Monetary Transmission Mechanism in Switzerland: An SVAR Approach*

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May 20, 2020

Abstract

This paper follows Gerlach and Smets (1995), Galí (1992), Kugler and Rich (2002), and Blanchard and Quah (1989) to estimate a structural vector autoregression (SVAR) model using both short-run and long-run restrictions. I analyze effects of monetary policy in Switzerland from 1985 to 2019 and focus on the dynamic interactions between real output, price level, and monetary policy. I find that Swiss monetary policy shocks generally lead to immediate responses from price level, but they have no long-run effects on real output or price level. Imposing both short-run and long-run restrictions seems to have solved the "price puzzle" found in many other VAR literature with only short-run restrictions. Lastly, price level and sight deposit do not react to each other in significant ways at the zero lower bound, hinting that manipulating sight deposit and monetary base is likely not a monetary policy tool that Swiss National Bank relies on to directly influence the economy.

Keywords: SVAR, Monetary Transmission Mechanism, Zero Lower Bound, Foreign Exchange Intervention

Honor Pledge: This paper represents my own work in accordance with University regulations.

*I would like to thank my advisor Prof. Iqbal Zaidi for guiding me through this project. I also express my sincere gratitude to Prof. Henry Farber, Prof. Michal Kolesár, Prof. Mark Watson, Princeton University data scientists Oscar Torres-Reyna and Bobray Bordelon, as well as Anna Belonog, Bruno Baranek, Juan Manuel Castro-Vincenzi, Dake Li, Evan Majic, Shumiao Ouyang, and Jason Zhang for all their kind help and support.

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1 Introduction

Scholars have long studied the effects and transmission mechanism of monetary policy. These terms can be broadly seen as the process through which monetary policy decisions are transmitted into changes in real GDP and inflation. There are many different views on the channels through which monetary policies exert their effects, and those views differ in the emphasis they place on money, interest rates, exchange rates, credit, asset prices or the role of financial institutions (Taylor 1995). This paper will focus on money supply, interest rate, and monetary base and their interactions with the real output and price level. While relatively little research has been done on the monetary transmission mechanism in Switzerland since the early 2000s, I hope to conduct a comprehensive overview on the topic from 1985 to 2019 and examine whether the results are generally compatible with the previously established view of monetary policy effects in Switzerland.

The contemporary literature on the effects on monetary policy can be generally divided into three categories. The first group focus on the rise and fall of economic activities after an exogenous monetary contraction or expansion (Bernanke and Blinder [1992], Christiano, Eichenbaum, and Evans [1999], Leeper, Sims, and Zha [1996], etc.). A second group focus on the monetary transmission mechanism, namely the actual effectiveness of monetary policies (Romer and Romer [1990], Boivin et al. [2010], etc.). And a third group has recently emerged to focus particularly on the efficacy of unconventional monetary policy after the 2008 financial crisis (Engen, Laubach, and Reifschneider [2015], Egea and Hierro [2019], etc.). The primary objective of this paper is to follow the second group and develop an understanding of the monetary transmission mechanism in a more traditionally defined sense as the interaction between monetary policy shocks and real variables. However, I also hope to combine the focuses of those three groups and develop an understanding on the effects of novel monetary policy tools in recent years after Switzerland entered the zero lower bound (ZLB) territory after 2008.

As I will soon show in my literature review section, Switzerland has experienced a series of monetary policy regime changes in the past four decades. In 1985, it switched its monetary targeting variable from monetary base to money stock M1. In 1999, it changed from monetary targeting to inflation targeting. Though the central bank still operates under the inflation targeting regime today, the ZLB has significantly limited the power of its traditional monetary policy instruments. Motivated by the regime changes outlined above, I will use quarterly data from 1985:Q1 to 2019:Q4 and monthly data from 2011:M8 to 2019:M9 to examine whether and how monetary transmission mechanism has changed across three different periods of estimation: 1985:Q1 to 1999:Q4 (monetary targeting with M1), 2000:Q1 to 2011:Q2 (inflation targeting with nominal interest rate), and 2011:Q3 to 2019:Q4 (inflation targeting at the ZLB, but in real effect monetary targeting with monetary base under my hypothesis).

More specifically, this paper seeks to ask: Do the dynamics between Swiss monetary policies and real variables align with economic consensus? Does inflation targeting allow monetary policy shocks to exert more or less permanent impacts on the real variables than monetary targeting would? When Switzerland engages in foreign exchange reserves (FX) intervention at the ZLB as an unconventional monetary policy instrument, does such policy have any short-term or long-term effect on real output and price level, or would it not be valid to consider it an integral part of the monetary transmission mechanism?

Methodologically, this paper follows Gerlach and Smets (1995), Kugler and Rich (2002), Galí (1992), and Blanchard and Quah (1989) and estimates a structural vector autoregression (SVAR) model imposing both short-run and long-run restrictions. Using VAR to study monetary transmission mechanism has been popular given the relative ease in setting up identification restrictions and demonstrating dynamic interactions between variables. As I will soon further explain, the choice of having both short-run and long-run restrictions is largely motivated by the relative shortcomings of identification schemes containing only short-run or only long-run restrictions.

2 Literature Review

2.1 VAR Literature on Monetary Transmission Mechanism

VAR models have been the predominant methodology for empirical analysis of monetary policy effects, at least in the 1990s and 2000s, before more advanced models became more popular. The advantages of VAR models are apparent – they require only a minimum number of restrictions in order to disentangle movements in endogenous variables into the parts due to underlying shocks as a result of changing monetary policies, while the transparency of identification restrictions make it easy for a reader to understand the assumptions made by the author a priori based on existing literature (Gerlach and Smets 1995).

The VAR studies about monetary transmission mechanisms in Europe have primarily focused on a subset of countries in the European Economic and Monetary Union (EMU) as comparative studies, so relatively little attention has been devoted solely and specifically to Switzerland. Ramaswamy and Slok (1997) used a three-variable reduced-form VAR with quarterly data on the levels of output, prices, and interest rate to estimate monetary policy effects in 12 EU countries. They found that the countries generally fall into two broad groups: the full effects of a contractionary shock typically take twice as long to occur in one group than the other, but the resulting decline in output is also almost twice as deep in the former than latter one. Ramaswamy and Slok chose to use levels rather than differences in their estimation, as they believed a VAR specified in differences would generate more efficient estimates but ignore potential long-run relationships of importance. This conclusion will be helpful in guiding my own choice of data in my model.

The primary issue for VAR models is the identification problem for structural shocks. One common approach is to adopt short-run restrictions. Bernanke and Blinder (1992) pioneered this approach through restricting that monetary policies have no contemporaneous effects on output or price level. One possible problem with this approach is that for a small open economy (SOE) like Switzerland, the link between monetary policy, exchange rates, and price levels might be more instantaneous than in other economic contexts, so the assumption that monetary policy shocks do not affect prices within a quarter might not hold (Gerlach and Smets 1995).

Another common identification scheme is through long-run restrictions. Economic theory and intuition could only help us so much in identifying short-run interactions between different macro variables, but they are much more helpful when used to explain long-run interactions. Blanchard and Quah (1989) pioneered in using long-run restrictions for supply and demand shocks, arguing that demand shocks would not have a long-term impact on real output. Similarly, Keating (1992) proposed that monetary policies would not have long-run effects on real variables such as real output, real interest rate, and real money stock. However, one issue with long-run restrictions is that monetary policy shocks in certain contexts might not behave like demand shocks in the long run, so using the same kind of logic by Blanchard and Quah might be questionable (Gerlach and Smets 1995).

An alternative yet rather unconventional approach is to impose both short-run and long-run restrictions. The idea of combining both short-run and long-run restrictions was first proposed by Galí (1992) to address some of the shortcomings of VAR model as previously explained. Following Galí (1992), Gerlach and Smets (1995) used a three-variable VAR (output, price level, and interest rate) with a combination of short-run and long-run restrictions for the G7-countries. They showed interesting implications for the issue of "price puzzle," which refers to the scenario when an increase in the price level is associated with a contractionary monetary policy shock, which is against economic intuition. The price puzzle commonly shows up in VAR literature where only short-run restrictions are used, but it disappeared when Gerlach and Smets (1995) combined both short- and long-run restrictions in their analysis, suggesting that only imposing short-run restrictions does not properly discriminate between contractionary aggregate supply shocks and monetary policy shocks. Similarly, Kugler and Rich (2002) ran an SVAR model imposing both short-run and long-run restrictions with quarterly data on price level, GDP, M1, and nominal interest rate. They focused on the Swiss monetary policy under low interest rates in the 1970s and found that a delay in eliminating monetary overhang and the adoption of monetary targeting rather than inflation targeting likely caused the rise in inflation in 1981 after experiencing a deflationary shock.

2.2 Monetary Policy Timeline for Switzerland

As previously mentioned, relatively little attention has been devoted to monetary transmission mechanism in Switzerland. I will now do a brief overview of the monetary policy changes that took place in the country from the 1970s to 2019 to provide the necessary background information for my empirical analysis. Much of the information below comes from Kugler and Rich (2002) and the Swiss monetary policy history timeline on SNB's website.

2.2.1 1970s-1990s: Monetary Targeting with Volatility

The period of late 1970s to early 80s was a volatile period for Swiss monetary policy. The collapse of the Bretton-Woods system forced the Swiss authorities to unpeg its exchange rate in the early 1970s, and the shift to a floating rate enabled the SNB to pursue more autonomous monetary policies, including adopting a M1 growth rate target to anchor its price level starting in December 1975. The country's economy, however, was still bothered by upsurges in exchange rate and price level, causing slumps in economy activity in 1978. Switzerland had to respond through setting a temporary exchange rate floor against the Deutsche mark and purchase foreign exchange on a large scale in 1978 – a practice we shall see again in recent years after the 2008 financial crisis. The exchange rate floor solved the threat to price stability, and Switzerland returned to monetary targeting in 1979, though now fixing growth rate targets to monetary base rather than M1. Unfortunately, the new regime failed to achieve price stability, as inflation soon rose back to over 7% in 1981.

After much struggle, Switzerland switched its target variable from monetary base back to money stock M1 in 1985 and kept it so until 1999. The only modification made during the period was changing its targeting objective from one year to five year in 1990. 1985-1999 is thus a period of stable monetary targeting without the frequent switches between M0 and M1 from 1975 to 1985. This paper, therefore, will use 1985-1999 as the first estimation time period, during which M1 was the monetary policy target.

2.2.2 2000-2008: Inflation Targeting

During the 1985-1999 period, many had suggested alternatives to the monetary targeting regime, most notably Lars Svensson's suggestion of inflation targeting, which the Swiss National Bank (SNB) only started to adopt in 1999. SNB ended the monetary targeting regime in 1999 and switched to medium-term (three-year) inflation forecast in 2000. It started to consider price stability and an annual inflation rate of less than 2 percent as its goal. Under this framework, SNB sets a target range for the three-month Libor, arguably the most important money market rate for the Swiss franc, and SNB would conduct short-term repo operations to indirectly influence the Libor rate. The inflation targeting regime is maintained until today.

2.2.3 2008-2019: Zero Lower Bound

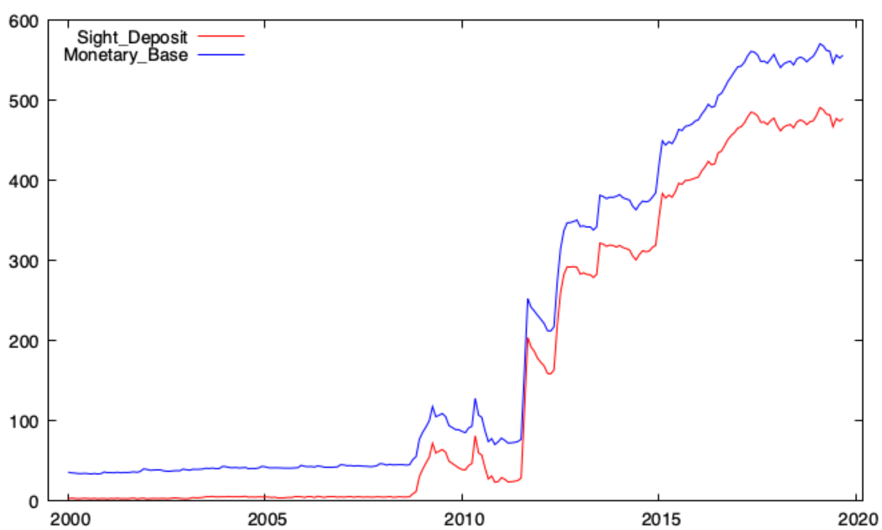
The next big shock to the system came in the aftermath of the 2008 financial crisis, when the U.S., Japan, and many other developed countries have stepped into the territory of zero lower bound (ZLB) and enacted unconventional monetary policies. ZLB refers to the lower limit of interest rates, at which the central bank may find it difficult to further lower the policy rate to respond to negative shocks, thus limiting the efficacy of monetary policies in crisis time. As it becomes clear that many developed countries will remain in the ZLB territory for the foreseeable future, many have begun to question whether the efficacy of monetary policies and the fiscal-monetary interaction in general would be improved or hurt.

Under the backdrop of global recession, SNB had no choice but to continue lowering the target range for the three-month Libor rate. The rate range fell drastically from 2.0-3.0% in October 2008 to 0.0-1.0% in December 2008. As the global recession deepened and the euro crisis unfolded, Swiss franc suddenly became an attractive "safe haven" currency, and the demand for it began to increase dramatically.

A rising currency valuation hurts the Swiss export industry, and the SNB has thus taken a two-pronged approach to control the currency – actively engaging in currency market interventions to help prevent high valuation of the currency, while keeping interest rates low or negative to dissuade any speculative buying of it. The SNB imposed an exchange rate floor at the rate of 1.20 CHF/EUR on September 6, 2011, a policy that ended on January 15, 2015. In December 2014, the SNB lowered the range for its operational target – i.e., for the three-month Libor – into negative territory to between 0.25% and -0.75%. In January 2015, it discontinued the euro-Swiss franc exchange rate floor and moved the target range further into negative territory to between -0.25% and -1.25%. As of July 1, 2019 (and until May 2020), the Swiss National Bank (SNB) maintains a negative interest rate policy with a target rate of -0.75%.

Starting in August 2011, the SNB began to engage in foreign exchange interventions to control the exchange rate. SNB significantly increased the supply of liquidity to the Swiss franc money market over the next few days, expanding banks' sight deposits at the SNB from around CHF 30 billion to CHF 200 billion in around two weeks. It later even set a minimum exchange rate floor of CHF 1.20 per euro, and maintained total sight deposits at the SNB at significantly above CHF 200 billion.

Figure 1: Monetary Base in Switzerland and Sight Deposit at SNB*



*Y-axis scale in CHF billions

2.2.4 FX Intervention as an Unconventional Instrument at the ZLB

Switzerland voluntarily chose to engage in FX interventions and push down its interest rate to stop the rising valuation of its safe haven currency after the sharp rise in demand since the financial crisis. To me, it seems that sight deposit (essentially the proxy for monetary base) has entered the central stage of Swiss monetary policy. One could even see it as a return of monetary base growth rate targeting after Switzerland switched its monetary target from monetary base to M1 in 1985. Because of the presence of the ZLB and the dominating concern of currency appreciation, I would argue that FX interventions (or the manipulation of sight deposits and thus M0) have in effect become the de facto "monetary policy instrument" for SNB.

The use of foreign exchange interventions as an unconventional monetary policy instrument was first proposed by McCallum (2000) and Svensson (2001) in the debate on Japan's difficult experience with deflation. Using the exchange rate as an instrument at the ZLB is defined as an approach where the central bank chooses the specific exchange rate level it wants to attain and is prepared to intervene in the FX market in unspecified and potentially unlimited amounts to attain that level.

According to Franta et al. (2014), one advantage of using exchange rate as a monetary policy instrument at the ZLB is to convey how the central bank is committed to achieve growth in the price level using potentially unlimited FX interventions, thus increasing inflation expectations. McCallum (2000) showed that at the ZLB, a central bank in an economy open to foreign trade can successfully apply exchange rate as an operating target of monetary policy and adjust the rate of depreciation of the domestic currency to stabilize inflation and the real economy. Svensson (2001) suggested that a devaluation of the currency and a temporary crawling exchange rate peg could lead to lower real interest rate and increased inflation expectation, thus jump-starting the economy and escaping deflation. Franta et al. (2014) documented that Switzerland's introduction of the exchange rate floor did not significantly affect the results of inflation expectations surveys in the following months of 2012, partly owing to the lagged effects of the previous sharp appreciation and additional anti-inflationary pressures.

Therefore, I would divide up the inflation targeting period into two parts: 2000:Q1-2011:Q2 where interest rate was the target, and 2011:Q3-2019:Q4 where sight deposit and exchange rate played a much more important role in the monetary policy regime.

3 Data

3.1 Summary Statistics

Quarterly macroeconomic data has been a more recent phenomenon given new data collection standards (SDDS) adopted by the IMF in 1996. The use of high-frequency (quarterly and even monthly) data allows for more robust and credible applications of the SVAR technique, and this paper will use quarterly, seasonally adjusted data from the 1st quarter of 1985 to the 4th quarter of 2019, as well as monthly data from August 2011 to September 2019. I have collected Swiss data on real GDP, price level, nominal interest rate, real effective exchange rate, sight deposit, monetary base, and M1. The Swiss data on real GDP and price level come from the IMF's International Financial Statistics (IFS) database. Other data are downloaded directly from the SNB data base.

Real output: quarterly real GDP; annualized, 2010.

Price level: consumer price index (CPI); seasonally adjusted according to real effective exchange rate; annualized index, year 2015 = 100.

Sight Deposit: monthly/quarterly average of sight deposit data from SNB.

Monetary base: quarterly average of monthly monetary base data from SNB.

M1: monetary aggregate; quarterly average of monthly M1 data from SNB.

Interest rate: quarterly average of three-month Libor rate for Swiss franc.

Real effective exchange rate: real, CPI-based, overall index provided by SNB.

The summary statistics is presented below according to time periods. The original data series in level are later transformed into growth rate through log-differencing, some of which are used in my estimation.

Table 1: Summary Statistics for 1985:Q1 to 1999:Q4

Variables	(Levels) Mean	(Levels) Median	(Levels) SD	(Growth) Mean	(Growth) Median	(Growth) SD
GDP	441.8	441.8	28.46	0.00446	0.00446	0.00621
Price Level	87.04	87.04	4.294	0.00134	0.00134	0.0233
M1	135.8	135.8	34.20	0.0135	0.0135	0.0227
Interest Rate	4.633	4.633	2.897	-0.0202	-0.0202	0.110
REER	101.0	101.0	5.498	0.00122	0.00122	0.0217
Frequency:	Quarterly					
Observations:	60					

Price level, REER in index; GDP, M1 in CHF billions; interest rate in percentage

Table 2: Summary Statistics for 2000:Q1 to 2011:Q2

Variables	(Levels) Mean	(Levels) Median	(Levels) SD	(Growth) Mean	(Growth) Median	(Growth) SD
GDP	557.0	557.0	39.87	0.00469	0.00469	0.00673
Price Level	85.34	85.34	4.134	0.00266	0.00266	0.0183
M1	290.6	290.6	71.00	0.0167	0.0167	0.0428
Interest Rate	1.395	1.395	1.143	-0.0197	-0.0197	0.140
REER	102.9	102.9	4.721	0.00377	0.00377	0.0173
Frequency:	Quarterly					
Observations:	42					

Price level, REER in index; GDP, M1 in CHF billions; interest rate in percentage

Table 3: Summary Statistics for 2011:Q3 to 2019:Q4

Variables	(Levels) Mean	(Levels) Median	(Levels) SD	(Growth) Mean	(Growth) Median	(Growth) SD
GDP	665.8	665.8	30.49	0.00416	0.00416	0.00359
Price Level	95.70	95.70	3.171	-0.000440	-0.000440	0.0248
Sight Deposit	364.3	364.3	51.50	0.0160	0.0160	0.0210
M1	584.4	584.4	59.62	0.0125	0.0125	0.0152
Interest Rate	-0.425	-0.425	0.392	-0.0426	-0.0426	0.331
REER	113.9	113.9	3.121	-0.00154	-0.00154	0.0231
Frequency:	Quarterly					
Observations:	34					

Price level, REER in index; GDP, M0, M1 in CHF billions; interest rate in percentage

Table 4: Summary Statistics for 2011:M8 to 2019:M9

Variables	(Levels) Mean	(Levels) Median	(Levels) SD	(Growth) Mean	(Growth) Median	(Growth) SD
GDP	99.96	99.96	0.358	-3.42e-05	-3.42e-05	0.000700
Price Level	95.64	95.64	3.244	-0.000520	-0.000520	0.0153
Sight Deposit	372.6	372.6	101.1	0.0287	0.0287	0.156
Monetary Base	440.3	440.3	110.4	0.0202	0.0202	0.0925
Interest Rate	-0.422	-0.422	0.388	-0.129	-0.129	0.838
REER	105.9	105.9	3.159	-0.000877	-0.000877	0.0156
Frequency:	Monthly					
Observations:	98					

GDP, Price level, REER, in index; sight deposit and monetary base in CHF billions; interest rate in percentage

Note: No monthly GDP data is available, so I use “Leading Indicators OECD: Reference series: Gross Domestic Product (GDP): Normalised for Switzerland” as a proxy.

3.2 Tests for Stationarity

Table 5: Unit Root Analysis

VARIABLES	(Levels) ADF	(Levels) ADF-GLS	(Log-Differences) ADF	(Log-Differences) ADF-GLS
Price Level	-2.404	-0.928	-10.297	-2.300
GDP	1.304	2.442	-6.833	-3.972
M0	3.072	1.874	-8.349	-2.985
M1	2.526	1.728	-8.430	-2.637
Interest Rate	-1.126	-0.786	-10.825	-2.107
REER	-2.369	-0.766	-10.372	-2.256

Augmented Dickey-Fuller 5% critical value = -2.889
ADF-GLS 5% critical value = -1.950

We can see from our unit root analysis that data for all the variables are non-stationary. I thus transform the variables into percent changes by taking the first differences of their natural logs to eliminate non-stationarity. Non of the transformed data series display evidence of unit root.

As previously mentioned in the literature review section, Ramaswamy and Slok (1997) chose to use levels rather than differences in their estimation, as they believed that a VAR specified in differences would generate more efficient estimates but ignore potential long-run relationships of importance. Kugler and Rich (2002) and Gerlach and Smets (1995), on the other hand, chose to use differenced data. The trade-off between estimation efficiency and accuracy has long been a debate within the econometrics community, and many have asserted that non-stationary data should be allowed if the analysis is not for obtaining point estimates of relevant variables, a view supported by Sims (1980) and Sims, Stock, and Watson (1990).

Regardless of the debate, one important caveat is that I shall treat my data series with consistency, i.e. not have GDP in differences but prices and money supply in levels, for instance. In my model, because I will be imposing both short-run and long-run restrictions, I have decided to use the log-differenced series for real output, price level, and M1/M0, as well as the original series of interest rate. I will then cumulate the impulse responses of the differenced series at the end to get the levels estimate.

3.3 Lag Length Selection

The optimal number of lags can be selected by using available lag length selection criteria as indicated below. However, the generated results do not seem to agree on one optimal number. For the purpose of consistency and in line with previous literature, I will use 4 lags for all my estimations with quarterly data and 8 lags for my estimation with monthly data.

Table 6: Lag Length Selection

Time period: 1985:Q1 - 1999:Q4
Variables: y_t, p_t, m_t

Lag	LogL	LR	p-value	FPE	AIC	HQIC	SBIC
0	-1627.99	NA	NA	4.1e+06	23.7298	23.773	23.8424
1	-382.152	463.65	0.000	770.452*	15.1597*	15.3323*	15.61*
2	-375.306	13.691	0.134	840.382	15.2426	15.5447	16.0306
3	-367.506	15.602	0.076	888.549	15.2887	15.7202	16.4144

∗indicates lag order selected by the specific criterion

Time period: 2000:Q1 - 2011:Q2
Variables: y_t, p_t, r_t

Lag	LogL	LR	p-value	FPE	AIC	HQIC	SBIC
0	-333.089	NA	NA	9655.42	17.6889	17.7349	17.8182
1	-155.134	355.91	0.000	1.33005	8.7965	8.98049	9.31363*
2	-141	28.268	0.001	1.02576	8.5263	8.84829*	9.43128
3	-131.896	18.207	0.033	1.04631	8.52086	8.98084	9.81369
4	-124.836	14.121	0.118	1.21595	8.62294	9.22091	10.3036
5	-115.884	17.903	0.036	1.32229	8.62548	9.36145	10.694
6	-99.4424	32.884	0.000	1.01614*	8.23381*	9.10777	10.6902

∗indicates lag order selected by the specific criterion

Time period: 2011:Q3 - 2019:Q4
Variables: y_t, p_t, m_t

Lag	LogL	LR	p-value	FPE	AIC	HQIC	SBIC
0	-303.27	NA	NA	1.4e+06	22.6867	22.7295	22.8307
1	-189.302	227.94	0.000	604.407	14.9113	15.0825	15.4872*
2	-176.248	26.11	0.002	461.109*	14.6109	14.9106	15.6188
3	-170.148	12.2	0.202	615.86	14.8258	15.2539	16.2656
4	-163.21	13.875	0.127	833.375	14.9785	15.5351	16.8503
5	-152.49	21.441	0.011	964.694	14.8511	15.5361	17.1548
6	-130.973	43.034	0.000	623.682	13.9239	14.7373	16.6595
7	-107.915	46.115*	0.000	559.604	12.8826*	13.8245*	16.0502

∗indicates lag order selected by the specific criterion

LR: sequential modified LR test statistic (each test at 5% level); FPE: Final Prediction Error; AIC: Akaike Information Criterion; HQIC: Hannan-Quinn Information Criterion; SBIC: Schwarz's Bayesian information criterion.

4 Methodology

4.1 SVAR Model

VAR is a set of k time series regressions, in which the regressors are lagged values of all k series. A VAR extends the univariate autoregression to a list, or "vector," of time series variables. Let Y_t be a vector of macro time series, and let ϵ_t denote some monetary policy intervention. The VAR model would be able to help us identify the dynamic causal effect of ϵ_t on Y_t. Such dynamic casual effect would be defined as the impulse response function (IRF) of Y_t to "shocks" ϵ_t. Impulse response functions and variance decomposition derived from VAR analysis can illustrate the dynamic characteristics of the empirical models.

Mathematically, the structural representation of a VAR model is:

$$B_0 Y_t = B(L) Y_{t-p} + \epsilon_t$$

where B_0 is the matrix of contemporaneous influences between the variables; Y_t is a $(n \times 1)$ vector of the endogenous macroeconomic variables in our model; $B(L)$ is a $(n \times n)$ matrix of lag-length p, representing impulse-response functions of the shocks to the elements of Y_t, and B is a $(n \times n)$ matrix of autoregressive polynomials that capture the linear relations between structural shocks and those in the reduced form; and lastly, ϵ_t is a $(n \times 1)$ vector of structural shocks, which should be uncorrelated and identically normally distributed.

SVAR (structural VAR) takes the VAR model a step further into a system of structural equations. A model is considered "structural" if it allows one to predict the effect of "structural shocks," such as deliberate policy decisions or changes in the economy of known types. A "structural" model would tell us how the intervention corresponds to changes in certain elements within the model, such as in the parameters, equations, or random variables. As a result, the parameters in SVAR are estimated by imposing contemporaneous structural restrictions, where the resulted impulse response functions and variance decomposition can now be given structural interpretations.

A more detailed introduction to the SVAR model can be found in the appendix, where I explain in depth the process of computing impulse responses and recovering structural shocks from reduced-form estimations.

4.2 Identification With Both Short-run and Long-run Restrictions

As mentioned in literature review, there are potential drawbacks of only imposing short-run or long-run run restrictions, despite the fact that those are the most conventional approaches to identification. In the context of this paper, imposing solely long-run restrictions does not seem to be the most effective way of identifying monetary policy shocks, which is one of the reasons why much fewer papers on monetary transmission mechanism use long-run rather than short-run restrictions. However, there are also important long-run dynamics between money supply, real output, and price level that it would be difficult to recognize if solely relying on short-run restrictions. Therefore, this paper will use both sets of restrictions.

Leaving aside the economic implications for a second, from a statistical viewpoint, it is indeed possible to combine the two sets of hypotheses into one as an alternative identification strategy. King, Plosser, Stock, and Watson (1991) applied such framework to a Real Business Cycle (RBC) analysis that combined restrictions on the long-run multiplier matrix with short-run identification restrictions to achieve full identification for responses to the common productivity shock and the remaining transitory shocks. Galí (1992) imposed short-run restrictions on contemporaneous interaction between monetary authority decisions and price level and long-run restrictions on the cumulated effects on GNP. This framework developed by those pioneers have inspired many later VAR analyses on effects of monetary policy, including the identification restrictions proposed by Kugler and Rich (2002) and Gerlach and Smets (1995). Their VAR models contain both short- and long-run restrictions in order to identify a monetary policy shock with a variance normalized to one, and my analysis will follow their application.

Recall the VAR model specification $B_0 Y_t = B(L)Y_{t-p} + \epsilon_t$, where the endogenous variable vector here is $Y_t^{'} = [y_t, p_t, m_t]$, with y_t denoting real output, p_t price level, and m_t the given monetary policy variable for the particular estimation period. After running our initial VAR estimation through OLS, we would invert VAR to get $MA(\infty)$ with the expression of $B(L)Y_t = \epsilon_t$. The long-run effects of the shocks on each of the endogenous variables would be related to the *sum* of their impulse responses or moving average coefficients. In other words, because we may express our vector of endogenous variables as $A(L)Y_t = u_t$ in a reduced-form VAR process, we may express the corresponding structural form as $B(L)Y_t = \epsilon_t$, where ϵ_t are the structural shocks. The effects of those structural shocks on the other observed variables can be obtained from the structural MA representation:

$$Y_t = B(L)^{-1}\epsilon_t = D(L)\epsilon_t.$$

In this analysis, because $Y_t \sim I(0)$, the effect of any one structural shock on Y_t will approach zero in the long run. However, the fact that Δy_t, Δp_t, or Δm_t will return to their initial values eventually does not imply that the real output, real price level, or monetary policy variable will necessarily return to their initial values. The effect of a given structural shock on the real GDP, for example, will in fact be the cumulative sum of its effects on Δy_t. Those long-run cumulative effects are summarized by our D matrix:

$$D(1) = \sum_{i=0}^{\infty} D_i = B(1)^{-1} = A(1)^{-1} B_0^{-1},$$

where the exclusion restrictions imposed on $D(1)$ are essentially implicit restrictions on B_0. We may further impose any additional short-run restrictions on the B_0 matrix to allow for contemporaneous shocks to be identified. Like the subsection above, more information on imposing long-run restrictions can be found in the appendix.

4.3 The Empirical Model

In the context of my analysis, I would like to categorize three kinds of shocks: aggregate supply shock, aggregate demand shocks, and monetary policy shocks, denoted respectively by ϵ_t^y, ϵ_t^p, and ϵ_t^m. Using SVAR would allow us to decompose movements in observed time series like real output, price level, and short-term interest rates into those three unobserved structural shocks, which can then be given economic interpretations.

As explained by Gerlach and Smets (1995), given the endogenous variables and structural shocks defined here, this model can essentially be thought of as a minimalist empirical version of a standard aggregate supply/aggregate demand macroeconomic model comprising an IS curve, a Phillips curve, and a monetary policy reaction function. By limiting the number of endogenous variables, the implicit assumption is that different supply and demand shocks (such as increases in government spending vs. shifts in consumption) have similar effects on income, prices, and interest rates, so they may be aggregated into a supply or demand shock.

Another important implication of the current model setup is the implicit assumption that output and prices capture all the information the central bank needs when setting monetary policies. For instance, exchange rate is purposely excluded from this model, which means any of SNB's responses to exchange rate movements that are not due to aggregate supply or demand developments will also be excluded (Gerlach and Smets 1995). The exclusion of exchange rate might not appear to be a reasonable assumption for an SOE like Switzerland, where money supply and interest rates are indeed adjusted in response to exchange rate market developments, but it is not uncommon to do so. Kugler and Rich (2002) excluded exchange from their model setup because they believed that the transmission of monetary policy via exchange rate would be indirectly captured by the impulse responses to money supply or interest rate. Explicit inclusion of the exchange rate would only be necessary if the variable has been influenced SNB behavior in a systematic way and is required to identify a monetary policy shock. Exchange rate is important from time to time, but not throughout the entire estimation periods in this analysis. Therefore, after careful consideration, I still decided to exclude exchange rate for the consistency and flexibility of the model across different estimation periods.

I impose one short-run and two long-run restrictions on my model. First, to identify supply shocks, I follow Gerlach and Smets (1995) and Galí (1992) in assuming that aggregate demand and monetary policy shocks do not have permanent effect on the level of real GDP, so only supply shocks can affect the level of real output in the long run. Suggesting that the long-run Phillips curve is vertical, those two long-run restrictions are frequently used in macroeconomic literature, as agreed by Kugler and Rich (2002) and McMillin (2001).

Then, in order to distinguish aggregate demand shocks from monetary policy shocks, I follow Gerlach and Smets (1995) and Galí (1992) in imposing a short-run restriction that monetary policy has no contemporaneous effect on real output. Alternatively, Kugler and Rich (2002) imposed the short-run restrictions such that monetary policy shocks do not affect consumer prices and GDP contemporaneously. To them, a sluggish response in prices and output seems to be a reasonable assumption for quarterly macroeconomic data. Gerlach and Smets (1995), however, disagreed in their paper that because quarterly data are used, monetary policy could well affect the price level contemporaneously through exchange rate, import prices, or other mechanisms, so it becomes less plausible to assume no instantaneous pass-through to prices. Therefore, I will only impose one short-run restriction that monetary policy has no contemporaneous effect on real output.

To sum up, I impose one short-run and two long-run restrictions: 1) monetary policy has no contemporaneous effect on real output; 2) & 3) aggregate demand and monetary policy shocks do not have permanent, but perhaps persistent, effects on the level of real output. My identification matrices will therefore take the shape of:

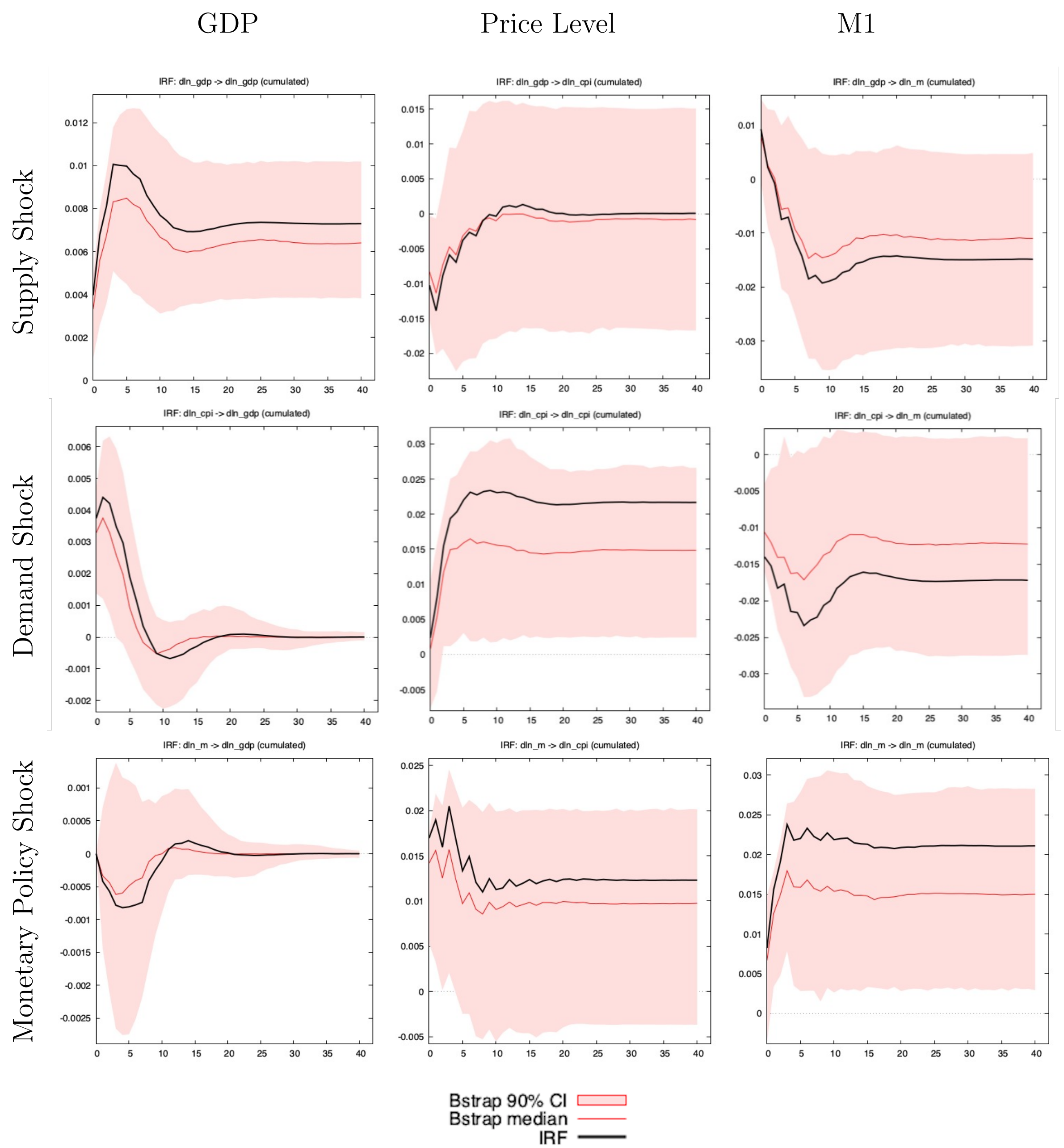
$$D(1) = \begin{bmatrix} * & 0 & 0 \\ * & * & * \\ * & * & * \end{bmatrix}; B_0 = \begin{bmatrix} * & * & 0 \\ * & * & * \\ * & * & * \end{bmatrix}$$

A quick note about statistical methodology – it is common to graph the response of the actual *level* of a macroeconomic variable, rather than its growth rate. This process involves creating an impulse response graph that cumulates the response of the growth rate of the estimated variable, while leaving the response of other variables unchanged if they were estimated in levels in the first place (Schenck 2016). I thus create a series of IRFs that contain the response of the *level* of GDP, price level, and monetary policy variables to various shocks. Graphing the response of the level of those variables will more clearly show the identification assumption I have made.

5 Results

5.1 Monetary Targeting with M1: 1985-1999

Figure 2: Impulse Response Graphs 1985:Q1 - 1999:Q4*



*The estimation and IRFs are produced by Gretl, an open-source software for econometic analysis. This choice was motivated by Stata's inability to impose both short- and long-run restrictions in SVAR.

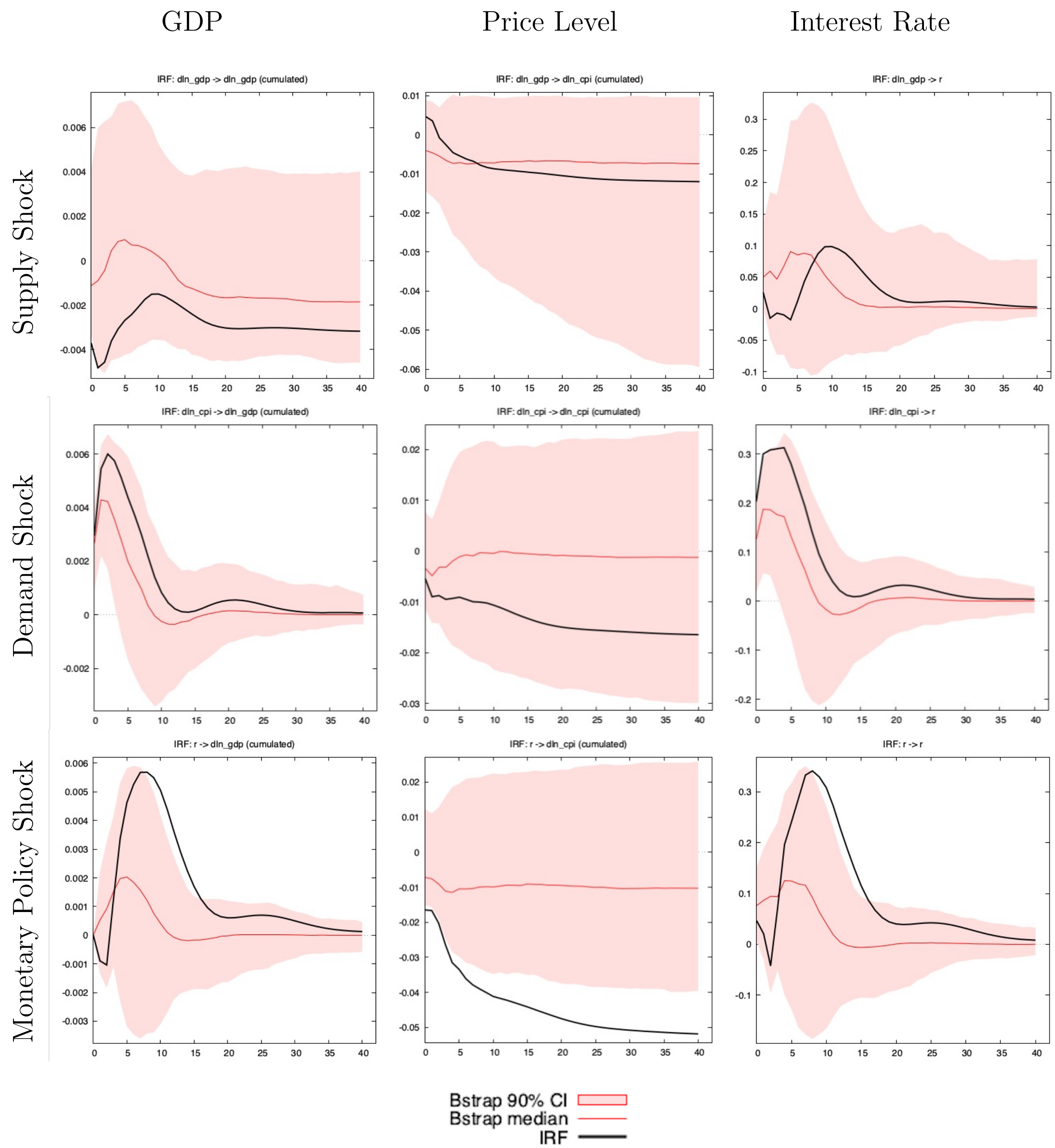
The graphs are organized such that each row represents a type of shock to the three macro variables, and each column represents a variable's responses to the three kinds of shocks. Here, we may observe that there is a permanent increase to the GDP level after a supply shock, while positive demand and monetary policy shocks have an immediate yet not permanent effect on it. A positive supply shock initially decreases price level before leveling out after 10 quarters or so; a demand shock causes a 2.5% permanent increase in the price level; and likewise, a monetary policy shock causes a permanent rise in price level. This is largely in line with the theory of long-run neutrality of money such that an increase in money supply would cause a permanent increase in price level.

We see that both a supply and a demand shock cause a permanent decline in money supply, and money supply was initially raised by a monetary policy shock and stayed at that increased level in the long run. The dynamic between the demand shock and money supply is confusing because one would typically expect money supply to increase after price level increases given the tight relationship in the long run between money supply and prices with a coefficient of one. For instance, if there is a positive price shock, inflation would rise, and the central bank would *not* try to control it with lower money supply. It would not be implausible, however, to explain this phenomenon with exchange rate dynamics, as SNB might decrease M1 supply to manipulate exchange rate and thus achieve the objective of taming inflation, though this has rarely been suggested or verified by other scholars.

The impulse responses to a monetary policy shock in this analysis are nearly identical to the ones estimated by Kugler and Rich (2002). The only difference is that consumer prices had a more sluggish process of increase in their analysis, really picking up after six quarters or so before flattening after 12 quarters. In my analysis, consumer prices had an immediate response and gradually came down after six quarters. One possible explanation of the difference is that Kugler and Rich (2002) chose to restrict the contemporaneous interaction between monetary policy and price level, and I chose not to do so as previously explained in my model specification. This might hint that monetary policy may indeed immediately affect price level through exchange rate, import prices or some other mechanism in an SOE like Switzerland.

5.2 Inflation Targeting: 2000-2011

Figure 3: Impulse Response Graphs 2000:Q1 - 2011:Q2



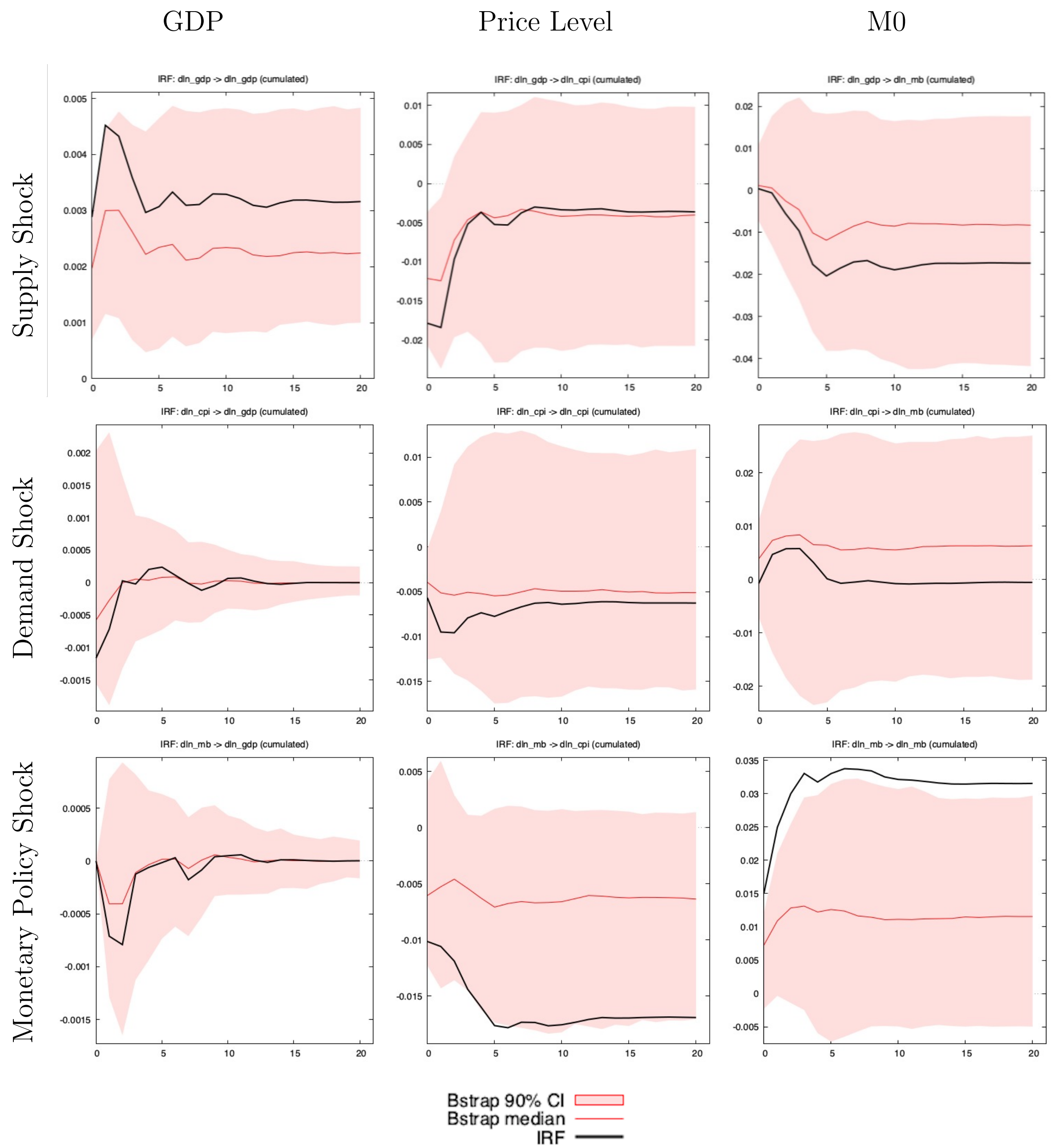
The SVAR restrictions here are the same as previously, except M1 is replaced with nominal interest rate data, and interest rate data is estimated in levels rather than logged differences. Here, we may observe somewhat conflicting results from the previous time period with monetary targeting. Price level sees a permanent decrease after a positive supply shock rather than an increase in the monetary targeting regime previously, and there is also a temporary rise in interest rate. Those two reactions are consistent with the results estimated by Gerlach and Smets (1995) – expansionary supply shocks increase the return to capital and thus real interest rate, but in the meantime, they reduce inflationary pressures and nominal interest rates. It is, however, puzzling to see a decline in real output after a positive supply shock, but because such fluctuation is not statistically significant in any way, I would not over-interpret its implication.

Moving on to demand shocks, the responses here are largely in line with expectation. We see a significant and instantaneous increase in real output after a demand shock, whose magnitude between 0.4% to 0.6% is reasonable. A demand shock should generally increase price level by 0.5% to 1.0% by the estimate of Gerlach and Smets (1995), but we are not seeing significant fluctuations here. A positive demand shock does lead to an increase in nominal interest rate before it flattens out after 10 quarters. Although it might be inconclusive how real interest rates would react to a demand shock, it is well expected that an expansion in government spending or consumer consumption could lead to higher nominal interest rates across a range of different countries (Gerlach and Smets 1995). Theory generally holds that an increase in the price level hints at inflation and will thus cause an increase in average interest rates in an economy. Fortunately, we are not seeing the "price puzzle" here.

A monetary policy shock has no long-run effect on GDP but does cause a temporary increase in real output. Increases in interest rates should depress output in any economy, and this statistically insignificant result should not be indicative of any larger trend in the Swiss economy. Meanwhile, the decline in consumer prices is well expected, but the more interesting phenomenon is how quickly price level declines in response to a monetary policy shock in Switzerland. The instantaneous response can likely be attributed to the tight connection between interest rate, exchange rate, and import prices in Swiss economy. In a larger and more closed economy like the U.S. or a country with fixed exchange rates, the prices would likely remain relatively unaffected by monetary policy shocks in the short term. Lastly, a monetary policy shock increases short-term interest rate by around 10 to 30 basis points, which is less in magnitude for typical interest rate adjustments in countries like Germany and Japan where the typical tightening could be around 40 basis points under the same monetary policy regime (Gerlachs and Smets 1995). The effect of a monetary policy shock could last for longer than 10 quarters – which is unusual – but it does not lead to the nominal interest rate dipping below its initial level.

5.3 Monetary Targeting with Monetary Base: 2011-2019

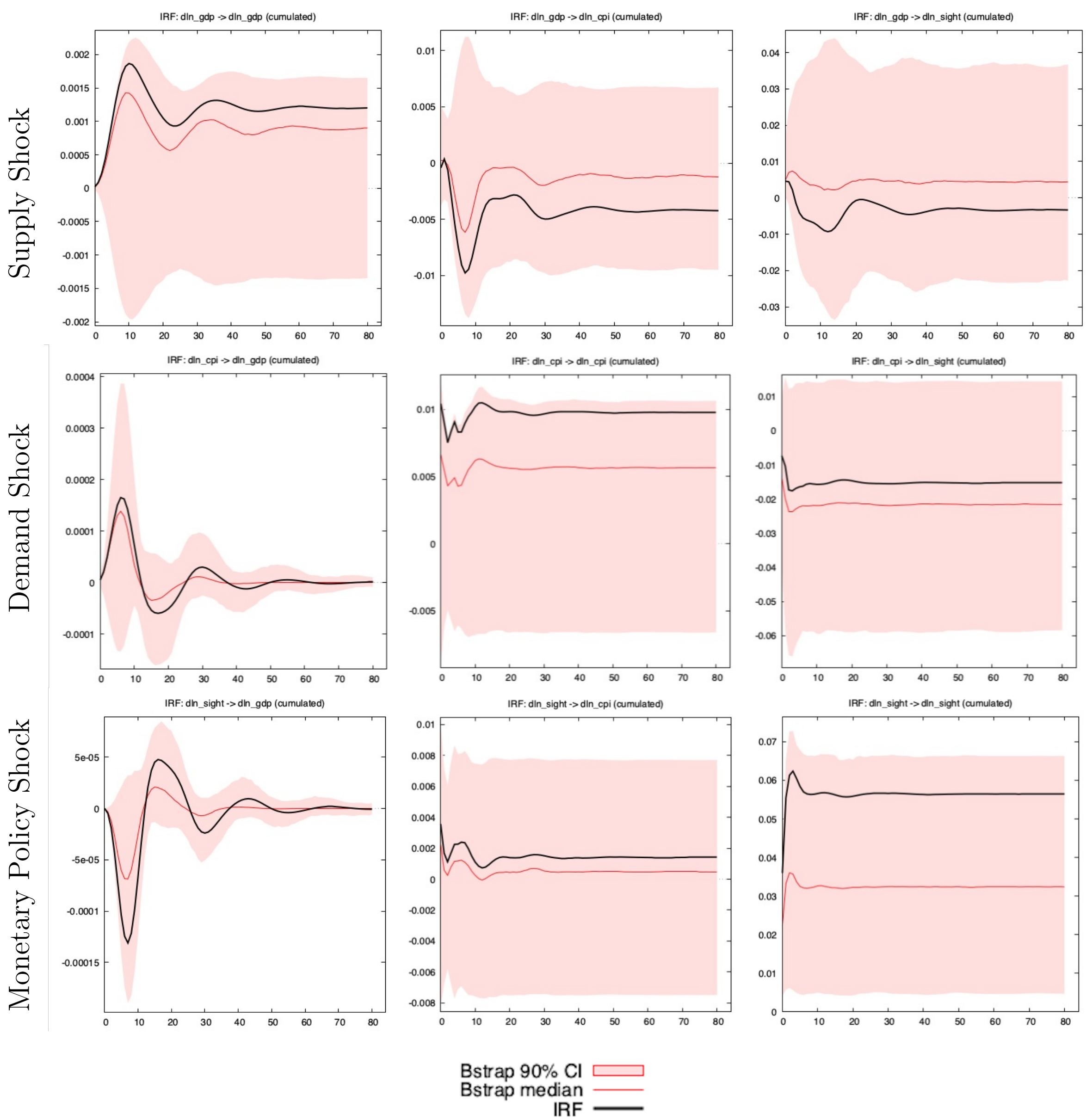
Figure 4: Impulse Response Graphs 2011:Q3 - 2019:Q4



The set of IRFs above are generated using quarterly data of GDP, price Level, and monetary base. As previously explained, in 2011, SNB started to engage in large-scale, frequent FX interventions, and I thus consider the fluctuation of M0 to be a form of monetary policy intervention from mid-2011 to 2019. Because the FX interventions are intensive and quickly adjusted for timely purposes, I hypothesize that using monthly instead of quarterly data may more accurately capture the dynamic over the period. Therefore, I estimated another set of IRFs using monthly data of GDP, price level, and sight deposits. It is important to reiterate that there is no official monthly GDP data but only the approximated index of real GDP produced by OECD. The reduced accuracy of real output is the trade-off for improved accuracy of sight deposit data being in monthly frequency:

Figure 5: Impulse Response Graphs 2011:M8 - 2019:M9

GDP Price Level Sight Deposit



The two sets of IRFs exhibit consistent trends. For responses to supply shocks, we see roughly the same result as in 2000-2011 that a positive supply shock leads to a permanent increase in real output, a 0.5% to 1% decline in price level, and a permanent decline in M0. These results are largely in line with our expectation. A positive demand shock leads to an insignificant yet permanent rise in price level in the monthly IRFs, while it does not lead to any long-run effect on real output. In general, demand shocks seem to be playing a relatively more minor role at the ZLB – both in comparison to the demand shocks in the previous two time periods, as well as compared to the aggregate supply or monetary policy shocks in the same ZLB period.

In the meantime, a monetary policy shock does not have any long-run effect on GDP level, which is in line with economic literature and the imposed long-run restriction. It is noteworthy, however, to see that real output had an immediate decline after a positive monetary policy shock, which may or may not confirm the worry that a rising exchange rate hurts the Swiss exports industry and overall output since the effect of exchange rate is only indirectly exhibited through fluctuations in sight deposits.

The dynamic between price level and sight deposit appears to be the most interesting one amongst all. A positive monetary policy shock causes little contemporaneous and almost no permanent effect on price level, while a positive demand shock leading to an insignificant decline in sight deposit. These trends are completely against the the theory of long-run neutrality of money and hints that monetary base expansion might not lead to the same long-run dynamic that M1 supply has with price level. Using changes in sight deposit to steer inflation is indeed an objective of SNB, but whether a positive monetary policy shock leads to higher or lower inflation at the ZLB should remain inconclusive. The permanent increase in sight deposit after a monetary policy shock confirms the expansion of SNB's balance sheet over the past years to use sight deposit as a monetary policy tool.

I want to iterate that these results are only preliminary estimates aimed at providing some economic intuitions at this point and cannot lead to any definitive conclusions on the monetary transmission mechanism at the ZLB, especially when the 90% confidence intervals do touch on zero in the graphs, indicating statistically insignificant results. I have to acknowledge that monetary transmission mechanism at the ZLB may require fundamentally different methodologies other than an SVAR model, and the dynamic between monetary policy and real variables at the ZLB is an area that needs continued research beyond the knowledge and scope of this paper.

5.4 Discussion

To summarize my findings on the similarities and differences between the effects of monetary policy across the three estimation periods: The period of 1985-1999 with monetary targeting (through M1 growth rate targets) seems to exhibit results most consistent with economic consensus and previous scholars' estimates of monetary transmission mechanism in SOEs. The period of 2000-2011 with inflation targeting shows some unintuitive results, such as how a positive demand shock would lead to an insignificant but permanent decline in price level. And lastly, the period of 2011-2019 reveals characteristics largely in line with the 1985-1999 monetary targeting period, except that the relationship between price level and monetary base does not seem to follow the same dynamic as that with M1 as dictated by long-run neutrality of money.

The relationship between monetary policy and price level is most noteworthy among all. On one hand, all three periods confirm that monetary policy shocks have contemporaneous effects on the price level, which is contrary to the phenomenon in many other SOEs. On the other hand, the long run impact of a price level shock on the monetary policy variable seems inconclusive. One would typically expect money supply to increase after price level increases given the tight relationship in the long run between money supply and prices with a coefficient of one, which we are seeing in the 1985-1999 period with M1 but not between 2011 and 2019 with M0.

One explanation is that monetary base and central bank sight deposit might not directly react to price level, but are rather adjusted according to the exchange rate, so the indirect mechanism makes it harder to gauge the dynamic between monetary base and price level. Monetary base and sight deposit are thus unlikely to be the monetary policy tools that SNB relies on to directly influence the economy at the ZLB. Lastly, the presence of ZLB could change the monetary transmission mechanism entirely, which means we cannot conclude definitively whether a positive monetary policy shock leads to higher or lower inflation at the ZLB.

5.5 Variance Decomposition

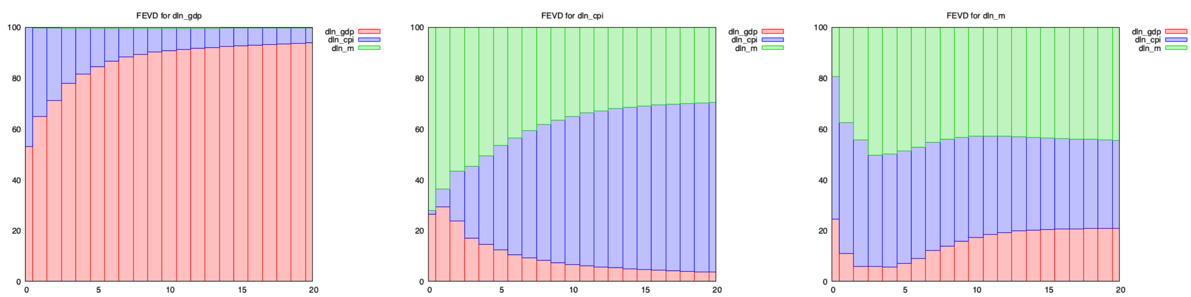
The forecast error variance decomposition (FEVD) measures the fraction of the forecast error variance of an endogenous variable that can be attributed to orthogonalized shocks from respective variables in the model. The graphs below indicate how much a shock from one variable to another impacts the variance of the forecast error of the response variable. One may observe that for instance, nearly all of the variance in the forecast error of GDP can be explained by itself, and that less than one tenth or so of the variance in the forecast error of GDP can be explained by a unit shock of price level.

If the variance in the forecast error can be more or less completely explained by the variable itself, that implies that the orthogonal shocks to other variables in the system would not increase the variance of that variable's forecast error. This is the case for GDP, while the other two variables can each attribute a decent portion of their variance to the other variables.

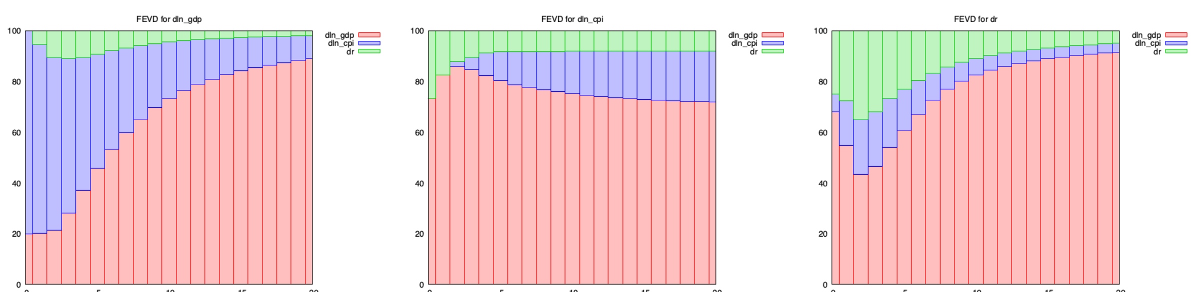
Figure 6: FEVD Graphs for GDP, Price Level, and Monetary Policy (in order)

Red: GDP; purple: price level; blue: monetary policy

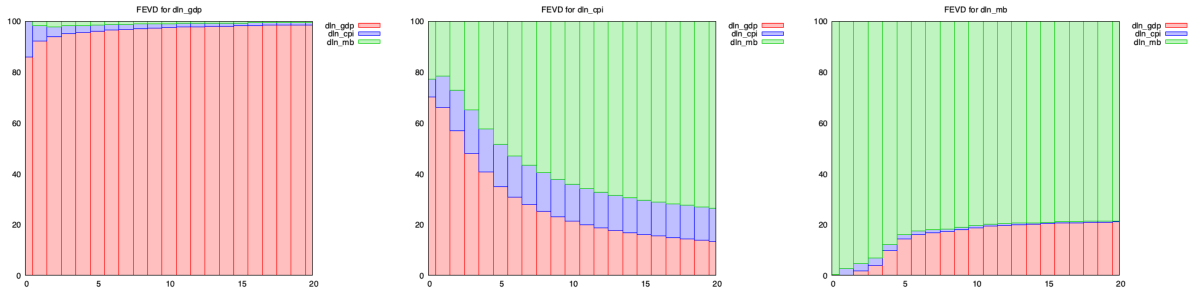
Graphs for 1985-1999:



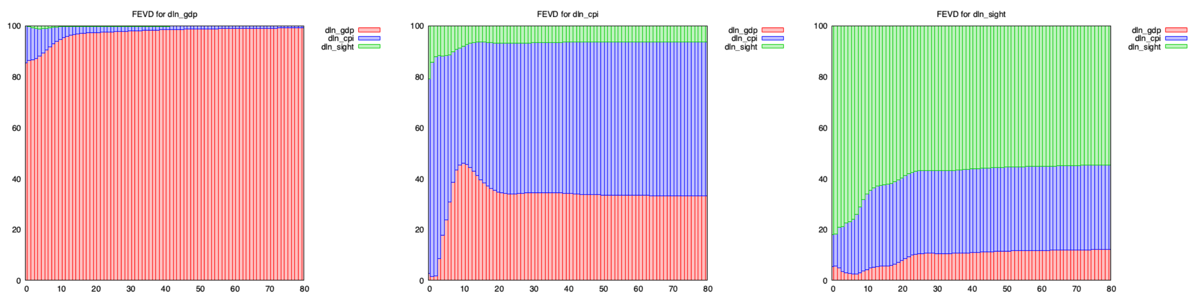
Graphs for 2000-2011:



Graphs for 2011-2019 (quarterly):



Graphs for 2011-2019 (monthly):



*A larger version of the graphs can be found in the Appendix

The figures above show a set of FEVD graphs produced by Gretl after both short-run and long-run restrictions were imposed on the model. One may observe that across all three time periods, much of the variance for GDP can be attributed to GDP itself. In periods where monetary targeting took place, monetary policy variables (M1 and M0) played a much larger role in accounting for variances in price level than interest rate would during the inflation targeting period. Much of the variance in interest rate during the inflation targeting period can be explained by GDP, while GDP plays very little role in causing variance in monetary policy variables in monetary targeting regimes, where monetary policy variables play a much more dominant role themselves.

In general, GDP seems to account for most of the variance for all variables in the inflation targeting regime. This suggests that much of the forecast errors for monetary policy and price level can be attributed to aggregate supply shocks. Gerlach and Smets (1995) found that supply shocks can explain approximately 90% of the forecast error on price level in Canada, for instance, and in this paper that ratio is around 85% for Switzerland. An interesting phenomenon here that is also similar to one of their conclusions is that the fraction of variance that GDP accounts for price level (and vice versa) does decline (and increase) in the long run, which could suggest that we are seeing an exchange of significance between supply and demand shocks when a longer forecast horizon is incorporated into the model.

It is very encouraging to see that monetary policy shocks can only account for a relatively small fraction of forecast errors for output, while they play a much larger role for price level, especially under the monetary targeting regimes. This finding is in line with Gerlach and Smets (1995) and suggests that the unsystematic parts in monetary policy should only play a small role in macroeconomic fluctuations in the long run.

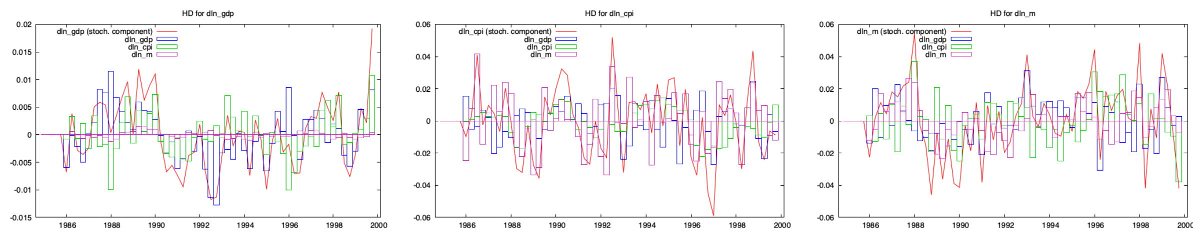
An additional interesting finding is that the variance decomposition for money supply shows that monetary policy shocks remain to account for a significant portion of the forecast error variance throughout the forecast horizon (more than 40% in 1985-1999 and more than 60% in 2011-2019), rather than declining significantly over the long run. Gerlach and Smets (1995) found that level to come down in the long run for short-term interest rates since it would be more intuitive to see monetary policy shocks play a more significant role in the short run rather than long run. Nevertheless, they still found in their study that half of the forecast error variance of Italy and Japan can be attributed to monetary policy shocks even in the long run, so the results obtained by this paper should not be too surprising and might in fact suggest the persistence of monetary policy effects in Switzerland in the long run.

5.6 Historical Decomposition

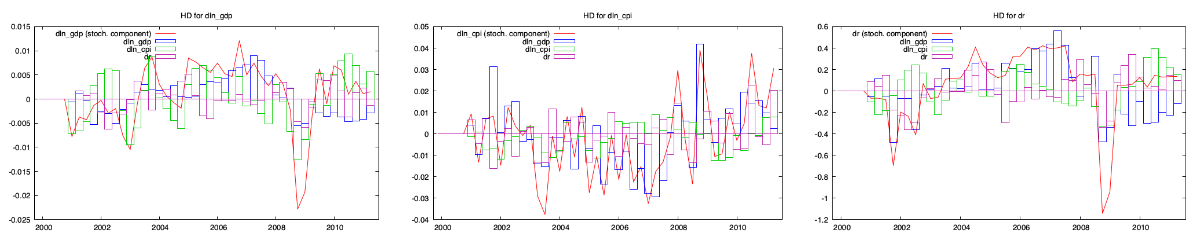
The following series of historical decomposition graphs present the time paths and estimates of structural disturbances for those four variables of interest. The graphs are produced by statistical software Gretl, and the methodology of its graphing is to depict the single contributions as histograms against time and their sum (the stochastic component) as a continuous line (Lucchetti and Schreiber 2018). Since the disturbances are orthogonal, uncorrelated, and have unit variance by construction, the graphs are particularly hard to interpret. As Gerlach and Smets (1995) warned, it should be kept in mind that historical decompositions are merely point estimates of the role of the three disturbances in different time periods and subject to uncertainty, so one should be careful not to over-interpret the smaller movements in these graphs. Another caveat brought up by the two scholars is that monetary policy shocks may be interpreted as deviations from the "average" response of monetary authorities to the estimated aggregate supply and demand disturbances, but the SVAR model does not allow one to identify the SNB's implicit reaction function, so we cannot directly distinguish the “direct” versus “indirect” effects that supply and demand shocks may have through the central banks policy reactions.

Figure 7: Historical Decomposition for GDP, Price Level, and Monetary Policy*

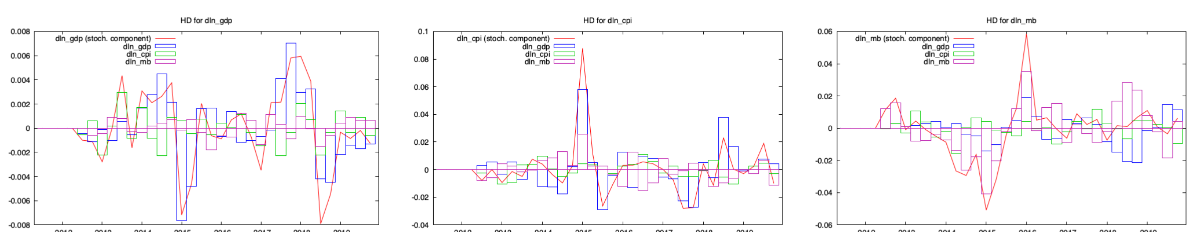
Graphs for 1985-1999:



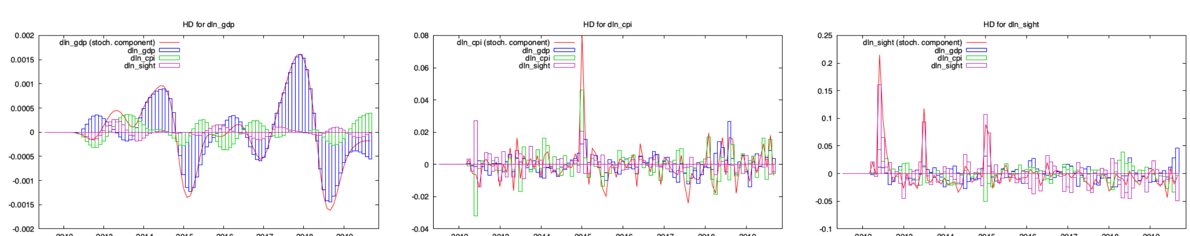
Graphs for 2000-2011:



Graphs for 2011-2019 (quarterly):



Graphs for 2011-2019 (monthly):



*A larger version of the graphs can be found in the Appendix

In general, it seems that the role of monetary policy disturbances in determining real output and price level fluctuations was limited, while interest rate certainly has actively responded to changes in real variables. The graphs for all three periods exhibit fairly similar decompositional attributes. It is noteworthy that using monthly data for 2011-2019 allows us to derive a much more detailed decomposition for the period, especially seeing the major role that supply shocks play in movements of GDP, the sharp movements in inflation in 2015, and the dramatic rise in sight deposit movements in 2012 at the beginning of the FX interventions.

We may observe from the graphs for the 2000-2011 period that the 2008 financial crisis resulted in large variations across all graphs. Contrary to the results from the variance decomposition analysis, much of the variation in GDP are explained by movements in CPI, and vice versa. An interesting observation is that while the fluctuations in money supply after 2008 was much due to money supply itself, the large decline in interest rate was driven by movements in inflation and output. More specifically, though the historical decompositions are not showing it explicitly, I would speculate that the continuous rate cuts after 2011 should not have much direct relationship with changes in money supply, but rather due to changes in GDP growth rate.

6 Conclusion

Despite the vast amount of research available on the effects of monetary policy, only a relatively small amount of research has been done about the topic in Switzerland in the past 30 years. Though there has been a rising trend after the 2008 financial crisis to research about the efficacy of unconventional monetary policy, most research has focused on the U.S. and ECB actions, despite how Switzerland is also a country that has been in the ZLB territory for years and has had a history of very dynamic interactions between monetary policy and other macroeconomic factors. This paper, therefore, largely seeks to continue much of the research on Swiss monetary policy done the 1990s and early 2000s to have a contemporary review of the matter.

In this paper, I used an SVAR model combining both short-run and long-run restrictions as my identification methodology. Because Switzerland has experienced a few major monetary policy regime changes, I decided to estimate the model in three different time periods: 1985-1999 (monetary targeting with M1), 2000-2011 (inflation targeting with nominal interest rate), and 2011-2019 (inflation targeting at the ZLB). The 2011-2019 period is the least researched and straightforward period because one could argue that the ZLB limits the central bank's ability to manipulate interest rate, which no longer seems to be an effective monetary policy tool. Instead, the expansion and contraction of SNB's sight deposit balance can be seen as the de facto monetary policy instrument as it is used to influence exchange rate and subsequently inflation and real output. I thus set out to verify this hypothesis in addition to examining the monetary transmission mechanism in the previous two periods.

I focused on the dynamic interaction between three variables – real output, price level, and whatever the monetary policy variable may be in that period. My estimation results are largely in line with established macroeconomic theories and views on the Swiss economy, which validates that the results have successfully captured some fundamental relationships at least to a certain degree. My results can be summarized in the following: I find that monetary policy shocks do often lead to immediate responses from price level, a phenomenon not seen in many other SOEs. In the long-run, however, GDP and price level both saw a more permanent increase in levels, though likely due to aggregate supply shocks rather than monetary policies, an explanation that the variance and historical decomposition analyses validate.

Fortunately, we are not seeing the "price puzzle" in the relationship between price level and interest rate during the 2000-2011 period. My estimation shows that an increase in price level would lead to an increase in interest rate, which aligns with the economic intuition that higher inflation would lead to an increase in interest rate. Meanwhile, an increase in interest rate led to lower price level, which confirms the economic theory that contractionary monetary policy should lead to deflation. Imposing both short-run and long-run restrictions in my model seems to have solved the so-call "price puzzle" found in many other VAR literature on monetary transmission mechanism that only used short-run restrictions. My analysis confirms the proposition by Gerlach and Smets (1995) that only imposing short-run restrictions might not properly discriminate between contractionary aggregate supply shocks and monetary policy shocks.

The dynamic between price level and money is less straightforward. Given the long-run neutrality of money, one would typically expect price level and money to respond to each other in a positively correlated way in the long run. We indeed see this relationship playing out during 1985-1999 between price level and M1, but not during the 2011-2019 period, in which monetary base growth does not react positively to increases in price level. Meanwhile, fluctuations in monetary base or sight deposit do not seem to cause any statistically significant responses from the real variables, either.

I previously made the hypothesis that FX interventions have essentially replaced the traditional approach of interest rate manipulation as a way to control exchange rate and inflation, since there is very little room for interest rate adjustment at the ZLB. However, the results above seem to have shown that monetary base and sight deposit are likely not the monetary policy tools that SNB relies on to directly influence the economy at the ZLB. As many scholars have already shown, the presence of ZLB could change monetary transmission mechanism entirely, and the largely statistically insignificant results in my analysis only reaffirm the difficulty of estimating a VAR model and exploring the true dynamic between monetary policies and real variables at the ZLB. I will not draw any definitive conclusions here and hope to further research about this topic in the future.

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Appendix

SVAR Model

The VAR method is a time series model of the economy that is estimated by ordinary least squares (OLS) and can be derived for a subset of the variables from a linear structural model. VAR is particularly helpful in helping identify the effect of a policy intervention on certain macroeconomic aggregates, and it has been widely used in the research for monetary transmission mechanism and effects of monetary policies. This explanation section for methodology largely follows the writings of Kilian and Lütkepohl (2017).

VAR is a set of k time series regressions, in which the regressors are lagged values of all k series. A VAR extends the univariate autoregression to a list, or "vector," of time series variables. Let Y_t be a vector of macro time series, and let ϵ_t denote some monetary policy intervention. The VAR model would be able to help us identify the dynamic causal effect of ϵ_t on Y_t. Such dynamic casual effect would be defined as the impulse response function (IRF) of Y_t to "shocks" ϵ_t. When the number of lags in each of the equations is the same and is equal to p, the system of equations is called a VAR(p). Impulse response functions and variance decomposition derived from VAR analysis can illustrate the dynamic characteristics of the empirical models.

Mathematically, the structural representation of a VAR model is:

$$B_0 Y_t = B(L) Y_{t-p} + \epsilon_t \tag{1}$$

where B_0 is the matrix of contemporaneous influences between the variables; Y_t is a $(n \times 1)$ vector of the endogenous macroeconomic variables in our model; $B(L)$ is a $(n \times n)$ matrix of lag-length p, representing impulse-response functions of the shocks to the elements of Y_t, and B is a $(n \times n)$ matrix of autoregressive polynomials that capture the linear relations between structural shocks and those in the reduced form; and lastly, ϵ_t is a $(n \times 1)$ vector of structural shocks, which should be uncorrelated and identically normally distributed.

Equivalent, the model can be written more compactly as

$$B(L) Y_t = \epsilon_t \tag{2}$$

where $B(L) \equiv B_0 - B_1 L - B_2 L^2 - ... - B_p L^p$ is the autoregressive lag polynominal. The variance-covariance matrix of the structural error term is typically normalized such that

$$E(\epsilon_t \epsilon_t^{'}) \equiv \Sigma_\epsilon = I_k.$$

SVAR (structural VAR) takes the VAR model a step further into a system of structural equations. A model is considered "structural" if it allows one to predict the effect of "structural shocks," such as deliberate policy decisions or changes in the economy of known types. A "structural" model would tell us how the intervention corresponds to changes in certain elements within the model, such as in the parameters, equations, or random variables. As a result, the parameters in SVAR are estimated by imposing contemporaneous structural restrictions, where the resulted impulse response functions and variance decomposition can now be given structural interpretations. In other words, SVARs require "identifying assumptions" that allow correlations to be interpreted causally.

We can usually begin the SVAR estimation process by running a reduced-form VAR model, which will express Y_t as a function of lags of Y_t only. We multiply both sides of the structural VAR representation by B_0^{-1}

$$B_0^{-1} B_0 Y_t = B_0^{-1} B_1 Y_{t-1} + B_0^{-1} B_2 Y_{t-2} + ... + B_0^{-1} B_p Y_{t-p} + B_0^{-1} \epsilon_t$$

and transform the model into a reduced-form representation:

$$Y_t = A_1 Y_{t-1} + ... + A_p Y_{t-p} + u_t,$$

where $A_i = B_0^{-1} B_i$ and $u_t = B_0^{-1} \epsilon_t$. Here, the reduced-form innovations u_t are a weighted average of structural shocks ϵ_t:

$$A(L) Y_t = u_t,$$

where $A(L) \equiv I_k - A_1 L - A_2 L^2 - ... - A_p L^p$.

Having estimated the reduced-form model, we then try to recover the structural representation of the VAR model. We may reconstruct ϵ_t from $\epsilon_t = B_0 u_t$, which makes it a priority for us to cover the elements of B_0 from consistent estimates of the reduced-form parameters. The decomposition of u_t may be able to help us:

$$\Sigma_u = E(u_t u_t^{'}) = B_0^{-1} E(\epsilon_t \epsilon_t^{'}) B_0^{-1'} = B_0^{-1} \Sigma_\epsilon B_0^{-1'} = B_0^{-1} B_0^{-1'},$$

since $\Sigma_\epsilon = I_k$. $\Sigma_u = B_0^{-1} B_0^{-1'}$ thus becomes a system of nonlinear equations that can be consistently estimated through imposing exclusion restrictions on selected elements of B_0^{-1} by forcing them to be zero, and thus becomes the necessity of the so-called "short-run" and "long-run restrictions" this analysis would use.

We shall compute structural impulse responses from this system, but the coefficients of this system are not identified, and we would need to place some restrictions on the parameters in order to identify the coefficients – thus comes the problem of identification and the need for SVAR.

Therefore, after we produce the combination of structural shocks and reduced-form regression errors through running a reduced-form VAR model initially, we can impose certain restrictions on the outcome to try to back out the actual relationships between the structural shocks and regressors of our interest. We now need to find a matrix D such that $Du_t = \epsilon_t$ where u_t are orthonormal and can be considered as structural shocks. We may then compute the impulse responses from $Y_t = \tilde{C}(L)u_t$, where $\tilde{C}_j = DC_j$.

Identification through Long-Run Restrictions

Blanchard and Quah (1989) achieved identification by imposing restrictions on how shocks influence endogenous variables "in the long run," i.e. the response of each endogenous variable to each shock must be zero in the long run. Their paper analyzes the U.S. economy with real gross national product (GNP) and unemployment rate data (both assumed to be stationary), and they classify two kinds of shocks – "supply" shocks and "demand" ones. The supply and demand shocks are each uncorrelated with the other, and neither has a long-run effect on unemployment. However, as for output, the demand shocks will have a temporary effect on output, while the supply shocks will have a permanent (long-run) effect on output. As a result, Blanchard and Quah (1989) explicitly impose the identifying restriction in their model that an impulse to the demand shock has no effect on the level of GNP in the long run (i.e. the cumulative response of GNP growth to the demand shock is constrained to zero in the long run), while the model would allow a supply shock to result in a change in the GNP level in the long run.

Recall our VAR model $B_0 Y_t = B(L) Y_{t-p} + \epsilon_t$, where in this particular analysis, $Y_t^{'} = [p_t, y_t, m_t, r_t]$. After running our initial VAR estimation through OLS, we would invert VAR to get $MA(\infty)$ with the expression of $B(L)Y_t = \epsilon_t$. Informally speaking, the moving average "piles up" over time, and the long-run response would essentially be the sum of those moving average coefficients. Formally, because we know that the impulse responses for our model $Y_t = A(L)Y_{t-p} + B_0^{-1}\epsilon_t$ are B_0^{-1} in the impact period, AB_0^{-1} after one period, $A^2B_0^{-1}$ after two periods, and $A^nB_0^{-1}$ after n periods, we can deduct that the long-run cumulative effects would be $D = (I + A + A^2 + ...)B_0^{-1}$, and the long-run responses are $D = (I - A)^{-1}B_0^{-1}$.

The long-run effects of the shocks on each of the endogenous variables would be related to the *sum* of their impulse responses or moving average coefficients. For instance, the long-run effect of the shock on y_t would be the sum of the shock's effects of Δy_t, Δy_{t+1}, Δy_{t+2} and so on. In other words, because we may express our vector of endogenous variables as $A(L)Y_t = u_t$ in a reduced-form VAR process (where $u_t \sim (0, \Sigma_u)$ is white noise), we may express the corresponding structural form as $B(L)Y_t = \epsilon_t$, where ϵ_t are the structural shocks. The effects of those structural shocks on the other observed variables can be obtained from the structural MA representation:

$$Y_t = B(L)^{-1}\epsilon_t = D(L)\epsilon_t.$$

In our analysis, we define our Y_t vector as

$$Y_t = \begin{bmatrix} \Delta y_t \\ \Delta p_t \\ \Delta m_t \end{bmatrix} \sim I(0)$$

where by assumption $Y_t \sim I(0)$, but p_t and $y_t \sim I(1)$. It becomes important to acknowledge that because Y_t is $I(0)$, the effect of any one structural shock on Y_t will approach zero in the long run. However, the fact that both Δp_t and Δy_t will return to their initial values eventually does not imply that the real price level or real output will necessarily return to their initial values. The effect of a given structural shock on the real GDP, for example, will in fact be the cumulative sum of its effects on Δy_t. Those long-run cumulative effects are summarized by our D matrix:

$$D(1) = \sum_{i=0}^{\infty} D_i = B(1)^{-1} = A(1)^{-1}B_0^{-1},$$

where the exclusion restrictions imposed on $D(1)$ are essentially implicit restrictions on B_0.

Then, we would need to impose identification assumption to find a matrix D such that $Du_t = \epsilon_t$. The Blanchard-Quah approach essentially identifies D by imposing restrictions on the long-run effects of one or more ϵ's on one or more Y's.

For instance, in the context of my analysis, say that I would like to categorize three kinds of shocks: aggregate supply shock, aggregate demand shocks, and monetary policy shocks, denoted respectively by u_t^y, u_t^p, and u_t^r. Then, we will subsequently have:

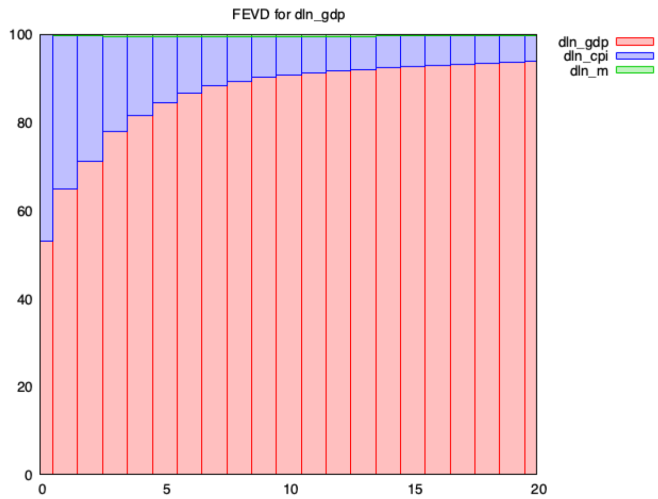
$$\epsilon_t = D \begin{bmatrix} u_t^p \\ u_t^y \\ u_t^m \end{bmatrix}; \begin{bmatrix} \Delta p_t \\ \Delta y_t \\ \Delta m_t \end{bmatrix} = \sum_{j=0}^{\infty} \tilde{C}_j \begin{bmatrix} u_{t-j}^p \\ u_{t-j}^y \\ u_{t-j}^m \end{bmatrix},$$

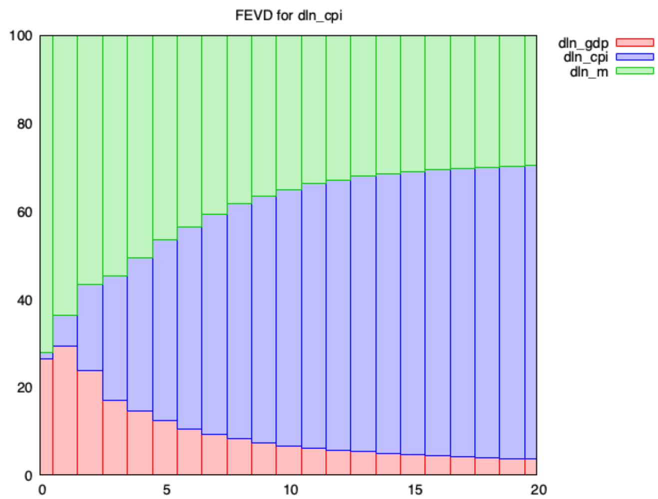
where $\tilde{C}_j = DC_j$.

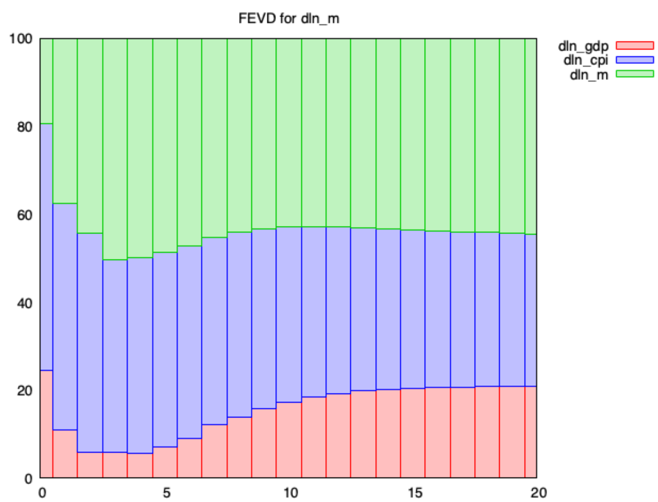
FEVD and HD Graphs

FEVD Graphs for GDP, Price Level, and Monetary Policy

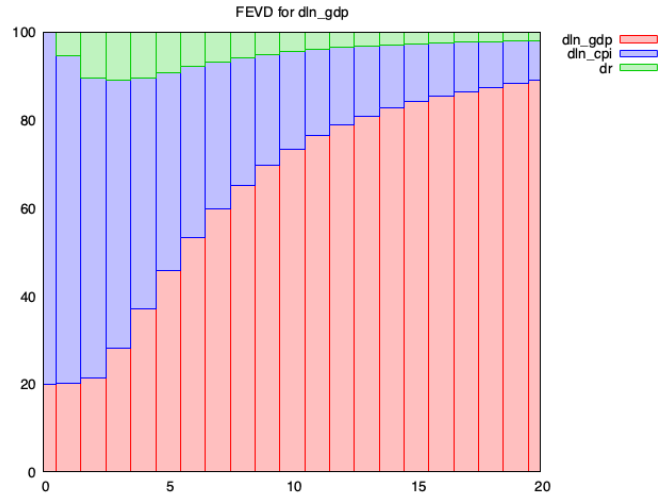
Graphs for 1985-1999:

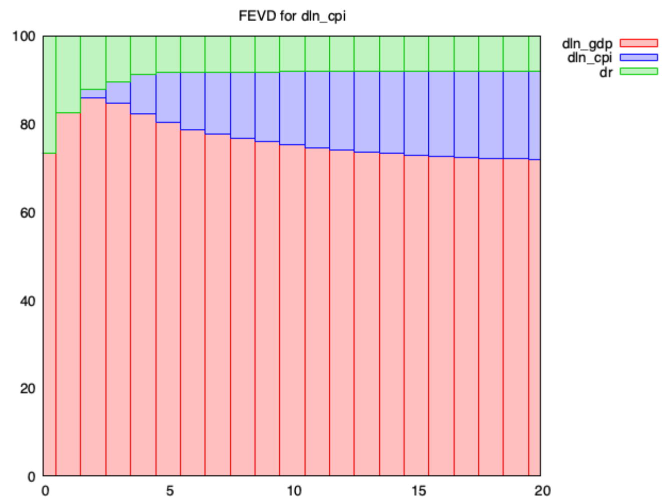


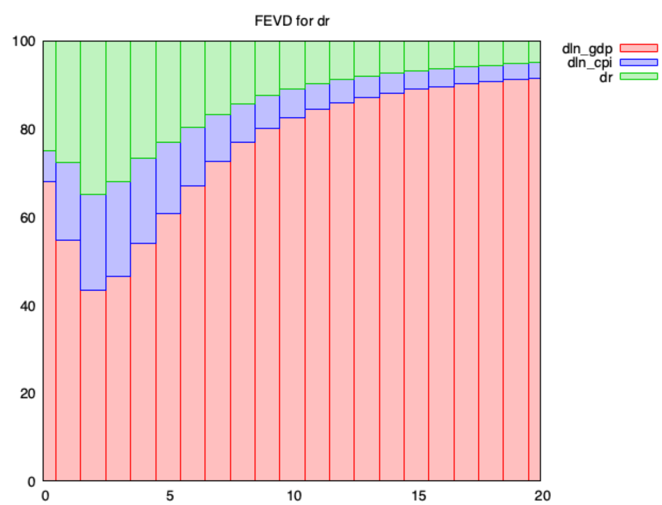




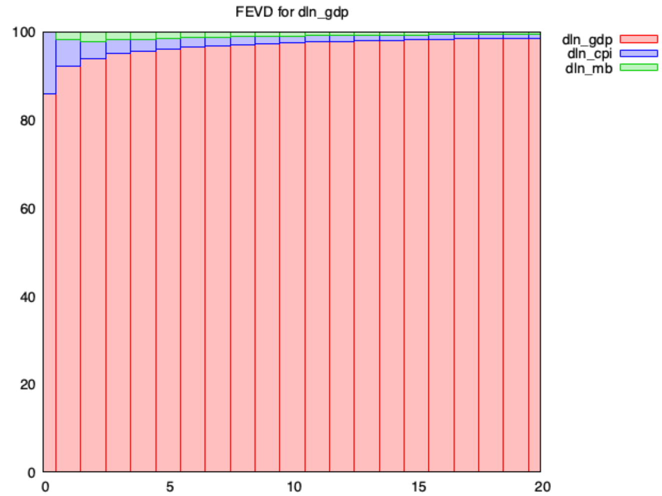
Graphs for 2000-2011:

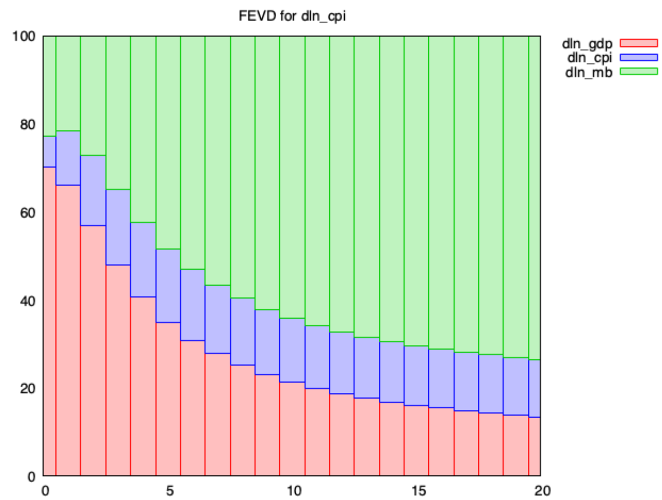


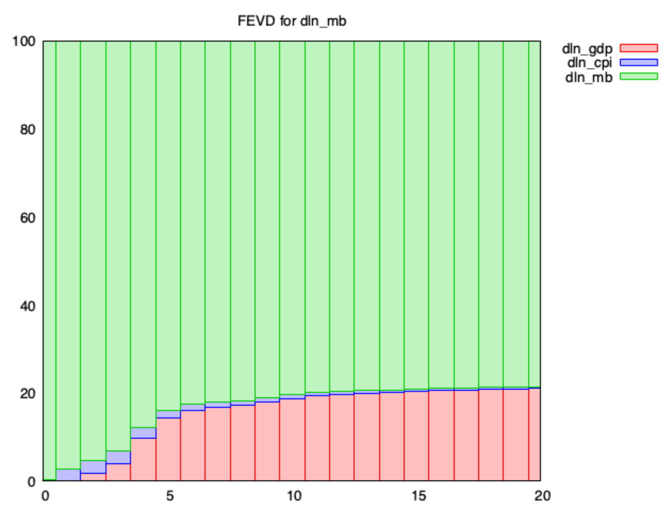




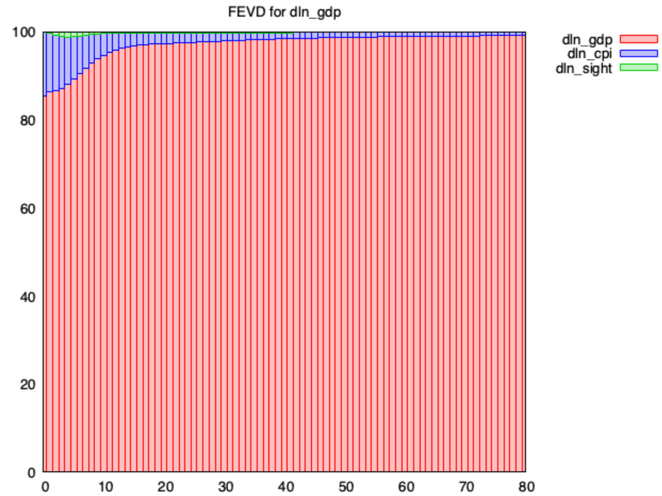
Graphs for 2011-2019 (quarterly):

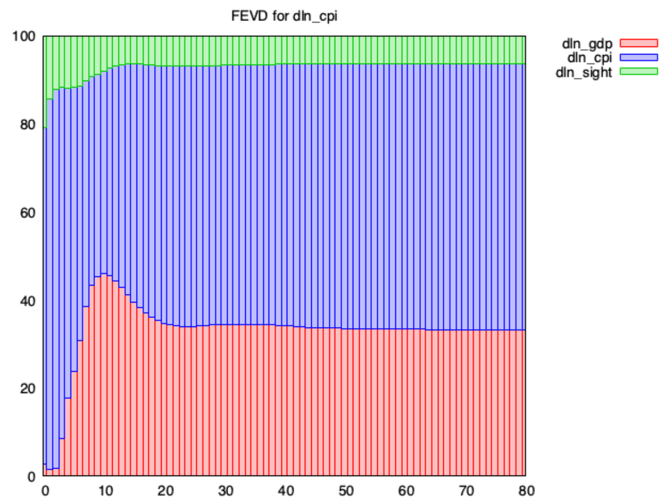


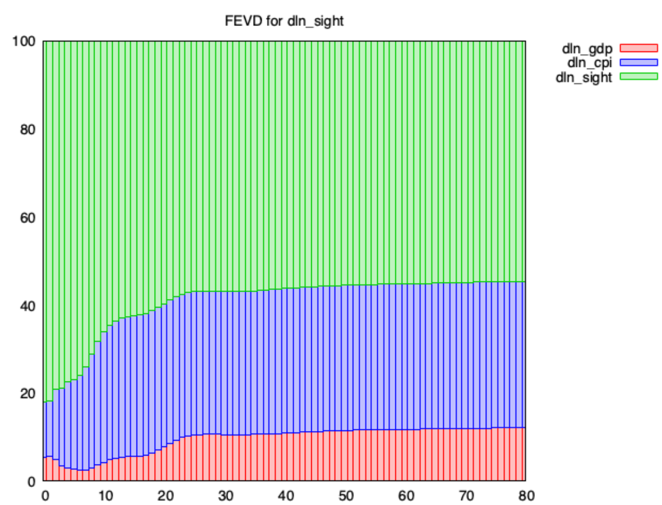




Graphs for 2011-2019 (monthly):

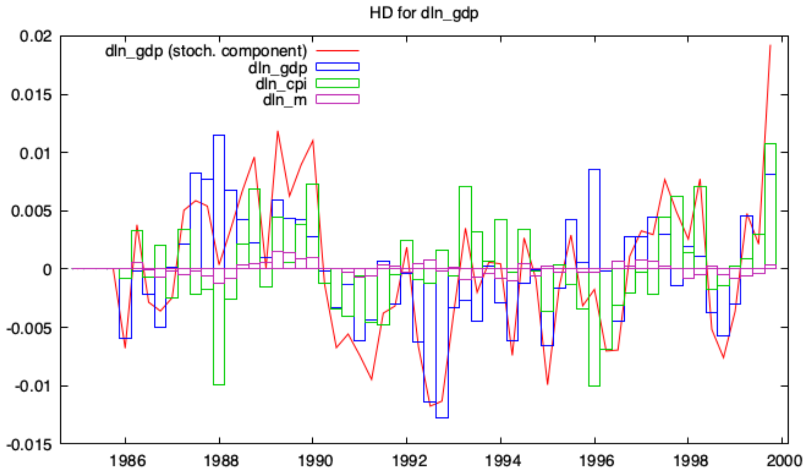


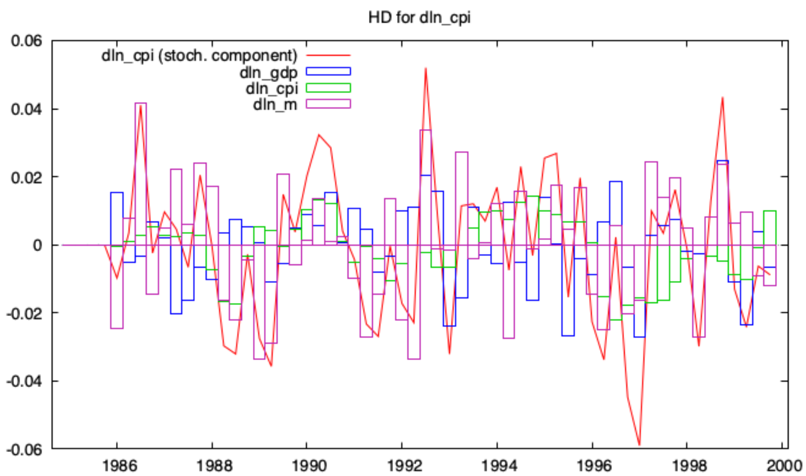


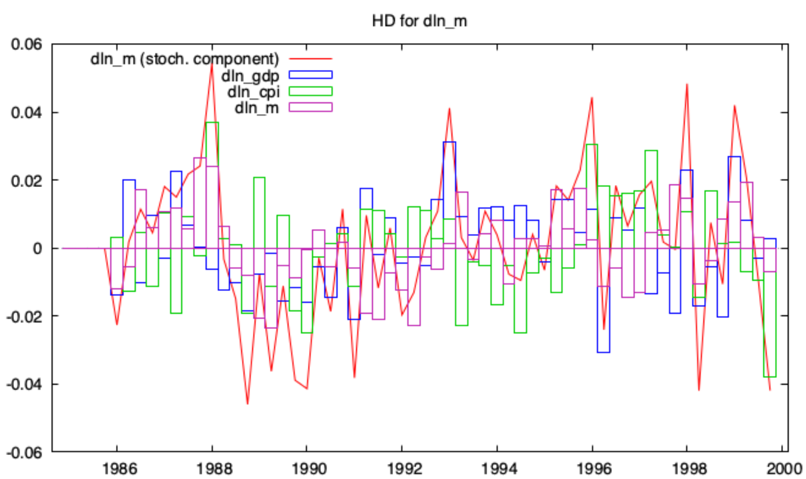


Historical Decomposition for GDP, Price Level, and Monetary Policy

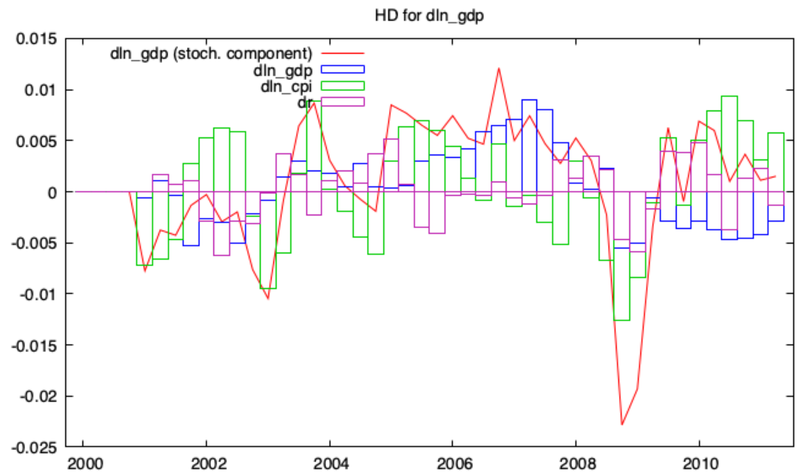
Graphs for 1985-1999:

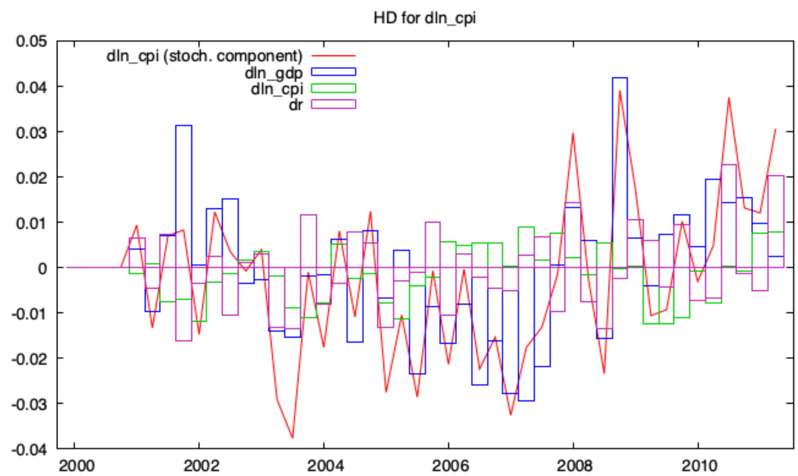


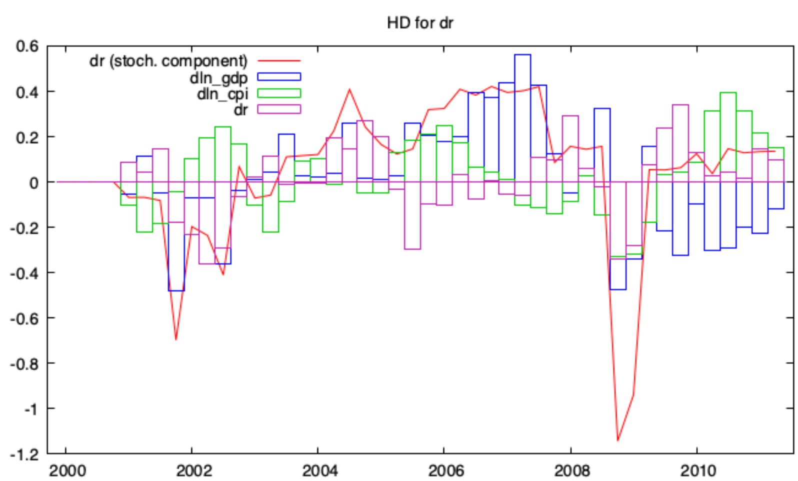




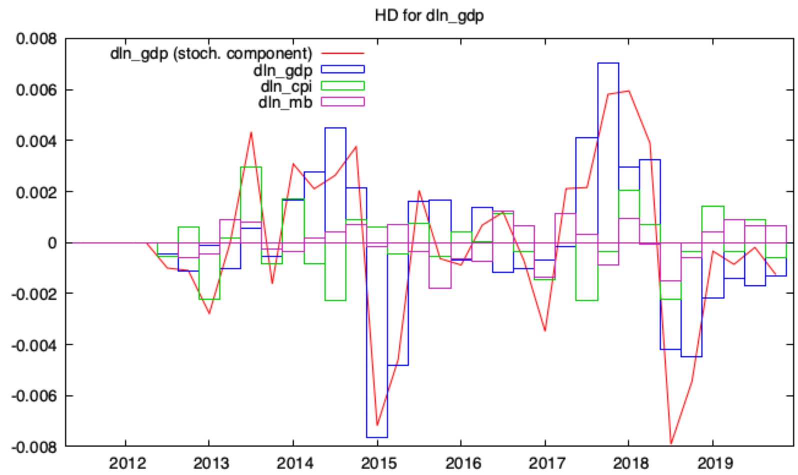
Graphs for 2000-2011:

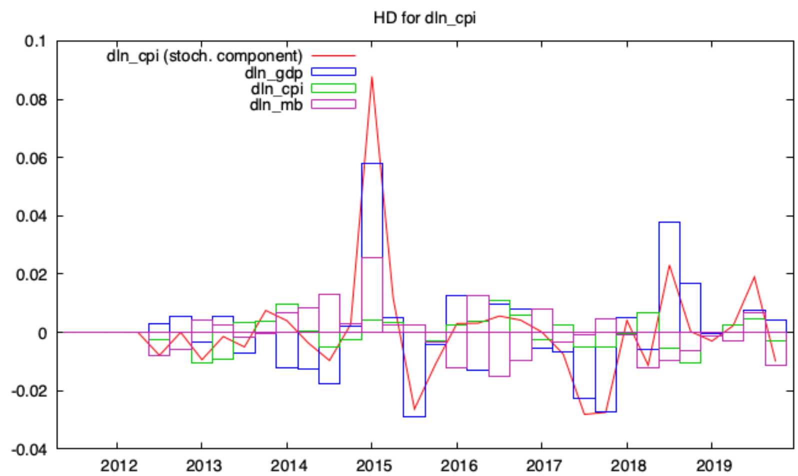


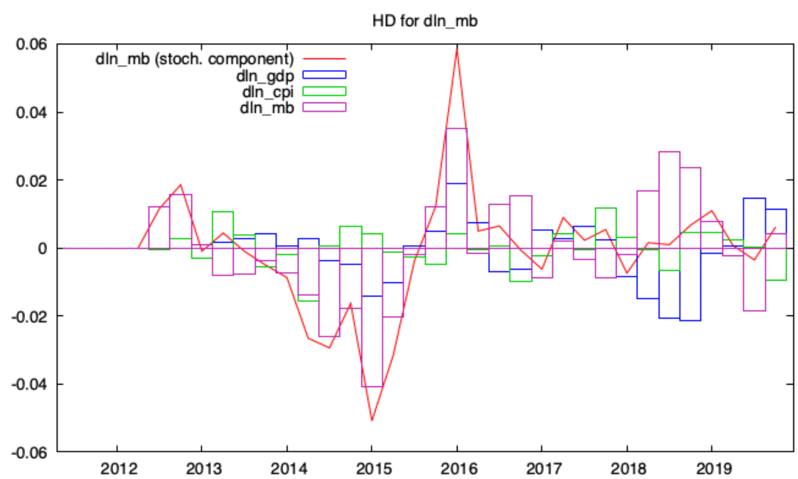




Graphs for 2011-2019 (quarterly):







Graphs for 2011-2019 (monthly):