_{AB})y_B + 1 \\
- \int_{-\infty}^{\infty} \phi\left(z\right)\Phi\left(D^A\left(z, k^{A0}(x_B^i), x_B^i\right)\right) dz = n
\end{aligned}
$$

implying that

$$
\begin{aligned}
k^{A0}(x_B^i) &= \frac{1}{H_{AA}}\Bigg\{ n - 1 - (1-H_{AA})y_A - H_{AB}x_B^i - (1-H_{AB})y_B \\
&+ \int_{-\infty}^{\infty} \phi\left(z\right)\Phi\left(D^A\left(z, k^{A0}(x_B^i), x_B^i\right)\right) dz \Bigg\}
\end{aligned} \tag{B.17}
$$

One can similarly show that

$$
\begin{aligned}
E(\theta_B + L_B \left|x^i\right.) &= H_{BB}x_B^i + (1-H_{BB})y_B + H_{BA}x_A^i + (1-H_{BA})y_A \\
&+ 1 - \int_{-\infty}^{\infty} \phi\left(z\right)\Phi\left(D^B\left(z, x_B^i, x_A^i\right)\right) dz
\end{aligned} \tag{B.18}
$$

and thus

$$k^{B0}(x_A^i) = \frac{1}{H_{BB}}\Big\{n - 1 - (1-H_{BB})y_B - H_{BA}x_A^i - (1-H_{BA})y_A + \int_{-\infty}^{\infty}\phi(z)\Phi\left(D^B\left(z, k^{B0}(x_A^i), x_A^i\right)\right)dz\Big\} \tag{B.19}$$

The definition of k^{AB} implies that with $x_A^i = k^{AB}(x_B^i)$, the equation $E(\theta_A + L_A | x^i) = E(\theta_B + L_B | x^i)$ is satisfied, thus combining this with equations (B.16) and (B.20) gives

$$\begin{aligned} &H_{AA}k^{AB}(x_B^i) + (1-H_{AA})y_A + H_{AB}x_B^i + (1-H_{AB})y_B \\ &+1 - \int_{-\infty}^{\infty}\phi(z)\Phi\left(D^A\left(z, k^{AB}(x_B^i), x_B^i\right)\right)dz \\ &= H_{BB}x_B^i + (1-H_{BB})y_B + H_{BA}k^{AB}(x_B^i) + (1-H_{BA})y_A \\ &+1 - \int_{-\infty}^{\infty}\phi(z)\Phi\left(D^B\left(z, x_B^i, k^{AB}\left(x_B^i\right)\right)\right)dz \end{aligned}$$

which can be rearranged into the following form:

$$k^{AB}(x_B^i) = \frac{H_{AB}-H_{BB}}{H_{AA}-H_{BA}}(y_B - x_B^i) + y_A + \frac{1}{H_{AA}-H_{BA}} \cdot \int_{-\infty}^{\infty}\phi(z)\left[\Phi\left(D^A(z, k^{AB}(x_B^i), x_B^i)\right) - \Phi\left(D^B\left(z, x_B^i, k^{AB}(x_B^i)\right)\right)\right]dz \tag{B.20}$$

One can similarly show that

$$k^{BA}(x_A^i) = \frac{H_{BA}-H_{AA}}{H_{BB}-H_{AB}}(y_A - x_A^i) + y_B + \frac{1}{H_{BB}-H_{AB}} \cdot \int_{-\infty}^{\infty}\phi(z)\left[\Phi\left(D^B(z, k^{BA}(x_A^i), x_A^i)\right) - \Phi\left(D^A\left(z, x_A^i, k^{BA}(x_A^i)\right)\right)\right]dz \tag{B.21}$$

■

Proof. (of Proposition 7) By using Banach fixed point theorem, I show that the cutoff function triplet $k = \{k^{A0}, k^{B0}, k^{AB}\}$ given by Proposition 6 indeed exists and is unique. For this in Lemma 10 I show that the set of cutoff function triplets $\mathcal{K}$ with some metric d is a complete metric space. In Lemma 11 I prove that the joint best response mapping $B : \mathcal{K} \to \mathcal{K}$ is a contraction map.

Lemma 10 *(Non-empty Complete Metric Space 2). The set of cutoff function triplet $\mathcal{K}$ with some metric d is a complete metric space.*

First let me define the metric d for any two sets of functions $F = \{f_1, f_2, \ldots f_N\}$ *and* $G = \{g_1, g_2, \ldots g_N\}$ *where both contain* N *number of functions, each with domain* $\mathbb{R}$*:*

$$d(F,G) \equiv max\left\{\sup_{y\in R}|f_1(y) - g_1(y)|, \sup_{y\in R}|f_2(y) - g_2(y)|, \ldots, \sup_{y\in R}|f_N(y) - g_N(y)|\right\}$$

From (B.17) we can establish that $k^{\mathbf{r0}} : \mathbb{R} \rightarrow [-1+n, n]$ *is bounded. While from (B.20) follows that* $k^{\mathbf{r(-r)}}(\mathbf{y}) - y : \mathbb{R} \rightarrow [-1, 1]$ *is bounded. Hence* $(\mathcal{K}, d)$ *is indeed a complete metric space.*

Lemma 11 *(Contraction Map 2). The joint best response mapping* $B : \mathcal{C} \rightarrow \mathcal{C}$ *is a contraction map.*

Given that everybody has cutoffs $k \equiv \{k^{A0}, k^{B0}, k^{AB}\}$*, the best response cutoffs of agent* i *is given by* $B(k) = \{b^{A0}(k), b^{B0}(k), b^{AB}(k)\}$*. Where from (B.17), (B.19) and (B.20) we have*

$$\begin{aligned} b^{A0}(v,k) &= \frac{1}{H_{AA}}\Big\{n - 1 - (1-H_{AA})y_A - H_{AB}v - (1-H_{AB})y_B \\ &+ \int_{-\infty}^{\infty}\phi(z)\Phi\left(D^A\left(z, k^{A0}(v), v\right)\right)dz\Big\} \end{aligned} \tag{B.22}$$

$$\begin{aligned} b^{B0}(v,k) &= \frac{1}{H_{BB}}\Big\{n - 1 - (1-H_{BB})y_B - H_{BA}v - (1-H_{BA})y_A \\ &+ \int_{-\infty}^{\infty}\phi(z)\Phi\left(D^B\left(z, k^{B0}(v), v\right)\right)dz\Big\} \end{aligned} \tag{B.23}$$

$$\begin{aligned} b^{AB}(v,k) &= \frac{H_{AB} - H_{BB}}{H_{AA} - H_{BA}}(y_B - v) + y_A + \frac{1}{H_{AA} - H_{BA}} \\ &\cdot \int_{-\infty}^{\infty}\phi(z)\left[\Phi\left(D^A(z, k^{AB}(v), v)\right) - \Phi\left(D^B\left(z, v, k^{AB}(v)\right)\right)\right]dz \end{aligned} \tag{B.24}$$

with $K^A(v) \equiv max\{k^{A0}(v), k^{AB}(v)\}$ *and* $K^B(v) \equiv max\{k^{B0}(v), k^{BA}(v)\}$*. In order to verify that the map is indeed a contraction map we have to show that* $d(k, k') > d(B(k), B(k'))$*. For this it is enough to show that* $d(k,k') > \sup_{v\in R}\left|b^{A0}(v,k) - b^{A0}(v,k')\right|$*,* $d(k,k') > \sup_{v\in R}\left|b^{B0}(v,k) - b^{B0}(v,k')\right|$ *and* $d(k,k') > \sup_{v\in R}\left|b^{AB}(v,k) - b^{AB}(v,k')\right|$

hold if the sufficient conditions are fulfilled.

First let me concentrate on b^{A0}

$$
\begin{aligned}
& \sup_{v\in R}\left|b^{A0}\left(v,k\right)-b^{A0}(v,k')\right| \\
= \;& \sup_{v\in R}\left|\frac{\int_{-\infty}^{\infty}\phi(z)\Phi(D^A(z,k^{A0}(v),v))dz}{H_{AA}}-\frac{\int_{-\infty}^{\infty}\phi(z)\Phi(D^A(z,k^{A0\prime}(v),v))dz}{H_{AA}}\right| \\
= \;& \frac{1}{H_{AA}}\cdot\sup_{v\in R}\left|\int_{-\infty}^{\infty}\phi(z)\left[\Phi(D^A(z,k^{A0}(v),v))-\Phi(D^A(z,k^{A0\prime}(v),v))\right]dz\right|
\end{aligned}
\tag{B.25}
$$

According to the mean value theorem there exists ξ *s.t.:*

$$\phi\left(\xi\right)=\frac{\Phi(D^A(z,k^{A0}(v),v))-\Phi(D^A(z,k^{A0\prime}(v),v))}{D^A(z,k^{A0}(v),v)-D^A(z,k^{A0\prime}(v),v)}$$

Since $\max_{\xi\in\mathbb{R}}\phi\left(\xi\right)=\phi\left(0\right)=\frac{1}{\sqrt{2\pi}}$ *we have*

$$
\begin{aligned}
& \Phi(D^A(z,k^{A0}(v),v))-\Phi(D^A(z,k^{A0\prime}(v),v)) \\
\leq \;& \phi(0)\left[D^A(z,k^{A0}(v),v)-D^A(z,k^{A0\prime}(v),v)\right] \\
= \;& \frac{\phi(0)\sqrt{1+H_{BB}}}{\sigma_A\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}}\cdot\Bigg\{H_{AA}\left[-k^{A0}(v)+k^{A0\prime}(v)\right] \\
& +K^A\Bigg(\sigma_B\sqrt{1+H_{BB}}z+H_{BA}k^{A0}(v)+(1-H_{BA})y_A+H_{BB}v+(1-H_{BB})y_B\Bigg) \\
& -K^{A\prime}\Bigg(\sigma_B\sqrt{1+H_{BB}}z+H_{BA}k^{A0\prime}(v)+(1-H_{BA})y_A+H_{BB}v+(1-H_{BB})y_B\Bigg)\Bigg\}
\end{aligned}
$$

Moreover for any v *the inequality* $-k^{A0}\left(v\right)+k^{A0\prime}\left(v\right)\leq\sup_{y\in\mathbb{R}}\left|k^{A0}\left(v\right)-k^{A0\prime}\left(v\right)\right|$ *has to hold. But from the definition of metric* d *follows that* $\sup_{v\in\mathbb{R}}\left|k^{A0}\left(v\right)-k^{A0\prime}\left(v\right)\right|\leq d\left(k,k'\right)$, *which implies* $-k^{A0}(v) + k^{A0\prime}(v) \le d(k,k')$. *Similarly holds*

$$\begin{aligned}
& K^A\Big(\sigma_B\sqrt{1+H_{BB}}z + H_{BA}k^{A0}(v) + (1-H_{BA})y_A + H_{BB}v + (1-H_{BB})y_B\Big) \\
& -K^{A\prime}\Big(\sigma_B\sqrt{1+H_{BB}}z + H_{BA}k^{A0\prime}(v) + (1-H_{BA})y_A + H_{BB}v + (1-H_{BB})y_B\Big) \\
\le\; & \sup_{v\in\mathbb{R}}\left|K^A(v) - K^{A\prime}(v)\right| \\
\le\; & \max\left(\sup_{v\in\mathbb{R}}\left|k^{A0}(v) - k^{A0\prime}(v)\right|, \sup_{v\in\mathbb{R}}\left|k^{AB}(v) - k^{AB\prime}(v)\right|\right) \\
\le\; & d(k,k')
\end{aligned}$$

for any v. *These imply that*

$$\Phi(D^A(z,k^{A0}(v),v)) - \Phi(D^A(z,k^{A0\prime}(v),v)) \le \frac{\phi(0)\sqrt{1+H_{BB}}(1+H_{AA})}{\sigma_A\sqrt{(1+H_{AA})(1+H_{BB}) - H_{AB}H_{BA}}}d(k,k')$$

Combining this with (B.25) gives:

$$\begin{aligned}
& \sup_{v\in\mathbb{R}}\left|b^{A0}(v,k) - b^{A0}(v,k')\right| \\
\le\; & \frac{1}{H_{AA}}\cdot\sup_{v\in\mathbb{R}}\left|\int_{-\infty}^{\infty}\phi(z)\left[\frac{\phi(0)\sqrt{1+H_{BB}}(1+H_{AA})}{\sigma_A\sqrt{(1+H_{AA})(1+H_{BB}) - H_{AB}H_{BA}}}d(k,k')\right]dz\right| \\
=\; & \frac{\sqrt{1+H_{BB}}(1+H_{AA})}{\sqrt{2\pi}\sigma_A H_{AA}\sqrt{(1+H_{AA})(1+H_{BB}) - H_{AB}H_{BA}}}d(k,k').
\end{aligned}$$

Thus $\sup_{z\in\mathbb{R}}\left|b^{A0}(z,k) - b^{A0}(z,k')\right| < d(k,k')$ *holds if the parameters are such that* $\frac{\sqrt{1+H_{BB}}(1+H_{AA})}{\sqrt{2\pi}\sigma_A H_{AA}\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}} < 1$ *(**condition 3A**).*

One can similarly show that $\sup_{z\in\mathbb{R}}\left|b^{B0}(z,k) - b^{B0}(z,k')\right| < d(k,k')$ *holds if the parameters are such that* $\frac{\sqrt{1+H_{AA}}(1+H_{BB})}{\sqrt{2\pi}\sigma_B H_{BB}\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}} < 1$ *(**condition 3B**).*

Now let me concentrate on b^{AB}. Equation (B.24) gives

$$\begin{aligned} & \sup_{v\in\mathbb{R}}\left|b^{AB}(v,k)-b^{AB}(v,k')\right| \\ = & \sup_{v\in R}\left|\begin{array}{c} \frac{\int_{-\infty}^{\infty}\phi(z)\left[\Phi(D^A(z,k^{AB}(v),v))-\Phi(D^A(z,k^{AB\prime}(v),v))\right]dz}{H_{AA}-H_{BA}} \\ -\frac{\int_{-\infty}^{\infty}\phi(z)\left[\Phi(D^B(z,v,k^{AB}(v)))-\Phi(D^B(z,v,k^{AB\prime}(v)))\right]dz}{H_{AA}-H_{BA}} \end{array}\right| \\ = & \frac{1}{H_{AA}-H_{BA}}\cdot\sup_{v\in R}\left|\int_{-\infty}^{\infty}\phi(z)\left[\begin{array}{c} \Phi(D^A(z,k^{AB}(v),v))-\Phi(D^A(z,k^{AB\prime}(v),v)) \\ +\Phi(D^B(z,v,k^{AB}(v)))-\Phi(D^B(z,v,k^{AB\prime}(v))) \end{array}\right]dz\right| \end{aligned}$$

Similarly as above, by using the mean value theorem, one can show that

$$\Phi(D^A(z,k^{AB}(v),v))-\Phi(D^A(z,k^{AB\prime}(v),v))\leq\frac{\phi(0)\sqrt{1+H_{BB}}(1+H_{AA})}{\sigma_A\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}}d(k,k')$$

and

$$\Phi(D^B(z,v,k^{AB}(v)))-\Phi(D^B(z,v,k^{AB\prime}(v)))\leq\frac{\phi(0)\sqrt{1+H_{AA}}(1+H_{BA})}{\sigma_B\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}}d(k,k')$$

These imply that

$$\begin{aligned} & \sup_{v\in\mathbb{R}}\left|b^{AB}(v,k)-b^{AB}(v,k')\right| \\ \leq & \frac{1}{H_{AA}-H_{BA}}\int_{-\infty}^{\infty}\phi(z)\left[\begin{array}{c} \frac{\phi(0)\sqrt{1+H_{BB}}(1+H_{AA})}{\sigma_A\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}}d(k,k') \\ +\frac{\phi(0)\sqrt{1+H_{AA}}(1+H_{BA})}{\sigma_B\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}}d(k,k') \end{array}\right]dz \\ = & \frac{1}{H_{AA}-H_{BA}}\left[\begin{array}{c} \frac{\phi(0)\sqrt{1+H_{BB}}(1+H_{AA})}{\sigma_A\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}}d(k,k') \\ +\frac{\phi(0)\sqrt{1+H_{AA}}(1+H_{BA})}{\sigma_B\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}}d(k,k') \end{array}\right]\int_{-\infty}^{\infty}\phi(z)dz \\ = & \frac{\sigma_A\sqrt{1+H_{AA}}(1+H_{BA})+\sigma_B\sqrt{1+H_{BB}}(1+H_{AA})}{\sqrt{2\pi}\sigma_A\sigma_B(H_{AA}-H_{BA})\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}}d(k,k') \end{aligned}$$

Thus if the parameters are such that $\frac{\sigma_A\sqrt{1+H_{AA}}(1+H_{BA})+\sigma_B\sqrt{1+H_{BB}}(1+H_{AA})}{\sqrt{2\pi}\sigma_A\sigma_B(H_{AA}-H_{BA})\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}} < 1$ *(**condition 4A**), then* $d(k,k') > \sup_{y\in\mathbb{R}}\left|b^{AB}(y,k)-b^{AB}(y,k')\right|$ *holds.*

One can similarly show that $\sup_{z\in\mathbb{R}}\left|b^{BA}(z,k)-b^{BA}(z,k')\right| < d(k,k')$ *holds if the parameters are such that* $\frac{\sigma_B\sqrt{1+H_{BB}}(1+H_{AB})+\sigma_A\sqrt{1+H_{AA}}(1+H_{BB})}{\sqrt{2\pi}\sigma_A\sigma_B(H_{BB}-H_{AB})\sqrt{(1+H_{AA})(1+H_{BB})-H_{AB}H_{BA}}} < 1$ *(**condition 4B**).*

Note that ***condition 3A*** *and* ***condition 3B*** *are always satisfied whenever* ***condition 4A*** *and* ***condition 4B****, respectively, hold. Hence if* $\frac{2\sigma_A+\sigma_B}{\sigma_A\sigma_B} < 2\sqrt{\pi}\sqrt{1-\rho^2}$*, for all* $r \in \{A, B\}$*, then*

$$\begin{aligned} & (B(k), B(k')) \\ = \; & \max\begin{pmatrix} \sup_{y\in\mathbb{R}} \left|b^{A0}(y,k) - b^{A0}(y,k')\right|, \sup_{y\in\mathbb{R}} \left|b^{B0}(y,k) - b^{B0}(y,k')\right|, \\ \sup_{y\in\mathbb{R}} \left|b^{AB}(y,k) - b^{AB}(y,k')\right|, \sup_{y\in\mathbb{R}} \left|b^{BA}(y,k) - b^{BA}(y,k')\right| \end{pmatrix} \\ < \; & d\left(k, k^{'}\right) \end{aligned}$$

is fulfilled. So in this case the mapping is indeed a contraction.

■