LUND UNIVERSITY
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The Influence of Credit Growth on Output Growth in Iceland

A VEC Model Approach

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Abstract

In this thesis we used a Vector Error Correction (VEC) model to analyse whether changes in credit growth have a significant effect on output in Iceland using monthly data for the period 1997-2017. Both our results from the error variance decompositions and the impulse response functions suggest that changes in credit and exports have the largest impact on Icelandic output. We conclude that changes in credit activity do affect Icelandic macroeconomic variables. There is a statistically significant relationship between output and credit growth and hence the 'credit view' is supported in the case of Iceland. This highlights the importance of implementing macroprudential rules that can minimize severe economic fluctuations caused by excessive credit growth.

Keywords: output growth, credit growth, Iceland, VAR model, VEC model, credit view, macroprudential policy.

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Table of Content

List of Tables

List of Figures

I Introduction

In this thesis we will utilize a Vector Error Correction (VECM) model approach to study whether changes in total loans, as a proxy for credit growth, have a significant effect on output in Iceland. The sample contains data from the period 1997-2017 and we will acknowledge that the breakdown of the banking sector in 2008 might have had an effect on real activity by hampering capital flows to several bank-dependent sectors of the Icelandic economy. These sectors mainly contain borrowers who cannot easily substitute intermediated forms of credit with other financial assets. For the purpose of our thesis we will employ the approach and structure presented by Anari et al. (2002), who used an unrestricted and restricted Vector Autoregressive (VAR) model to explore the impact of bank credit availability on macroeconomic activity in Finland. Anari et al. concluded that the largest fluctuations in GDP were explained by money supply shocks and bank credit, and consequently they deduce that the credit view is supported in the case of Finland. In support of this argument, Kelly, McQuinn and Stuart (2013) state that "it has long been shown that there is an empirical link between GDP and credit growth" (p. 6). We wish to further contribute to research concerning the credit view by applying a restricted VAR model (also known as a VEC model) approach to Icelandic macroeconomic data in order to analyse the relationship between credit growth and output growth. Furthermore, our results could prove useful to macroprudential policy makers in Iceland.

The 'credit view' can be summarized best under the debate 'money versus credit'. Defenders of the credit view argue that changes in the availability of credit and loan risk underestimation cause adjustments in the interest rates, which then affect macroeconomic activity. While monetarists believe that the origins of changes in real activity lie in shocks to the supply of money (Hein and Mercado-Mendez, 1992). The monetarist view can essentially be outlined as a propagation mechanism in the economy where money supply shocks cause changes in the interest rate, which induce shifts in investment and output. In our thesis we want to test whether the credit view is in fact backed by Icelandic macroeconomic data.

We believe macroeconomic activity is especially likely to be affected by changes in credit availability if there are large fractions of borrowers in the economy. In particular, medium-sized privately-owned companies have no opportunities to substitute bank loans from commercial banks with any other financial product. Hence, under the credit view commercial banks can influence the macroeconomic activity through their contemporaneous amount of

lending. There was an extreme increase in private sector debt before the 2008 crisis, but it decreased significantly after the restructuring of the financial sector and reached levels similar to other European countries (Central Bank of Iceland, p. 71, 2016). Consequently, we have chosen to focus on Iceland because its economy is highly bank dependent, and thus we believe that changes in credit growth will affect output growth to a significant extent. There is a large fraction of small- and medium-sized enterprises (SMEs) in Iceland. Thus, the majority of Icelandic firms depend on credit availability in order to finance their expenses and sustain their level of investment. This leads us to anticipate that the credit view is more profoundly supported in Iceland compared to for example the United States, and more in line with that of Finland. Also, studying Iceland is noteworthy due to the unusual pre-crisis expansion of the financial sector, and subsequently its post-crisis transformation.

Researchers have examined the impact that excessive credit growth can have on the economy and the financial crisis of 2008 has stressed the importance of implementing capital requirements for financial institutions (Capiello, 2010; Rondorf, 2012; Banu, 2013; Kaminsky and Reinhart, 1999). Restrictions on capital can counter extreme fluctuations in the financial cycle and thus minimize the effect that excessive credit growth can have on macroeconomic variables. Extreme fluctuations of credit from its long-term trend in both directions are unwanted. Thus, macroprudential policy should be correlated with the level of bank dependency of the respective country's economy and the methods that financial authorities use in order to deal with large threats to the economic system.

We created a dummy variable for the financial crisis from 2008 until 2011 because we identified a structural break at the beginning of October 2008. The dummy variable is in effect up until August 2011 because that is when Iceland stopped receiving financial aid from the IMF, and we presume this to be the end of the official recession period. We discovered two cointegration equations, which indicate that there are underlying long-run relationships between the variables. Hence, we will employ a Vector Error Correction (VEC) model instead of applying a regular VAR model. Additionally, we obtained the error variance decomposition to conclude how much of the error variance in output can be explained by shocks to the individual independent variables. The variance decompositions confirm that in the short run, exogenous shocks to loans and exports have the strongest effect on output. Thus, there is evidence for a strong short-run relationship between credit and output in Iceland. Subsequently we analysed impulse response functions that depict the degree to

which a shock to one of the variables in the VEC model can influence the development of the other variables over time. It turns out that a positive shock of one standard deviation to loans leads to a subsequent increase in output during the first four months after the shock, and subsequently output decreases steeply. From our results we conclude that credit growth does indeed have an effect on output growth in the case of Iceland.

We do however acknowledge that there are some statistical limitations to our model since monthly data was only available for loans, CPI, and money supply and not for exports and output. The assumption is then that we do not expect any major changes in exports and output during a quarter. Another limitation addresses the fact that there might be additional structural breaks in our model, none however as big as the one resulting from the financial crisis. Overall, we do find that our results yield realistic and statistically significant values given the limitations.

The thesis will be organized as follows: We will begin in section 2 by acknowledging previous work and research on this topic. In section 3, we will shed light on the overall economic system in Iceland, with a special focus on the economic crisis of 2008 and its impact on the economy. Section 3 will also introduce the current structure of the financial sector and the level of bank-dependency in Iceland. In section 4, we describe the fundamental theoretical framework. Section 5 provides information about the data used in this thesis. Consequently, in section 6 we state our empirical results from the estimations. Section 7 discusses both Icelandic capital regulations and macroprudential policy in Iceland in relation to credit availability. Section 8 concludes.

II Literature

Recessions in the past give rise to research of whether credit growth has an effect on the overall macroeconomic activity and whether output growth can recover faster with a certain level of credit growth. Different theories and methods have been developed which all contribute further to a deeper understanding of this relationship. Most countries' governments and monetary authorities work systematically towards maintaining stability within the economy so as to foster prosperity and a higher standard of living. It is therefore evident that as the pool of research becomes larger, there is higher potential to succeed in maintaining a good economic balance. Thus, we would like to acknowledge some of the more ground-breaking research and different methods within this topic.

The literature on the relationship between credit growth and output growth dates back as far as 1933 when Irving Fisher reported evidence that the harsh extent of the economic downturn during the Great Depression was a result of poorly performing financial markets (cited in Gertler, 1988). He argues that an increased level of debt of the private sector in combination with increasing deflation accelerated the reduction in economic activity. Due to the high rate of deflation, the economy's wealth was transferred from the debtors to the creditors. As a result, the household's net worth declined and this caused a severe cut in current expenditures, leading to a downward spiral in macroeconomic activity. Irving Fisher also explains that in a state of high debt, there is bound to be an increase in liquidation. This, in turn, alarms actors on the financial market to sell their assets, called 'distress selling', causing the price level to fall even further. He reasons that ultimately this induces "a still greater fall in the net worths of business" (p. 342). Hence, this great fall in the net worth of firms can result in bankruptcies and a subsequent reduction in output.

Additional research on the Great Depression includes the work of Barro (1978) who estimated a model with unexpected monetary shocks and output, including a proxy for financial distress in the economy to distinguish whether the variations in output could be better explained by a decline in bank liabilities (money) or a decline in bank assets (credit). Barro found that there clearly was a relationship, backed by empirical evidence, between the credit market and real economic activity.

Gurley and Shaw (1955) were the first ones who examined the relationship between credit supply and output growth in developed countries, and not the relationship between credit

supply and money supply which Friedman and Schwartz (1963) investigated later. Gurley and Shaw argued that financial intermediaries play a significant role in improving the efficiency of the allocation of loans between savers and investors and thus they came to the conclusion that intermediaries generally have a large impact on economic activity.

One of the more prominent macroeconomists of recent decades, Ben Bernanke (1983), examined whether a strong credit effect in connection with widespread bank and business failures worsened reductions in output during the Great Depression in the United States beyond the bounds of what Friedman and Schwartz (1963) explained by monetary factors. Friedman and Schwartz argued that monetary shocks have real effects and consequently that monetary contractions and errors in the Federal Reserve's reactions to the economic downturn were a major part of the origin of the Great Depression. However, Bernanke (1983) concluded that the monetary factors alone were insufficient in explaining the large reductions in output during the Great Depression. He stated that the crash of the financial system in this period was the leading factor in explaining the severe consequences in the economic activity. In support of this view, Anari and Kolari (1999) found evidence that long-lasting banking sector problems during the Great Depression caused large negative shocks to credit availability that eventually diminished macroeconomic growth.

Another approach to examining the relationship between credit and output is panel data analysis such as the one developed by Driscoll (2004), who tested the relationship between bank loans and output in the United States. Driscoll (2004) used state-level panel data and used shocks to money demand as an instrument to deal with the endogeneity problem and reverse causality between loans and GDP. He found a clear and significant correlation between money demand shocks and bank loan supply. Using the money demand shocks as an instrument to estimate loan shocks unrelated to GDP, he found that those loan shocks have negative and statistically insignificant effects of on output in the US. Hence, it is debatable whether the existing lending channel has a macroeconomic effect in the US.

Driscoll's method has been replicated and applied to various countries across the world, including ten of the founding member countries of the European Union by Rondorf (2012) and the Euro area by Cappiello et al. (2010). Rondorf analysed the impact of changes in bank loans and credit on output in Europe, while Cappiello et al. explored whether credit standards can affect output. The authors find that the European countries in their panel data sets are more dependent on financial intermediaries, and especially on banks, than the U.S. states.

Thus, changes in bank lending are thought to have a greater impact than in Driscoll's results, which is confirmed by Rondorf's and Cappiello's et al. regressions. In addition, the authors state that their samples are less homogenous than the sample that Driscoll used since economic developments have been quite different across Europe, and that the EU countries were affected differently by the financial crisis of 2008. Their conclusions are unanimous that due to the bank dependency of European economies, increases in bank loans due to money demand shocks do have a positive effect on output. This in turn implies that this significant relationship can lead to slower economic recovery during a recession since output growth depends to a degree on bank lending in the economy. In this context, the authors point out the importance of financial regulation to prevent financial crises. A special focus in monetary policy should be put on the monitoring of changes in credit availability.

There exists a whole array of research on the effect of monetary policy on household credit, for example the work by Gertler and Gilchrist (1993). They found evidence that a tightening in money supply leads to a decline in credit to households and small firms and a rise in credit to larger firms. In this case, financial intermediaries tend to shift to less risky borrowers after a decrease in money supply. They also conclude from their estimations that it does not make a difference whether this is bank credit or nonbank credit. Furthermore, they assert that short-term borrowing by large firms increases to a great extent. However, small firms usually do not change their borrowing itinerary even though they anticipate a proportionally higher plunge in sales. They attribute this behaviour to frictions and imperfections on the credit market.

In further studies on the financial markets, Garcia-Escribano and Han (2015) examine the relationship between credit growth, the composition of the credit portfolio, and economic growth. Using a cross-country panel approach, they find significant evidence of a propagation mechanism of credit on real activity. However, they stress that the degree of the impact on real economic activity depends on the type of credit. The authors conclude that consumer credit shocks are associated with private consumption, while corporate credit shocks cause changes in GDP mainly through investment. These findings are important because of possible policy implications.

The importance of analysing data through different approaches is crucial to acquire a deeper understanding of the underlying relationship between credit growth and output growth. It is evident from previous research that some methods are more common than others and VAR

models are the most popular. The VAR approach has its benefits and disadvantages. It uses time-series data to determine to what degree variables are mutually dependent on each other. In particular, the VAR approach allows a more detailed and comprehensive study of an individual country or region, while it does not allow a study of a group of countries or regions. Analysing several countries as a whole entity is beneficial when regions are highly integrated because a decrease in credit growth can have rippling effects on neighbouring regions. For the purpose of our paper, we choose to use the restricted VAR approach (VEC model) to analyse the relationship between credit and output in Iceland in light of the country's macroprudential policy aimed at controlling credit growth and thus minimizing swings in macroeconomic variables.

III The Icelandic Economy

Given the size of the Icelandic economy, the collapse of the Icelandic banking sector was the most extreme in any European country's economic history. The banking sector's collapse led to an intense economic downturn. As shown in Figure 1, the seasonally adjusted GDP decreased by 13% from 463,569.6 million in the fourth quarter of 2007 to 403,522.5 million Icelandic króna in the first quarter of 2010. It took the Icelandic economy three years until it started to recover from the global financial crisis, and the economy has been growing ever since. The forecasts estimated by the Central Bank of Iceland for the next two years suggest slightly decreasing but still positive GDP growth rates (n.d.). The fall in GDP during the period from 2007-2010, coincides with a drastic rise and subsequent fall in total bank loans (see Figure 1 & 2). Due to the volatility of the Icelandic króna, the depreciation of the currency then led to a sharp increase in exports in 2008 (see Figure 3). Moreover, it is exceptional how much total bank loans exceeded the supply of money during that time span. During the first months of 2008, the amount of bank loans was 482% higher than the supply of money and the banking system was equivalent to 900% of Iceland's GDP (Benediktsdottir et al., 2017). These extraordinary numbers do indicate abnormal and excessive activity in the financial markets that inevitably can have catastrophic consequences for the economy.

Figure 1: Icelandic gross domestic product (GDP): 1997Q1-2017Q1

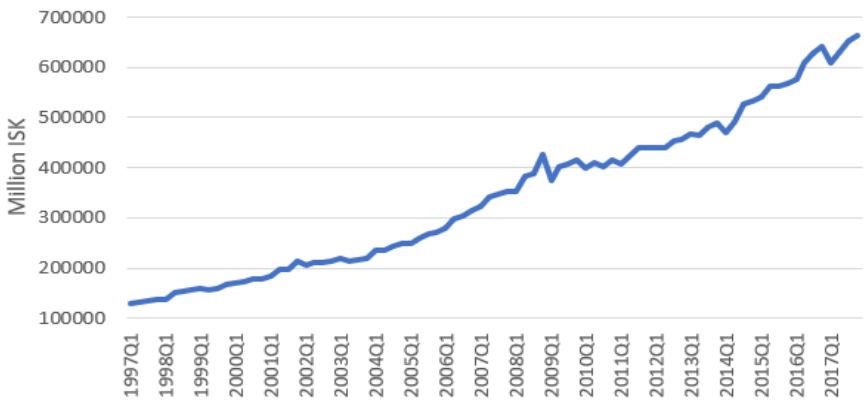


Figure 2: Money supply (M2) and total loans: 1997Q1-2017Q1

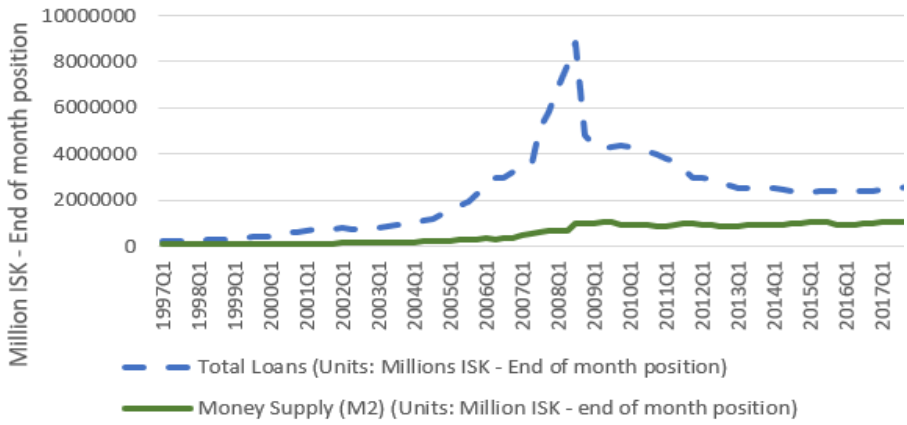
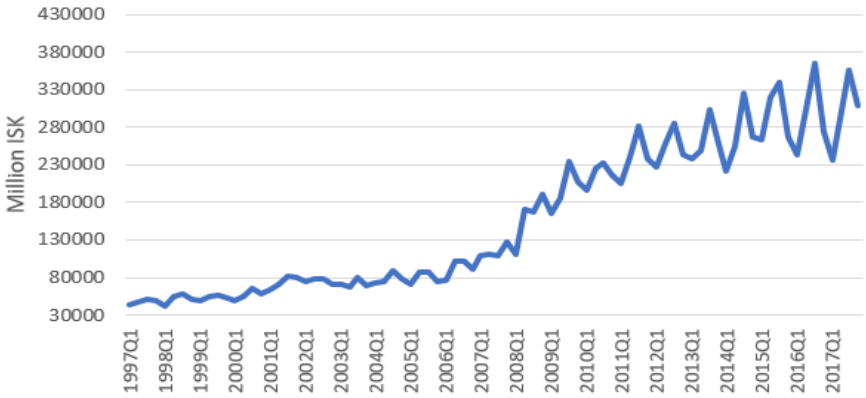


Figure 3: Total exports: 1997Q1-2017Q1

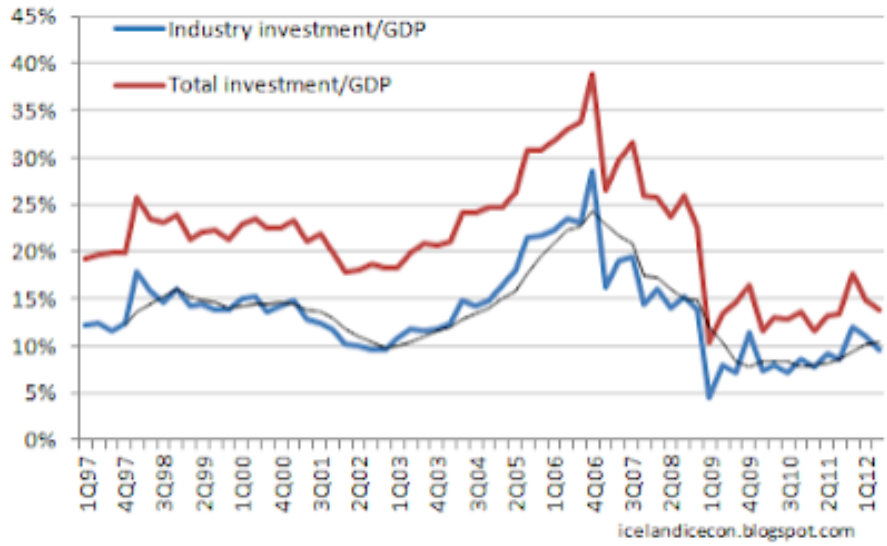


Source: Central Bank of Iceland and Statistics Iceland

In 2001, a new deregulation of the banks was passed in Iceland which granted them the legal right to use debts as a mean to take over foreign companies (Jackson, 2008). This deregulation then consequently set the framework for the financial crisis in the way that banks acquired extreme volumes of debt in order to finance the purchases of foreign companies. When the crisis hit the economy, Icelandic banks were not able to refinance all the debt they had burdened themselves with. At the end of 2007, the three largest Icelandic banks held a volume of debt of about 50 billion euros. The extent of the debt becomes even clearer when we compare this amount with the country's GDP at the time: 8.5 billion euros (Jackson, 2008). Because the Icelandic banking system had grown so extraordinarily fast during the years before the economic bubble burst, the Central Bank of Iceland and the Icelandic government could not guarantee the payment of the banks' debts anymore. This is when the economic crisis finally unfolded.

As we can see in Figure 4, in the years before the crisis, investment rose to an extraordinary high level, and as a result of the abrupt decrease in bank loans after 2008, the level of investment suffered greatly during the crisis. Especially SMEs, which the Icelandic economy mostly consists of, could not afford to invest to the extent as before. Availability of capital is important to maintain a certain level of investment. In this way, the level of loans can affect investment, which in turn affects the level of output in the economy.

Figure 4: Icelandic industry investment as a ratio to GDP and Icelandic total investment as a ratio to GDP



Source: Margeirsson, Ólafur (2012)

Additionally, there was a boost in the Icelandic consumption levels before the crisis. This can be traced back to the exceptionally heavy immersion of Icelandic consumers into foreign credit markets. Households took large volumes of credit, which accrued to a debt level of 237% of their disposable income in 2009 (Bender, 2011). To compare, personal debt to personal disposable income ratios in Germany, the UK and the US were 100%, 164% and 140%, respectively (The Economist, 2008). Private consumption was mostly financed by credit at this time. This strong dependence on the foreign credit markets raised inflation and greatly accelerated the impact of the financial crisis on the Icelandic economy. The foreign debt also imposed risk to the Icelandic króna and made households and businesses more vulnerable to abrupt changes in the economic environment.

Bank Restructuring After the Crisis

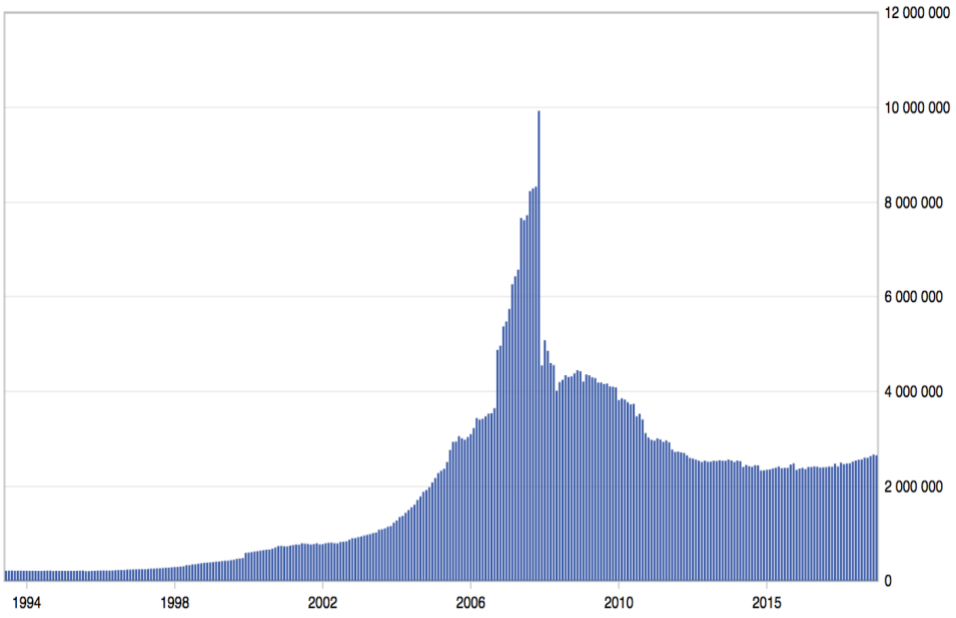
In examining the relationship between credit and output in Iceland, there is a need to address the major systematic failure and the restructuring of the banking sector after the financial crisis. The lending environment changed drastically as a consequence and this will most likely lead to a structural break in our estimation model, which we will address statistically later on in this paper. This however, sheds light on intriguing questions regarding the major changes caused by the financial bust; how did Iceland confront the crisis, and what were the implications for lending activity in the financial sector? In this section, we aim to address these issues and identify shifts in the investment environment.

The ownership of the Icelandic banks was in the hands of the state up until 2003 (Baldursson et. al., 2017). In the five years thereafter, two of the major commercial banks were privatized and grew so immensely that they could be considered as "international banking franchises" (Benediktsdottir et. al., 2017). The sheer size of the banks at the brink of the crisis in 2008 was so vast that the three largest banks owned assets that were worth 900% of Icelandic GDP. Due to the size of the banking sector the government could not bail them out of the crisis, and the only possible solution for Iceland was to let the banks go bankrupt. Consequently, Iceland received a rescue package from the International Monetary Fund (IMF) and from several other European countries. The grant was given on the condition that it had to be used for the restructuring of Iceland's banking system, repaying its creditors and stabilizing the Icelandic krona.

After the failure of the financial sector, the Financial Supervisory Authority assumed control and installed new management boards to set up three new banks: Landsbanki, Íslandsbanki (former Glitnir) and Arion Banki (former Kaupþing). The government is the owner of two of Iceland's biggest commercial banks, Landsbankinn and Íslandbanki; plus, it holds stakes in the third largest bank, Arion Bank. Most of the domestic assets were transferred to the new banks, while other assets and liabilities stayed in the old banks (Kristinsson, 2012). The government issued bonds to the newly established banks so that creditors that had lost their healthy assets in the economic downturn of the crisis were compensated with new equity stakes in two of the three post-crisis banks. In order to restore the efficiency of the Icelandic banking system, the commercial banks had to restructure their household and corporate loan portfolios to a great extent. Due to the major restructuring, the ratio of non-performing bank loans declined from their unparalleled height of 20% in 2010 to just 2% in 2015 (Central

Bank of Iceland, 2016). However, the whole restructuring process of the banking system took its toll on the economy and the country has yet to witness the output growth observed in the years preceding 2008.

Figure 5: Total loans, million ISK



Source: Central Bank of Iceland

When looking at the period around the crisis in Figure 5, we see that there is a continuation of lending even though the banks went bust. The Central Bank of Iceland (n.d.) describes its variable 'Loans' as the net amount after write-offs of defaulted losses. The government, together with the help of the IMF, took over some of the assets and liabilities of the banks and hence allowed for the continued lending even though we notice a sharp decline in loans in the economy after September 2008. The amount of defaulted loans coupled with the currency risk of foreign debt led the government to implement stringent capital controls and more regulated loan requirements.

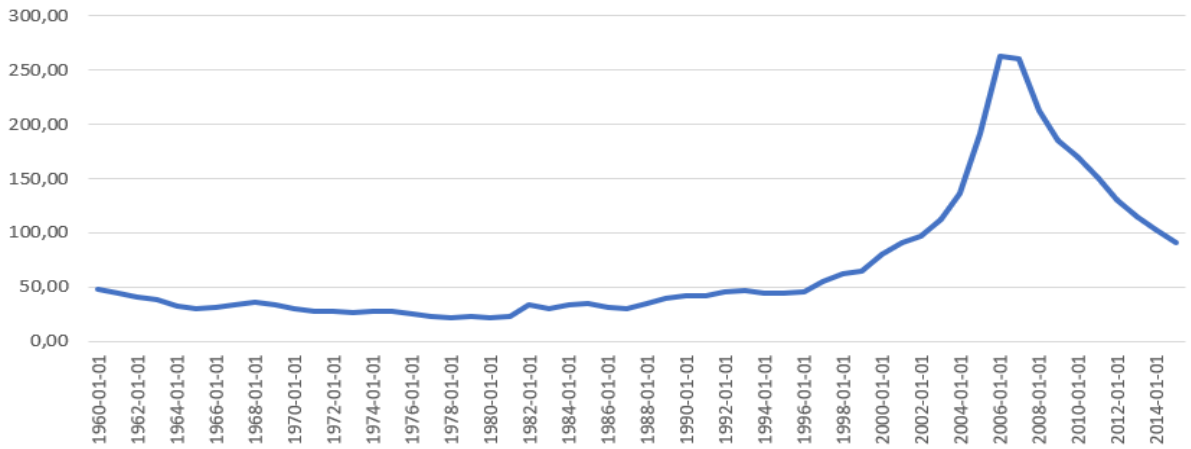
Current Structure of the Financial Sector and Level of Bank-dependency in Iceland

Directly after the financial crisis, there was only a small-scale variety of assets available on the Icelandic financial market. In recent years, the assets have become more diverse and thus the financial market is gradually growing and aligning to foreign financial markets. The government had strong concerns about the whole economic system and foreign investors lost trust in Icelandic enterprises. Consequently, credit accessibility steeply declined and is still nowhere near its pre-crisis level in Iceland. However, it is slowly rising and credit ratings by

Moody's and S&P have gradually improved over the last years (SBA Fact Sheet Iceland, European Commission, 2014). The European Commission states that there are two reasons for the persistence of the low level of credit availability in Iceland. Firstly, the willingness of foreign investors to get involved in the Icelandic economy is still significantly lower than it was before the crisis, even though Icelandic firms are slowly regaining the investor's trust. And secondly, the presence of harsh credit controls in Iceland dampens credit levels and investment. We believe that the two reasons are inextricably intertwined. The strict capital controls deter foreign investors since the requirement process is too complex and costly given the level of investment risk.

These harsh credit controls in combination with probable pre-crisis overinvestment led to exceptionally low investment levels in post-crisis years (see Figure 4). This supports the credit view: the lack of credit availability causes a decline in investment, which then results in a downslide of macroeconomic activity. Data on the Icelandic annual growth rate of GDP supports this statement, and it shows that the growth rate declined severely in the years directly after the financial crisis of 2008 (Costa, 2016). The Icelandic economy is more bank-dependent than the average European economy, due to a large market share of SMEs. Yet, due to the large number of approximately 4000 SMEs that had to default after the crisis, employment has shifted from SMEs to mostly larger companies in the post-crisis years. None of the large companies went bankrupt during the crisis. We suspect this shift in employment and production from SMEs to larger firms led to a decline in credit granted by banks during the crisis (see Figure 6). Larger firms were more often able to finance their expenses independently, without a need for credit from financial intermediaries.

Figure 6: Private credit by deposit money banks and other financial institutions to GDP for Iceland (%, annual, not seasonally adjusted)



Source: Federal Reserve Economic Data, Federal Reserve Bank of St. Louis

The main obstacles for SMEs in Iceland are capital controls, currency fluctuations and inflation (SBA Fact Sheet Iceland, European Commission, 2014). Especially the high capital requirements that constrain smaller firms from applying for credit, dampen production in smaller firms, leading to a lower overall output level. We will discuss this in more detail in Section 7.

In comparison to other European countries, the Icelandic economy experienced a harsher hit with respect to the low levels of credit that were granted during the financial crisis. We believe this can be linked to two attributes. Firstly, the large number of less risk averse entrepreneurs in Iceland, who would have liked to take credit but were restrained from doing so. They would have contributed to a higher level of investment and subsequently a higher level of output. Secondly, the excessive pre-crisis usage of credit which the Icelandic population had gotten accustomed to. However, the willingness of banks to provide entrepreneurs with necessary loans has increased since the crisis and the conditions set by the banks have significantly improved (SBA Fact Sheet Iceland, European Commission, 2014). Subsequently there is now a much different investment environment in Iceland that is intended to prevent the mistakes that contributed to the economic crisis.

IV Methodology

As mentioned before, concerning the underlying methodology of this paper, we use a VEC model to estimate the relationship between credit growth and output growth. Sims (1972) was the first to use a reduced form bivariate time series model for the estimation of the relationship between money and output, and his paper *Macroeconomics and Reality* (1980) lays the foundation for using VAR models for multivariate time-series in order to analyse the underlying relationship between different macroeconomic variables. Sims argues that VAR models offer valuable implications for forecasting and for devising macroeconomic policy. Other researcher, for example Anari et al. (2002) and Lahura (2011), followed his example and they concurred that Sims' suggestion of using lagged values of money was a valid econometric instrument in forecasting future variations in output.

When a VAR model includes non-stationary series that are recognized to be cointegrated it is important to run a restricted VAR model known as a VEC model. Research on credit and output using VEC models includes the work of Lahura (2011), who investigated the empirical relation between credit and output in Peru. He finds that there is a significant "long-run relationship between real credit growth, output and terms of trade" (Lahura, 2011). Furthermore, he stresses that credit growth inhibits useful information for a forecast of output levels in the long run and that there is a positive permanent response of output to positive permanent shocks to real credit. This further supports Sim's idea of using versions of vector autoregressive models for macroeconomic analysis.

V Data

The data used in this thesis was obtained from the Central Bank of Iceland and Statistics Iceland. The data consists of the following five variables listed in Table 1: gross domestic product (*gdp*) for the macroeconomic activity, the consumer price index (*cpi*) for the price level, money supply (*m2*), total loans (*loans*) for bank credit and exports (*exports*). We chose to incorporate these variables in our model, since the credit view essentially supports the idea that non-monetary factors, such as the availability and cost of credit, enlarge monetary variables like the money supply and the price level and thus have a significant effect on macroeconomic activity. We used *total loans* as a proxy for the availability of credit following the work of Anari and Kolari (2002).

Table 1: List of Variables

Notation	Variable	Source
gdp	ln of total output	Statistics Iceland
loans	ln of total loans (domestic and non-resident loans and claims)	Central Bank of Iceland
total exports	ln of total exports	Statistics Iceland
cpi	ln of consumer price index	Statistics Iceland
m2	ln of M2 (The money stock (M1) plus general savings)	Central Bank of Iceland

All variables were obtained in a monthly frequency from 1997-2017, except for the datasets on GDP and total exports, which were quarterly observations. Since VEC models increase in precision with the number of time periods covered by the datasets, we used the monthly data under the assumption that GDP and total exports do not change during the time-span of a quarter. In support of this assumption, Polasek (2013) states that the origin of fluctuations in GDP are business cycles and he investigated the length of those business cycles in Iceland, which he found to be an average of 12 quarters long. Furthermore, he states that exports do in fact fluctuate positively with the business cycle. Hence, we assume there are no major changes in GDP and exports within one quarter, and therefore we utilized the same values of the variables for all three months of a quarter. All monetary variables are measured in million Icelandic króna (ISK), except for the CPI (index). Gross Domestic Product, the Consumer Price Index and total exports were acquired from Statistics Iceland, while total loans and the money supply (M2) were obtained from the Central Bank of Iceland.

VI Empirical Results

For our estimations we used the software EVIEWS. In setting up the model, we decided to incorporate changes in the country's money supply (M2), shifts in the CPI, and as Iceland's economy strongly depends on its foreign trade we also included total exports as an explanatory variable in our VEC model. Furthermore, we chose to include a dummy for the economic crisis of 2008 to assess whether there was a structural break in our data during that period. The dummy variable takes the value of 1 in the months from October 2008 to August 2011; and the value of zero otherwise. In order to verify the necessity of the dummy variable, we ran a Chow-test (see Table 2) to evaluate whether there are any structural breaks in our data. The result was that there was a break at the beginning of the tenth month of 2008.

Table 2: Chow Breakpoint Test: 2008M10

Null Hypothesis: No breaks at specified breakpoints Equation Sample: 1997M01-2017M12			
F-statistic	70.69392	Prob. F (5,242)	0.0000
Log likelihood ratio	226.9040	Prob. Chi-Square (5)	0.0000
Wald Statistic	353.4696	Prob. Chi-Square (5)	0.0000

The dummy variable is in effect from October 2008 because it was then that the Icelandic government first requested a Stand-By Arrangement from the IMF and the dummy stays in effect up until August 2011, which is the month Iceland stopped receiving financial aid from the IMF. Hence, we presume this to be the end of the official recession period. Thereafter, we did a Likelihood Ratio (LR) test to conclude whether the inclusion of the dummy variable significantly improved the performance of the model. The LR test yielded a value of 11.41 versus the F-distribution critical value of 11.07, so we reject the hypothesis of no structural break. Thus, we should include our dummy variable in the model.

In order to determine whether our data was stationary we conducted two different unit root tests for concreteness; the Augmented Dickey and Fuller test, and the Phillips-Perron test. We found that the level variables were all non-stationary but became stationary after first differencing (see Table 3). Thus, all variables are integrated of order one, (I(1)).

Table 3:Augmented Dickey-Fuller (ADF) test results

Variable	Augmented Dickey and Fuller	Phillips-Perron
GDP	-0.876847	-1.098404
CPI	-0.886231	-0.636500
M2	-1.040291	-0.981413
Loans	-2.092648	-2.165926
Exports	-0.939994	-1.437545
ΔGDP	-6.738458*	-19.26634*
ΔCPI	-3.587581*	-12.17145*
ΔM2	-17.43020*	-17.73404*
ΔLoans	-7.129385*	-18.42386*
ΔExports	-3.330939**	-21.29788*

*Indicates significance at the following levels: *1%, **5%*

To impose the lag length for the VAR model (and VECM) we assessed the two most common model selection criteria: the Akaike's (AIC) and Schwarz's Bayesian (SBIC) information criteria (see Table 4). In general, the Akaike criterion is more efficient but less consistent, and Schwarz's Bayesian criterion is asymptotically consistent but less efficient (Vrieze, 2012). In general, the SBIC suggests the more parsimonious model. This is also true for our results from the estimations: while the AIC suggests a lag length of six for our VAR model, the SBIC proposes zero lags. In the literature considering VAR model estimation neither of the two alternative criteria is clearly preferred.

Table 4: Lag length criteria

Lag	LR	FPE	AIC	SC	HQ
0	NA	6.19e-16	-20.82869	-20.68494*	-20.77079
1	80.01228	5.42e-16	-20.96196	-20.45885	-20.75931
2	44.76476	5.49e-16	-20.94999	-20.08750	-20.60259
3	82.76026	4.68e-16	-21.11042	-19.88857	-20.61827
4	30.62418	5.01e-16	-21.04323	-19.46201	-20.40633
5	47.60361	4.95e-16	-21.05786	-19.11727	-20.27621
6	231.9554*	2.03e-16*	-21.95141*	-19.65145	-21.02501*
7	29.37362	2.17e-16	-21.88824	-19.22891	-20.81709

**indicates lag order selected by the respective criterion*
LR: sequential modified LR test statistic (each test at 5% level)
FPE: Final prediction error
AIC: Akaike information criterion
SC. Schwarz Bayesian information criterion
HQ: Hannan-Quinn information criterion

However, the Chi-squared test for lag exclusion proposed by Sims (1981) is often used in VAR model estimations. The results obtained from the Sims procedure also support a lag length of six (see Table 5). Thus, we decided to use a lag length of six since it was confirmed by both the AIC and the Chi-squared test. We did not choose a lag length of zero as proposed by the SBIC since it is economically quite unrealistic that there is absolutely no lagging effect.

Table 5: Chi-squared lag exclusion test statistics (Sims)

	Joint significance of the lags
Lag 1	984.1710 (0.0000)
Lag 2	37.62596 (0.0503)
Lag 3	71.69516 (0.0000)
Lag 4	67.12532 (0.0000)
Lag 5	28.95804 (0.2657)
Lag 6	196.7225 (0.0000)
df	25

P-values in parentheses

In our model, we suspect an underlying endogeneity problem concerning the relationship between credit growth and output growth. To circumvent endogeneity, we use the lags of total loans as an instrument for the growth of credit. This procedure was also used by Beine, Docquier and Oden-Defoort (2011) in order to ensure exogeneity in their model. Testing for Granger-causality between the lags of total loans and output revealed that there is a significant granger-causal relationship of *loans* to *gdp* (see Table 6). However, the reverse is not true: *gdp* does not influence *loans*. Thus, there is no reverse causality in our data.

Table 6: Granger Causality Results Based on VECM

	Independent Variables				
Dependent Variable	χ^2 -statistics of lagged terms [p-value]				
	ΔGDP	ΔExports	ΔCPI	ΔLoans	ΔM2
ΔGDP	--	18.90*** [0.004]	5.84 [0.441]	29.89*** [0.000]	18.19*** [0.006]
ΔExports	10.31 [0.11]	--	20.44*** [0.002]	34.13*** [0.000]	26.46*** [0.000]
ΔCPI	8.48 [0.205]	8.16 [0.227]	--	7.56 [0.272]	10.18 [0.117]
ΔLoans	1.49 [0.960]	9.03 [0.172]	22.91*** [0.001]	--	16.02** [0.014]
ΔM2	9.06 [0.169]	27.14*** [0.000]	13.61** [0.034]	4.47 [0.613]	--

***Note**: *** and ** denote significance levels of 1% and 5%, respectively. P-values are reported in the squared brackets*

Since our time series data is integrated of order one, I(1), this led us to the natural question of whether the variables in our model are cointegrated and therefore converge to a long-run equilibrium. Variables are cointegrated with each other when they are integrated of the same order, but there exists a linear combination of the variables such that the residuals are stationary. If there is a cointegrating relationship between the variables, then a VAR model in first differences is likely to be misspecified (Engle and Granger, 1987). In this case, Engle and Granger suggest using a restricted VAR model (VEC model). A VEC model replicates the error correction process and thus it shows how fast the system of time series equations returns to its equilibrium.

All our variables are integrated to the same order I(1). Thus, we can run Johansen's Cointegration Test on the non-stationary data in levels to analyse whether there is a long-run relationship between our variables. The trace test rejects the null hypothesis (H_0: there is no

cointegration) and indicates that there are two cointegrating equations at the 0.05 significance level (see Table 7). This means there is a long-run relationship between the variables and the residuals of the series become stationary after the VAR model is restricted by the cointegration vectors. The maximum eigenvalue test also confirms that there are two cointegration equations.

Table 7: Johansen's Trace Test

Hypothesized No. of CE(s)	Eigenvalue	Trace Statistic	0.05 Critical Value	Prob. **
None*	0.156523	115.1294	88.80380	0.0002
At most 1*	0.148711	73.42488	63.87610	0.0064
At most 2	0.077899	33.97903	42.91525	0.2894
At most 3	0.042894	14.10949	25.87211	0.6486
At most 4	0.013654	3.368289	12.51798	0.8302

Trace test indicates 2 cointegrating equation at the 0.05 level
*denotes rejection of the hypothesis at the 0.05 level
**MacKinnon-Haug Michelis (1999) p-values

After determining that there are two long-run relationships between our variables we can restrict our VAR model and instead run a VEC model to analyse the short-run and long-run dynamics. For the purpose of our thesis, we will mostly focus on the coefficients concerning *gdp* and *loans*. In the first cointegration equation, that represents the long-run relationship between *gdp* as the dependent variable and all our other explanatory variables, the cointegrating coefficient for *loans*, that is normalized to *gdp*, is -0.108006 (standard error = 0.01751). In the long run, the sign of the coefficient is reversed, thus there is a positive relation in the long run and this means that an increase in *loans* is associated with a rising value of *gdp*, which is consistent with economic theory. The adjustment coefficient of the cointegrating equation linking *gdp* and *loans* tells us the speed of adjustment towards the economy's long-run equilibrium. In our results, this coefficient is -0.183508. This means after a deviation the model gradually converges back to its long-run equilibrium with a speed of adjustment of 18.35% per period.

Table 8: Cointegration Equation

1 Cointegrating Equation(s):	Log likelihood	2864.979		
Normalized cointegrating coefficients (standard error in parentheses)				
LN_GDP	LN_EXPORTS	LN_CPI	LN_LOANS	LN_M2
1.000000	-0.514602	1.599088	-0.108006	-0.153087
	(0.10695)	(0.27205)	(0.01751)	(0.04226)
Adjustment coefficients (standard error in parentheses)				
D(LN_GDP)	D(LN_EXPORTS)	D(LN_CPI)	D(LN_LOANS)	D(LN_M2)
-0.088541	0.260214	-0.034212	-0.183508	0.004488
(0.03748)	(0.12711)	(0.00944)	(0.11831)	(0.10583)

We used level data variables for our model because the EVIEWS software automatically converts the variables into their first differences when running the VEC model. In addition to the estimations derived above, we obtained the error variance decomposition of *gdp* in the VEC model. The purpose is to conclude how much of the error variance in *gdp* can be explained by shocks to the individual explanatory variables. The results in Table 9 are given in percentages. We have conducted the Cholesky error variance decomposition twice, since it depends highly on the ordering of the variables in the VEC model; originally, we put *gdp* in the first place with all other variables ordered descending according to the level of exogeneity: *cpi, loans, m2* and *exports*. In our model, *cpi* is the most exogenous variable since we assume prices are sticky and thus prices cannot be influenced and cannot influence contemporaneous values of the other variables. The variable *loans* has been lagged one period, ensuring its exogeneity in the model. However, concerning the exogeneity of money supply (*m2*), there has been a constant debate for decades within economics on the question of whether the supply of money is in fact exogenous or endogenous to business cycles and consequently to GDP. Kydland and Prescott (1990) state that "if anything, the monetary base lags the cycle slightly" (p. 14). We support this statement but are aware of the ongoing debate about the endogeneity of money and thus *m2* is the second least exogenous variable in our model. *Exports* are the least exogenous due to the fact that they are a direct component of real GDP.

Then we estimated the decomposition again with *gdp* ordered last, whilst all other variables are still in the same order as before. Consequently, we took the average of these two variance decompositions to eliminate the dependence of the variables on the Cholesky ordering, following the work of Anari et al. (2002).

Table 9: Variance Decomposition averages with variables ordered according to level of exogeneity: cpi, loans, m2, exports

Forecast Horizon: months	GDP	Exports	CPI	Loans	M2	Standard Error
6	72,44346	11,60064	5,08871	6,294767	4,572425	0,032131
12	70,485115	10,72962	5,89311	4,257952	8,6342	0,041826
18	72,4327	9,86059	4,715055	3,805314	9,186344	0,048822
24	71,661335	10,89795	3,95086	3,286409	10,20345	0,055274
30	71,737075	11,20563	3,612803	3,041141	10,40335	0,060981
36	70,564345	12,35476	3,68246	2,745189	10,65324	0,066722

According to the results of our model, an exogenous shock to *loans* in the short-run (6 month forecast horizon) accounts for 6.29% of change in *gdp*. However, this influence slowly decreases over the following forecast horizons. The impact of *exports* on *gdp* initially (6 month forecast horizon) explains 11.60% of the shift in *gdp*, and then increases to around 12.35% during the next 3-year forecast horizons. The impact of money supply accounts for around 4.57% in the short-run and significantly increases over time and accounts for 10.65% after the 36-month forecast horizon. This leads us to the conclusion that shocks to the supply of money are propagated through various channels before they have an effect on *gdp*. Additionally, the influence of *cpi* on *gdp* explains 5.09% of changes in *gdp* after six months. This impact slowly decreases over time and after three years it only accounts for 3.68% of the change in *gdp*. In summary, the variance decompositions confirm that in the short run, exogenous shocks to *loans* and *exports* have the strongest effect on *gdp*. Thus, we can conclude that there is evidence for a strong short-run relationship between credit and output in Iceland. The data supports our hypothesis that changes in loans affect changes in output and hence the credit view is backed by empirical evidence in the Icelandic data.

Gertler and Gilchrist describe the credit view as being "essentially a story about impulses to the economy" (1993, p.47), and so we have computed the impulse response functions (IRFs) that originate from our VEC model in first differences in order to identify the effects of impulses to the Icelandic economy. In the interpretation of our IRFs, first and foremost it is important to assess whether the econometric model is correctly identified and there is no misspecification present. As Anari et al. (2002) state, a macroeconomic model is identified when "the response of output to a shock in prices is positive (negative) and the response of price to output is negative (positive)" (p. 274). We can conclude that our model is identified,

since our results show that an increase in *cpi* leads to a decline in *gdp* (see Figure 7), while an increase in *gdp* causes a rise in *cpi* (see Figure 8). The demand side of the economy is represented by the negative response, whilst the supply side is replicated by the positive relationship.

Figure 7: Response of gdp to a positive shock to cpi

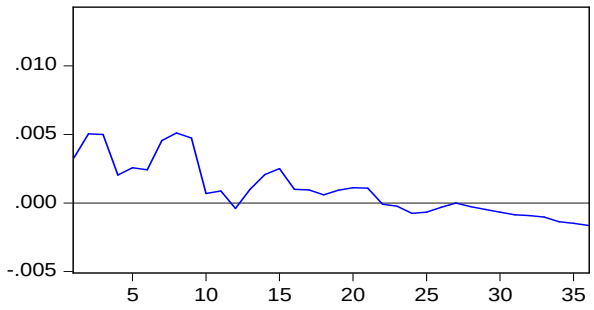
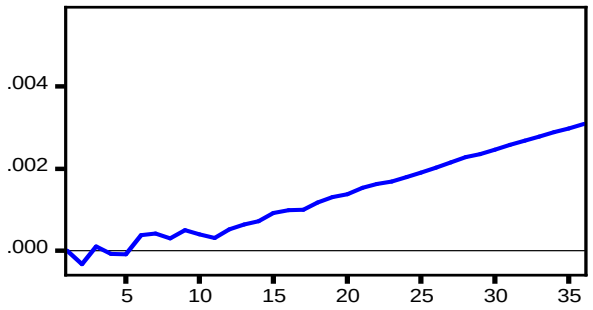


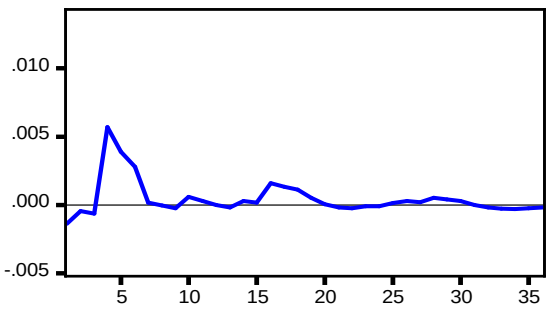
Figure 8: Response of cpi to a positive shock to gdp



In general, IRFs depict the degree to which a shock to one of the variables in the VEC model can influence the development of the other variables over time. Interpreting the form of the IRFs and the estimations of the variance decompositions according to the ordering procedure of Cholesky, lets us determine whether the dynamic responses of the variables are in line with the macroeconomic theory. Generally, using an unrestricted VAR model displays IRFs that converge towards zero over time. Conversely, using the restricted VAR model approach, our IRFs will not converge to zero. This is due to the fact that the VEC model has an implied long-run matrix that contains unit roots, given by the number of cointegrating relationships, which lets the IRFs converge to a non-zero constant. This is supported by our results.

As we can see in Figure 9 of the IRF, a positive shock of one standard deviation to *loans* leads to a subsequent increase in *gdp* starting around four months after the shock. After the first four months, *gdp* decreases steeply. After about seven months the shock's impact starts fluctuating around zero.

Figure 9: Response of gdp to loans



The impact on *gdp* due to a shock to *loans* is only exceeded by the influence of a shock to *exports* on *gdp* (see Figure 10). A shock to *exports* generates an increase in *gdp*. A shock to *cpi* also has a contemporaneous effect on *gdp*, even though this impact is only half as strong as the *exports'* influence on *gdp*. A positive shock to money supply (*m2*), however, provokes a small increase in *gdp* after two months which is followed by a strong and permanent decrease (see Figure 11).

Figure 9: Response of gdp to exports

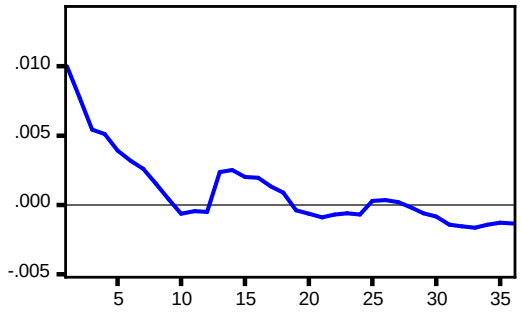
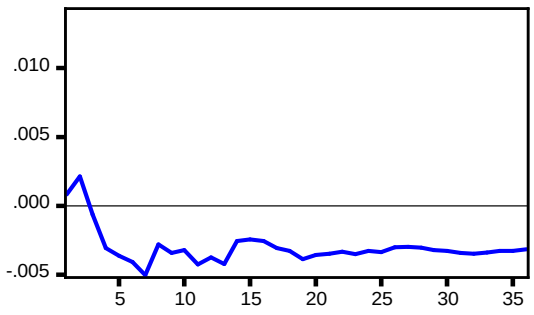


Figure 10: Response of gdp to m2



The short-run positive relationship between *m2* and *gdp* is supported by standard macroeconomic theory, which states that the increase in money supply lowers interest rates, and thus generates an increase in consumption, and lending and borrowing. Consequently, this leads to a rise in *gdp*. However, it is more controversial to interpret the long-run relationship between money supply and economic growth. In the long run, asset prices such as housing or stock prices could rise after a steep increase in an economy's liquidity. The resulting maldistribution of the economy's capital would then cause an increase in speculations on the asset markets and risky investments, which would in turn lead to economic bubbles and recessions. However, in the case of no maldistribution of the capital, the only effect of an increase in the money supply would be a rise in the overall price level. This leads us to conclude that there was a misallocation of capital in Iceland due to the financial crisis, which then resulted in a negative relationship between money supply (*m2*) and *gdp* in our impulse response functions.

VII Discussion

Following the economic crisis in 2008, capital controls were provisionally imposed to prevent excessive depreciation of the Icelandic krona and capital flight (Iceland Chamber of Commerce, 2016). In recent years, the Central Bank has lifted these capital controls in small steps and is slowly establishing a firmer foundation for foreign investment and investment abroad. Before 2009, the banks had been issuing loans in foreign currency and the post-crisis implemented capital controls were instrumental in saving the households that still had not defaulted on their loans, thereby preventing an even worse downward spiral of the economy.

According to the website of the Icelandic Central Bank (n.d.), they, alongside the Financial Supervisory Authority and the Systemic Risk Committee, work on overseeing the financial system and provide analysis and recommendations for the Financial Stability Council which determines actions on how to counter apparent economic risks. In light of the severe repercussions of the crisis, the Financial Stability Council's role is to implement macroprudential policy to ensure stable financial infrastructure. Its tools include imposing capital buffers on financial institutions to reduce excessive credit growth, and monitoring and regulating lending activity in the financial sector (Government Office of Iceland, n.d.). This highlights Icelandic institutional support of the credit view that non-monetary factors worsen declines in output during severe economic contractions and the importance of being able to influence these factors in order to stabilize the economy. The results of our research are in line with the work of Anari et al. (2002), and the statement of Kelly, McQuinn and Stuart (2013) that the discovered connection between excessive credit growth and financial crises is now acknowledged and it is generally agreed upon that credit booms can be viewed as an "early warning indicator" (p. 8). This indicator can therefore be useful when outlining macroprudential policy.

When we conducted the Johansen cointegration test for our model, we found that there is a positive relation between *loans* and *gdp,* which is consistent with the economic theory of the credit view. The components of GDP are: investment, private consumption, government expenditures, and net exports. Loans are crucial for investment and consumption (both private and public) since financial institutions can act as financial intermediaries between parties seeking capital. People tend to smooth consumption over time in order to maximize their lifetime utility, and hence they can invest or consume subject to their needs. Credit growth is the change in the supply for loans between periods and is therefore an important

indicator of the economy's condition, as well as, consumption and investment behaviour. Thus, the impact of an increase in the supply of loans is propagated through consumption and investment in the economy and ultimately has a significant effect on GDP. As mentioned previously, Heins and Mercado-Mendez' (1992) work supports this argument as they conducted an analysis of the credit view in more detail. Additionally, the credit view is further supported by the work of the relationship between credit and output by Peek, Rosengren and Tootell (2003) and Bottero, Lenzu and Mezzanotti (2017) amongst others.

Keeping in mind the credit view, Iceland is one among a few countries that has implemented the Countercyclical capital buffer (CCyB), which was introduced by the Basel Committee on Banking Supervision in 2010 in *Basel III: A global regulatory framework for more resilient banks and banking system*s. This buffer's purpose is to dampen excessive credit growth during expansionary phases of the financial cycle and work as an additional reserve of capital for future downturns for financial institutions (BIS, 13 February 2018). The implementation of the buffer was first recommended by the Financial Stability Council on 22 January 2016 which stated that "releasing the buffer gives credit institutions the scope to lend money during a financial cycle downturn, thereby mitigating its impact on the real economy". The Basel III countercyclical capital buffer is supposed to work against the procyclical behaviour of credit availability and output to counteract severe recessions in economic crises. Guidelines proposed in Basel III are used when deciding on implementing the buffer, among which the "indicator is based on the deviation of the credit-to-GDP ratio from trend" (Financial Stability Council, 22 January 2018). The Financial Supervisory Authority determines if and how to implement this buffer according to recommendations from the Financial Stability Council. The CCyB rate of 1 percent was activated as of 1 March 2017 (Financial Supervisory Authority, 1 March 2016). Future levels of the capital buffer will depend on the progression of output growth and credit growth and could possibly serve as a successful prevention tool for a severe banking crisis in the future.

Angelini et al. (2011) support this statement with their research on whether the implementation of a countercyclical capital buffer in an economy can reduce the standard deviation of output. Their macroeconometric models yield evidence in favour of a direct significant relationship between the implementation of the CCyB and the standard deviation of output. Nonetheless, they emphasize that their results are sensitive to a number of factors in their models, including amongst others the type of shocks to the economy and the setting

of the parameters in the macroeconomic policy of their models. However, we believe there might also be a major cost to the implementation of capital buffers. Requiring banks to hold more capital for every loan that is granted or the introduction of a certain minimum of leverage will restrain the banks' abilities to grant loans and thus hamper economic growth.

However, contrary to our results and the work of Anari et al. (2002), there have also been a few studies which showed results of no significant relationship between the amount of credit and the output in an economy. Türkay (2013) finds that while credit is affected by shocks to output in Turkey, the reverse is generally not true. Greenstone, Mas and Nguyen (2015) investigated the relationship between small business lending and economic activity. They conclude that although declines in lending are statistically significant, they only have a small economic impact and thus cannot account for deviations of overall macroeconomic growth from its trend. In addition, Ibrahim (2004) states that there is no significant impact of bank loans on macroeconomic activity in Malaysia.

In relation to the work of Bernanke (1983) and subsequently Anari and Kolari (1999), the credit view supports the idea that "non-monetary factors worsen declines in output during severe economic contractions which has been a prominent rationale for stringent bank regulation" (p.1). This brings us to the question whether this was also the reason for the implementation of the CCyB in Iceland? Based on our results we find that there is a strong correlation between credit and output, and that the credit view is supported in the case of Iceland. Whether the implementation of the CCyB was beneficial has yet to be proven and only the future will tell whether it will be successful in reducing the effect of an economic downturn or not. In light of the heterogeneous results in the research on the credit view, we believe further research needs to be devoted to this topic. Especially, the impact of changes in different kind of loans should be investigated further.

VIII Conclusion

In this thesis, we investigated the relationship between credit growth and output growth. In order to avoid endogeneity between *gdp* and credit growth in our vector autoregressive model, we used lags of *total loans* as an instrumental variable for credit growth following the work of Anari et al. (2002). The first finding is that the lags of *total loans* cause significant changes in *gdp*. Secondly, there is cointegration between our variables and thus the model converges to a long-run equilibrium. Estimating the variance decompositions of the model allowed us to interpret how much of the deviations of output from its trend can be attributed to changes in the individual explanatory variables. In summary, the variance decompositions confirm that in the short run, exogenous shocks to *loans* and *exports* have the strongest effect on *gdp*. However, in the long run, money supply (*m2*) and *exports* seem to be the most prominent influences on *gdp*. The impulse response functions are in line with our results from the variance decomposition. Exogenous shocks to *exports* and *loans* have the largest influence on the development of *gdp* over time.

In light of the results deduced from our model, we see that the credit view is supported in Iceland and that there is a statistically significant relationship between output growth and credit growth. These results further motivate active macroprudential policy and justify future interventions of the Icelandic government in times of economic downturns. The Central Bank of Iceland should carefully observe the development of credit growth and bank lending and intervene via recapitalization and bank deleveraging in case of severe recessions. In addition, we believe the implementation of the countercyclical capital buffer will be beneficial to the Icelandic economy since previous research suggests that the buffer lowers the standard deviation of output and thus lessens the extent of economic recessions. However, only time will tell whether this is the case in Iceland.

Our results are in line with former research by Rondorff (2012) who states that "economic recovery after a recession can be harmed because firms may not be able to finance profitable projects" (p. 116). This was also the case in Iceland during the financial crisis when loans to the non-financial sector declined dramatically. Our estimations suggest that this decline in loans hampered economic growth and thus exacerbated the economy's recovery from the crisis. Further research should be devoted to exploring the impact of changes in different kinds of loans on output; mortgage loans might affect output in another way than small

business loans. Moreover, it should be studied whether the implementation of the countercyclical capital buffer was beneficial to the Icelandic economy.

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X Appendix

Theoretical Framework

The underlying empirical framework used in this paper is based on the vector autoregressive model introduced by Sims (1980) to analyse the underlying relationships of multiple variables, the variance decomposition, and impulse response functions. This method has consistently been applied in macroeconomic research to explain long-run and short-run dynamics of variables, among which is the work of Anari et al. (2002) cited previously.

The vector autoregressive model is a multi-equation autoregressive distributed lag model (ADL model). The p-th order VAR - or VAR(p) - is given by

$$y_t = \mu + \Theta_p y_{t-1} + \cdots + \Theta_p y_{t-p} + \varepsilon_t$$

Where y_t is a vector of m time series (t=1,…,T), μ is an m-vector of intercepts, Θ_p are $m \times m$ matrices (k =1,…,p) and ε_t is a white noise m-vector, such that

$$E(\varepsilon_t) = 0, \text{ for all t}$$
$$E(\varepsilon_s \varepsilon_t') = \begin{cases} \Sigma, if\ s = t \\ 0, if\ s \neq t \end{cases}$$

Where the prime expresses transpose. Generally, this is an Autoregressive Distributed Lag model, ADL, with p lags for every explanatory variable. A vector autoregressive model of this kind can be estimated efficiently by employing the Ordinary Least Squares (OLS) method to every equation separately.

However, a first obstacle in the estimation of our time series is the selection of the number of lags of our explanatory variables. In order to determine to number of lags that should be included in the model, a multivariate version of the Akaike criterion (AIC) can be used.

$$AIC(p) = \ln(\det(\hat{\Sigma})) + \frac{k(k \cdot p + 1) \cdot 2}{T}$$

Where $\hat{\Sigma}$ is the determinant of $\hat{\Sigma} = \sum_{t=1}^{T} \hat{\varepsilon_t}\, \hat{\varepsilon_t}'/T$, k is the number of variables in the vector autoregressive model and $\hat{\varepsilon_t}$ is the Ordinary Least Squares residual.

The Schwarz Bayesian criterion (BIC) is obtained in a similar fashion; the "2" just needs to be replaced by "ln(T)" in the formula given for the AIC.

Typically, the second difficulty in estimating the model is the possible existence of cointegration relationships within the series. If the time series in a model exhibit unit roots but there is a linear combination such that their residuals are stationary, then those series are cointegrated. Then, the VAR model can equivalently be stated in the following vector error correction model form (VECM):

$$\Delta y_t = \mu + \Pi y_{t-1} + \Gamma_1 \Delta y_{t-1} + \cdots + \Gamma_{p-1} \Delta y_{t-p+1} + \varepsilon_t$$

Where $\Pi = -I + \Theta_1 + \cdots + \Theta_p$ and $\Gamma_k = -\Theta_{k+1} - \cdots - \Theta_p$, and k=1,…,p-1 are p×p parameter matrices.

VEC models are routinely used whenever multivariate time series are cointegrated. A VAR model in first differences would be misspecified in this context, since important information (i.e., Πy_{t-1}) would be left out of the estimation. A VEC model results in consistent estimations in our case since all our variables are integrated of the same order, I(1).

Let the rank of Π be equal to r, where $0 \leq r \leq p$. There are three possible cases:

1. $r = 0$, then the series are not cointegrated and Πy_{t-1} is removed from the regression
2. $r = p$, the series are stationary and the traditional VAR can be applied
3. $0 < r < p$, there are r cointegrating relationships

In the third case, we can use Granger's representation theorem and write $\Pi = \alpha\beta'$, where α and β are $p \times r$ matrices. The long-run relationships can then be presented as $\beta' y_t$ and the short-run average speed of adjustment to the long-run relationship is depicted by the matrix α.

Impulse Response Functions