UNIVERSITY OF LJUBLJANA
SCHOOL OF ECONOMICS AND BUSINESS

MASTER'S THESIS

MACROECONOMIC DRIVERS OF THE YIELD CURVE

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AUTHORSHIP STATEMENT

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LIST OF ABBREVIATIONS

sl. – Slovene

eng. – English

CPI – (sl. indeks cen življenskih potrebščin) – Consumer Price Index

CUSIP – (sl. Odbor za enotno identifikacijo vrednostnih papirjev); Committee on Uniform Securities Identification Procedures

FAVAR – (sl. faktorsko razširjena vektorska avtoregresija); Factor Augmented Vector Autoregression

Fed – (sl. Zvezne rezerve); Federal Reserve

FRED – (sl. ekonomski podatki Zveznih rezerv); Federal Reserve Economic Data

GDP – (sl. bruto domači proizvod); Gross Domestic Product

GNP – (sl. bruto nacionalni proizvod); Gross National Product

MBS – (sl. hipotekarno zavarovani vrednostni papirji); Mortgage Backed Security

NBER – (sl. Državni urad za ekonomske raziskave); National Bureau of Economic Research

QE – (sl. količinsko sproščanje/popuščanje); Quantitative Easing

RMBS – (sl. vrednostni papirji zavarovani s stanovanjsko hipoteko); Residential Mortgage-Backed Securities

UK – (sl. Združeno Kraljestvo); United Kingdom

US – (sl. Združene države); United States

VAR – (sl. vektorska avtoregresija); Vector Autoregression

VECM – (sl. vektorski model popravka napak); Vector Error Correction Model

INTRODUCTION

The term structure of interest rates or the yield curve describes the relationship between spot rates of different maturities and is one of the most important concepts in finance and economics. The current yield curve contains information about the future condition of the economy and it can be employed for forecasting as yield spreads contain predictive content for future short-term yields, real economic activity and inflation (Stock & Watson, 1989; Mishkin, 1990a; Mishkin, 1990b). The term structure represents a basis for decisions about investments, savings and policy decisions by firms, consumers and policy makers. The yield curve is also an indicator of the market's beliefs about the expected course of future monetary policy. Wu (2003) argues it is important to understand the forces behind the yield curve movements since policymakers, when pursuing policy objectives, change the policy rate in response to fundamental macroeconomic shocks. The yield curve is a key part of the transmission mechanism and the effectiveness of monetary policy. Central banks move the very short end of the yield curve through monetary policy measures. The effects of these measures are expected to spread to medium- and longer-term rates. The monetary policy impulse spreads to asset pricing, which is relevant for the financial conditions of households and firms, affecting their consumption, production, investment decisions and inflation by affecting the term structure. It is in policymakers' interest to understand the transmission of changes from the short- to medium- and long-term interest rates as the interest rates of longer maturities determine borrowing costs and consequently aggregate demand. Therefore, the analysis of the term structure can convey some inferences about how the monetary policy affects the term structure. Moreover, studying the yield curve and its relationship with the economy is important for government debt policy in terms of debt issuance and debt servicing decisions. Risk management strategies including derivatives pricing, hedging and future interest rates scenarios depend on the yield curve as well since the prices of coupon bonds and derivatives such as swaps, futures and options on interest rates are priced on the basis of the zero-coupon term structure of interest rates. Moreover, yield curve movements affect banks' management of balance sheet flows, assets and liabilities. Consequently, the yield curve can be regarded as an incremental tool and indicator for the economy and financial industry (Wu, 2003, p.24-26; Piazzesi, 2010, p. 694-695).

Initially, studies concerning the relationship between the yield curve and the macroeconomy focused on the ability of the yield curve slope to predict inflation and output. The predictive power of the slope of the yield curve for real economic activity and inflation shows that the yield curve slope is a very effective tool for forecasting recessions in real time (Estrella, Rodrigues & Schich, 2003; Estrella, 2004; Estrella & Trubin, 2006). Examination of the link between the yield curve spread and the macroeconomy was eventually replaced by more complex and sophisticated studies implementing joint macro-finance models of the yield curve and macroeconomic variables. Studies focusing on the factors that move the yield curve assume that term structure movements are driven by unobserved financial factors. The decomposition of the term structure into three latent factors has a long tradition in the financial literature. Most of the literature discussing such term structure models employs Nelson and Siegel's (1987) three factors term structure model, where the factors moving the term structure are named the level, slope and curvature due to the effect they have on the term structure movement (Nelson & Siegel, 1987; Diebold & Li, 2006). In order to capture the relation between the macroeconomy and the yield curve, Gurkaynak and Wright (2012) stress the importance of connecting the term structure with macroeconomic fundamentals, which gave rise to the appearance of joint macro-finance models. The purpose is to find a dynamic relation between the shape of the yield curve, more precisely the level, slope and curvature of the yield curve, and the main macroeconomic variables. This kind of bi-directional relationship is relevant for policymakers due to the vast information contained in the yield curve that can be used for predicting business cycles, inflation and monetary policy. Furthermore, it is important because of the informative nature of the yield curve about the transmission of monetary policy and the dynamic effects of shocks on the macroeconomy. A breakthrough regarding this line of research is represented by the research conducted by Ang and Piazzesi (2001), wherein they introduced two macroeconomic factors into an affine term structure model. Ang and Piazzessi (2001) were followed by several peers who estimated joint macro-finance models using an affine arbitrage-free specification of the term structure and macroeconomic variables. On the other hand, researchers, such as Rudebusch and Wu (2004), used a more structural approach in estimating the macro-finance model that combines the arbitrage-free term structure representation with macroeconomic variables. The third methodologic group, which deals with macro-finance modelling and the links between the yield curve and macroeconomic variables, consists of studies moving away from an affine arbitrage-free specification of the term structure. These studies jointly integrate parsimonious Nelson and Siegel (1987) yield curve representation and macroeconomic variables into joint macro-finance models. Since several studies present evidence of the changing relationship between the yield curve and the macroeconomy in periods of changing monetary policy stance, an interesting question appears that deserves some attention. In particular, what happens to yield curve factors and their relation with the macroeconomy, notably the monetary policy, after the introduction of non-standard monetary policy measures, more precisely QE. This question, together with the examination of the standard yield curve-monetary policy relationship and determination of main macroeconomic drivers of the yield curve, represents the subject of this master's thesis.

The purpose of this master's thesis is to determine how monetary policy affects the yield curve and whether the response of the yield curve to monetary policy shock alters after the implementation of QE. By employing the Svensson (1994) term structure representation that consists of four latent yield curve factors, this master's thesis goes further than the three-factor Nelson and Siegel (1987) yield curve representation, which is the most widely used in macro-finance models. In addition, the usage of the FAVAR model for jointly modelling the dynamics of yield curve factors and macroeconomic variables enables the use of a greater variety of observable macroeconomic time series data. Furthermore, the master's thesis also studies the relationship between the yield curve and macroeconomic variables other than the monetary policy instrument. The objective is to add some additional information regarding the relationship between the yield curve and monetary policy, as well as other macroeconomic variables through the greater variety of observable macroeconomic variables and the use of a less parsimonious yield curve model. Moreover, the objective is to examine whether the relationship changes after the implementation of QE.

The Master's thesis is constructed from two parts in terms of the research methodology. The first part of the master's thesis is the descriptive part. This consists of the theoretical overview of the literature, research papers and studies discussing yield curve models with macroeconomic factors and the yield curve-macro relationship. The descriptive part discusses the two structure models that are the most widely used and most important for its purposes. Moreover, it includes an overview of empirical findings, discussions, analyses and modelling approaches from different authors examining the relationship between the yield curve and macroeconomic variables. In order to give the reader an insight into the effect of QE on the yield curve, the overview of the literature discussing this topic is included in the descriptive part as well. The first part of the master's thesis is therefore based on the descriptive method and the compilation method since it consists of the literature overview and research papers findings. The second part of the master's thesis is the empirical part and is based on the method of econometric modelling. In order to analyse how monetary policy affects the yield curve and whether there is a change in the relationship following the implementation of QE, the Svensson (1994) yield curve latent factors and macroeconomic variables dynamics are modelled in FAVAR. I use the two-step estimation procedure to estimate the joint macro-finance model with the estimation of latent yield curve factors preceding FAVAR estimation. Following the Svensson (1994) yield curve model parameters estimation, FAVAR is estimated using the two-step estimation procedure presented by Bernanke, Boivin and Eliasz (2004). In order to determine other macroeconomic drivers, simple regressions of yield curve factors on lagged macroeconomic variables, and vice versa, are estimated. The empirical research is conducted for the United States of America because of the previous employment of non-standard monetary policy measures, notably the QE. The latter means that the period after the implementation of the QE is longer, which increases the reliability of results.

The master's thesis deals with the following research questions:

- How does a monetary policy shock affect the yield curve through latent yield curve factors?
- Does the relationship between the monetary policy and the yield curve change after the implementation of QE?
- Does the potentially changed relationship between the monetary policy and the yield curve affect the response of macroeconomic variables to a monetary policy shock?
- Which are the main macroeconomic variables that drive the yield curve through yield curve factors?

- Is the relationship between the yield curve factors and macroeconomic variables bi-directional and does the relationship change after the implementation of QE?

The master's thesis consists of seven chapters. In the first chapter, the two most widely used term structure models are presented. The second chapter is comprised of the compilation of research papers' findings on the relationship between macroeconomic variables and yield curve factors and the literature overview of the information contained in the yield curve. Moreover, the second chapter also presents different approaches to modelling the yield curve-macroeconomic dynamics. The third chapter discusses the effects of QE on the yield curve and its transmission channels. In the following chapter, the joint macro-finance model with all its constituent parts is presented. In the fifth chapter, the data used for model estimation is presented. The sixth chapter describes the estimation of both parts of the model, the Svensson (1994) yield curve model and FAVAR. In the seventh chapter, the estimation results are presented and discussed in the context of the previously presented theoretical overview and research questions. The master's thesis concludes by summarizing its main findings.

1 TERM STRUCTURE OF INTEREST RATES

1.1 Relation between spot rates, yields to maturity and forward rates

1.1.1 Spot rates and yields to maturity

Implied forward rates can be estimated from interest rates on existing financial instruments, and computing implied forward interest rates from yields to maturity on zero-coupon bonds is quite straightforward. However, the computation of implied forward interest rates from yields to maturity on coupon bonds is more challenging. The fact that the majority of bonds whose time to maturity exceeds 12 months are coupon bonds represents an inconvenience in terms of computing the implied forward interest rates. Yields to maturity on coupon bonds and zero-coupon bonds of the same maturity are not identical. A coupon bond can be treated as a portfolio of zero-coupon bonds of different maturities where each zero-coupon bond corresponds to a particular coupon payment based on the amount and the timing of that coupon. As a consequence, yields to maturity on coupon bonds can be obtained as an average of yields to maturity on zero-coupon bonds from a portfolio that represents a particular coupon bond for the time span from the first to the last coupon payment and the payment of the face value. Implied forward rates from coupon bonds are estimated in two steps. The first step is the estimation of implied spot rates from yields to maturity on coupon bonds, and in the second step, implied forward interest rates are computed from the previously obtained implied spot rates (Svensson, 1994, p. 2).

The continuously compounded spot interest rate for a zero-coupon bond at time t that matures at time $T > t$ is denoted by $i(t,T)$ and the time to maturity is denoted by $m = T - t$. The term structure of interest rates at a particular date t is represented by combinations of spot rates $i(t, t+m)$ and the times to maturity m belonging to those spot rates (Svensson, 1994, p. 3). If the rates are continuously compounded, the price of a zero-coupon bond with a par value A at time t with maturity date T and denoted by $P_{ZERO}(t,T)$ is given by

$$P_{ZERO}(t,T) = A\,exp\left(-\frac{i(t,T)}{100}(T-t)\right) \tag{1}$$

where the expression $\exp(x)$ in equation (1) denotes the exponential function e^x. From equation (1), the following discount function denoted by $d(t,T)$ can be extracted.

$$d(t,T) = exp\left(-\frac{i(t,T)}{100}(T-t)\right) \tag{2}$$

Since a coupon bond can be seen as a portfolio of zero-coupon bonds, the discount function is used in its pricing (Svensson, 1994, p. 3). A coupon bond with a coupon rate of c percent per year (annual coupons) and a face value equal to A paid at the maturity date T with m years to maturity has the price $P(t, t+m)$ at trade date t.

$$P(t, t+m) = \textstyle\sum_{k=1}^{m} A\,c\,d(t, t+k) + Ad(t, t+m) \tag{3}$$

The yield to maturity is the internal rate of return for the coupon bond. This is the constant interest rate that equalizes the present value of the bond's coupon payments and the face value with the bond's price (Svensson, 1994, p. 3). The yield to maturity $y(t, t+m)$ expressed in percent per year of the coupon bond solves the following equation.

$$P(t, t+m) = \textstyle\sum_{k=1}^{m} A\,c\,exp\left(-\frac{y(t,t+m)}{100}k\right) + A\,exp\left(-\frac{y(t,t+m)}{100}m\right) \tag{4}$$

The yield to maturity $y(t, t+m)$ can be regarded as an average of the spot rates of zero-coupon bonds forming a portfolio representing a particular coupon bond up to the time to maturity. This kind of yield cannot precisely represent the term structure of interest rates. The present value of a coupon bond in equation (3) is computed by the usage of spot rates from equation (2) and those spot rates differ among maturities. Conversely, the present value of the coupon bond in equation (4) is computed with a constant yield to maturity, equalizing the present value of a coupon bond with the present values of its coupons and par value. It is essential to consider the impact of the coupon effect on the yield to maturity. The yield to maturity of a coupon bond depends on its coupon rate, taking a term structure of spot rates and maturity as given, which is why yields to maturity for coupon bonds with the same maturity date and different coupon rates differ. Moreover, bonds' duration and convexity also differ for bonds with the same maturity but different coupon rates. The implication of a higher coupon rate is an increase in the share of early cash flows, which is why the impact of short spot rates on the yield to maturity is greater than in the case of a lower coupon rate.

The term structure of interest rates can be represented precisely only by the usage of spot rates but there is a problem regarding the availability of spot rates. For shorter maturities, spot rates can be obtained as rates on zero-coupon bonds but for longer maturities, zero-coupon bonds are not sufficiently available. Spot rates need to be estimated from yields on coupon-bonds (Svensson, 1994, p. 3-4).

1.1.2 Forward rates

As described, implied forward rates can be calculated from spot rates. A forward investment can be reproduced by a sale of a zero-coupon bond that matures on the settlement date of the forward contract and a purchase of a zero-coupon bond that matures on the maturity date of this particular forward contract. Market values of zero-coupon bonds reproducing a particular forward investment are the same at the time of the sale and purchase. Thus, we can denote $f(t,t',T)$ as the forward rate on a forward contract with the trade date at time t, the settlement date $t' > t$, and maturity date $T > t'$ (Svensson, 1994, p. 4). In the case of continuously compounded rates, the following equation expresses the relation of forward rate and spot rates.

$$e^{(t'-t)i(t,t')}e^{(T-t')f(t,t',T)} = e^{(T-t)i(t,T)} \tag{5}$$

Equation (5) implies that investing at rate $i(t,t')$ for time period $t'-t$ and reinvesting the return at rate $f(t,t',T)$ for time period $T-t'$ yields the same as investing at rate $i(t,T)$ for time period $T-t$. Solving equation (5) for $f(t,t',T)$ yields the equation for calculating a forward rate from spot rates (Svensson, 1994, p. 4).

$$f(t,t',T) = \frac{(T-t)i(t,T)-(t'-t)i(t,t')}{(T-t')} \tag{6}$$

Consider the instantaneous forward rate, where the difference between the maturity date and the settlement date of a particular forward contract is infinitesimally small. The instantaneous forward rate is defined as the limit of $f(t,t',T)$ where $T \to t'$ (Svensson, 1994, p. 4).

$$f(t,t') = \lim_{T\to t'} f(t,t',T) \tag{7}$$

The finite-maturity forward rate $f(t,t',T)$ is the average of instantaneous forward rates $f(t,\tau)$ with settlement between t' and T where $T > t'$.

$$f(t,t',T) = \frac{\int_{\tau=t'}^{T} f(t,\tau)d\tau}{T-t\prime} \tag{8}$$

The instantaneous forward rate can be regarded as the marginal increase of the total return resulting from the marginal increase in the time span of the investment. Instantaneous forward rates are related to finite-maturity spot rates. Therefore the spot rate $i(t,T)$ at time

t with the maturity at time T is equal to the average of instantaneous forward rates with settlements between the trade date t and the maturity date T (Svensson, 1994, p. 5).

$$i(t,T) \equiv \frac{\int_{\tau=t}^{T} f(t,\tau)d\tau}{T-t} \tag{9}$$

Taking the derivative with respect to T gives the identity that describes the relation between the instantaneous forward rate and the spot rate.

$$f(t,T) \equiv i(t,T) + (T-t)\frac{\delta i(t,T)}{\delta T} \tag{10}$$

Shiller and McCulloch (1990) suggest that the instantaneous forward rate is related to the spot rate in the same way as marginal costs are related to average costs. In order to depict this relation, they suggest imagining the term $T - t$ as the produced output and the spot rate $i(t,T)$ as a price of one unit of output or average cost. The instantaneous forward rate is then regarded as a marginal cost. The instantaneous forward rate equals the instantaneous spot rate whenever the difference between T and t is equal to zero. By increasing the time to maturity represented by T, assuming other variables remain constant, the instantaneous forward rate decreases or increases in comparison to the spot rate. The forward rate is less than the spot rate when the slope of a term structure is negative and greater when the slope is positive. The representation of the relationship between forward and spot rates suggested by Shiller and McCulloch (1990) is also reflected in the shapes of their curves, since they are similar to the shapes of marginal and average curves known from microeconomics (McCulloch, 1975; Shiller & McCulloch, 1990; Svensson, 1994, p. 5)

1.2 Nelson – Siegel term structure model

Nelson and Siegel (1987) introduce a simple parametric or parsimonious model with enough flexibility to represent the yield curve and to capture its stylized facts. The Nelson and Siegel (1987) term structure model can be regarded as an affine arbitrage-free term structure model with several restrictions. Nelson and Siegel's (1987) instantaneous forward rate function is a member of a class of functions that are able to generate the typical yield curve shapes depending on the values of estimated coefficients. This class of functions can adapt to monotonic, humped or S-shaped forward curves. They are associated with solutions to differential equations where spot rates are generated by a differential equation and the instantaneous forward rate is the solution to the second order differential equations with two equal roots. The instantaneous forward rate function $f(\tau;b)$ has the following form.

$$f(\tau;b) = \beta_0 + \beta_1 e^{-\tau/\lambda_1} + \beta_2 \frac{\tau}{\lambda_1} e^{-\tau/\lambda_1} \tag{11}$$

In equation (11), $f(\tau)$ denotes the instantaneous forward rate $f(t, t+\tau)$ on a given trade date t, time to settlement is denoted as τ, and $b = (\beta_0, \beta_1, \beta_2, \lambda_1)$ represents a vector of the parameters. The instantaneous forward rate function consists of three components. The first component is a constant β_0. The second component is an exponential term $\beta_1 e^{-\tau/\lambda_1}$ that monotonically decreases towards zero in the case of positive β_1 or increases towards zero in the case of negative β_1 by the increase of the time to maturity. The third component is the term $\beta_2 \frac{\tau}{\lambda_1} e^{-\tau/\lambda_1}$ and generates a hump shape. The third component is a function of τ as well as the second component. Due to the described properties of the three components, the instantaneous forward rate approaches the constant β_0 as τ approaches infinity and it is regarded as the asymptotic long-term value of the instantaneous forward rate. The instantaneous forward rate approaches the constant $\beta_0 + \beta_1$ in cases where τ approaches zero and consequently $\beta_0 + \beta_1$ can be regarded as the short-term rate. Parameter λ_1 determines the position of the first hump or the position of the maximum of the loading on β_2 (lower λ_1 means greater hump shape) and β_2 specifies the direction and the degree of the hump. The parameter λ_1 determines the exponential decay rate. Lower values of λ_1 produce faster decay and better fit of the yield curve at short maturities.

Additionally, equation (11) can be, according to Nelson and Siegel (1987), regarded as a Laguerre function because it is composed of a polynomial multiplied by an exponential decay term. Nelson and Siegel (1987) suggest that the coefficients of the function can be interpreted as contributing to the function due to the previously described properties of the instantaneous forward rate function components. β_0 is the contribution of the long-term component, β_1 is the contribution of the short-term component and β_2 represents the contribution of the medium-term component.

From the instantaneous forward function written in equation (11), the spot rate $i(t, t+\tau)$ for a particular date t and time to maturity τ can be derived by integration according to equation (9). The result is the following Nelson and Siegel (1987) expression for the spot rate.

$$i(\tau; b) = \beta_0 + \beta_1 \frac{1 - e^{-\tau/\lambda_1}}{\tau/\lambda_1} + \beta_2 \left(\frac{1 - e^{-\tau/\lambda_1}}{\tau/\lambda_1} - e^{-\tau/\lambda_1} \right) \tag{12}$$

The properties described for the instantaneous forward rate also apply to the spot rate including the following limiting results:

$$\lim_{\tau \to 0} i(\tau; b) = \beta_0 + \beta_1; \ \lim_{\tau \to \infty} i(\tau; b) = \beta_0 \tag{13}$$

Diebold and Li (2006) interpret Nelson and Siegel's (1987) functional form from equation (12) as a dynamic latent factor model. They estimate it for each period to extract the three-dimensional parameters that evolve dynamically. They use these to forecast the yield curve. Diebold and Li (2006) interpret $\beta_{0,t}$, $\beta_{1,t}$ and $\beta_{2,t}$ as three latent dynamic factors where the Nelson and Siegel (1987) framework imposes structure on factor loadings. They interpret the factors as level, slope and curvature. The first latent factor $\beta_{0,t}$ can be interpreted as the overall level of the yield curve as its loading is the same for all maturities. Another reason for regarding the $\beta_{0,t}$ as the level factor is due to the previously stated property of Nelson and Siegel's (1987) functional form that the rate approaches $\beta_{0,t}$ as m approaches infinity. The second latent factor $\beta_{1,t}$ has a maximum loading at the shortest maturity, which monotonically decays through zero as maturities increase. The short-term factor $\beta_{1,t}$ is related to the yield curve slope since increasing $\beta_{1,t}$ increases short-term yields more than long-term yields due to the loadings of the factor being greater for the short rates. Furthermore, the yield curve slope can be defined as the difference in the rates when m is equal to infinity and m is equal to zero. The difference is equal exactly to $-\beta_{1,t}$ which is another reason for regarding $\beta_{1,t}$ as the slope factor. Diebold and Li (2006) showed that $\beta_{1,t}$ corresponds to the negative of the traditionally defined slope, which is conventionally expressed as the difference between the long- and short-term yields. Therefore in the context of Diebold and Li (2006), a positive value of $\beta_{1,t}$ indicates an inversion of the yield curve. A decrease in the $\beta_{1,t}$ factor means that the slope of the yield curve has increased and vice versa. The loading of the third latent factor $\beta_{2,t}$ equals zero at the shortest maturity, attains its maximum at the intermediate maturity and then decays back to zero as maturities increase. Increasing $\beta_{2,t}$ has little effect on short- or long-term yields and a great effect on medium-term yields due to loadings of the factor being the greatest for the medium-term rates (Diebold & Li, 2006; Christensen, Diebold & Rudebusch, 2009; Christensen, Diebold & Rudebusch, 2011).

1.3 Svensson term structure model

Svensson (1994) increases the flexibility and improves the fit of Nelson and Siegel's (1987) function by extending their instantaneous forward rate function. According to De Pooter (2007), the design of the Svensson (1994) model enables a better fit of the model to term structure shapes with more than one local maximum or minimum along the maturity spectrum. Moreover, De Pooter's (2007) empirical findings suggest that an additional fourth latent yield curve factor, in contrast to the Svenson (1994) model, which is interpreted as a dynamic latent factor model, improves the in-sample fit and the forecasting performance of the model. The original three term Nelson and Siegel (1987) function was extended by a second hump-shape or U-shape term $\beta_3 \lambda_2 \tau e^{-\lambda_2 \tau}$ with two additional parameters β_3 and λ_2 where λ_2 must be positive. Parameter β_3 has an impact on the direction and the degree of the second hump and parameter λ_2 affects the position of the second hump. For components that are the same as in Nelson and Siegel's (1987) forward rate function, the same properties apply as in the case of Nelson and Siegel (1987) model. The instantaneous forward function has the form written in equation (14) (Svensson, 1994, p. 6-7).

$$f(\tau; b) = \beta_0 + \beta_1 e^{-\tau/\lambda_1} + \beta_2 \frac{\tau}{\lambda_1} e^{-\tau/\lambda_1} + \beta_3 \frac{\tau}{\lambda_2} e^{-\tau/\lambda_2} \tag{14}$$

In the forward rate function (14), b represents all parameters, $b = (\beta_0, \beta_1, \beta_2, \lambda_1, \beta_3, \lambda_2)$ and τ is the notation for time to settlement. From the instantaneous forward function written in equation (14), the spot rate $i(t, t+\tau)$ for a particular date t and time to maturity τ can be derived by integration according to equation (9) (Svensson, 1994, p. 6-7).

$$i(\tau; b) = \beta_0 + \beta_1 \frac{1-e^{-\tau/\lambda_1}}{\tau/\lambda_1} + \beta_2 \left(\frac{1-e^{-\tau/\lambda_1}}{\tau/\lambda_1} - e^{-\tau/\lambda_1}\right) + \beta_3 \left(\frac{1-e^{-\tau/\lambda_2}}{\tau/\lambda_2} - e^{-\tau/\lambda_2}\right) \quad (15)$$

The discount function is consequently expressed as

$$d(\tau; b) = exp\left(-\frac{i(\tau;b)}{100}\tau\right) \quad (16)$$

and it is consistent with the expression for the discount function (2).

The limiting results expressed in equation (13) also apply for the Svensson (1994) functional form of the yield curve expressed in equation (15), since the fourth component predominantly affects medium-term maturities. The same holds as well for the other properties of the spot rate described in Nelson and Siegel's (1987) model. The only difference in comparison to Nelson and Siegel (1987) is the extended second hump-shaped factor with a separate decay parameter, which increases the flexibility and the fit of the yield curve model proposed by Nelson and Siegel (1987) (Svensson, 1994, p. 6-7).

2 YIELD CURVE AND THE ECONOMY

2.1 Yield curve relationship with output and inflation

Harvey (1988) considers a version of the consumption-based asset pricing model that implies a linear relation between expected returns and expected consumption growth. The latter is described by the first order condition characterizing the solution of a consumer's planning problem. The usage of an appropriate utility function and the consumption-based asset pricing model's properties enables Harvey (1988) to link the marginal utility ratio in the first-order condition to the consumption growth rate, meaning the real interest rate may predict future economic consumption growth. Harvey (1988) also empirically confirms the informative content of the real term structure for the future consumption growth. Furthermore, Stock and Watson (1989) develop the business cycle leading indicators model to track economic downturns in real time and identify a connection between economic activity and the spread between yields on 10-year and 1-year Treasury securities. Stock and Watson (1989) recognize that a declining yield curve represents a signal of a future downturn in economic activity. Stock and Watson (1989) identify that each NBER-dated peak of the economic cycle is preceded by a negative yield spread by approximately 12 months. Estrella and Hardouvelis (1991) build on Harvey (1988) and especially Stock and Watson (1989) when studying the ability of the term structure to predict real economic activity. Their empirical research is based on US data from 1955 to 1988. Estrella and Hardouvelis (1991) implement a simple regression model, where the dependent variable is the annualized cumulative percentage change in the seasonally-adjusted real GNP and the independent variable is the spread between yields on the 10-year government bond and the 3-month Treasury Bill. Moreover, Estrella and Hardouvelis (1991) implement a simple probit model using the spread and binary variable described based on NBER-dated recessions. The results show that the increase in the slope of the yield curve predicts an upturn and the decrease in the slope of the yield curve predicts a downturn in economic activity. Estrella and Hardouvelis (1991) conclude that the yield curve slope predicts real GNP and its private sector components, consumption, consumer durables and investment. However, the slope was unable to predict the economic downturn that followed shortly after the publication of the research. As a consequence, in subsequent years other researchers conceptually followed and built their studies on Estrella and Hardouvelis (1991).

Plosser and Rouwenhorst (1994) study the predictive content of the yield spread for various countries over the time period from 1973 to 1988. Plosser and Rouwenhorst's (1994) findings suggest that the yield spread has a significant in-sample predictive ability for future changes in economic activity for horizons of up to five years with the strongest predictability power for horizons of up to two years. Furthermore, the results indicate the usefulness of the longer end of the term structure for predicting future economic activity. Estrella and Mishkin (1997) obtain consistent results for the US and several European countries. The relationship between the yield curve and output examined by Estrella and Hardouvelis (1991) is confirmed across countries with minor differences in strength. Furthermore, Dotsey (1998), studies the predictive ability of the yield spread through yield spread decomposition. Defined as a difference in nominal interest rates on bonds of different maturities, the yield curve spread consists of the real term spread, the expected difference in inflation and a term premium. The yield curve spread is affected solely by temporary changes in its respective components because a permanent change has the same effect on the long- and short-term interest rates. Dotsey (1998) builds his study on the idea that the spread behaviour is consistent with the real business cycle theory and that the spread could signal changes in the economy that are not necessarily backed by monetary shocks. Similarly to Estrella and Hardouvelis (1991), Dotsey (1998) confirms that the predictive content of the spread is not affected by controlling for monetary policy stance. Empirical results exhibit greater responsiveness of output growth to low spread values than to high spread values. Dotsey (1998) explains this finding by pointing out that recessions are generally short and severe. Estrella, Rodrigues and Schich (2003) create models to prediction economic growth and recessions for Germany and the US that confirm the predictive power of the yield spread. Rudebusch and Williams (2009) follow Estrella and Hardouvelis (1991) in forecasting recessions using a probit model based on the yield spread and the consistent results obtained from it. Estrella and Hardouvelis's (1991) findings support the stability of the relationship since the middle of the 1980s. However, Estrella, Rodrigues and Schich (2003) note the instability in output growth predictions using the yield spread as a predictor. The strong relationship between the yield curve and economic activity is also confirmed by Rudebusch and Williams (2009) as their probit model outperforms benchmark models in predicting recessions over longer horizons. Rudebusch and Williams (2009) credited the strong predictive power of the yield curve slope to the lagging impact of the monetary policy stance on the economy encompassed in the yield curve.

Estrella and Mishkin (1998) focus on predicting recessions in the US with the emphasis on the out-of-sample performance of the probit model. Estrella and Mishkin's (1998) findings support the fact that the inverted yield curve signifies an economic downturn in the next four quarters as noted by Stock and Watson (1989). Estrella and Mishkin (1998) detect a negative relationship between the probability of recession and the yield curve spread. The yield spread also retains its predictive power when extending the probit model to include macroeconomic indicators, stock prices, several different spreads, and the indicators used by Stock and Watson (1989). Hamilton and Kim (2002) argue that the expectation hypothesis of the term structure and the temporary influence of monetary policy are the reasons for the yield spread's predictive ability for economic activity. They refer to a general empirical finding of Estrella and Mishkin (1997) that in comparison to the short rate, yields of longer maturities increase by less in response to an increase of the monetary policy instrument. Hamilton and Kim (2002) and Estrella and Wu (2008) decompose the yield spread into expectations and term premium components to examine the role of both components in predicting recessions. They identify that both effects are relevant for real GDP growth predictions although the majority of the informative content is in the expectations component. Estrella and Trubin (2006) emphasize the role of monetary policy and investor expectation as an explanation for the relationship between the yield curve and recessions. Estrella and Trubin (2006) see the yield curve as a more forward-looking indicator of economic conditions since the relationship between the yield curve and recessions relies heavily on long-term investor expectations, which are influenced by the monetary policy stance. In Estrella (1997) and Estrella (2004), the monetary policy reaction function is presented as the main reason for the relationship between the yield curve spread and output. A small dynamic rational expectation model containing the Philips curve, the dynamic IS curve, the monetary policy rule, the term structure considering expectation hypothesis, and the Fisher equation is implemented. The results presented in Estrella (1997) and Estrella (2004) suggest that the strength of the relationship depends on the monetary policy regime, in particular the monetary policy authority's aim. The strength of the relationship increases by increasing the importance of targeting output as Estrella (2004) finds that the strength of the relationship depends on parameters in the monetary policy reaction function.

Contemporaneously with the appearance of studies dealing with the predictive ability of the yield curve for economic activity, Mishkin (1990a, 1990b, 1990c) examines the yield curve's predictive ability for inflation. According to Mishkin (1990a, 1990b) and Estrella, Rodrigues and Schich (2003), the relationship between the slope and inflation is based on the Fisher decomposition of interest rate, which states that the m-period nominal interest rate i_t^m can be separated into two components. The first component is the m-period expected real interest rate $E_t r_t^m$ and the second component is the expected inflation rate over the time span m, $E_t \pi_t^m$ (Mishkin, 1990a; Mishkin, 1990b).

$$i_t^m = E_t r_t^m + E_t \pi_t^m \tag{17}$$

In the case of rational expectations, realized inflation π_t^m can be divided into the expected inflation rate over the next m periods and the error term ε_{t+m}^m uncorrelated with the information at time t.

$$\pi_t^m = E_t \pi_t^m + \varepsilon_{t+m}^m \tag{18}$$

Combining equations (17) and (18) gives the following expression for realized inflation π_t^m.

$$\pi_t^m = i_t^m - E_t r_t^m + \varepsilon_{t+m}^m \tag{19}$$

In order to define the relationship between the slope of the term structure and inflation, the difference between inflation over the next m periods and over the next n needs to be expressed as follows.

$$\pi_t^m - \pi_t^n = -(E_t r_t^m - E_t r_t^n) + \beta^{m,n}(i_t^m - i_t^n) + (\varepsilon_{t+m}^m - \varepsilon_{t+n}^n) \tag{20}$$

$$\pi_t^m - \pi_t^n = \alpha^{m,n} + \beta^{m,n}(i_t^m - i_t^n) + \eta_{t+n}^{m,n} \tag{21}$$

Equation (21) represents a cornerstone for studies examining the relationship between the yield curve and inflation. Mishkin (1990a, 1990b, 1990c) empirically examines whether the term structure contains information regarding the future path of inflation since it contains information about the future interest rates movements. Mishkin (1990a, 1990b) finds that the long end of the term structure interest rates contains substantial information about the future inflation but little information about the term structure of real interest rates. On the other hand, the short end contains substantial information about the real interest rates movements and little information regarding the future expected inflation. Mishkin (1990a, 1990b) concludes that a steepening yield curve signifies a rise in expected rate of inflation while a decrease in the slope of the yield curve signifies the opposite. Mishkin (1990c) and Estrella and Mishkin (1997) confirm that the described relationship holds also for other countries besides the US although the significance differs across the countries considered. Estrella, Rodrigues and Schich (2003) implement continuous and binary models for the US and Germany, and the usage of the continuous model confirms that the term structure of interest rates is informative regarding future inflation. Mishkin's (1990c) multi-country study also suggests that changing monetary policy conduct is likely to alter the relationship. Estrella (2004) demonstrates that the predictive power of the yield curve slope for inflation depends on the monetary policy rule parameters, which makes it dependent on monetary policy. Estrella (2004) presents an empirically more stable relationship between the slope and the inflation in periods corresponding to a stable monetary policy.

2.2 Yield curve latent factors and macroeconomic variables

Different methodologies are used in studies dealing with joint models of the yield curve and macroeconomic dynamics. An affine arbitrage-free specification of the term structure and macroeconomic fundamentals follows the encouraging results presented in section 2.1. The dynamics between unobservable yield curve factors and macroeconomic variables are examined through estimation of joint macro-finance models. Furthermore, several studies are more inclined to use a more structural approach when joining affine arbitrage-free term structure models and macroeconomic fundamentals. Finally, several studies move away from an affine arbitrage-free specification of term structure to the usage of a popular parsimonious Nelson and Siegel (1987) model, thereby implementing Nelson and Siegel's (1987) yield curve model into joint macro-finance models.

2.2.1 Affine arbitrage-free term structure models and macroeconomic variables

Ang and Piazzesi (2003) present the basis for joint macro-finance models, although Evans and Marshall (2001) precede them by examining the effect different types of macroeconomic shocks have on nominal yields through yield curve unobservable factors. Evans and Marshall (2001) claim that the cornerstone of the informative content of the yield curve is the decomposition of nominal interest rate movements into real rate movements and changes in inflation expectations. Each part of the decomposed nominal interest rate could be associated with various macroeconomic shocks. Evans and Marshall (2001) estimate several versions of the VAR model consisting of macroeconomic variables such as industrial production, CPI, Federal Funds rate, real interest rate, real M1 balances, and bond yields of different maturities using monthly data for the US from 1959 to 2000. Initial analysis demonstrated that 22% of short-run variation in the short end of the yield curve can be attributed to macroeconomic variables, primarily the Federal Funds rate changes, while the long-run variation of the shorter and the longer end of the yield curve can be attributed mainly to macroeconomic variables other than the Federal Funds rate, explaining 86% of variation. Evans and Marshall (2001) define the level, slope and curvature of the yield curve by extracting three principal components out of the yield data to be able to study their responses to macroeconomic shocks. The behaviour of the extracted factors does not differ largely from the latent factors obtained by Ang and Piazzesi (2003). Evans and Marshall (2001) suggest that aggregate demand shocks induce persistent and significant large shifts of the yield curve level, due to the reinforcing effect on real rate and inflation level, while monetary policy shock is responsible for substantial changes in the slope of the yield curve. Since it affects primarily the short end of the yield curve, a contractionary monetary policy shock flattens the yield curve. The response of the slope to the aggregate demand shock is insignificant but persistent in the longer end of the yield curve. Evans and Marshall (2001) explain this as a consequence of a significant and persistent response of term premiums that conveys the yield curve response to the aggregate demand shock from the slope to the level of the yield curve. Households are apparently more risk averse regarding the business cycle, mainly because of preference or demand shocks, resulting in the term premium and yield curve behaviour described. Considering fiscal policy shocks, constructed as the shock to the government deficit, Evans and Marshall (2001) could not find any empirical evidence suggesting that fiscal policy shocks have a significant effect on the yield curve. However, Bikbov and Chernov (2010) identify that the effects of exogenous monetary and fiscal shocks on the long end of the yield curve are as important as inflation and real activity shocks. Inflation, real activity and their persistent past values explain up to 50% of variation in the slope of the yield curve while the remaining part is strongly correlated with exogenous fiscal shocks. Not only fiscal developments, but also global developments affect the yield curve since Diebold, Li and Yue (2008) and Abbritti, Dell'Erba, Moreno and Sola (2013) identify that global factors are important drivers of country bond yields. The importance of global factors for yield determination increases with the maturity of yields.

Ang and Piazzesi (2003) include macroeconomic factors in an affine term structure model and explain joint dynamics of the yield curve and macroeconomic variables in VAR. This represents a breakthrough in the field of studying the relationship between the yield curve and macroeconomic variables in the context of joint macro-finance models. Subsequent studies implementing macroeconomic variables into affine term structure models follow the conceptual framework introduced by Ang and Piazzesi (2003). However, Ang and Piazzesi (2003) only allow for unidirectional dynamics in their macro-finance model, meaning that macroeconomic variables can determine yields, but yield curve factors cannot determine macroeconomic variables. In the model, macroeconomic variables are represented by extracted first principal components from two groups of variables, i.e. inflation and real activity. Furthermore, Ang and Piazzesi (2003) implement the macroeconomic factors obtained into a Taylor-rule-based equation for the short rate and introduce a specification of the short rate as an affine function of observable macroeconomic and unobservable yield factors. Ang and Piazzesi (2003) conclude that introducing macroeconomic factors does not affect the level factor effect on the yield curve while a considerable amount of effect from slope and curvature factors is transferred to macroeconomic factors, especially inflation. Ang and Piazzesi's (2003) results suggest that the yield curve reacts to inflation and real activity shocks in the same direction but to different extents. Inflation has the greatest effect on the yield curve at the short end while responses to real activity shocks are less dependent on maturity. However, Ang and Piazzesi's (2003) results demonstrate that inflation influences the yield curve more than real activity irrespective of the maturity. At the short and the middle end of the yield curve, macro factors can explain up to 85% of the variation. The explanatory proportion decreases as maturity increases, explaining only approximately 40% of variation at the long end. As a consequence, Ang and Piazzesi (2003) argue that longer-end movements of the yield curve are mainly driven by latent yield curve factors while inflation and real activity mainly affect the yield curve at the short and the middle end. A positive shock of any macro factors considered induce yield curve flattening. Besides the improved understanding of the yield curve and macroeconomic dynamics, Ang and Piazzesi (2003) point out that introducing macroeconomic variables into the model improves the forecast performance since macroeconomic variables bear additional information regarding the yield curve. Since Ang and Piazessi (2003) point out that macroeconomic factors affect mainly the short-run interest rates dynamics while unobservable factors account for the dynamics of the longer-run interest rates, Dewachter and Lyrio (2006) present an affine term structure model with incorporated macroeconomic factors and their long-run expectations that makes it possible to interpret factors affecting the long-run interest rates dynamics as well. The four macroeconomic factors are the output gap, inflation, the real interest rate, and the long-run inflation expectation. Dewachter and Lyrio (2006) find that two types of factors drive the yield curve. Inflation, the real interest rate and the output gap drive the yield curve at its short end and represent the first type of factors. The second type of factors affect the longer end of the yield curve, in particular the long-run inflation expectation. Dewachter and Lyrio's (2006) results suggest the level factor is mainly explained by the long-run inflation expectations. A positive relation between slope to inflation and the output gap shocks indicates a connection to the business cycle and the validity of its representation of business cycle conditions. The effect of the business cycle is temporary and important mainly for the shorter end of the yield curve, being consistent with the slope effect. Contrary to Ang and Piazzesi (2003), Dewachter and Lyrio (2006) interpret the curvature factor and conclude that contractionary monetary policy increases short- and medium-term interest rates through the curvature factor.

In the same year as Ang and Piazzesi (2003), Bomfim (2003) examines an economic interpretation for a standard arbitrage-free two-factor affine term structure model for the US. Bomfim (2003) builds his research on a postulate that monetary policy participates in determination of market interest rates and the expectation hypothesis of the yield curve, which states that long-term yields encompass future expectation regarding short-term yields influenced by the monetary policy. Bomfim (2003) suggests that the current and the expected monetary policy stance are important drivers of the yield curve as the first factor corresponds to a short-term interest rate and moves closely with the Federal Funds rate while the second factor corresponds to future expectations of the monetary policy instrument. Moreover, Ang, Piazzesi and Wei (2004) assign the predictive power of the yield curve to the risk premium and the expectation hypothesis since the behaviour of the yield curve changes across the business cycle due to changes in risk premium and the central bank's actions. Contrary to the majority of related studies, Dewachter, Iania and Lyrio (2011) model macroeconomic and term structure dynamics using VECM and find that the term premium component is mainly driven by financial factors and the expectation component by macroeconomic factors.

Mönch (2005) designs a term structure model using common components of a large number of observable macroeconomic variables and the short rate. In fact, Mönch (2005) combines the FAVAR model with the standard affine term structure model by using FAVAR as the state equation. Mönch (2005) extracts first three principal components from the yields dataset, used for estimating the term structure model, and treats them as level, slope and curvature. This enables Mönch (2005) to study the relationship between macroeconomic factors extracted from a large macroeconomic dataset and latent yield factors. All macroeconomic factors contribute significantly to the yield curve level variation, explaining almost the entire variation. However, the predominant explaining forces are the short-term interest rate, the first macroeconomic factor related to the business cycle and the second macroeconomic factor related to inflation. Furthermore, variation of the yield curve slope is almost entirely explained by macroeconomic factors, which explain 80% of its variation. The business cycle and inflation factors exhibit a positive relation with the yield curve slope being, according to Mönch (2005), consistent with the expected flattening of the yield curve in a case of inflationary pressure. The yield curve slope, as identified by Mönch (2005), is negatively related to the short-term interest rate, being consistent with the fact that increases in the short-rate are followed by a decrease in the yield curve slope. Mönch (2005) claims that variations in the relative size of yields do not depend heavily on macroeconomic developments since only 48% variation of the yield curve curvature is explained by macroeconomic factors. Mönch (2005) stresses the importance of including a larger dataset of macroeconomic variables since his model provides a good in-sample fit of the yield curve and strongly outperforms benchmark models.

Ang, Boivin, Dong and Loo-Kung (2011) study the implications for the term structure of interest rates induced by changes in the conduct of monetary policy, as expressed by the shifting response to inflation and real activity. In their affine arbitrage-free term structure model, short rate dynamics follow Taylor's policy rule and the model allows for varying central bank responses to inflation and output where policy parameters are persistent and might be influenced by past economic developments. As a consequence, they include parameters from the policy reaction function into the state equation represented by VAR. Ang, Boivin, Dong and Loo-Kung (2011) find that changes in the conduct of the monetary policy affect the term structure quantitatively. A non-anticipated increase in the sensitivity of the Fed to inflation fluctuations induces a rise in short rates and an increase of the term spread. Ang, Boivin, Dong and Loo-Kung (2011) explain this finding by investors' perception of increased sensitivity to inflation fluctuations at the short end of the yield curve as bonds over the whole maturity spectrum become more exposed to inflation. Conversely, a non-anticipated increase in the sensitivity of the Fed to output gap fluctuations raises the short rate and decreases the term spread.

2.2.2 Affine arbitrage-free term structure models and macroeconomic variables – the structural approach

Rudebusch and Wu (2004) create a macro-finance model combining the two-factor arbitrage-free term structure representation and a structural specification of macro-finance factors. In a standard affine arbitrage-free specification of the term structure and macroeconomic fundamentals, the short-term interest rate is determined by a monetary policy reaction function such as the Taylor rule. However, Rudebusch and Wu (2004) claim that the short-term interest rate can be decomposed into two latent yield curve factors from the arbitrage-free term structure model. Moreover, Rudebusch and Wu (2004) claim that the financial representation of the short rate (represented by two latent yield factors) and macroeconomic representation of the short rate (the Taylor rule) can be connected. Rudebusch and Wu (2004) specify the short-term interest rate as the sum of the long run level of the short-term interest rate (consisting of the equilibrium real rate and monetary policy inflation target) and cyclical adjustments responding to deviations from the inflation target and long-run potential real output. The connection between the financial representation and macroeconomic representation is established by identifying the level factor as the inflation target in the Taylor rule and the slope factor as the cyclical adjustment part of the Taylor rule. Rudebusch and Wu (2004) refer to Gurkaynak, Sack and Swanson (2005), who argue that long rates movements reflect inflation expectations rather than real rates to support their assumption that the variation of the central bank's inflation target accounts for the majority of the level factor fluctuations. Since the level factor, seen as an inflation objective, is probably a complicated function of past and expected future inflation, macroeconomic conditions and monetary policy objectives, Rudebusch and Wu (2004) simplify the level factor expression as being equal to a weighted average of the lagged level factor and current inflation. Estimating the two connections separately suggests that the Taylor rule decomposition of the short rate into the long-term level of the short rate and a cyclical component coincides with the decomposition of the short rate into level and slope factors. Consequently, the macro-finance model implemented by Rudebusch and Wu (2004) combines an affine arbitrage-free term structure model with a small modified New Keynesian macroeconomic model. Estimation results suggest high correlation between the level and slope factors obtained in the estimation of the term structure alone and the level and slope factors obtained in the estimation of the macro-finance model. This underpins the bi-directional relationship and identifications of the level factor as medium-term central bank inflation target and the slope factor as cyclical fluctuation in inflation and output gap. Furthermore, Hördahl, Tristani and Vestin (2004) implement a joint model of macroeconomic and yield curve dynamics by combining a small structural macroeconomic model with an affine arbitrage-free term structure model. The framework presented by Hördahl, Tristani and Vestin (2004) is similar to the one presented by Rudebusch and Wu (2004) and Wu (2005). Three key macroeconomic variables used are inflation, output gap and the short-term monetary policy interest rate. A small structural macroeconomic model consists of only three equations. Two equations describe the evolution of inflation and the output gap while the third one represents the monetary policy rule, which is similar to the Taylor rule but enhanced by including the interest rate smoothing. Results suggest that changes in the perceived inflation target induce a parallel and persistent upward shift of the yield curve and a positive monetary policy shock induces flattening of the yield curve by affecting the slope. Moreover, as Rudebusch and Wu (2004), Hördahl, Tristani and Vestin (2004) note, the importance of macroeconomic factors as yield curve drivers decreases as maturity of yields increases. Wu (2005) expresses yields as linear functions of macroeconomic variables whose dynamics are underpinned by the underlying New

Keynesian general equilibrium model. Wu (2005) concludes that slope factor movements are mainly influenced by exogenous monetary policy shocks while level factor movements correspond to output shocks. Wu (2005) refers to Evans and Marshall (2001) and concludes that a contractionary monetary policy shock has a transitory effect on the yield curve since it tilts and flattens the yield curve. Bekaert, Cho and Moreno (2010) modify the structural models presented by implicitly deriving the term structure model in the IS curve and using a standard optimizing sticky price model with endogenous persistence. Strong contemporaneous responses of the entire yield curve to different macroeconomic shocks is suggested, although two are dominant. Inflation target shocks predominantly affect the level factor while the majority of variation in the slope and curvature factors could be attributed to monetary policy shocks. Contrary to Rudebusch and Wu (2004), Bekaert, Cho and Moreno (2010) argue that the inflation target shock has a stronger positive effect on the shorter than on the longer end of the yield curve while Rudebusch and Wu (2004) claim the opposite.

2.2.3 Nelson-Siegel term structure model and macroeconomic variables

Following the findings of Diebold and Li (2006), studies are moving away from an affine arbitrage-free specification of the term structure to the usage of popular Nelson-Siegel parsimonious representation of the yield curve. The framework was introduced by Diebold, Rudebusch and Aruoba (2006), who focus on examining the interconnectivity between the yield curve factors and macroeconomic fundamentals. Diebold, Rudebusch and Aruoba (2006) propose a joint macro-yields model with latent yield curve factors complemented with observable macroeconomic variables. The measurement equation incorporates Nelson and Siegel’s (1987) yield curve functional representation following the approach of Diebold and Li (2006). The transition or state equation including latent yield curve factors and macroeconomic variables is specified as VAR. Such model design, contrary to Ang and Piazzesi (2003), allows for bidirectional dynamic interactions between macroeconomic variables and yield curve factors. Diebold, Rudebusch and Aruoba’s (2006) analysis suggests that the Federal Funds rate responds to slope shocks and a positive level shock increases all macroeconomic variables considered. Moreover, yield curve responses to macro shocks exhibit unresponsiveness of the curvature factor to macro shocks. However, the slope factor responds to shocks of all macro variables considered (real economic activity, Federal Funds rate and inflation). An increase in the Federal Funds rate immediately flattens the yield curve. Similarly, an increase in real activity or inflation imposes a similar, although delayed, reaction of the slope factor whereby the response to inflation is less pronounced. An increase in inflation announces a long-lasting increase in the level factor as inflation shocks affect the level factor by changing future inflation expectations. A surprise increase of real activity has a similar effect, imposing inflationary pressure. Diebold, Rudebusch and Aruoba (2006) find that the causality from macroeconomic variables to yield curve is significantly stronger than the causality from yields to macroeconomic variables. However, Diebold, Rudebusch and Aruoba (2006) argue that bidirectional interactions are present and important. Acatrinei (2017) and Hoffmaister, Roldos and Tuladhar (2010) identify that macro-financial linkages, described by Diebold, Rudebusch and Aruoba (2006), are in general quite similar across countries. Ang, Dong and Piazzesi (2005) methodologically follow Diebold, Rudebusch and Aruoba (2006). They find that the portion of yield variation that can be explained by macroeconomic factors relies on the structure of the macro-finance model, in particular whether bidirectional interactions are allowed or not. In the case of unidirectional interactions, macroeconomic factors can explain only a small part of the longer maturity yields variation. However, in the case of bidirectional interactions, macroeconomic factors are able to explain more than half of the variance of the longer end of the yield curve. Gurkaynak, Sack and Swanson (2005) study the effects of macroeconomic and monetary policy shocks on the yield curve and show that the long end of the yield curve responds to many macroeconomic and monetary policy shocks through the adjusted expectations of the private sector regarding the long-term inflation level.

Mönch (2012), contrary to Diebold, Rudebusch and Aruoba (2006), allows for more lags in the joint dynamics of macroeconomic variables and yield curve latent factors. Moreover, Mönch (2012) considers a larger macroeconomic dataset and identifies shocks using the sign restrictions approach in order to allow for contemporaneous responses of yield curve factors to all macroeconomic shocks and vice versa. Mönch (2012) manages to give a broader economic underpinning to the curvature factor than his peers as the curvature factor was previously regarded as being unrelated to macroeconomic variables. Mönch's (2012) results suggest that a surprise change in the curvature factor is informative about the future evolution of the yield curve and output dynamics. A positive curvature shock implies a significant and extremely persistent hump-shaped response of the slope factor and a notable decrease of the level, leading to the yield curve flattening that precedes an economic downturn. Output growth also responds to curvature shocks and Mönch (2012) summarizes that a surprise increase of the curvature factor that is not exceeded by contemporaneous changes of the other two yield curve factors suggests an economic downturn. Mönch (2012) also concludes that surprise positive movements of the slope precede economic slowdowns, which is consistent with the vast majority of the literature on the ability of the yield spread to predict recessions.

Afonso and Martins (2010) study the dynamic relation between fiscal policy behaviour and the shape of the sovereign term structure methodologically following Diebold, Rudebusch and Aruoba (2006). However, latent yield curve factors are considered in country-specific VAR models together with macroeconomic and fiscal variables. Contrary to Evans and Marshall (2001), Afonso and Martins's (2010) empirical findings suggest that fiscal policy developments affect the yield curve and reactions of the yield curve to fiscal behaviour are country-specific. Furthermore, Afonso and Martins (2010) identify greater responsiveness of the long end of the yield curve to government debt ratio shocks than to budget balance shocks. The relation between fiscal developments and the yield curve depends on the initial level of government debt ratios, and interest rates respond more to the budget deficit than to government debt. Furthermore, Afonso and Martins (2010) obtain differing responses regarding the fiscal measure. A positive shock to the rate of change of the debt-to-GDP ratio induces an increase of the longer end of the yield curve, while a positive shock to the budget balance induces a decrease. Fiscal policy shocks affect the yield curve mainly through level and slope factors.

Coroneo, Giannone and Modugno's (2016) research objective is to identify factors that outline macroeconomic information not covered by common latent yield curve factors. Coroneo, Giannone and Modugno (2016) estimate a macro-finance model that incorporates macroeconomic factors as unobservable components. Macroeconomic factors are, contrary to pre-existing studies, extracted simultaneously with the yield curve latent factors identified by Nelson and Siegel's (1987) functional form. As a consequence, the joint macro-finance model implemented by Coroneo, Giannone and Modugno (2016) is actually a dynamic factor model with an assumption that macroeconomic factors do not affect the yield curve contemporaneously. Coroneo, Giannone and Modugno (2016) find that the uncaptured macroeconomic content of the yield curve has two macroeconomic drivers closely connected with economic growth and real interest rates. Hautsch and Ou (2008) implement a dynamic Nelson-Siegel yield curve factor model with stochastic volatility of factors. The results demonstrate that yield curve factors has a long-term predictive power for macroeconomic fundamentals. Furthermore, Hautsch and Ou (2008) suggest that the yield curve latent factors and volatility factors are closely linked to macroeconomic activity, inflation, monetary policy and employment growth. Moreover, they observe that macroeconomic variables are important long-run term structure volatility predictors as macroeconomic activity represents an important level and slope volatility predictor. Conversely, curvature volatility represents an important predictor for macroeconomic activity.

2.3 Variation in yield curve-macro relationship

A downward sloping yield curve is, in general, an indicator of an economic downturn, although Hamilton (2010) points out the inverted yield curve in August 2006 was not followed by the imminent economic downturn as was the case for previous recessions. The latter indicates an instability in the relationship between the yield curve and economic activity. Evidence of instability in the relationship between the yield curve and macroeconomic fundamentals was exhibited long before Hamilton (2010). Mishkin (1990a) observes and empirically confirms large changes of coefficients in inflation forecasting for the three sub-periods considered, from February 1964 to October 1979, from November 1979 to October 1982 and from November 1982 to December 1985. Moreover, he observes that the relationship between the yield curve spread and inflation changes in the period from November 1979 to October 1982, a period consistent with the monetary policy regime switch, as a contractionary monetary policy was conducted in order to bring inflation down in the US. Furthermore, Haubrich and Dombrosky (1996) examine the yield curve's ability to predict future economic activity and their research displays a decline in the predictive ability of the yield curve spread for the period from 1985 to 1995. Some evidence regarding the instability of the relationship between the yield spread and output growth is also found by Dotsey (1998). Moreover, Stock and Watson (1999) empirically study relationships between the aggregate business cycle and cyclical components of many macroeconomic time-series in the post-war period in the US and find instability in the cyclical behaviour of the slope of the term structure.

Estrella and Mishkin (1997) state that a possible explanation for the unstable relationship between the yield curve and the monetary policy stance is the varying credibility of the central bank. Furthermore, monetary policy regime shifts cause a varying relationship between the yield curve, real economic activity and inflation. Giacomini and Rossi (2006) perform several tests for structural breaks, predictive ability and potential forecast breakdowns and support the conclusion of Estrella and Mishkin (1997). They assert that the stability of the relationship between the yield spread and output growth depends on the stability of the economic environment and monetary policy regime. Estrella (2004) derives a macroeconomic model suggesting more stable empirical results regarding the relationship between the slope of the yield curve, output and inflation in periods of stable monetary policy. Therefore, the model suggests that changes in the monetary policy conduct affects the relationships considered. Estrella (2004) observes structural breaks in 1980 and 1987, approximately corresponding to the switch in monetary policy regime. Estrella, Rodrigues and Schich's (2003) findings of structural shifts in the parameters of binary and continuous models describing the predictive content of the yield spread for economic activity and inflation coincide with the monetary policy regime changes in the US. Moreover, Benati and Goodhart (2008) study variation in the predictive content of the yield spread for the US, the UK, the Eurozone, Canada and Australia, taking into account the monetary policy regime changes. They obtain strong evidence that the forecasting power of individual variables they controlled for changed over time. In the case of the US, Benati and Goodhart (2008) confirm that monetary policy regime changes are related to varying predictive power of the yield curve.

Examination of the predictive content of the yield curve spread does not represent the only evidence for the instability of the relationship between the yield curve and macroeconomic variables. It is similarly confirmed also by studying latent yield curve factors. De Pooter, Ravazzolo and Van Dijk (2010) find that the predictive ability of term structure models varies over time and models incorporating macroeconomic information exhibit greater accuracy in times of greater uncertainty regarding the future path of interest rates. Furthermore, Aguiar-Conraria, Martins and Soares (2010) notice a clear structural break in the relation between the yield curve slope and real economic activity in the second half of 1980s. From 2000 to 2006, Aguiar-Conraria, Martins and Soares (2010) observe the inability of an inverted yield curve to predict an economic downturn. They explain this phenomenon as a consequence of the decrease observed in the level of the yield curve from the mid-1980s that affected the slope's capability to predict real economic activity. The observed decrease of the yield curve level coincides with the monetary policy regime shift in the mid-1980s. Aguiar-Conraria, Martins and Soares (2010) in the early 1990s observe a structural change in the relation between the yield curve and inflation as a consequence of disinflationary monetary policy. Furthermore, they observe that the strength of the relationship between the curvature factor and real economic activity varies over time as an increase in the curvature predicts an increase in real economic activity. Aguiar-Conraria, Martins and Soares (2010) notice a structural break regarding the relation between the slope of the yield curve and inflation as well, explaining the increased strength of the relation as an increased effectiveness of the monetary policy since the 1990s. Moreover, their research demonstrates shifts in the relation between the Federal Funds rate and the level of the yield curve. In the early 1980s, coinciding with the monetary policy stance changes, Aguiar-Conraria, Martins and Soares (2010) observe an increased effect of the Federal Funds rate on the yield curve level, which is explained by successful anchoring of inflation by monetary policy authorities. Moreover, the strength of the relation between the slope and the Federal Funds rate has increased since the late-1980s. Furthermore, Dewachter, Iania and Lyrio (2011) observe a decrease in the predictive power of the yield curve spread, expectations and term premium components for GDP growth and inflation over time. However, the decrease in the predictive content over time is smaller in the case of inflation than in the case of GDP forecasting. Halberstadt (2015) asserts that the behaviour of economic agents plays an important role in determining the yield curve and macroeconomic fundamentals linkages. Halberstadt (2015) modifies the model presented by Mönch (2005). Estimation results for the time period from 1994 to 2010 indicate stronger macro-financial linkages in periods of economic distress. Halberstadt (2015) explains this phenomenon by referring to the bounded rationality of economic agents.

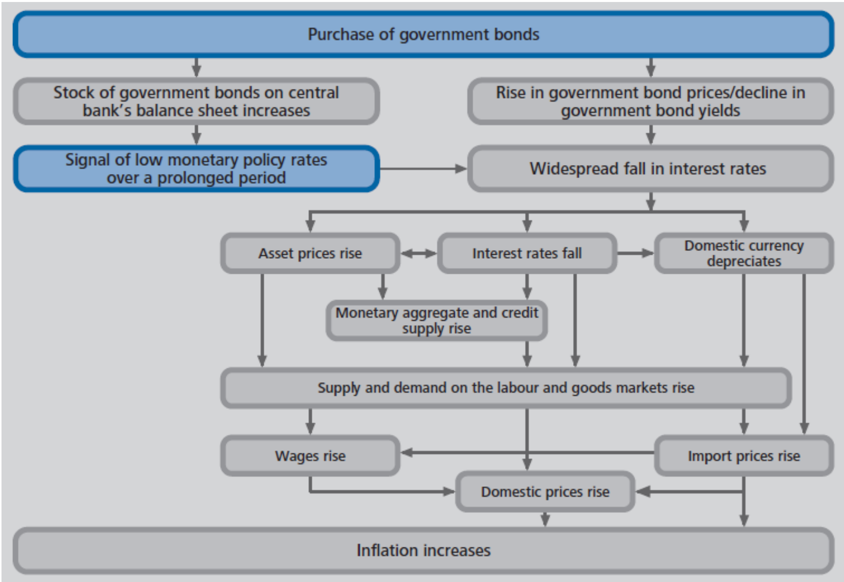
3 QUANTITATIVE EASING AND THE YIELD CURVE

In the previous section, several findings of variation in the relationship between the yield curve and macroeconomic fundamentals are presented. The main reason for a structural change in the relationship is the monetary policy regime shift or the change of the monetary policy conduct. Unconventional monetary policy measures, in particular QE, represented a deviation from the standard conduct of monetary policy, meaning it can be regarded as a monetary policy shift and a possible break in the relationship between the yield curve and macroeconomic fundamentals. Since the yield curve can be represented as a function of four latent factors, as suggested by Svensson (1994), it would be interesting to examine whether the relationship between yield curve latent factors and macroeconomic variables changes with the implementation of unconventional monetary policy measures. QE affects the economy through various transmission channels and fundamentally affects the yield curve. This makes it a candidate for a structural break in the relationship between the yield curve (yield curve latent factors) and macroeconomic fundamentals.

3.1 Quantitative easing transmission channels

Regardless of the Fed's decrease of the Federal Funds rate, which is its target policy rate, to its zero lower bound in late 2008, the US economy was faced with a threat of price deflation and a decline in economic growth. In response, to push down bond yields and to ensure further monetary policy stimulus, the Fed implemented purchases of longer-term securities. The objective was to stimulate inflation and increase economic activity by stimulating investment and consumption. Many central banks, not only the Fed, employed large-scale asset purchases or QE in order to ensure further monetary stimulus to the economy as conventional policy rates approached their constraints at the zero lower bound. Similarly to conventional interest rate monetary policy, QE affects macroeconomic developments through different channels. In principle, QE operates through the asset prices or yields being influenced by purchases of government bonds. In theory, open-market asset purchases by the monetary authority do not necessarily mean an effective monetary policy operating through asset prices and yields in the event of a liquidity trap. At the zero lower bound, if risk-free short-term assets are identical to central bank money from the bank's point of view, the only result of the central bank's asset purchases is that banks exchange short-term government bonds for central bank money. As a consequence, banks hold fewer short-term government bonds and correspondingly pile up central bank money, meaning that asset purchasing for monetary policy is neutral and has no effect on real economic activity and inflation. In theory, long-term risky asset purchases by the central bank can also be neutral in terms of macroeconomic impact according to Wallace neutrality. Wallace neutrality is based on three assumptions. Losses incurred by the central bank are offset and financed by taxes imposed on the private sector, by the absence of financial constraints, and by the fact that market segmentation is assumed and securities are valued exclusively on their monetary returns ignoring other factors that could possibly affect the holding of certain assets. The real economic impact remains unchanged despite long-term asset purchases by the central bank, whose objective is to ease long-term assets' risks, since the private sector still bears these risks, although through imposed taxes. However, the three stated assumptions are too restrictive to apply in practice since financial markets are not completely frictionless due to the presence of liquidity limitations, funding constraints, and market segmentation. Moreover, market participants probably have certain preferences regarding asset maturities and classes which affect the holding of certain assets. Consequently, QE has real economic effects influencing aggregate price developments and economic activity through several transmission channels. The portfolio balance channel and the signalling channel affect the economy by decreasing yields, while the exchange rate channel and bank capital and balance sheet channel influence the economy in a more direct way (Christensen & Rudebusch, 2012; Deutsche Bundesbank, 2016, p. 33-37).

Figure 1: Transmission process of the QE



Source: Deutsche Bundesbank, 2016, p. 35

3.1.1 Portfolio balance channel

The portfolio balance channel operates through diminishing the available supply of the assets that are actively purchased by the central bank. A lower supply of assets raises their prices and the prices of their substitutes, thereby affecting risk premium and decreasing yields. Christensen and Krogstrup (2015) distinguish between a supply-induced portfolio balance channel and a reserve-induced portfolio balance channel. QE induces investors to adjust their portfolios and results in relative shifts of individual asset classes' yields. The portfolio balance channel is based on combining liquidity premium theory and market segmentation theory. The liquidity premium theory argues that risk-averse investors prefer liquid short-term assets in comparison to long-term assets, which is why long-term assets whose residual maturity is greater than the investment horizon of risk-averse investors are purchased exclusively when these long-term assets have a premium increasing over the investment horizon. The market segmentation theory asserts that certain investors prefer specific maturities, meaning the term premium does not automatically rise with maturity. The market segmentation theory suggests that the bond market consists of several segments. Furthermore, the arbitrage opportunities are limited since it is assumed that bonds of different maturities are not perfect substitutes. Investors have different preferences regarding bonds' properties because of institutional or regulatory factors. As a consequence, a potential change in the market price of particular bonds can result from potential changes in supply and demand for these particular bonds. Taking the previously described liquidity premium theory and the market segmentation theory into the account, purchases of long-term government bonds affects the yield curve. Purchases of long-term government bonds decrease the supply in the segment of the bonds market in which purchases are conducted.

For the market segmentation theory, there is a crucial postulate of preferred-habitat investors who purchase bonds based on their maturity and have maturity-specific preferences regarding bonds. According to market segmentation theory, investors that prefer a particular segment of bonds are inclined to pay more for the desired bonds, thereby increasing their prices. Such behaviour and actions result in the reduction of yields for the desired bond class as well as for close substitutes. Partially segmented markets and preferred-habitat investors, whose demand for maturity specific bonds cannot be completely offset by market participants not having maturity-specific demand for bonds, affect term premiums and yields. Furthermore, large-scale asset purchase programmes remove a considerable amount of long-term assets with high duration from the markets, which decreases the aggregate duration of assets held by investors. Since duration risk is alleviated, the market may require a lower premium for holding that risk. As a consequence, term premiums and yields decline. Moreover, the drop in yields may transfer across different segments of assets as the central bank removes assets with longer durations from non-preferred-habitat investors' portfolios, who substitute those assets by purchasing other assets with similar durations. Consequently, the demand for those assets increases, which results in decline in yields. This portfolio balance channel was named by Christensen and Krogstrup (2015) as a supply-induced portfolio balance channel (Krishnamurthy & Vissing-Jorgensen, 2011; Christensen & Rudebusch, 2012; Thornton, 2014; Christensen & Krogstrup, 2015; Deutsche Bundesbank, 2016, p. 34).

3.1.2 Signalling channel

The signalling channel operates through influencing the expectations of market participants about the future monetary policy stance. The signalling channel is based on expectation theory, which argues that the long-term interest rate is equal to the average short-term interest rate expectation. The expectation theory asserts that an investor may obtain the same yield whether their investment consists of several short-term assets or a long-term bond since assets are perfect substitutes. As a consequence, QE affects all interest rates equally through the signalling channel. In general, central banks employ forward guidance and provide information regarding future monetary policy and rates to the public as a standard monetary policy tool. A central bank's announcement of a large scale asset purchase programme, besides standard forward guidance, may influence market participants to perceive such an announcement as a strong indicator or a commitment to an expansionary monetary policy. Considering the expectation hypothesis, the announcement of the QE supports the expansionary monetary policy stance, and if market participants perceive it as a signal of policy rates staying at the effective lower bound for a prolonged time period, long-term interest rates would drop correspondingly as a result of revised expectations. As a consequence, there comes the improvement of general financing conditions resulting in increased credit demand, which encourages aggregate demand and inflation. Krishnamurthy and Vissing-Jorgensen (2011) recognize as a part of the signalling channel the inflation channel, which works through directly affecting inflation expectations of market participants as a consequence of forward guidance and its reinforcement in the form of a large-scale asset purchase programme (Krishnamurthy & Vissing-Jorgensen, 2011; Christensen & Rudebusch, 2012; Deutsche Bundesbank, 2016, p. 35).

3.1.3 Bank capital and balance sheet channel

A bank balance sheet channel or a reserve-induced portfolio balance channel as described by Christensen and Krogstrup (2015) is based on the expansion of a central bank's reserves and balance sheet as a consequence of large-scale asset purchases. It is an alternative portfolio balance sheet channel through which long-term interest rates may be decreased. Commercial banks hold assets with increasing prices due to the central bank's large-scale asset purchase programme and consequently the structure of banks' portfolios change and reserves increase. This balance sheet expansion encourages commercial banks to rebalance their portfolios in order to achieve their profitability and risk objectives since their portfolios pile up with risk-free, highly liquid and low or even negative-yielding reserves. Therefore, commercial banks are inclined to diversify out of excess reserves and invest in bonds with greater duration, increasing their prices and affecting their yields correspondingly. At the same time, the profit from the increase in asset prices induces growth in the capital of commercial banks, which enables them to comply with higher capital requirements corresponding to increasing loan portfolios. Moreover, commercial banks are encouraged to provide credit since their increased capital and piled up reserves improve banks' access to funding necessary for loans refinancing and urge them to diversify. Similarly, non-bank market participants may be influenced by large-scale asset purchases as well. The higher the borrower's capital due to the increased prices of assets, the more creditworthy the borrower becomes as a result of lower credit default risk. As a consequence, the cost of borrowing is lower since the risk premium charged by the lender is lower for more creditworthy borrowers. Consequently, external financing becomes more affordable, facilitating investment projects, thereby stimulating aggregate demand and inflation (Christensen & Krogstrup, 2015; Deutsche Bundesbank, 2016, p. 38).

3.1.4 Exchange rate channel

The exchange rate channel is important especially for open economies, as international trade represents a significant part of their economic activity. Where the asset purchase programme successfully decreases the yields of assets denominated in the domestic currency relative to assets denominated in a foreign currency, domestic assets become less attractive for foreign investors and the demand for domestic currency decreases as the foreign demand for the domestic currency decreases. The decreased demand for the domestic currency induces at least interim downward pressure and depreciation of the domestic currency. The latter cheapens exports of domestic goods and services, which increases the foreign demand for domestic goods. Furthermore, depreciation of the domestic currency makes foreign goods relatively more expensive, which means domestic demand focuses primarily on domestic goods. As a consequence, domestic aggregate demand is encouraged and domestic inflation rises (Deutsche Bundesbank, 2016, p. 38).

3.2 Effects of Quantitative Easing on the yield curve

The indisputable effect that the large-scale asset purchase programmes had on the yield curve was the decrease of long-term yields and the flattening of the yield curve. However, different researchers attribute the long-term yields decline resulting from the QE to different transmission mechanism channels and different reasons. The yield of a bond can depend on the term structure, decomposed into a risk-neutral component, which is equivalent to the average expected future short-term rates influenced by the central bank, and a term premium component. Implementation of asset purchase programmes and corresponding reserve expansions influence both components of the yield whereby the signalling channel affects the risk-neutral part and the portfolio balance channel affects the term premium part as described in previous subsections. The outcome is therefore the drop in long-term yields. Gagnon, Raskin, Remache and Sack (2011) report that the main eight announcements of the Federal Reserve's first large-scale asset purchase program were followed by a cumulative drop of the 10-year US treasury yield equal to 91 basis points. They assert that the portfolio balance channel was the mechanism responsible for this drop. Hamilton and Wu (2012) obtain somewhat lower results for the US than Gagnon, Raskin, Remache and Sack (2011). Hamilton and Wu (2012) identify that the policy of reducing public holdings of long-term bonds can potentially induce a decline in the overall level of interest rates in a zero lower bound environment. In other words, Hamilton and Wu (2012) suggest that the asset purchase programme decreased yields and may have worked through the mechanism described as the portfolio balance channel, although in the implemented model of the zero lower bound they assume that the ability to affect long-term yields was based on investor's perceptions regarding future economic fundamentals when the normal conditions are reinstated. Krishnamurthy and Vissing-Jorgensen (2011) report that the Federal Reserve's large-scale asset purchase programmes QE1 (2008-2009) and QE2 (2010-2011) significantly decreased nominal interest rates on Treasury bonds, Agency bonds, corporate bonds and MBS. However, Krishnamurthy and Vissing-Jorgensen (2011) reveal that the extent of the influence differed across bonds, maturities and even across the two QE programs. According to Krishnamurthy and Vissing-Jorgensen (2011), yields were affected through various reinforcing transmission mechanism channels. D'Amico, English, Lopez-Salido and Nelson (2012) conceptually divide the portfolio balance channel described in the previous subsection into the duration channel and the scarcity channel. The first operated through decreasing the aggregate duration of debt held by investors, which decreases term premiums and yields, while the second operates through increasing prices of securities as a consequence of increased demand, leading to decreasing yields. According to D'Amico, English, Lopez-Salido and Nelson (2012), alongside the signalling channel, the two channels may have affected long-term yields and term premiums although only the duration channel and the scarcity channel exhibit significant effects on the long-term yields. Thornton (2014) follows Gagnon, Raskin, Remache and Sack (2011) and uses the methodology they implemented. Results obtained by Thornton (2014) suggest that the portfolio balance channel and reducing the public's holdings of long-term debt did not play a significant part in the decline of long-term yields (Gagnon, Raskin, Remache & Sack, 2011; Hamilton & Wu, 2012; D'Amico, English, Lopez-Salido & Nelson, 2012; Thornton, 2014; Christensen & Krogstrup, 2015).

Christensen and Rudebusch (2012) analyse declines in government bond yields as a result of the Fed's and the Bank of England's purchases of longer-term securities by using an event study methodology. By implementing dynamic term structure models following an arbitrage-free Nelson-Siegel representation presented by Christensen, Diebold and Rudebusch (2009), Christensen and Rudebusch (2012) decompose yields into expected future short-term interest rates and term premiums. Results obtained by Christensen and Rudebusch (2012) demonstrate that declines in yields in the US corresponded mainly to lower expectations regarding future short-term interest rates. On the other hand, in the case of the UK, yields declined due to reduced term premiums. Results obtained by Christensen and Rudebusch (2012) regarding the drop of long-term yields in the US contradicts Gagnon, Raskin, Remache and Sack (2011) and D'Amico, English, Lopez-Salido and Nelson (2012) and confirm Thornton's (2014) findings since they diminish the importance of the portfolio balance channel and indicate that the signalling channel was the main mechanism that brought down the yields. Christensen and Rudebusch (2012) conclude that differences in institutional structures of particular market and central bank communication policies determined which of the two transmission mechanism channels, the portfolio balance channel or the signalling channel, was relatively more important for the drop in yields. Alongside the institutional and investor differences in financial markets across the US and the UK, the Fed was more inclined to provide monetary policy forward guidance near the zero lower bound and asset purchase programme announcements reinforced it. On the other hand, in the UK forward-looking guidance on interest rates was not expressed with emphasised by the central bank, resulting in different reactions (Christensen & Rudebusch, 2012).

4 MACRO-FINANCE MODEL

4.1 Dynamic yield curve model

Arbitrage-free term structure models and methodologic approaches following Ang and Piazessi (2003) are very popular in the macro-finance literature for studying the macroeconomic determinants of the yield curve. However, Diebold and Li (2006) and Diebold, Rudebusch and Aruoba (2006) argue that it is not clear whether arbitrage-free models are desirable or necessary for macro-finance studies of latent yield curve factors and macroeconomic variables. For instance, Afonso and Martins (2010) and Mönch (2012) use the parsimonious Nelson and Siegel (1987) approach in order to obtain latent yield curve factors. The functional form of the yield curve presented by Svensson (1994) is only an extension of the Nelson and Siegel (1987) representation of the yield curve expressed in equation (22) where $y(\tau)$ represents the yield of a certain maturity and other notations are the same as in sections 1.2 and 1.3.

$$y(\tau) = \beta_{0,t} + \beta_{1,t}\frac{1-e^{-\lambda_{1,t}\tau}}{\lambda_{1,t}\tau} + \beta_{2,t}\left(\frac{1-e^{-\lambda_{1,t}\tau}}{\lambda_{1,t}\tau} - e^{-\lambda_{1}\tau}\right) + \beta_{3,t}\left(\frac{1-e^{-\lambda_{2,t}\tau}}{\lambda_{2,t}\tau} - e^{-\lambda_{2,t}\tau}\right) \quad (22)$$

Following Diebold and Li (2006), Diebold, Rudebusch and Aruoba (2006) and Christensen, Diebold and Rudebusch (2011), the Nelson and Siegel (1987) representation of the yield curve can be regarded as a dynamic latent factor model where $\beta_{0,t}$, $\beta_{1,t}$ and $\beta_{2,t}$ are time-varying parameters that can be interpreted as level, slope and curvature due to their effects on the yield curve. The terms corresponding to a particular latent factor are the respective latent yield curve factor loadings. Since the Svensson (1994) representation is only an extension of Nelson and Siegel's (1987) approach, the same can be assumed and interpreted for the Svensson (1994) representation of the yield curve's functional form. Following De Pooter (2007), the Svensson (1994) representation can be interpreted as a dynamic latent factor model with an additional $\beta_{3,t}$ time-varying parameter, thereby providing four time-varying parameters and four factor loadings. Slope $\beta_{1,t}$, first curvature $\beta_{2,t}$ and second curvature $\beta_{3,t}$ factors may be interpreted as the short-end and medium- to long-term components of the yield curve where coefficients $\lambda_{1,t}$ and $\lambda_{2,t}$ determine the rate of decay of the short-term $\beta_{1,t}$ factor loading and the maturity at which medium-term factors $\beta_{2,t}$ and $\beta_{3,t}$ reach their maximum. According to Gurkaynak, Sack and Wright's (2007) view of Svensson's (1994) representation of the yield curve, the first hump of the yield curve is usually located at relatively short horizons. Short horizons of the yield curve generally need to encompass the effects of short-term monetary policy expectations. The second hump, as described by Gurkaynak, Sack and Wright (2007), is in general located at longer horizons affecting the convexity of the yield curve. Gurkaynak, Sack and Wright (2007) describe the Svensson (1994) yield curve specification as sufficiently rich to encompass the shape of the yield curve corresponding to monetary policy expectations and convexity of longer-term securities.

Following the analogy for the Nelson-Siegel dynamic yield curve model of Diebold and Li (2006), Diebold, Rudebusch and Aruoba (2006), Mönch (2012) and De Pooter (2007), the dynamic Svensson (1994) yield curve model can be expressed as a state space system. In vector/matrix notation, the state or the transition equation of the state space system that governs the state vector is given by

$$\left(f_t^y - \mu\right) = A\left(f_{t-1}^y - \mu\right) + \eta_t \quad (23)$$

for $t = 1, \ldots, T$. The measurement equation relating a set of N yields to four latent yield curve factors is written as

$$y_t = \Lambda(\lambda_1, \lambda_2) f_t^y + \varepsilon_t \tag{24}$$

for $t = 1, \dots, T$, where y_t is the yields vector of size $N \times 1$, Λ is the loading matrix of size $N \times 4$ depending on λ_1 and λ_2 where the ith row of Λ is equal to $\Lambda_i = \left[1 \ \frac{1-e^{-\lambda_1 \tau_i}}{\lambda_1 \tau_i} \ \frac{1-e^{-\lambda_1 \tau_i}}{\lambda_1 \tau_i} - e^{-\lambda_1 \tau_i} \ \frac{1-e^{-\lambda_2 \tau_i}}{\lambda_2 \tau_i} - e^{-\lambda_2 \tau_i}\right]$, f_t^y is the state vector of size 4×1 that consists of yield curve latent factors, i.e. $f_t^y = \left[\beta_{0,t} \ \beta_{1,t} \ \beta_{2,t} \ \beta_{3,t}\right]^T$, μ is the 4×1 mean vector and A is the 4×4 coefficient matrix. The measurement and state equation errors are represented by ε_t and η_t respectively, and they are normally distributed and uncorrelated.

$$\begin{bmatrix} \varepsilon_t \\ \eta_t \end{bmatrix} \sim \mathcal{N}\left(\begin{bmatrix} 0_{N \times 1} \\ 0_{4 \times 1} \end{bmatrix}, \begin{bmatrix} \Sigma_\varepsilon & 0_{N \times 4} \\ 0_{4 \times N} & \Sigma_\eta \end{bmatrix}\right) \tag{25}$$

The measurement equation covariance matrix Σ_ε and the state equation covariance matrix Σ_η have dimensions $N \times N$ and 4×4 respectively. Furthermore, the standard assumption of uncorrelated measurement errors means that the measurement equation covariance matrix Σ_ε is diagonal. Conversely, state errors are not assumed to be uncorrelated, which is why the state equation covariance matrix Σ_η is not restricted to being diagonal. Christensen, Diebold and Rudebusch (2011) find that making the restriction of Σ_η diagonal improves the forecast performance of the model. However, they did not model yield curve factors together with macroeconomic factors. Furthermore, Diebold, Rudebusch and Aruoba (2006) do not assume orthogonal state errors and restrict the Σ_η matrix to being diagonal. This allows state variables to interact dynamically and have correlated shocks, which is desirable when studying the dynamic interactions between latent yield curve factors and macroeconomic factors that are subsequently included into the model.

The dynamic Svensson (1994) model, which was implemented by adapting the standard state space system proposed by Diebold and Li (2006) and Diebold, Rudebusch and Aruoba (2006) and is presented in equations (23) and (24), is enhanced in the state equation part of the system (23) by the inclusion of numerous macroeconomic variables or factors in order to obtain a joint macro-finance model of macroeconomic and yield curve dynamics. The enhanced state or transition equation part of the model is presented in section 4.2. Furthermore, the restriction that yield curve factors must follow an autoregressive process of order one is lifted. The autoregressive order is determined during the estimation procedure in order to attain the best possible performance of the model.

4.2 Joint dynamics of the yield curve and macroeconomic factors

Diebold, Piazzesi, Rudebusch (2005) claim that a joint macro-finance model enables the most comprehensive understanding of the term structure of interest because it combines macroeconomic and financial viewpoints. A model of yield curve factors and macroeconomic variables is necessary in order to be able to simultaneously determine dynamics and effects of the bi-directional relationship between the yield curve, in particular yield curve latent factors, and macroeconomic variables. De Pooter, Ravazzolo and Van Dijk (2010) consider multiple models for forecasting the term structure of interest rates and stress the importance of incorporating macroeconomic information into term structure models. De Pooter, Ravazzolo and Van Dijk's (2010) comparative analysis of different term structure models suggests that incorporating macroeconomic information into term structure models improves forecasts and therefore conclude that the macroeconomic information accounts for a certain degree of movement in the term structure. Using VAR is not an appropriate solution for the purposes of modelling the dynamics of yield curve factors together with a large number of macroeconomic variable. Diebold and Li (2006) use VAR (1) in order to model yield curve factors' dynamics, and Diebold, Rudebusch and Aruoba (2006) – and studies following them – use VAR to jointly model yield curve factor dynamics and macroeconomic variables dynamics. However, in the case of many variables, a standard VAR has the dimensionality or the degrees-of-freedom problem, which makes it an appropriate solution for the state equation when dealing with large datasets. As an answer to VAR's dimensionality problem, Bernanke, Boivin and Eliasz (2004) introduce FAVAR in order to model the information contained in large datasets. Following Stock and Watson (2002), a small number of estimated factors is able to summarize the information contained in a large dataset of macroeconomic data, and consequently Bernanke, Boivin and Eliasz (2004) propose an augmented standard VAR with estimated factors. Since FAVAR is actually an augmented standard VAR, Mönch (2005) and studies following his methodology use FAVAR as the state equation in order to model joint dynamics of yield curve latent factors and many macroeconomic variables. I assume that a large number of macroeconomic variables drive the yield curve and vice versa, which is why I consider a large macroeconomic dataset when modelling joint macro-finance dynamics. As a consequence, a standard VAR analysis is inappropriate to determine macroeconomic drivers of the yield curve. Consequently, the state equation (23) in the state space system presented in subsection 4.1, which follows VAR (1), is replaced by FAVAR as proposed by Bernanke, Boivin and Eliasz (2004) in order to be able to handle a large macroeconomic dataset. The measurement equation (24) remains intact, which is why there follows only a further presentation of the state equation in the form of FAVAR.

Bernanke, Boivin and Eliasz (2004) assign Y_t to a $M \times 1$ vector of observable economic variables and F_t to a $K \times 1$ vector of unobserved factors that are important for the modelling of dynamics of Y_t. A small number of factors K summarize and represent economic information contained in a large economic dataset. Bernanke, Boivin and Eliasz (2004) present the joint dynamics of F_t and Y_t as

$$\begin{bmatrix} F_t \\ Y_t \end{bmatrix} = \Phi(L) \begin{bmatrix} F_{t-1} \\ Y_{t-1} \end{bmatrix} + v_t \qquad (26)$$

where $\Phi(L)$ is a corresponding lag polynomial of finite order d in which restrictions as in the structural VAR can be contained. The error term v_t has a mean equal to zero and a covariance matrix Q. The representation of the joint dynamics of F_t and Y_t is a VAR. The system can be simply reduced to a standard VAR, as described by Bernanke, Boivin and Eliasz (2004), if the terms of $\Phi(L)$ that relate Y_t and F_{t-1} are restricted to be equal to zero. The representation of the joint dynamics of F_t and Y_t in equation (26), as presented by Bernanke, Boivin and Eliasz (2004), is referred to as a Factor-Augmented Vector Autoregression or FAVAR. Due to the unobservable nature of factors F_t, they need to be estimated or extracted from observed large dataset of economic variables as proposed by Stock and Watson (2002).

The exact dynamic factor model represented by Stock and Watson (2002) and Stock and Watson (2005) expresses X_t, a $N \times 1$ vector of stationary time series of observed variables, as a distributed lag of a small number of unobserved common factors f_t and an idiosyncratic disturbance that is allowed to be serially correlated,

$$X_{it} = \gamma_i(L) f_t + u_{it}, i = 1, \dots, n \tag{27}$$

$$u_{it} = \delta_i u_{it-1} + v_{it} \tag{28}$$

where f_t is a $k \times 1$ vector of unobserved dynamic factors, $\gamma_i(L)$ is a $1 \times k$ vector finite lag polynomial that is called the dynamic factor loadings and u_{it} represents the idiosyncratic disturbance. Stock and Watson (2002) assume that the factors and idiosyncratic disturbances are uncorrelated, meaning that $E(f_t u_{is}) = 0$ for all i, t and s. Furthermore, idiosyncratic disturbances are assumed to be mutually uncorrelated at all leads and lags, meaning that $E\left(u_{it} u_{js}\right) = 0$ for all i, j, t and s where $i \neq j$.

Stock and Watson (2002) assumed that $\gamma_i(L)$ is a finite order polynomial of order p, where $F_t = (f_t', \dots, f_{t-p}')'$ and λ_i is a $1 \times K$ vector of factor loadings, which enables them to write the dynamic factor model in a static form in which factors are assumed to follow a stable VAR process. The static form of the dynamic factor model is expressed as follows:

$$X_{it} = \lambda_i F_t + u_{it} \tag{29}$$

$$F_t = \phi(L) F_{t-1} + \varepsilon_t \tag{30}$$

Bernanke, Boivin and Eliasz (2004) refer to Stock and Watson's (1998) representation of the dynamic factor model in equations (29) and (30) assume that the informational time series X_t is related to the observable factors Y_t and unobservable factors F_t. According to Bernanke, Boivin and Eliasz (2004), equation (29) represents the essence that F_t and Y_t are drivers of common dynamics of X_t and the relation is expressed as following.

$$X_t = \Lambda^f F_t + \Lambda^y Y_t + e_t \tag{31}$$

A $N \times K$ matrix of factor loadings is denoted by Λ^f, Λ^y is a $N \times M$ matrix and e_t is a $N \times 1$ vector of zero mean error terms that are assumed to be, depending on the estimation method, weakly correlated or uncorrelated.

Bernanke, Boivin and Eliasz (2004) consider two approaches for estimating equations (26) and (31). The first approach is a two-step principal components approach. The second approach they consider is a single-step Bayesian likelihood approach where equations (26) and (31) are jointly estimated by maximum likelihood. For the one-step approach, Bernanke, Boivin and Eliasz (2004) consider the joint estimation by likelihood-based Gibbs sampling techniques to alleviate problems related to maximum likelihood estimation in the context of very large dimensional models. Bernanke, Boivin and Eliasz (2004) claim that it is not evident which of the two approaches should prevail despite being different in a variety of aspects. Bernanke, Boivin and Eliasz (2004) argue that the two-step approach has an advantage in computational simplicity while the one-step approach has an advantage in exploitation of the structure of the transition equation in the estimation of factors. Since the two-step approach proposed by Bernanke, Boivin and Eliasz (2004) has an advantage over the one-step approach in computational simplicity, I use the two-step approach.

The two-step approach is based on Stock and Watson (1998) and Stock and Watson (2002), where they show that the principal components can be used for consistent estimation of the space spanned by factors F_t. Furthermore, Stock and Watson (2002) show that the principal components can be used for consistent estimation of the space spanned by F_t and Y_t whenever N is large and the number of principal components used is at least as large as the genuine number of factors. In the first step of the two-step approach, the common components $C_t = (F_t, Y_t)'$ are estimated by the usage of first $K + M$ principal components of X_t following Bai and Ng (2002) criteria while, despite being observed, Y_t is not treated any differently to F_t. The estimated factors $\hat{F}_t$ required are obtained as the part of the space spanned by the estimated common components $\hat{C}_t$ that is not spanned by the observed factors Y_t. In order to obtain the estimated factors $\hat{F}_t$, the two-step approach of FAVAR estimation proposed by Bernanke, Boivin and Eliasz (2004) consists of categorizing variables as slow-moving and fast-moving variables. The first group consists of variables that are largely predetermined and do not respond contemporaneously to economic shocks. The fast-moving group consists of variables that contemporaneously respond to economic shocks. First, Bernanke, Boivin and Eliasz (2004) extract the slow-moving factors F_t^s by using the principal components of variables categorized as slow-moving as proposed by Stock and Watson (1998), Bai (2004) and Bai and Ng (2002). The extraction of the slow-moving factors is followed by regressing $\hat{C}_t$ on extracted slow-moving factors F_t^s and observed variables Y_t as written in equation (31).

$$\hat{C}_t = b_{F^s} F_t^s + b_Y Y_t + e_t \tag{32}$$

The estimated factors $\hat{F}_t$ are then obtained from $\hat{C}_t - \hat{b}_Y Y_t$ and are orthogonal to variables treated as observable. In the second step of the two-step procedure approach, the FAVAR as expressed in equation (26) is estimated by using standard VAR estimation methods and a replacement of F_t with $\hat{F}_t$, while the observable part Y_t remains intact. Since the two step-approach consists of using "generated regressors" in the second step, as estimated factors are named by Bernanke, Boivin and Eliasz (2004), confidence intervals in the case of impulse responses analysis need to be bootstrapped in order to account for the uncertainty in the estimation of factors.

The joint macro-finance model combines the yields measurement equation (24) with the yield curve factors enhanced economy's measurement equation (31) and the yield curve factors enhanced FAVAR transition equation (26). Therefore, the joint macro-finance model is expressed by the following three equations

$$y_t = \Lambda(\lambda_1, \lambda_2) f_t^y + \varepsilon_t \tag{33}$$

$$X_t = \Lambda^f F_t + \Lambda^y Y_t + \Lambda^{f^y} f_t^y + e_t \tag{34}$$

$$\begin{bmatrix} F_t \\ f_t^y \\ Y_t \end{bmatrix} = \Phi(L) \begin{bmatrix} F_{t-1} \\ f_{t-1}^y \\ Y_{t-1} \end{bmatrix} + v_t \tag{35}$$

where equation (33) represents the measurement equation for yields, equation (34) is the measurement equation for the economy and equation (35) represents the transition or the state equation for the economy and yield curve latent factors $f_t^y = [\beta_{0,t}\ \beta_{1,t}\ \beta_{2,t}\ \beta_{3,t}]^T$. Latent yield curve factors in the FAVAR part of the model are treated as observable, as is the monetary policy instrument in Y_t.

5 DATA

5.1 Yield curve data

The yield curve data consists of US government securities. In more detail, the data consists of 4-week, 8-week, 13-week, 26-week and 52-week US Treasury Bills, 2-year, 3-year, 5-year, 7-year and 10-year US Treasury Notes and 30-year US Treasury Bonds historical prices and descriptive data for each Treasury security. Treasury Bills are zero coupon debt securities while Treasury Notes and Bonds are coupon debt securities with semi-annual coupons paid until the maturity of the security. The Treasury securities data is obtained from Bloomberg Professional Terminal. Bloomberg Professional Terminal enables downloading of historical bonds data up to mid-1987, but only for US treasury securities of longer maturities. The data for US Treasury Bills is available from the 1990s. The data for US Treasury Bills is incremental in order to obtain bootstrapped zero coupon yields from longer-term maturities US treasury securities such as Treasury Notes and Treasury Bonds. The yields dataset is limited by the availability of sufficient data for short-term maturities US treasury securities, i.e. US Treasury Bills, and spans from 1998 to 2018. The data is downloaded based on CUSIP numbers of Treasury Bills, Notes and Bonds gathered from Treasury Direct, the online platform that enables the purchase of government securities from the US Treasury through auction processes (data available at https://www.treasurydirect.gov/instit/annceresult/annceresult_query.htm).

The number of Treasury Bills, Notes and Bonds differ between observation dates due to data availability, the maturity of Treasury securities and issues of new Treasury securities. As a consequence, the number of Treasury securities that represent the basis data for yield curve estimation varies over time. Furthermore, Treasury Notes and Treasury Bonds with less than three months until maturity are discarded from the sample of observations due to the behaviour of coupon debt securities near the maturity date. Moreover, several Treasury Notes and Treasury Bonds from seasoned or off-the-run issues are discarded since it is conventional for the zero coupon yield curve estimation to be based on the most recent on-the-run issues of government debt securities. The number of Treasury securities per observation date therefore varies from 133 to 342. Since the objective is to model the zero-coupon yield curve and only Treasury Bills are zero-coupon government securities, zero-coupon yields for Treasury Notes and Bonds need to be bootstrapped from their prices, taking into the account coupons paid until the maturity of a particular government debt security. Therefore, I use a standard procedure for bootstrapping zero-coupon yields where yields on Treasury Bills (since they are zero-coupon yields) represents the basis for bootstrapping zero-coupon yields for coupon debt securities with maturities greater than one year. Since Treasury Bills are quoted on a discount basis rate, yields on Treasury Bills or their money market yield equivalents are calculated from Treasury Bills' bank discount yields based on the following formula:

$$r_{MM} = \frac{360 r_{BD}}{360-(t)(r_{BD})} \tag{36}$$

where r_{MM} denotes the money market equivalent yield, r_{BD} denotes the bank discount yield and t represents days until maturity of the Treasury Bill. Zero-coupon yields are recursively bootstrapped, moving along the maturity spectrum on a particular observation date, from Treasury Notes and Treasury Bonds prices taking into the account their "future" coupons, Treasury Bills yields and already bootstrapped zero-coupon yields for maturities that are lower than the maturity of a particular security. Since yield curve latent factors are modelled as autoregressive processes together with macroeconomic variables with monthly frequency, bootstrapped zero-coupon yields from the end of the month are considered for the time span of 21 years, from January 1998 to December 2018.

5.2 Macroeconomic data

McCracken and Ng (2015) developed FRED-MD which is a macroeconomic database that provides monthly macroeconomic data for 128 time series of US indicators. The dataset starts in January 1959 and the macroeconomic database is updated monthly using the FRED database. The dataset may be downloaded from the website http://research.stlouisfed.org/econ/mccracken/sel/. McCracken and Ng (2015) classify the macroeconomic dataset into eight categories: (1) output and income, (2) labour market, (3) housing, (4) consumption, orders and inventories, (5) money and credit, (6) interest and exchange rates, (7) prices and (8) stock market. However, I do not use the entire 128 monthly macroeconomic time series provided by FRED-MD and McCracken and Ng (2015) for model estimation as I exclude several financial time series from the analysis. I discard times series corresponding to different Treasury rates and spreads from the Interest and Exchange rates category of the McCracken and Ng (2015) macroeconomic dataset. The Treasury rates and spreads are represented by the yield curve latent factors estimated from the data described in the previous section instead of data from FRED-MD and McCracken and Ng (2015), since yield curve latent factors are seen as containing financial information of excluded financial time series. As a consequence, I consider 115 monthly macroeconomic time series spanning from January 1998 to December 2018, taking into the account the limitations of the available data on Treasury securities described in the previous section. The description and a list of the macroeconomic time series data used and the transformations applied are described in Appendix 2. Furthermore, Effective Federal Funds Rate from the dataset of McCracken and Ng (2015) is, for corresponding periods of zero lower bound, complemented by Wu and Xia’s Shadow Federal Funds Rate in order to quantify the stance of monetary policy more appropriately. Wu-Xia’s Shadow Federal Funds Rate series can be obtained from the official website of Federal Reserve Bank of Atlanta (https://www.frbatlanta.org/cqer/research/shadow_rate.aspx).

6 MODEL ESTIMATION

6.1 Yield curve model estimation

Several procedures may be used to estimate yield curves and the decision regarding the estimation procedure may depend on the yield curve representation and its specifics. For instance, McCulloch (1975) uses a weighted least-squares regression in order to obtain estimates of parameters from a discount function approximated by a polynomial spline fitted to price data. Nelson and Siegel (1987) estimate the parameters of their functional representation of the yield curve by using least squares over a grid of possible values for the decay parameter in order to obtain the optimal estimates. Svensson (1994) estimates parameters of his non-linear functional form of the yield curve for each trade date by minimizing the sum of squares of yield errors or price errors. Contrary to McCulloch (1975) and Nelson and Siegel (1987), whose yield curve functional forms are also non-linear, Svensson (1994) uses maximum likelihood estimation in order to estimate the yield curve parameters. Furthermore, Diebold and Li (2006) use a two-step procedure for modelling the yield curve. Latent factors are estimated in the first step and the factors' dynamics are modelled in the second step. Diebold and Li (2006) fix the decay parameter at a pre-specified value, considering that the decay parameter determines the maturity at which the curvature factor achieves its maximum. Fixing the decay parameter enables them to use ordinary least squares to obtain the estimates of yield curve latent factors whose dynamics are subsequently modelled in a VAR (1). De Pooter (2007) examines various extensions of the Nelson and Siegel (1987) model, consisting of two, three and four yield curve factors, and several estimation techniques in order to fit and forecast the term structure of interest rates. De Pooter (2007) applies a two-step estimation approach with fixed decay parameters for which the value of the decay parameters are fixed and pre-specified, a two-step approach with estimated decay parameters whereby latent factors' dynamics decay parameters are not included in the part of modelling yield curve, and for forecasting he uses the median of estimated decay parameters and a one-step state-space approach using Kalman filtering and estimating parameters and factor dynamics simultaneously. Factor loadings are time-varying where decay parameters are estimated and not pre-determined and fixed. De Pooter's (2007) results indicate that more flexible models improve the in-sample fit and the out-of-sample predictability of the term structure of interest rates. The in-sample fit improves when decay parameters are estimated and not fixed. However, De Pooter's (2007) results suggest that the benefits from estimating decay parameters are minor in terms of the in-sample performance of the model. De Pooter (2007) argues the existing difference between the two-step and one-step estimation are very close despite the time-series of estimated factors. De Pooter (2007) constructed empirical factors for level, slope and curvature and found that the factors estimated using a two-step approach mimic empirical factors very closely and are highly correlated. The best forecasting performance comes from a one-step approach of estimation although it is closely followed by the two-step approach with estimated decay parameters. Increasing the forecasting horizon improves the accuracy of forecasts although the difference is that in the one-step approach, forecasts accuracy improves more than in the case of two-step approach.

Following De Pooter (2007), I deploy a two-step estimation approach of the yield curve model and the macro-finance model presented in section 4. In the first step, yield curve parameters are estimated for each observation date, while in the second step I jointly model yield curve factors' and macroeconomic fundamentals' dynamics. I estimate the parameters of Svensson's (1994) yield curve model by using maximum likelihood estimation as proposed by Gurkaynak, Sack and Wright (2007). Contrary to Gurkaynak, Sack and Wright (2007), I deal with yield errors instead of price errors as they minimize the weighted sum of squared deviations between actual and predicted prices of Treasury securities, choosing the weights as the inverse of the duration of each particular security. Gurkaynak, Sack and Wright (2007) assert that their procedure is approximately equal to dealing with yield errors.

Moreover, Svensson (1994) notes that using price errors results in rather larger yield errors for securities with shorter maturities in comparison to yield errors while both procedures perform similarly regarding longer maturities.

Gilli, Große and Schumann (2010) and De Pooter (2007) address estimation problems regarding the Svensson model calibration. Gilli, Große and Schumann (2010) state that due to the identification problem, λ-values need to be restricted in order to meaningfully estimate parameters since for many λ-values the factor loadings are highly correlated. In a case when λ_1 and λ_2 are approximately equal, β_2 and β_3 therefore have the same factor loading and there are consequently two perfectly collinear regressors (when fixing λ_1 and λ_2 to pre-specified values and estimating with least squares). Therefore, Gilli, Große and Schumann (2010) and De Pooter (2007) refer to this problem as the multicollinearity problem. If the objective is only to fit a yield curve then correlation between factor loadings is not problematic since the focus is on the goodness of fit and interpolation of the yield curve, and not on the parameters and their interpretation, as estimated yield curves with different values of parameters can fit the data equally well. However, the problem arises when trying to predict coefficients or model them as autoregressive processes in the way presented by Diebold and Li (2006). Gilli, Große and Schumann (2010) advocate prudence when the objective is to identify the parameters in order to model their evolution over time. Inappropriate λ-values cause higher correlation between respective factor loadings, which affects yield curve factor values, causing detriment to parameters' identification and stability over time. Gilli, Große and Schumann (2010) and De Pooter (2007) in the case of two-step estimation, advocate imposing restrictions on λ_1 and λ_2 values to ranges where practical identification is still possible. Gilli, Große and Schumann (2010) claim, based on their experiment with the Nelson-Siegel model, that λ-values up to around 5 comply with the desired low correlation of yield curve factor loadings. Furthermore, in the case of the Svensson model, it is important to restrict λ_1 and λ_2 such that their values do not become too similar in order to avoid the multicollinearity problem. As a consequence, I implement restricted estimation of yield curve parameters in line with Gilli, Große and Schumann's (2010) propositions. In compliance with Gilli, Große and Schumann (2010), I impose the following yield curve decay parameters restrictions while no restriction is imposed on yield curve factors.

$$0 \leq \lambda_1 \leq 2.5 \quad 2.5 \leq \lambda_2 \leq 5.5 \tag{37}$$

The lower and upper bounds of yield curve decay parameters' intervals coincide with Gilli, Große and Schumann's (2010) findings. Estimated values for λ_1 and λ_2 should therefore generate acceptable correlations between factor loadings and diminish the problem of multicollinearity and identification. In order to be able to estimate the yield curve parameters with restrictions imposed on decay parameters, I used, instead of the Newton-Raphson algorithm, a quasi-Newton method presented by Byrd, Lu, Nocedal, and Zhu (1995) that allows for box constraints and therefore enables implementation of lower and upper bounds for decay parameters in numerical root finding of the Log-Likelihood function. The method used is a quasi-Newton method since the Hessian matrix is approximated and not computed. Gilli, Große and Schumann (2010) claim that several restarts of the optimization procedure are imperative when estimating the yield curve model parameters with numeric methods. The optimization procedure is performed 500 times for each observation date where values of parameters for the initial guess were drawn randomly from the restriction intervals for each yield curve parameter. The estimated yield curve with the best fit was then selected as the estimation result for a particular observation date.

Figure 2: Estimated and numeric yield curve factors

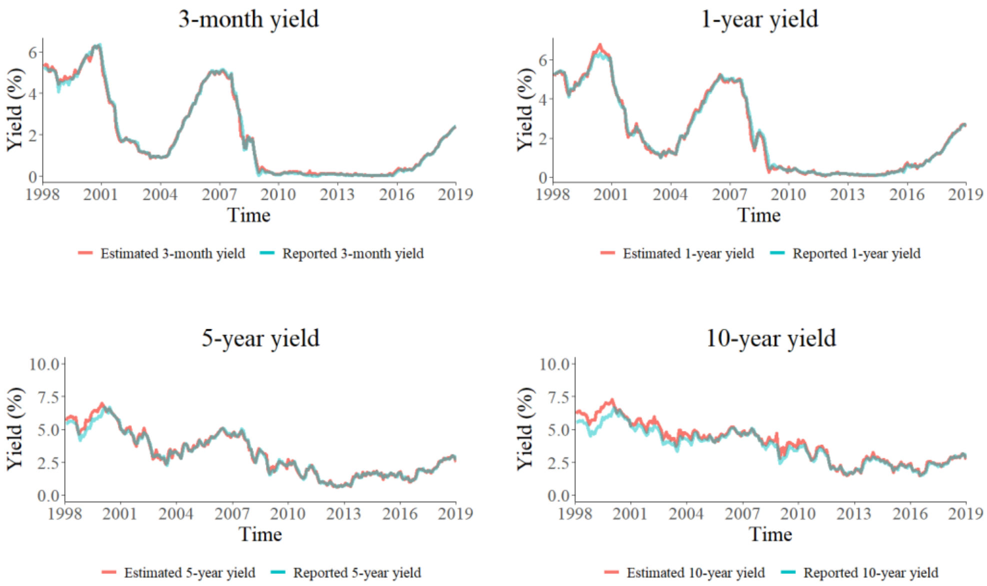
Source: Own work

Figure 2 presents estimated yield curve factors and compares them to numeric proxies of yield curve factors. Numeric proxies of yield curve factors are computed by following Diebold and Li (2006). The numeric level factor proxy is equal to the longest maturity (30 year) yields. The numeric slope factor proxy is computed as the difference between the longest (30 years) and the shortest (3 months) maturity yields while the numeric curvature factor proxy is computed as two times the medium maturity yields (3 years) minus the shortest (3 months) and the longest (30 years) maturity yields. Computed numeric proxies for yield curve factors coincide with the Nelson and Siegel (1987) model thereby yielding only one numeric proxy of the curvature factor. As a consequence, in Figure 2 estimated curvature factors β_2 and β_3 are scaled by 0.3 when they are compared to the numeric proxy of the curvature factor. Figure 2 demonstrates that estimated level and slope factors correspond fairly well to their respective numeric proxies. The correspondence of the two estimated curvature factors β_2 and β_3 with numeric proxy varies over time and depends on factors' loadings. The two curvature factors β_2 and β_3 become "one" curvature factor that corresponds to the Nelson and Siegel (1987) curvature factor in a case when factor loadings are the same due to equal values of decay parameters λ_1 and λ_1 as a consequence of the inappropriate model estimation. In such a case the "joint" curvature factor would correspond quite justifiably to the numeric curvature factor proxy as the yield curve model becomes even more parsimonious by reducing from the four factor Svensson (1994) model to the three factor Nelson and Siegel (1987) model. Since I implemented restrictions on decay parameters λ_1 and λ_2 in order to avoid the identification and multicollinearity problem, respective decay parameters are never the same, meaning factor loadings are never perfectly correlated. As a consequence, the numeric curvature proxy corresponds to the respective estimated curvature factors differently over time depending on the estimated value of the respective decay parameter. Therefore, at some points in time numeric curvature factor proxy corresponds more to the β_2 curvature factor values while at others to the β_3 curvature factor values. The Pearson correlation coefficients between estimated yield curve factors and their respective numeric proxies provide a different insight into the numeric proxies and estimated factor correspondence. They demonstrate that estimated yield curve factors track respective numeric proxies reasonably well. The Pearson correlation coefficient between the numeric proxy for the level factor and the estimated level factor β_0 equals 0.71 and the correlation between the numeric proxy for the slope factor and the estimated slope factor β_1 is equal to 0.90. Since Svensson's (1994) model consists of two curvature factors and the numeric proxy for curvature factor is only one, the Pearson correlation coefficient is computed between each particular estimated curvature factor and the numeric proxy for curvature factor. Correlations suggest that the estimated curvature factor β_2 corresponds better to the movement of the numeric curvature proxy as results display correlations equal to 0.53 for the estimated factor β_2 and 0.16 for the estimated curvature factor β_3.

Gurkaynak, Sack and Wright (2007) assert that the first hump, which is reflected in the first curvature factor β_2 and respective factor loading, is located at short to medium horizons. Meanwhile the second hump, reflected in the second curvature factor β_3 and respective factor loading, is located at comparatively longer horizons. Factor loadings for estimated slope β_1, curvature β_2 and curvature β_3 yield curve factors based on restrictive estimation of decay parameters λ_1 and λ_2 values are presented in Appendix 4. The factor loadings of level factor β_0 are not reported since its loading is constant and equal to 1. Results confirm the statement of Gurkaynak, Sack and Wright (2007) as they demonstrate that the curvature factor β_2 attains its maximum loading at shorter maturities in comparison to the curvature factor β_3. The slope factor β_1 loading decreases with maturity and asymptotically approaches zero. The rate of decay of β_1 factor loading depends on the value of the decay parameter λ_1 and it is true that the lower the decay parameter λ_1 value the faster the decrease of respective factor loading. For curvature parameters β_2 and β_3, it is true that the greater the decay parameter value λ_1 and λ_2, the greater the maturity at which the respective factor loading attains its maximum.

The estimated Svensson (1994) yield curve model parameters can fit a variety of yield curve shapes that occur over the observed time period, such as a normal or concavely increasing or upward-sloping yield curve, a decreasing or downward-sloping or inverted yield curve, a hump shaped yield curve and a flat yield curve. All of these yield curve shapes are presented in Appendix 4 while Appendix 3 presents some descriptive statistics, autocorrelation coefficients, Augmented Dickey-Fuller test statistics and KPSS test statistics in order to obtain a better insight into estimated yield curve factors β_0, β_1, β_2 and β_3

Figure 3: Comparison of selected constant maturity yields



Source: Own work

Figure 3 presents estimated yield curves for the whole observation period, from January 1998 to December 2018. Furthermore, Figure 5 illustrates the goodness of fit of several constant maturity zero-coupon yields to constant maturities zero-coupon yields reported by the Federal Reserve available at https://www.federalreserve.gov/datadownload/Choose.aspx?rel=H15. The time series of fitted constant maturities zero-coupon yields coincide better with the ones reported by Federal Reserve as time passes, meaning the goodness of fit increases over time. The main reason for discrepancies between the estimated constant maturity yields and the yields reported by the Federal Reserve is quality and availability of US Treasury Securities data. It is important to mention that the quality and quantity of US Treasury Securities available via the Bloomberg Professional Terminal increase over time, in particular for US Treasury Securities with the shortest maturities. As a consequence, Figure 3 displays the greatest discrepancies between estimated and reported constant maturity yields at the beginning of observation period. Moreover, discrepancies between the estimated and reported constant maturity yields are due to differences in methodology and differences in the portfolios of US Treasury Securities used for yield curve estimation. For more detailed insight into discrepancies between the estimated constant maturities yields and constant maturities yields reported by the Federal Reserve, consult Appendix 3 displaying some basic statistics of yields errors computed as a difference between estimated and Federal Reserve's reported constant maturity yields. Furthermore, Appendix 4 presents the estimated zero-coupon yield curves for the entire period examined, from January 1998 to December 2018, as a plane.

6.2 Factor Augmented Vector Autoregression (FAVAR) estimation

FAVAR estimation represents the second step in the two-step approach estimation of the yield curve model enhanced with macroeconomic variables or the macro-finance model.

6.2.1 Factors estimation

In order to estimate the factors $\hat{F}_t$, as described in section 4.2, I take first $K + M$ (M equals the number of variables treated as observable) principal components of X_t (the macroeconomic dataset). The number of estimated common components $\hat{C}_t$ in space spanned by F_t, Y_t and f_t^y is determined by criteria presented by Bai and Ng (2002), as described in more detail in Appendix 5.

As aforementioned in section 4.2, the latent yield curve factors f_t^y are treated as observable variables. As a consequence, the estimated factors $\hat{F}_t$ that replace F_t in the FAVAR need to be orthogonal to yield curve latent factors $f_t^y = [\beta_{0,t}\ \beta_{1,t}\ \beta_{2,t}\ \beta_{3,t}]^T$ as well as to the monetary policy instrument in Y_t. Consequently, the estimated factors $\hat{F}_t$ are obtained by regressing estimated common components $\hat{C}_t$ on extracted slow-moving factors F_t^s, observed variables Y_t, in this case the monetary policy instrument, and latent yield curve factors $f_t^y = [\beta_{0,t}\ \beta_{1,t}\ \beta_{2,t}\ \beta_{3,t}]^T$ as follows:

$$\hat{C}_t = b_{F^s} F_t^s + b_Y Y_t + b_{f^y} f_t^y + e_t \tag{38}$$

The estimated factors $\hat{F}_t$ are then obtained from $\hat{C}_t - \hat{b}_Y Y_t - \hat{b}_{f^y} f_t^y$ and are thus orthogonal to the monetary policy instrument in Y_t and yield curve latent factors $f_t^y = [\beta_{0,t}\ \beta_{1,t}\ \beta_{2,t}\ \beta_{3,t}]^T$.

Bernanke, Boivin and Eliasz's (2004) comment that Bai and Ng's (2002) criteria do not necessarily exactly determine the number of factors that should be included in the VAR and the desire for low dimensionality are motivators for reconsidering Bai and Ng's (2002) criteria. Therefore, I determine the number of static factors by relying on Bai and Ng's (2002) criteria, taking into the account the desired low dimensionality of the model. Arbitrarily, I allow for a maximum number of ten factors in the estimations of Bai and Ng's (2002) criteria and the estimated criteria suggest ten factors to be included in the VAR. However, in order to keep the low dimensionality of the FAVAR, I implemented three unobservable macroeconomic factors in the empirical analysis. As the model should be as parsimonious as possible, taking into the account the fact that the FAVAR I includes four estimated yield curve factors and a monetary policy instrument variable, which makes five observable variables already, the number of estimated unobservable macroeconomic factors should be small in order to keep the dimensionality of the whole FAVAR model relatively low. The total number of factors modelled in the FAVAR, observable and unobservable, is therefore eight, which is close to the number proposed by Bai and Ng's (2002) estimated criteria. Moreover, considering more than eight factors induces really small decreases in Bai and Ng's (2002) criteria and the marginal decrease of Bai and Ng's (2002) criteria is the greatest for eight factors in comparison to marginal decreases when considering more than eight factors.

6.2.2 Model specification and estimation

As a part of FAVAR model specification, it is essential to determine the appropriate autoregressive order, and a potential inappropriate model specification is reflected in the model checking. In order to specify the autoregressive order of the FAVAR model, I considered different information criteria that are widely and commonly used for determining the autoregressive order, i.e. the Akaike information criterion (AIC), the Hannah-Quinn information criterion (HQ), the Schwarz-Rissanen information criterion (SC), and the final prediction error (FPE). Lütkepohl and Krätzig (2004) assert that the AIC criterion asymptotically overestimates the autoregressive order with positive probability whereas HQ and SC criteria estimate the autoregressive order consistently. Lütkepohl and Krätzig (2004) claim that the latter holds in cases where the data generating process has a finite VAR order and when the maximum autoregressive order considered for information criteria computation is larger than the true autoregressive order. Moreover, Lütkepohl and Krätzig (2004) claim that under-fitting a VAR model regarding the lag length in most cases generates autocorrelated errors while over-fitting of a VAR model causes an increase in the mean-squared forecast errors.

The Akaike information criterion (AIC), the Hannah-Quinn information criterion (HQ), and the final prediction error (FPE) suggest the usage of two lags, while the Schwarz-Rissanen information criterion (SC) suggest the usage of only one lag. A more detailed inspection of the estimated criteria reveals that the difference in the Schwarz-Rissanen information criterion (SC) values, when considering one lag and two lags, is not substantial. Consequently, since three out of the four information criteria considered suggest two lags and there is a relatively small difference in the values of the Schwarz-Rissanen information criterion for one and two lags, I decided to implement a model with two lags.

6.2.3 Impulse response functions

Impulse response analysis represents the cornerstone of the analysis conducted in this master's thesis. Using a stable VAR process for y_t, i.e. $I(0)$ (the VAR process is integrated of order 0) and holding it stationary gives a Wold moving average representation in the form of

$$y_t = \Phi_0 u_t + \Phi_1 u_{t-1} + \Phi_2 u_{t-2} + \cdots = \sum_{i=0}^{\infty} \Phi_i u_{t-i} \tag{39}$$

with $\phi_0 = I_K$. Let ϕ_i represent the corresponding moving average coefficients matrix, A_k represent corresponding VAR coefficients matrix and p be equal to the autoregressive order of estimated VAR process. The matrices ϕ_i can be computed recursively in compliance with the following expression

$$\Phi_i = \sum_{k=1}^{i} \Phi_{i-k} A_k \quad i = 1, 2, 3, \ldots \tag{40}$$

where $\phi_0 = I_k$ and $A_k = 0$ when $k > p$.

The matrix Φ_s element represents impulse responses of y_t with respect to shocks v_t. The response of $y_{i,t+s}$ to a unit shock to $y_{j,t}$ is expressed as

$$\frac{\delta y_{j,t+i}}{\delta y_{k,t}} = \frac{\delta y_{j,t+i}}{\delta u_{k,t}} = \Phi_i(j,k) \tag{41}$$

therefore the ijth element of matrix Φ_i, i.e. $\Phi_i(j,k)$ represents the expected response to a unit shock to $y_{k,t}$ of $y_{j,t+i}$.

Sims (1980) proposed a Cholesky decomposition of the variance-covariance matrix Σ_v in order to obtain orthogonalized shocks ε_t,

$$\Sigma_u = PP^T \tag{42}$$

which makes P lower triangular. The orthogonalized shocks are expressed as $\varepsilon_t = P^{-1} u_t$ and they have unit variance-covariance matrix, i.e. $E(\varepsilon_t {\varepsilon_t}^T) = I_K$. The moving average representation is then expressed as

$$y_t = \Psi_0 \varepsilon_t + \Psi_1 \varepsilon_{t-1} + \Psi_2 \varepsilon_{t-2} + \cdots = \sum_{i=0}^{\infty} \Psi_i \varepsilon_{t-i} \tag{43}$$

where $\Psi_0 = P$ and matrices $\Psi_i = \Phi_i P$ for $i = 1, 2, 3, \ldots$ while the orthogonalized impulse responses are the respective elements of Ψ_i (Lütkepohl, 2005).

As described above, impulse responses of variables treated as observable i.e., Y_t and f_t^y, and factors $\hat{F}_t$ are estimated. Taking into the account the measurement equation for the economy (34), impulse responses of every variable in the macroeconomic dataset X_{it} are obtained by regressing each X_{it} on observable variables, i.e. Y_t and f_t^y, and rotated factors $\hat{F}_t$, and inserting the obtained impulse responses of variables modelled using the VAR process from the second step of FAVAR estimation. In order to obtain confidence intervals of the impulse responses, the bootstrapping procedure presented by Kilian (1998) is implemented and confidence intervals are computed based on bootstrapped impulse responses distributions.

6.2.4 Forecast error variance decomposition

Forecast error variance decomposition analysis complements impulse responses analysis. The forecast error variance decomposition is based on the orthogonalized impulse response coefficient matrices Ψ_i. Lütkepohl (2005) describes that a particular VAR (p) process in the form of equation (44)

$$y_t = v + A_1 y_{t-1} + \cdots + A_P y_{t-P} + u_t \tag{44}$$

can be converted to a VAR (1) structure by writing the VAR (p) process in companion form (45)

$$Y_t = v + AY_{t-1} + \cdots + U_t \tag{45}$$

where A is a Kp by Kp dimensional matrix, y_t are K dimensionl column vectors and Y, V and U are Kp dimensional column vectors, of the following forms

$$A = \begin{bmatrix} A_1 & A_2 & \cdots & A_p \\ I_K & 0 & \cdots & 0 \\ \vdots & \ddots & \vdots & \vdots \\ 0 & \cdots & I_K & 0 \end{bmatrix}, Y = \begin{bmatrix} y_1 \\ \vdots \\ y_p \end{bmatrix}, V = \begin{bmatrix} v \\ 0 \\ \vdots \\ 0 \end{bmatrix} \text{ and } U_t = \begin{bmatrix} u_t \\ 0 \\ \vdots \\ 0 \end{bmatrix}.$$

The orthogonalized impulse response coefficient matrices Ψ_i are computed as

$$\Psi_i = \Phi_i P \tag{46}$$

where P is the known lower triangular matrix obtained by using Cholesky decomposition on covariance matrix Σ_y as proposed by Sims (1980) and moving average matrices Φ_i are computed as

$$\Phi_i = JA^i J^T \tag{47}$$

where J is a K by Kp dimensional matrix, i.e. $J = [I_K \; 0 \; \cdots \; 0]$.

Following the explanation in Lütkepohl (2000) and Lütkepohl (2005), denote y_{t+h} as the optimal h-step forecast in period t. The corresponding forecast error can be expressed as equation (48).

$$y_{t+h} - y_t(h) = \sum_{i=0}^{h-1} \Phi_i u_{t+h-i} \tag{48}$$

Under the assumption that the ε_{kt} are contemporaneously and serially uncorrelated and have unit variances, i.e. $E(\varepsilon_t {\varepsilon_t}^T) = I_K$, by construction since $\varepsilon_t = P^{-1}u_t$, Cholesky decomposition can be used as proposed by Sims (1980), to express the forecast error in equation (49).

$$y_{t+h} - y_t(h) = \sum_{i=0}^{h-1} \Phi_i P P^{-1} u_{t+h-i} = \sum_{i=0}^{h-1} \Psi_i \varepsilon_{t+h-i} \tag{49}$$

Denoting the mn-th element of Ψ_i by $\psi_{mn,i}$, the h step forecast error of j-th component of y_t can be expressed as equation (50)

$$y_{j,t+h} - y_{j,t}(h) = \sum_{i=0}^{h-1} (\psi_{j1,i}\varepsilon_{1,t+h-i} + \cdots + \psi_{jK,i}\varepsilon_{K,t+h-i}) \tag{50}$$

or equivalently as equation (51).

$$y_{j,t+h} - y_{j,t}(h) = \sum_{k=1}^{K} (\psi_{jk,0}\varepsilon_{k,t+h} + \cdots + \psi_{jk,h-1}\varepsilon_{k,t+1}) \tag{51}$$

The forecast error of the j-th component likely consists of all the innovations $\varepsilon_{1,t}, \ldots, \varepsilon_{K,t}$. Since $\varepsilon_{k,t}$'s are uncorrelated and have unit variances, the MSE of $y_{j,t}(h)$ is expressed as equation (52).

$$E(y_{j,t+h} - y_{j,t}(h))^2 = \sum_{k=1}^{K} \left(\psi_{jk,0}^2 + \cdots + \psi_{jk,h-1}^2\right) \tag{52}$$

As a consequence, the contribution of innovations in variable k to the forecast error variance or MSE of the h-step forecast of variable j is expressed as equation (53):

$$\psi_{jk,0}^2 + \psi_{jk,1}^2 + \cdots + \psi_{jk,h-1}^2 = \sum_{i=0}^{h-1} {e_j^T \Psi_i e_k}^2 \tag{53}$$

where e_k and e_j are the k-th and j-th columns of I_K. The proportion of the h-step forecast error variance of variable j accounted for by innovations in variable k is obtained by dividing equation (53) by equation (54).

$$MSE\left[y_{j,t}(h)\right] = \sum_{i=0}^{h-1} \sum_{k=1}^{K} \psi_{jk,i}^2 \tag{54}$$

The latter gives the following equation (55) for the h-step forecast error variance of variable j accounted for by innovations in variable k.

$$\omega_{jk,h} = \sum_{i=0}^{h-1} (e_j^T \Psi_i e_k)^2 \, / \, MSE\left[y_{j,t}(h)\right] \tag{55}$$

Using the relationship from (55), the h-step forecast MSE matrix is equal to

$$\Sigma_y(h) = \sum_{i=0}^{h-1} \Psi_i \Psi_i^T = \sum_{i=0}^{h-1} \Phi_i P P^{-1} \Phi_i^T \tag{56}$$

and the diagonal elements of matrix $\Sigma_y(h)$ are the MSEs of the $y_{j,t}$ variables, which may be used in computation of $\omega_{jk,h}$. Therefore, the h-step forecast error variance of variable j accounted for by innovations in variable k is expressed as

$$\omega_{jk,h} = \sum_{i=0}^{h-1}(e_j^T \Psi_i e_k)^2 \, / \, \Sigma_y(h)_{jj} \tag{57}$$

where $\Sigma_y(h)_{jj}$ is denoted as the jj-th element of matrix $\Sigma_y(h)$ (Lütkepohl, 2005).

In order to obtain forecast error variance decomposition of every variable in the macroeconomic dataset X_{it}, it is important to recall once again that the model is written as equation (58):

$$X_t = \Lambda^f \hat{F}_t + \Lambda^y Y_t + \Lambda^{f^y} f_t^y + e_t \tag{58}$$

As a consequence, the importance of a structural shock needs to be assessed only to the portion of the variable explained by the common factors, using corresponding coefficients from the matrix Λ. The variance decomposition of X_{it} can be expressed (in percentage) as

$$\frac{\Lambda_i Var(y_{t+h} - y_t(h) | \varepsilon_{kt}) \Lambda_i^T}{\Lambda_i Var(y_{t+h} - y_t(h)) \Lambda_i^T} \tag{59}$$

where Λ_i represents ith row of matrix $\Lambda = (\Lambda^f, \Lambda^y, \Lambda^{f^y})$.

7 MODEL ESTIMATION RESULTS AND IMPLICATIONS

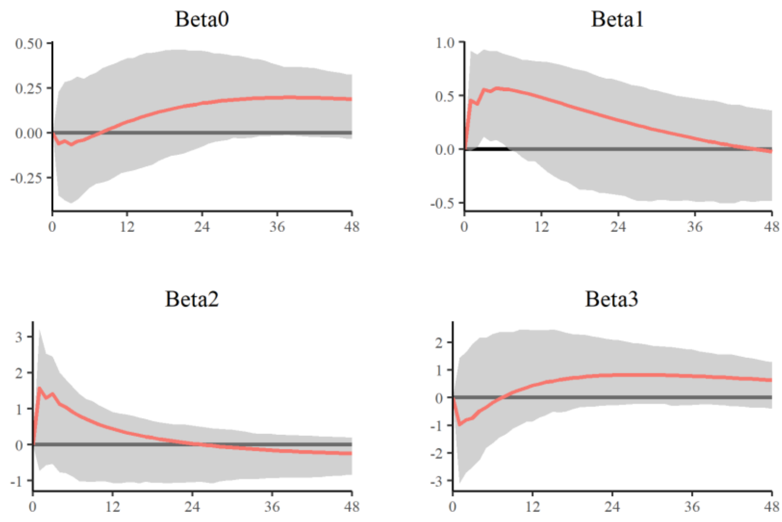
7.1 Monetary policy and latent yield curve factors

The objective of this section is to describe how monetary policy affects latent yield curve factors and key macroeconomic variables. The impulse responses of yield curve factors and macroeconomic variables to a contractionary monetary policy shock are presented for a 48-month horizon with 90% confidence intervals. The confidence intervals are generated by using the bootstrap procedures presented by Kilian (1998). In section 7.1.1, I discuss baseline results regarding general interactions between monetary policy, latent yield curve factors and macroeconomic variables. Previous studies suggest relationships between latent yield curve factors and macroeconomic variables change as monetary policy regime or monetary policy stance change. Moreover, the effect of monetary policy on yield curve factors apparently changes with monetary policy stance. Therefore, the implementation of unconventional monetary policy measures, i.e. the QE, is used as the dividing point of the time period considered from January 1998 to December 2018 into two sub-periods. The Pre-QE sub-period represents the time period before the implementation of the unconventional monetary policy measures and it spans from January 1998 to including November 2008. The Post-QE sub-period represents the time period after the implementation of unconventional monetary policy measures and it spans from December 2008 to December 2018. The division of the total sample into the two described periods is based on the Federal Reserve's announcement of QE1 on 25 November 2008. The Fed launched QE1 in December 2008. The two sub-periods are discussed in section 7.1.2.

7.1.1 General relationships

A shock to the monetary policy instrument, which is represented by the Effective Federal Funds Rate complemented with the Shadow Federal Funds rate calculated by Wu and Xia, affects the yield curve. The effect of a monetary policy instrument increase is insignificant for the β_0 factor affecting the level of the yield curve, although estimated impulse responses suggest a slight decrease of the β_0 factor followed by an almost significant increase 36 months after the monetary policy shock. The effects on β_2 and β_3 factors are regarded as curvature factors, with the first affecting the most short- to medium-term maturity parts of the yield curve and the second affecting the medium- to long-term maturity part of the yield curve, and are insignificant. The estimated impulse response of β_2 factor suggests an increase while the estimated impulse response of β_3 factor suggests a decrease, albeit an insignificant one. The only impulse response of yield curve factors exhibiting a significant effect is the response of the β_1 factor, which is regarded as the slope factor. As described in previous sections, it can be regarded as an approximation for the negative of the spread between the short- and long-term maturities yields. The impulse response of β_1 factor suggests an increase in the slope factor and due to the Svensson's (1994) yield curve model functional form, the significant increase of the β_1 factor causes the flattening of the yield curve. The flatter yield curve, resulting from an increase in the slope factor, is due to β_1 factor loading attaining its maximum at the shortest maturities and decreasing as maturities increases. Therefore, the shorter-term part of the yield curve is affected more by the increase in the β_1 factor than the mid- and the longer-term parts, meaning short-term yields increase more than long-term yields. The result obtained regarding the effect of contractionary monetary policy on the yield curve is consistent with the results obtained by other researchers as presented in section 2. Since the slope factor can be regarded as the negative of the yield spread, the increase in the slope factor and corresponding flattening of the yield curve results in the decrease of the yield spread as yields of shorter maturities increase more than yields of longer maturities. Furthermore, forecast error variance decomposition demonstrates the greatest percentage of the explained variance for the β_1 factor among all four yield curve factors. After a 48-month horizon, the monetary policy shock is able to explain 3.59% of the variation in β_1 factor while for the β_0, β_2 and β_3 factors the monetary policy shock accounts for 2.07%, 1.67% and 1.42% of forecast error variance respectively. Therefore, the effect of the monetary policy shock on the yield curve is the most profound through the β_1 factor.

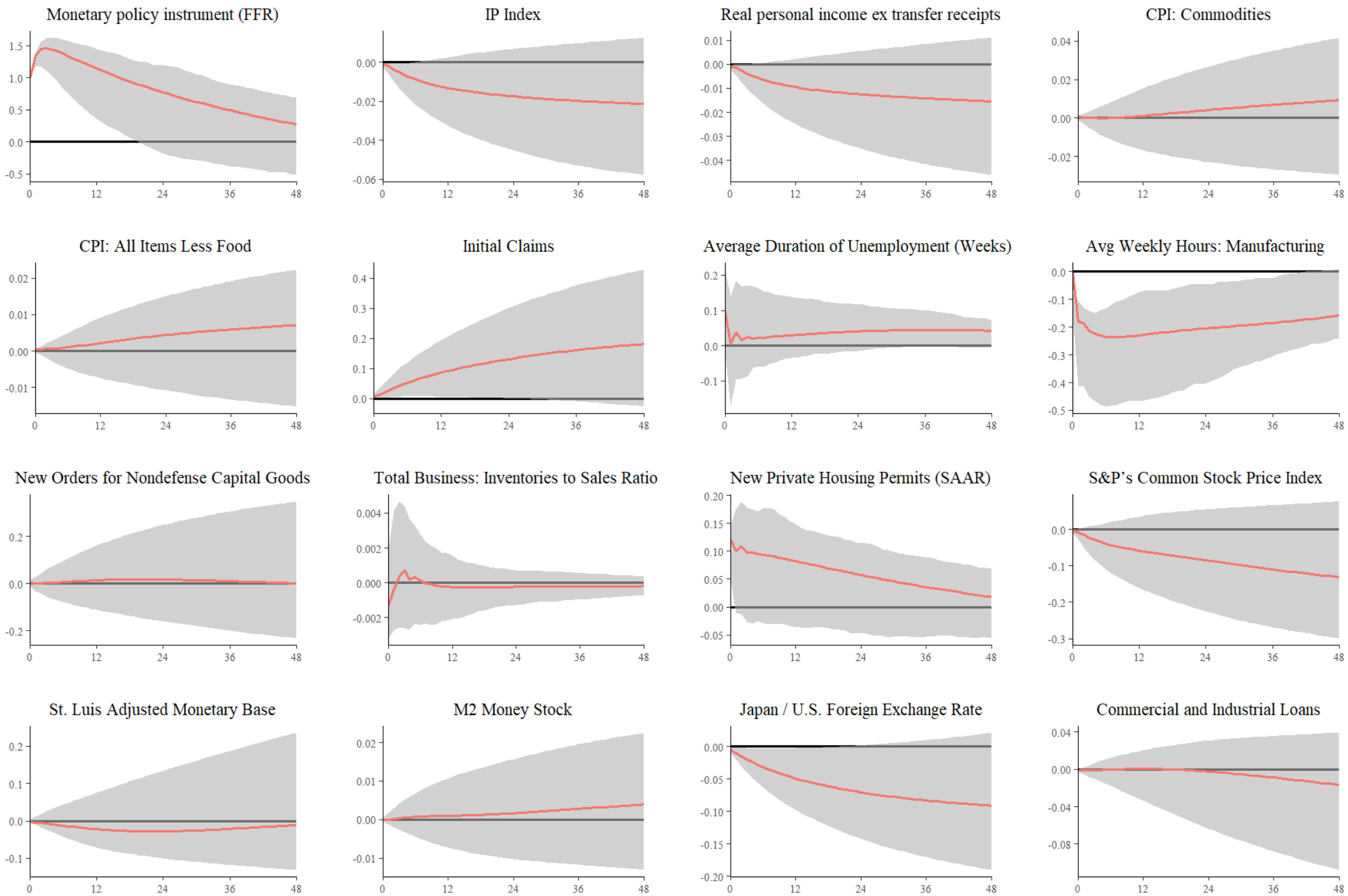
Figure 4: Impulse responses of yield curve latent factors – Total period



Source: Own work

I also present impulse responses of several macroeconomic variables that are regarded as leading, coincident and lagging economic indicators. The interest rate spread between 10-year treasury yields and the Federal funds rate is regarded as a very informative leading economic indicator as presented in section 2 since a narrower spread anticipates an economic downturn and a wider spread anticipates an economic upswing. As discussed in the previous paragraph, a contractionary monetary policy affects the yield curve through the increase of β_1 factor, which flattens the yield curve and narrows the yield spread. From this point of view, the result regarding a significant increase in the β_1 factor and its effect on the yield curve is consistent as well. Moreover, the Industrial Production Index, which is regarded as a coincident economic indicator, decreases in response to the increase in the monetary policy instrument, suggesting an economic downturn. Real personal income (less transfer receipts) is another coincident economic indicator suggesting an economic downturn as it measures the current state of the economy. Both reported price level indicators exhibit the "price puzzle" phenomenon. It is more profound for prices of commodities than for the core inflation represented as CPI: All Items Less Food. Furthermore, Initial Claims, being a leading economic indicator for unemployment, increases with the contractionary monetary policy. Another labour market indicator is Average Duration of Unemployment, which is a lagging indicator since businesses wait to implement layoffs until a genuine economic downturn happens. There is a lag in its increase, although there is also evidence of an initial increase coincident with the monetary policy shock but it quickly decays. Average Weekly Hours Manufacturing is another popular economic indicator related to the labour market. It is a leading indicator since businesses tend to cut overtime before starting layoffs in the event of economic downturn. Therefore, the measure is generally moving up and down with the economy. It decreases in response to the monetary policy shock as anticipated. New Orders for Nondefense Capital Goods increase slightly, inconsistently with its nature as a leading indicator, as it measures business expectations, and the anticipated result would be a decrease. However, the increase is barely noticeable. The Inventory to Sales Ratio is regarded as a lagging indicator as inventories accumulate when the sales decline as a result of economic downturn, thereby lagging the increase in the ratio, although the impulse response initially exhibits a dubious decrease in the ratio that is followed by an increase and a decrease. The response is to an extent consistent since there is a lag in businesses' adaptation of inventories to decreased sales. Another peculiar result relates to New Private Housing Permits, which is a leading economic indicator and which is supposed to result in a decrease corresponding to a contractionary monetary policy, however it exhibits an increase. A peculiar result is also obtained for M2 money stock as it increases, contrary to the decrease expected. However, the monetary base consistently decreases. Furthermore, the S&P 500 Index, a leading indicator, exhibits consistent results as stock prices decrease in anticipation of an economic downturn as a result of a contractionary monetary policy. Commercial and Industrial Loans Outstanding exhibit a lagged decrease in response to the contractionary monetary policy, which is consistent with the variable's nature as a lagging economic indicator. Moreover, the exchange rate decreases despite the expected increase. However, the result is consistent with the forward parity of exchange rate movements as the increase in the domestic interest rates decreases the forward exchange rate, resulting in a forward exchange rate depreciation in view of the indirect quotation convention, as is the case for the exchange rate presented. Moreover, in the case of the forward parity of exchange rate, the forward exchange rate remains unchanged when the domestic interest rate increase is not offset by the change in the foreign interest rate but it is accommodated by the spot exchange rate depreciation (indirect quotation convention). However, I must state that the impulse responses of the described macroeconomic variables are insignificant for the majority of variables. Several variables' impulse responses are almost significant by only a few exhibit significant impulse responses at the 90% level confidence interval. Regarding the forecast error variance decomposition for macroeconomic variables, the fraction of the forecast error variance explained as a result of monetary policy shock is the greatest for New Private Housing Permits (1.79%) despite their exhibiting an unanticipated peculiar impulse response. It is followed by Commercial and Industrial Loans (1.62%), which is tightly connected with the economic cycle and interest rates, Industrial Production Index (0.95%) and CPI: All Items Less Food representing the core inflation (0.94%) all producing consistent results. The lowest fraction of explained variance corresponds to New Orders for Nondefense Capital Goods, which is a leading indicator (0.09%).

Figure 5: Impulse responses of macroeconomic variables – Total period

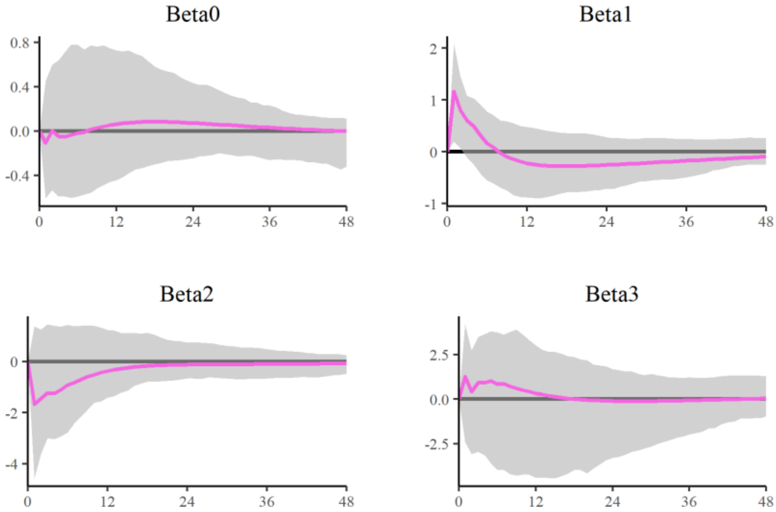


Source: Own work

7.1.2 Effects of unconventional policy measures

One of the most important observations when examining the Pre- and Post-QE periods concerns the persistence of the effect of monetary policy shock on the monetary policy instrument. The results demonstrate that it is much more persistent in the Post-QE period than in the Pre-QE Period. This is presented by the respective impulse responses of the monetary policy instrument as well as the forecast error variance decomposition. After the 48 months, the percentage of explained forecast variance of monetary policy instrument corresponding to monetary policy shock for Pre-QE and Post-QE periods are 1.41% and 18.98% respectively, indicating a substantial difference in persistence. The latter suggests possible differences in the effects of the monetary policy shock on yield curve factors as well as macroeconomic variables between the Pre-QE and Post-QE periods. As expected, there are differences in the responses of yield curve factors to monetary policy shock. The β_0 factor's response to monetary policy shock does not differ substantially between the Pre-QE and the Total period, although for the Post-QE period it suggests a decrease contrary to the increase exhibited in the Pre-QE and Total periods. The effect of the monetary policy instrument increase on the β_0 factor is insignificant in both sub-periods so it cannot be stated that the level of the yield curve is affected in any of the sub-periods by the monetary policy shock. In the case of the β_1 factor, impulse responses in the Pre-QE and the Post-QE are different. In the Pre-QE period, the monetary policy shock affects the β_1 factor similarly to the Total period, representing the general result regarding the relationship between the monetary policy instrument and the slope factor. In the Pre-QE period, the increase in the monetary policy induces a significant increase in the β_1 factor that causes the flattening of the yield curve due to the functional form of the Svensson (1994) model. Furthermore, in the Pre-QE period, the impulse responses of β_2 and β_3 factors have the opposite directions to the general result from the Total period. The β_3 factor impulse response suggests an insignificant increase in the curvature factor that affects the medium- to long-term parts of the term structure. The β_2 factor, contrary to the general result, suggests an insignificant decrease as a consequence of the restrictive monetary policy. The cumulative effect of the monetary policy shock on the yield curve as a result of the significantly increased β_1 factor results in a flatter yield curve, similarly to the yield curve shape described when considering the general result. However, the magnitude of the impulse response of the β_1 factor is greater in the case of the Pre-QE period in comparison to the general result, therefore resulting in a more substantial flattening of the yield curve.

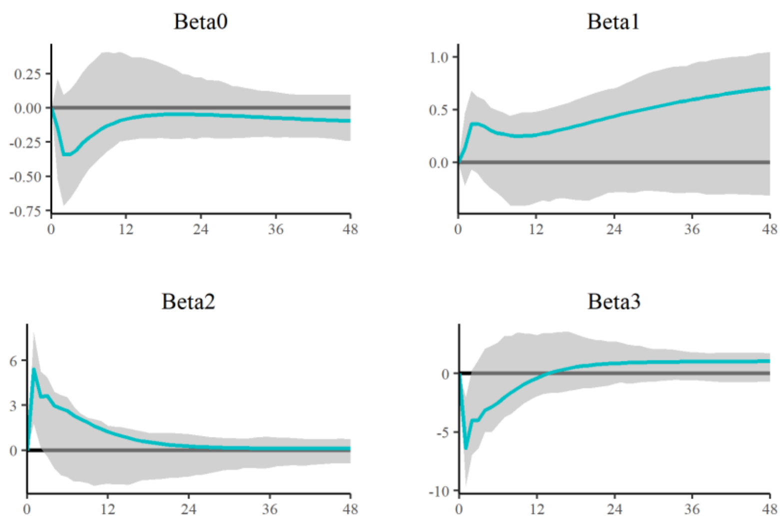
Figure 6: Impulse responses of yield curve latent factors – Pre-QE period



Source: Own work

In terms of the Post-QE period, the effect of the monetary policy shock on the β_1 factor is much smaller than in the Pre-QE period. The response of the β_1 factor still suggests an increase in the slope factor, however the magnitude of the increase in the β_1 factor is significantly smaller than in the Pre-QE period. Moreover, examining the impulse response of the β_1 factor in the Post-QE period in isolation suggests an insignificance of the β_1 factor impulse response to the monetary policy shock when considering a 90% confidence interval. Furthermore, β_2 and β_3 factors' impulse responses suggest completely different effects of monetary policy shock on the respective yield curve factors than in the Pre-QE period. The direction of β_2 and β_3 factors' impulse responses in the Post-QE period resembles those from the general result. However, the magnitude exhibited is substantially greater. The β_2 factor increases in response to a contractionary monetary policy and the β_3 factor decreases. Considering the 90% confidence intervals, both of the curvature factors' impulse responses are significant. The cumulative effect on the yield curve as a consequence of yield curve factors movements in response to restrictive monetary policy shock results in a narrower yield curve spread similar to that of the Pre-QE period and the Total period (general result). However, the monetary policy shock affects the yield curve in the Post-QE through different yield curve factors, resulting in a different shape of the yield curve to the Pre-QE period. As stated, in the Post-QE period, the yield curve moves in response to both curvature factors, β_2 and β_3 factors. The narrower yield curve spread that gives a flatter yield curve in the Post-QE period, resulting from contractionary monetary policy, is the consequence of the simultaneously decreasing β_3 factor and increasing β_2 factor. The increase in the β_2 factor increases the short- to medium-term parts the most while the contemporaneous decrease in the β_3 factor decreases the medium- to long-term parts of the term structure the most. Therefore, the medium- to long-term part of the yield curve decreases and the short- to medium-term part increases, resulting in a flatter yield curve in terms of the yield curve spread. The described effects on the yield curve are due to the Svensson (1994) model functional form. The amplitudes of the β_2 and β_3 factors impulse responses are relatively balanced. However, the cumulative result of the movement in curvature factors resulting from the monetary policy shock does not result in the yield curve having the same shape in the Post-QE period as in the Pre-QE period. The yield curve becomes flatter, considering the yield spread, but it also becomes slightly hump-shaped and starts to invert. Therefore, the exact cumulative effect on the yield curve shape through the yield curve factors' responses to the contractionary monetary policy is a slightly hump-shaped yield curve starting to invert. Moreover, the shape is also the reason that the effect of the monetary policy shock on the yield curve slope (spread) through the yield curve factors is greater in the Post-QE period than in the Pre-QE period. Forecast error variance decomposition confirms the more profound roles of β_2 and β_3 factors in shaping the yield curve than the β_1 factor in the Post-QE period as the fractions of forecast error variances are equal to 7.79%, 5.82% and 6.54% respectively. It is evident that the importance of the β_1 factor, the slope factor, for the shape of the yield curve decreased substantially from the Pre-QE period to the Post-QE period relative to other yield curve factors. The percentages of the explained forecast error variance in the Pre-QE period for β_0, β_1, β_2 and β_3 factors are 0.06%, 1.09%, 0.73% and 0.08% respectively, while in the Post-QE period the fractions of the explained forecast variance increase to 2.41%, 6.54%, 7.79% and 5.82% respectively. Moreover, the latter is an indicator that the monetary policy shock affects the shape of the yield curve much more in the Post-QE period than in the Pre-QE period.

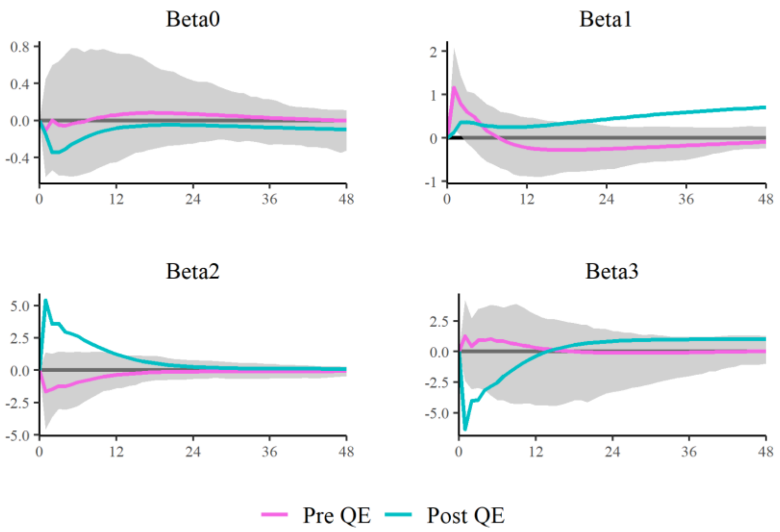
Figure 7: Impulse responses of yield curve latent factors – Post-QE period



Source: Own work

After the implementation of the QE and other unconventional monetary policy measures, the yield curve becomes more responsive to monetary policy measures than in the period before the implementation. As discussed, the effect on the yield curve spread or slope is still the same in terms of the direction of the change, as an increase in the monetary policy induces the flattening of the yield curve as before the implementation. The magnitude of the change in the yield curve spread is more profound in the Post-QE period than in the Pre-QE period. However, the difference is in the yield curve factors through which the monetary policy affects the yield curve and in the shape of the yield curve itself. Since in the Post-QE period the yield curve is affected through curvature factors while in the Pre-QE period it is affected through the slope factor, the shape of the yield curve differs. Therefore, in periods before the implementation of the QE, a contractionary monetary policy resulted only in the flattening of the yield curve while after the implementation, the yield curve becomes slightly hump-shaped and inverted and therefore flatter. Accordingly, results suggest that after the implementation of the QE, the medium- and longer-term maturities part of the yield curve became more responsive to monetary policy shocks than before the implementation. Despite the differences in the effects on the shape of the yield curve, the monetary policy shock translates quickly into the yield curve shape in both of the periods. Therefore, there is no difference in timing in terms of the responses of the yield curve factors resulting from the monetary policy shock in the Pre-QE and the Post-QE period. However, in the Post-QE period, the yield curve starts to invert sooner in response to the restrictive monetary policy shock than in the Pre-QE period due to the differences in yield curve factors through which the shock affects the yield curve shape. Therefore, it could be said that in the Post-QE period, the transmission of monetary policy shocks into the yield curve shape is faster than in the Pre-QE period and the yield curve is more responsive to monetary policy shocks than before the implementation of the QE. Moreover, the change in the shape of the yield curve in response to the restrictive monetary policy shock in the Post-QE period in comparison to the Pre-QE period suggests greater uncertainty regarding the slowing of economy in the Post-QE period.

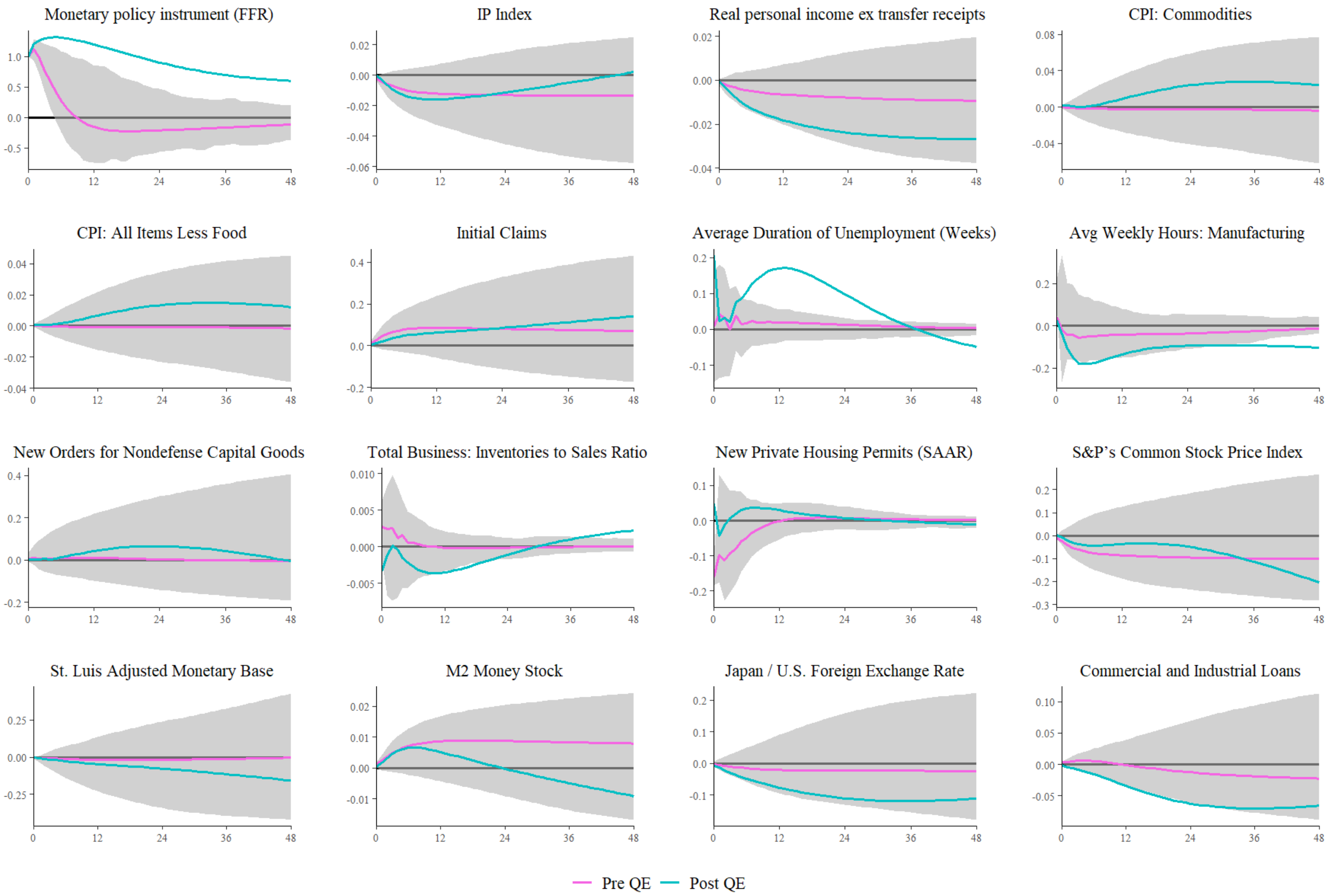
Figure 8: Impulse responses of yield curve latent factors – comparison of sub-periods



Source: Own work

As discussed in the previous paragraph, the general result regarding the yield curve and yield curve spread still holds in both sub-periods, which is the flattening of the yield curve due to the increase in the monetary policy instrument, despite different effects on the exact shape of the yield curve. The flattening of the yield curve or the yield curve spread is, as discussed, a leading economic indicator. Since the flattening of the yield curve means a narrower yield curve spread that anticipates an economic downturn, results are consistent from this point of view. The Industrial Production Index, which is a coincident economic indicator and measures industrial output, decreases in both sub-periods. However, in the Post-QE period the negative response of the Industrial Production Index decays faster than in the Pre-QE period. Furthermore, Real Personal Income Less Transfer Payments decreases in both sub-periods as well, and the decrease is more profound in the Post-QE period. Regarding prices and inflation, there are interesting results for the two sub-periods. The Post-QE period exhibits the well-known "price puzzle" while the Pre-QE period results in terms of inflation are to an extent consistent with the contractionary monetary policy as impulse responses suggest a barely noticeable decrease in core inflation and commodities prices. The Initial Claims' Impulse responses present consistent results for both sub-periods, although the increase in the Post-QE period is slightly more profound. Average Duration of Unemployment, being a lagging economic indicator, in the Post-QE period increases as anticipated, as well as in the Pre-QE period. The impulse response is substantially greater in the case of the Post-QE period than in the case of the Pre-QE period. Consistent results are exhibited for another labour market indicator as well. The Average Weekly Hours in manufacturing decrease in both sub-periods as anticipated, but as in the case of Average Duration of Unemployment, the Post-QE period reveals a greater impact of the monetary policy shock on the respective leading economic indicator. As a leading economic indicator, New Orders for Nondefense Capital Goods reveals some peculiar results. In the Pre-QE period, this economic indicator is genuinely unaffected by the monetary policy shock, while in the Post-QE period it exhibits an unexpected increase, as also presented in the general result. The Inventories to Sales Ratio's impulse responses present consistent results in the Pre-QE period as the ratio increases in response to depressed sales, which is a consequence of a contractionary monetary policy and an economic downturn. In the Post-QE period a peculiar result emerges, since the ratio initially decreases until after approximately 30 months it increases. New Private Housing Permits, being a leading economic indicator, decreases in the Pre-QE period as anticipated, while in the Post-QE period it unexpectedly initially increases, slightly decreasing with a lag and then unexpectedly increasing again. The impulse responses of the S&P 500 Index are consistent, although the results suggest a more profound impact of the monetary policy on the stock market in the Post-QE period. The latter is confirmed also by the percentage of the forecast error variance since it is much greater in the Post-QE period (2.19%) than in the Pre-QE period (0.28%). The monetary base decreases consistently in response to the contractionary monetary policy, although the decrease in the Pre-QE period is merely small. M2 Money Stock unconventionally increases in the Pre-QE period, while in the Post-QE period it experiences an initial increase followed by a decrease after 24 months. Regarding the exchange rate impulse responses, results for both sub-periods are consistent with the Total period, although there is a difference in the magnitude between the two sub-periods, the decrease being more profound in the Post-QE period than in the Pre-QE period. The impulse responses of the exchange rate are consistent with the previously described forward parity of the exchange rate when using the indirect quotation convention. The last economic indicator presented is Commercial and Industrial Loans, which is a lagging indicator. The impulse responses are consistent since in both sub-periods the amount of loans outstanding decreases in response to the monetary policy shock. However, in the Pre-QE period, Commercial and Industrial Loans emphasize to an extent the variable's capacity as a lagging economic indicator due to the revealed lag in the decrease. Conversely, in the Pre-QE period, there is no lag in the response of the variable to the monetary policy shock. The majority of economic indicators exhibit different results in the two sub-periods in terms of the intensity of responses. Results suggest that in the Post-QE period, the responses of macroeconomic indicators are more intense than in the Pre-QE period. The latter is confirmed by the fractions of forecast error variance explained for respective variables. Therefore, the monetary policy is more influential regarding the macroeconomic variables in the Post-QE period than in the Pre-QE period. Furthermore, there are differences in adjustments of economic agents to the monetary policy shock in the two sub-periods as is evident from the differing impulse responses. For example, in the case of Commercial and Industrial Loans, in the Pre-QE period there is a lag before the reduction of loans outstanding while in the Post-QE period the adjustment to the monetary policy shock is much quicker and the lag genuinely disappears. Moreover, in the case of the Inventories to Sales Ratio, in the Pre-QE period the ratio increases in response to the reduction in sales as businesses cannot immediately adjust, while in the Post-QE period the ratio's decrease is followed by an increase. It suggests that businesses overreact in the Post-QE period to the monetary policy shock as they slash inventories more than sales drop and after the time needed for adjustment to and reaching an actual state of economy they start to build up their inventories again and outpace sales. However, as in the case of general results, it needs to be emphasized that very few impulse responses are significant at the 90% confidence interval.

Figure 9: Impulse responses of macroeconomic variables – comparison of sub-periods



Source: Own work

7.2 Macroeconomic variables and latent yield curve factors

In order to be able to discuss relationships between yield curve factors and macroeconomic variables, yield curve factors are regressed on lags of macroeconomic variables (one lag) used in FAVAR. Moreover, macroeconomic variables are also regressed on lagged latent yield curve factors (one lag) since the studies presented in section 2 suggest a bi-directional relationship between the yield curve and economy. Such analysis design of the relationship between the yield curve factors and macroeconomic variables results in the macroeconomic variables being treated as yield curve drivers when yield curve factors are regressed on lagged macroeconomic variables and the yield curve factors being treated as the drivers of macroeconomic variables when regressing macroeconomic variables on lagged yield curve factors. Only results for variables whose total period F statistic's level of significance is lower than 5% and total period coefficient of determination exceeds 0.05 are taken into account when discussing bi-directional relationships between the yield curve and macroeconomic variables. In general, the results exhibit a great interdependence between the yield curve and the economy. In addition, it is important to note that the results are discussed in isolation, meaning that each particular yield curve factor and its general effect on the yield curve is discussed separately.

7.2.1 Level or Beta0 factor

Results regarding the β_0 or the level factor suggest that the level of the yield curve is driven by some labour market variables, specifically four of the labour market variables that pass the described filtering or selection criteria. In general, the results suggest an increase in the yield curve level as a consequence of deteriorated conditions in some segments of the labour market. It is important to state that labour market variables with the most explanatory power are Average Weekly Hours: Manufacturing and Average Weekly Hours: Goods-Producing, with the first being established as a leading economic indicator. Therefore, a possible explanation for the described relationship between the yield curve level and the labour market is that signs of weakness in the labour market and the mentioned leading economic indicator affect investors' outlook for the economy, causing them to act more cautiously in financial markets more, giving rise to the increase in yields over the entire maturity spectrum. However, in terms of the effect of the level of the yield curve on the labour market, the results suggest that in general the lower level of the yield curve induces an improvement in the labour market conditions and vice versa. Chow test results indicate that the bi-directional relationship between the level of the yield curve and the labour market were indeed changed by the implementation of the QE and other unconventional monetary policy measures. Moreover, according to the F statistic and R-squared, some labour market variables lost a substantial part of their explanatory power in the Post-QE, especially when considering the effect of the level of the yield curve on the labour market variables. Furthermore, the results suggest that housing is an important driver of the β_0 factor since many of the housing macroeconomic variables included in the FAVAR pass the filtering. The general result for the Total period suggests that improved conditions in the housing market induce an increase in the level of the yield curve. The same relationship holds in the Pre-QE period as well, while in the Post-QE period, there is a contrasting result regarding the effect of the housing market variables on the yield curve level. The possible explanation is that investors invested a greater parts of their portfolios in asset-backed securities connected with the financing of the housing market, e.g. MBS, RMBS, etc., in the Pre-QE period since their yields were greater than the yields on Treasury securities and they were regarded as safe as Treasury securities due to high credit ratings. As a consequence, the demand for Treasury securities decreased and the yields on Treasury securities increased, therefore increasing the level of the yield curve. After the 2008 financial crisis and the introduction of the QE, the relationship is the opposite as securitization and the misuse of mentioned asset-backed securities were the reason for the financial crisis and investors' flight to quality. Chow test results confirm the structural change and the relationship is stronger in the Post-QE period than in the Pre-QE period. Moreover, as presented in the previous subsection where the relationship between the monetary policy instrument and the housing market changed, it is suggested that there is a similar change in the relationship between the level of the yield curve and the housing market when considering the Pre-QE and Post-QE periods. The same also holds when considering the effect that the level of the yield curve has on the housing variables, confirming the bi-directional relationship. In conjunction with the described pattern for the housing market, Real Estate Loans, as a part of money and credit variables, drives the level of the yield curve and the relationship changes between the Pre-QE and Post-QE periods in the same way as in the case of housing. The structural change is suggested by the Chow test result as well. The relationship is bi-directional. Unfulfilled Orders for Durable Goods show some explanatory power for the β_0 factor movement. The relationship is positive and bi-directional. Furthermore, the monetary policy affects the level of the yield curve and vice versa. The same holds for the spread between the 3-Month Commercial Paper and the Federal Funds Rate. For both interest rates variables, it holds that their increase induces a decrease in the level of the yield curve. The relationship is bi-directional and changes from the Pre-QE period to the Post-QE period according to the Chow test. The most important result regarding the relationship between the β_0 factor and macroeconomic variables is that inflation is positively related to the level of the yield curve. The latter means inflation increases the level of the yield curve such that it is transmitted into the yields along the entire maturity spectrum as investors need to be compensated for inflation risk. Inflation is the most profound driver of the level of the yield curve. Moreover, there are far more price variables that affect the β_0 factor than price variables affected by the β_0 factor, although the relationship between the level of the yield curve and inflation is bi-directional. The results regarding the relationship between inflation and the level of the yield curve is consistent with results obtained by studies using the different methodologies presented in section 2. Furthermore, the results suggest a structural change in the bi-directional relationship between the β_0 factor and inflation since the Chow test statistics are significant for all prices variables passing the filtering. In general, the bi-directional relationship between inflation and the β_0 factor is stronger in the Post-QE period than in the Pre-QE period. All the variables demonstrate that, despite the relationship between the β_0 factor and the macroeconomic variables being bi-directional, the effect of macroeconomic variables on the level of the yield curve is stronger than the effect of the β_0 factor on macroeconomic variables. This is shown, in general, by correlation coefficients and by coefficients of determination. In the case of inflation, the stronger effect of macroeconomic variables on the level factor is reflected in a greater number of price variables passing the filtering when considering prices variables affecting the level of the yield curve.

Table 1: Regression of Beta0 factor on lagged macroeconomic variables

Variable	Rho	R-squared	F stat	p-value
All Employees: Mining and Logging: Mining	0.3296	0.1086	30.3470	*0.01
All Employees: Nondurable Goods	-0.2899	0.0840	22.8451	*0.01
Avg Weekly Hours: Goods-Producing	-0.4848	0.2350	76.4968	*0.01
Avg Weekly Hours: Manufacturing	-0.4799	0.2303	74.4966	*0.01
Housing Starts: Total New Privately Owned	0.3966	0.1573	46.4748	*0.01
New Private Housing Permits (SAAR)	0.3999	0.1599	47.3946	*0.01
PPI: Finished Goods	0.2545	0.0648	17.2396	*0.01
PPI: Finished Consumer Goods	0.2537	0.0643	17.1221	*0.01
PPI: Intermediate Goods	0.3447	0.1188	33.5733	*0.01
PPI: Metals and metal products	0.2563	0.0657	17.5054	*0.01
CPI: All Items	0.2917	0.0851	23.1644	*0.01
CPI: Medical Care	0.2603	0.0678	18.1033	*0.01
CPI: Commodities	0.2421	0.0586	15.5042	*0.01
CPI: Services	0.2985	0.0891	24.3606	*0.01
CPI: All Items Less Food	0.2718	0.0739	19.8559	*0.01
CPI: All Items Less Shelter	0.2829	0.0800	21.6604	*0.01
CPI: All Items Less Medical Care	0.2852	0.0813	22.0421	*0.01
Personal Consumption Expenditures: Chain Index	0.3133	0.0982	27.1035	*0.01
Personal Consumption Expenditures: Nondurable Goods	0.2499	0.0625	16.5864	*0.01
Personal Consumption Expenditures: Services	0.2820	0.0795	21.5042	*0.01

Source: Own work

Table 2: Regression of macroeconomic variables on lagged Beta0 factor

Variable	Rho	R-squared	F stat	p-value
All Employees: Mining and Logging: Mining	0.3675	0.1351	38.8784	*0.01
All Employees: Nondurable Goods	-0.2437	0.0594	15.7177	*0.01
Avg Weekly Hours: Goods-Producing	-0.4647	0.2159	68.5615	*0.01
Avg Weekly Hours: Manufacturing	-0.4670	0.2181	69.4526	*0.01
Housing Starts: Total New Privately Owned	0.3994	0.1595	47.2671	*0.01
New Private Housing Permits (SAAR)	0.3926	0.1541	45.3750	*0.01
PPI: Intermediate Goods	0.2648	0.0701	18.7710	*0.01
CPI: Medical Care	0.2657	0.0706	18.9190	*0.01
CPI: Services	0.2922	0.0854	23.2523	*0.01
Personal Consumption Expenditures: Chain Index	0.2456	0.0603	15.9867	*0.01
Personal Consumption Expenditures: Services	0.2879	0.0829	22.4999	*0.01

Source: Own work

7.2.2 Slope or Beta1 factor

Considering the relationship between the β_1 or the slope factor and macroeconomic variables, the most notable conclusion is that the monetary policy instrument affects the slope of the yield curve the most, as is consistent with the results of the impulse response analysis. The increase in the Effective Federal Funds Rate increases the slope factor and flattens the yield curve. Moreover, the β_1 is affected by the spreads of corporate bonds over Federal Funds Rate, as the increase in spread decreases the slope factor and increases the slope of the yield curve. The latter is consistent with the finding that the increase in the Effective Federal Funds Rate increases the slope and vice versa, therefore the increase of the corporate bond spread, as a result of decreasing Effective Funds Rate, decreases the β_1 factor and steepens the yield curve. Relationships between the β_1 factor and the Interest and Exchange Rates variables mentioned are bi-directional and the Chow tests conducted indicate a structural change in relationships when considering the Pre- and the Post-QE periods. Besides interest rates variables, the β_1 is driven by one labour market variable in that positive signs in the labour market increases the β_1 factor. The relationship between the labour market variables and the slope factor is bi-directional and when considering the effect of the β_1 factor on the labour market variables, two labour market variables survive the filtering. The results suggests that the bi-directional relationship between the labour market variables and the β_1 factor changed with the implementation of the QE. In addition, the relationship between the labour market and the slope factor is insignificant in certain sub-periods. The results suggest that the β_1 factor affects output and income as it is the one variable from that group passes the selection procedure. An increase in the β_1 factor decreases the output and income variable, which is consistent with the narrow yield curve spread being a leading economic indicator for an economic downturn. As described, an increase in the β_1 flattens the yield curve and decreases the yield curve spread, leading to the decrease in the output and income variable. In addition, many housing variables make it through the filtering and suggest a general relationship that a growing housing market induces an increase in the β_1 factor and a flatter yield curve. The positive relationship is bi-directional and was apparently changed by the introduction of the QE and unconventional monetary policy measures at the end of 2008. The results suggest that the relationship between the housing market and the β_1 factor was negative in the Pre-QE period, meaning that the growing housing market decreased the β_1 factor and steepened the yield curve. The relationship in the Pre-QE period is in some ways intuitive, as weaknesses in the housing market indicate a forthcoming economic downturn, which is also indicated by a lower yield curve spread and an increase in the β_1 factor. The general result of a positive relationship between the slope and the housing market variables is due to the strong positive relationship in the Post-QE period after the housing bubble burst. Furthermore, the β_1 is driven by M1 Money Stock as an increase in M1 Money Stock decreases the slope factor and steepens the yield curve as short-term yields decrease more than the medium- and long-term yields. The relationship did not change after the implementation of the QE. There are also some other Money and Credit variables that pass the filtering such as Commercial and Industrial Loans and Real Estate Loans. The former exhibits a positive bi-directional relationship with the β_1 factor while the latter drives the β_1 factor and is not driven by the slope factor. Moreover, the effect of Commercial and Industrial Loans on the β_1 factor changed while the effect of the β_1 factor on Commercial and Industrial Loans did not change according to the Chow test statistic. It should be noted that F statistics shows insignificance for the relationship between the β_1 factor and the Money and Credit variables in some sub-periods. In general, macroeconomic variables affect the β_1 factor more than the β_1 factor affects macroeconomic variables despite there being one more variable that passes the selection when the effect of the β_1 on the macroeconomic variable is considered. However, it is important to stress that the β_1 factor is mainly driven by the monetary policy instrument in the form of Effective Federal Funds Rate complemented with the Shadow Short Rate. Moreover, it seems that the relationship between the macroeconomic variables described and the slope of the yield curve is mainly driven by the relationship between the monetary policy and the β_1 factor, since the former affects the β_1 factor, and consequently the latter influences macroeconomic variables and vice versa.

Table 3: Regression of Beta1 factor on lagged macroeconomic variables

Variable	Rho	R-squared	F stat	p-value
All Employees: Service-Providing Industries	0.2917	0.0851	23.1647	*0.01
Housing Starts: Total New Privately Owned	0.4043	0.1635	48.6626	*0.01
New Private Housing Permits (SAAR)	0.3857	0.1487	43.5038	*0.01
M1 Money Stock	-0.2424	0.0587	15.5378	*0.01
Commercial and Industrial Loans	0.3263	0.1065	29.6675	*0.01
Real Estate Loans at All Commercial Banks	0.2295	0.0527	13.8445	*0.01
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	0.7778	0.6050	381.4191	*0.01
Moody's Aaa Corporate Bond Minus FEDFUNDS	-0.8179	0.6689	503.1481	*0.01
Moody's Baa Corporate Bond Minus FEDFUNDS	-0.7684	0.5905	359.0250	*0.01

Source: Own work

Table 4: Regression of macroeconomic variables on lagged Beta1 factor

Variable	Rho	R-squared	F stat	p-value
Capacity Utilization: Manufacturing	-0.2317	0.0537	14.1227	*0.01
All Employees: Service-Providing Industries	0.2525	0.0638	16.9620	*0.01
Avg Hourly Earnings: Goods-Producing	0.2351	0.0553	14.5675	*0.01
Housing Starts: Total New Privately Owned	0.3805	0.1448	42.1442	*0.01
New Private Housing Permits (SAAR)	0.3648	0.1331	38.2315	*0.01
Commercial and Industrial Loans	0.2556	0.0653	17.4021	*0.01
MZM Money Stock	0.3254	0.1059	29.4931	*0.01
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	0.7876	0.6203	406.8235	*0.01
Moody's Aaa Corporate Bond Minus FEDFUNDS	-0.8027	0.6442	450.9286	*0.01
Moody's Baa Corporate Bond Minus FEDFUNDS	-0.7451	0.5552	310.8147	*0.01

Source: Own work

7.2.3 First curvature or Beta2 factor

The β_2 factor has a positive bi-directional relationship with the labour market since a strong labour market increases the β_2 factor and the β_2 factor increases positively affect labour market variables. A strong labour market induces the increase in short- to medium-term yields. The bi-directional relationship changed with the introduction of the QE, although not in terms of direction. The same holds for the housing market and its bi-directional relationship with the β_2 factor as the growing housing market induces the increase in the β_2 factor and the increase in the β_2 factor causes the improvement in the labour market. In general, the described bi-directional relationship changed when considering the two sub-periods although, as in the case of the labour market, not in terms of direction. Furthermore, an increase in the St. Luis Adjusted Monetary Base decreases the β_2 factor. This induces the decrease in short- to medium-term yields more than the long-term yields consistently with the increased monetary base. Considering the effect of the increase in the β_2 factor on Money and Credit variables, the monetary base is replaced by M1 Money Stock, but the direction of the movement is preserved. Therefore in general, an increase in the β_2 factor is driven by the decrease in the amount of money and the increase in the amount of money is affected by the decrease in the β_2 factor. However, it is important to note that the relationship is not particularly strong. Other Money and Credit variables driving the β_2 factor are Commercial and Industrial Loans and Real Estate Loans. However, the β_2 factor drives only Commercial and Industrial Loans. The bi-directional relationship is positive and according to the Chow test was changed by the implementation of the QE. The note regarding the strength of the bi-directional relationship holds also for this Money and Credit variable. Furthermore, some Interest and Exchange Rate variables pass the filtering. In particular, the results suggest that the β_2 is to some extent driven by the monetary policy instrument and vice versa, as already presented by the impulse response analysis, and that the relationship changes between the two sub-periods. Moreover, the β_2 factor is driven by corporate bonds spreads over the Effective Federal Funds Rate and financial commercial paper rates and vice versa. As expected, bi-directional relationships changed due to the implementation of the QE, as they are dependent on the Effective Federal Funds Rate, whose relationship with the yield curve factors changes. The results suggest that the β_2 factor partially drives Consumption, Orders and Inventories and that it is partially driven by inflation. Furthermore, the results exhibit a bi-directional relationship between the β_2 factor and the stock market, in particular its volatility. It appears that increased volatility in the stock market decreases the β_2 factor, therefore decreasing short- to medium-term yields more than long-term yields. The explanation could be that the increased volatility in the stock market motivates investors to invest more in Treasury Securities, thereby increasing the demand for Treasury Securities, increasing their prices and decreasing the yields. From another perspective, the increase in the β_2 factor induces a decrease in the stock market volatility. More expensive and lower-yield-bearing Treasury Securities induce investors to increase their investments in the stock market, therefore increasing volume and decreasing volatility of the stock market. The Chow test suggests that, as for the majority of other variables, the bi-directional relationship changed when considering the Pre- and Post-QE period. The effect of macroeconomic variables on the β_2 factor is generally stronger than the effect that the β_2 factor has on the relevant macroeconomic variables. There are also more variables passing the filtering and affecting the β_2 factor than there are variables that are affected by the β_2 factor. As described in section 2, some of the studies presented relate the curvature factor of the Nelson-Siegel term structure representation to the business cycle. A similar statement could be made for the β_2 factor, which is one of the two curvature factors in the Svensson (1994) term structure functional form. As described, the β_2 factor is positively related to many labour and housing market variables, which are in fact business cycle indicators. A sufficiently low unemployment rate that induces economy overheating and a potential housing bubble can sufficiently increase the β_2 factor to alter the form of the yield curve. Therefore, the β_2 factor could be in some way regarded as a leading business cycle indicator since a sufficient increase in the β_2 factor, if not offset by other factors, generates a hump-shaped yield curve that starts to invert, which precedes the completely inverted yield curve that is an established economic downturn predictor.

Table 5: Regression of Beta2 factor on lagged macroeconomic variables

Variable	Rho	R-squared	F stat	p-value
All Employees: Total Nonfarm	0.3030	0.0918	25.1727	*0.01
All Employees: Goods-Producing Industries	0.2549	0.0650	17.2961	*0.01
All Employees: Construction	0.2307	0.0532	13.9946	*0.01
All Employees: Manufacturing	0.2323	0.0540	14.1997	*0.01
All Employees: Durable Goods	0.2354	0.0554	14.6012	*0.01
All Employees: Service-Providing Industries	0.3016	0.0910	24.9175	*0.01
All Employees: Trade, Transportation & Utilities	0.2249	0.0506	13.2679	*0.01
Avg Weekly Hours: Goods-Producing	0.2514	0.0632	16.8026	*0.01
Avg Weekly Hours: Manufacturing	0.2400	0.0576	15.2216	*0.01
Housing Starts: Total New Privately Owned	0.3681	0.1355	39.0291	*0.01
New Private Housing Permits (SAAR)	0.3719	0.1383	39.9655	*0.01
St. Luis Adjusted Monetary Base	-0.2362	0.0558	14.7145	*0.01
Commercial and Industrial Loans	0.2747	0.0754	20.3171	*0.01
Real Estate Loans at All Commercial Banks	0.2253	0.0507	13.3092	*0.01
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	0.3595	0.1293	36.9648	*0.01
3-Month AA Financial Commercial Paper Rate	0.2960	0.0876	23.9127	*0.01
Moody’s Aaa Corporate Bond Minus FEDFUNDS	-0.4705	0.2214	70.7918	*0.01
Moody’s Baa Corporate Bond Minus FEDFUNDS	-0.4724	0.2231	71.5158	*0.01
CPI: Services	0.2402	0.0577	15.2448	*0.01
VXO	-0.3180	0.1011	28.0166	*0.01

Source: Own work

Table 6: Regression of macroeconomic variables on lagged Beta2 factor

Variable	Rho	R-squared	F stat	p-value
All Employees: Total Nonfarm	0.2789	0.0778	21.0040	*0.01
All Employees: Goods-Producing Industries	0.2461	0.0606	16.0558	*0.01
All Employees: Manufacturing	0.2286	0.0522	13.7253	*0.01
All Employees: Durable Goods	0.2264	0.0513	13.4562	*0.01
All Employees: Service-Providing Industries	0.2683	0.0720	19.3205	*0.01
All Employees: Trade, Transportation & Utilities	0.2239	0.0501	13.1400	*0.01
Avg Weekly Hours: Goods-Producing	0.2331	0.0543	14.3080	*0.01
Avg Weekly Hours: Manufacturing	0.2269	0.0515	13.5179	*0.01
Housing Starts: Total New Privately Owned	0.3674	0.1350	38.8611	*0.01
New Private Housing Permits (SAAR)	0.3664	0.1342	38.6102	*0.01
Unfilled Orders for Durable Goods	0.2294	0.0526	13.8310	*0.01
M1 Money Stock	-0.2603	0.0678	18.1038	*0.01
Commercial and Industrial Loans	0.3259	0.1062	29.5911	*0.01
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	0.4142	0.1716	51.5734	*0.01
3-Month AA Financial Commercial Paper Rate	0.2965	0.0879	23.9963	*0.01
Moody's Aaa Corporate Bond Minus FEDFUNDS	-0.5220	0.2724	93.2444	*0.01
Moody's Baa Corporate Bond Minus FEDFUNDS	-0.5175	0.2678	91.0741	*0.01
VXO	-0.2900	0.0841	22.8658	*0.01

Source: Own work

7.2.4 Second curvature or Beta3 factor

Contrary to the β_2 factor, the β_3 factor has a negative bi-directional relationship with labour market variables, therefore β_3 factor increases are driven by the weakening conditions in the labour market or an increase in unemployment in different segments of the labour market. The same negative relationship holds for the β_3 factor affecting the labour market. In isolation, this means that the weakening labour market induces the increase in medium- to long-term maturity yields and vice versa. For some of the labour market variables driving the β_3 factor, the effect on the β_3 in the Pre-QE period is insignificant. Similar conclusions hold for β_3 factor movements affecting the labour market. Moreover, the Chow test suggests that the described bi-directional relationship changes. Contrary to the β_2 factor, the β_3 factor is also driven by two Consumption, Orders and Inventories variables, which is why the relationship is to an extent bi-directional and negative. An increase in inventories and unfilled orders for durable goods decreases the β_3 factor, leading to a decrease in medium- to long-term parts of the term structure. The relationship changes with the implementation of the QE and unconventional monetary policy measures. Money and credit variables are further drivers of the β_3 factor. The relationship between the β_3 factor and Commercial and Industrial Loans is apparently bi-directional since the results indicate that an increase in loans decreases the β_3 factor. The same negative relationship also holds when the effect of the β_3 on loans is considered, leading to the relatively greater increase in the mid- to long-term maturity yields decreasing the amount of loans. Moreover, the β_3 is driven by the monetary base as well, and the results suggest that an increase in the monetary base increases the β_3 factor. The relationship between Money and Credit variables and the β_3 changes from the Pre-QE to the Post-QE period. As expected, Interest and Exchange Rate variables affect the β_3 factor. The Effective Federal Funds Rate is also a factor when discussing the bi-directional relationship between the interest rates and the β_3 factor. However, the bi-directional relationship is not significant when considering the two sub-periods. Financial commercial paper rates pass the filtering and suggest a negative bi-directional relationship with the β_3 curvature factor, which changes when the QE is implemented. The last variable that affects the β_3 factor, and vice versa, is the stock market volatility. The relationship is positive, contrary to the bi-directional relationship with the β_2 factor, and according to the Chow test result, it changed from the Pre-QE to the Post-QE period. Similarly to other three latent yield curve factors, macroeconomic variables are stronger drivers of the β_3 factor than the β_3 factor is of the macroeconomic variables. Although the β_2 factor is in some ways behaving like a leading or business cycle indicator, it can be said that the β_3 factor has some features of a lagging economic indicator, especially in the Post-QE period. The β_3 factor increases in response to the decrease in labour market variables. Moreover, the β_3 factor increases in response to consumption, orders and inventories decrease. Decreasing inventories and a weakening labour market or increasing unemployment increase the β_3 factor, which, if increased sufficiently, causes a hump-shaped yield curve to start to invert. Inventories in general decrease during the previously noted economic downturn as sales decrease. The decrease in inventories is usually delayed as businesses need some time to cut production to or even below the level of depressed sales. Moreover, unemployment increases when the economic downturn is well established. In response to these macroeconomic variables' movements, the β_3 factor increases and, if its increase is not outdone by other factors, it initiates the inversion of the yield curve. Since macroeconomic variables movements suggest that the economic downturn is well established and the β_3 factor in response causes the yield curve shape preceding the economic downturn, the β_3 factor could be somehow regarded as a lagging business cycle indictor. The latter could be concluded to be due to an increase in the β_3 factor and hump-shaped yield curve when the labour market and consumption, orders and inventories are already signalling an established economic downturn.

Table 7: Regression of Beta3 factor on lagged macroeconomic variables

Variable	Rho	R-squared	F stat	p-value
All Employees: Total Nonfarm	-0.2518	0.0634	16.8621	*0.01
All Employees: Goods-Producing Industries	-0.3382	0.1144	32.1607	*0.01
All Employees: Manufacturing	-0.3612	0.1305	37.3617	*0.01
All Employees: Durable Goods	-0.3395	0.1153	32.4358	*0.01
All Employees: Nondurable Goods	-0.3496	0.1222	34.6756	*0.01
All Employees: Trade, Transportation & Utilities	-0.2333	0.0544	14.3281	*0.01
All Employees: Wholesale Trade	-0.2494	0.0622	16.5091	*0.01
Avg Weekly Hours: Goods-Producing	-0.3135	0.0983	27.1355	*0.01
Avg Weekly Hours: Manufacturing	-0.3186	0.1015	28.1384	*0.01
Unfilled Orders for Durable Goods	-0.3031	0.0919	25.1931	*0.01
Total Business Inventories	-0.2399	0.0576	15.2084	*0.01
St. Luis Adjusted Monetary Base	0.2402	0.0577	15.2488	*0.01
Commercial and Industrial Loans	-0.2823	0.0797	21.5616	*0.01
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	0.2421	0.0586	15.5084	*0.01
3-Month AA Financial Commercial Paper Rate	-0.2404	0.0578	15.2727	*0.01
VXO	0.5063	0.2563	85.8309	*0.01

Source: Own work

Table 8: Regression of macroeconomic variables on lagged Beta3 factor

Variable	Rho	R-squared	F stat	p-value
All Employees: Total Nonfarm	-0.2392	0.0572	15.1181	*0.01
All Employees: Goods-Producing Industries	-0.3207	0.1028	28.5443	*0.01
All Employees: Manufacturing	-0.3277	0.1074	29.9657	*0.01
All Employees: Durable Goods	-0.2931	0.0859	23.4010	*0.01
All Employees: Nondurable Goods	-0.3617	0.1308	37.4751	*0.01
All Employees: Wholesale Trade	-0.2386	0.0569	15.0275	*0.01
Avg Weekly Hours: Goods-Producing	-0.3107	0.0965	26.6024	*0.01
Avg Weekly Hours: Manufacturing	-0.3143	0.0988	27.2855	*0.01
Unfilled Orders for Durable Goods	-0.2757	0.0760	20.4760	*0.01
Commercial and Industrial Loans	-0.3379	0.1142	32.0880	*0.01
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	0.2076	0.0431	11.2097	*0.01
3-Month AA Financial Commercial Paper Rate	-0.2365	0.0559	14.7460	*0.01
VXO	0.5049	0.2549	85.1837	*0.01

Source: Own work

CONCLUSION

This master's thesis studies the effect that monetary policy shocks have on the yield curve and its latent factors. Furthermore, since previous studies suggest that the macro-yield curve relationship changes when the monetary policy stance changes, the implementation of QE could be a potential reason for a possible change in the relationship between the yield curve and the monetary policy. The same analogy can be made for the macro-yield curve relationship in general, considering also other macroeconomic drivers of the yield curve besides the monetary policy. In order to examine these links between the yield curve and the economy, I implemented a joint macro-finance model consisting of the Svensson (1994) functional form of the yield curve and FAVAR presented by Bernanke, Boivin and Eliasz (2004). The joint macro-finance model represents the main part of the master's thesis in terms of the empirical analysis to answer the research questions postulated in the Introduction. The model is estimated in two steps. In the first step, I estimate the Svensson (1994) yield curve model parameters. The Svensson (1994) model parameters are estimated by using maximum likelihood estimation with restrictions imposed on decay parameters, λ_1 and λ_2. In the second step, I use a two-step Bernanke, Boivin and Eliasz's (2004) procedure to estimate the joint dynamics of macroeconomic variables and yield curve factors in the FAVAR. The estimation is based on data for the United States of America due to the greater availability of data following the implementation of the QE. In order to complement the research and to identify other macroeconomic variables besides the monetary policy, I also estimate simple regressions based on estimations of yield curve factors obtained in the first step of the macro-finance model estimation and macroeconomic data for the United States.

The monetary policy in general affects the yield curve mainly through the slope or the β_1 factor of the yield curve. As a consequence, a restrictive monetary policy shock results in the flattening of the yield curve. Since the slope or the β_1 factor can be regarded as the negative of the yield curve spread, the increase in the slope factor and a flatter yield curve, resulting from the contractionary monetary policy, are consistent with the narrowing of the yield spread being a leading economic indicator for economic downturn. However, the relationship between the yield curve and the monetary policy changed after the implementation of the QE. The general results regarding the monetary policy effect on the yield curve through affecting the slope or the β_1 factor still hold. In the period after the implementation of the QE, the monetary policy did not affect the yield curve significantly through the slope or the β_1 factor. Following the implementation of the QE, the yield curve was affected significantly by both curvature factors, β_2 and β_3. The latter means that the shape of the yield curve takes on a different shape in response to a contractionary monetary policy after the implementation of the QE. In the Post-QE period, the yield curve spread indeed narrows in response to the restrictive monetary policy, similarly as in the Pre-QE period, but the yield curve shape differs. After the implementation of the QE, the yield curve becomes slightly hump-shaped when the economy is faced with a contractionary monetary policy shock. Moreover, the effect of the monetary policy shock on the yield curve is greater than before the implementation of the QE, increasing the responsiveness of the yield curve to monetary policy shocks. Furthermore, the results suggest faster transmission of the monetary policy shock into the yield curve shape after the implementation of the QE and greater uncertainty regarding the economic downturn. Since the response of the yield curve to monetary policy shock is changed by the implementation of QE, some macroeconomic variables' responses to monetary policy shocks change, although predominantly in terms of the magnitude of responses. The results suggest that the monetary policy is one of the main and most important drivers of the yield curve. In fact, it is the most important driver of the slope or the β_1 factor. However, there are also some other macroeconomic variables that move the yield curve. The main driver of the level or the β_0 factor is inflation. Curvature factors, β_2 and β_3, tend to be related to the business cycle, with the β_2 factor exhibiting some features of a leading business cycle indicator and the β_3 factor exhibiting some features of a lagging business cycle indicator. The relationship between the yield curve and macroeconomic variables is bi-directional, although macroeconomic variables affect the yield curve factors more than yield curve factors affect macroeconomic variables. Moreover, the links between the yield curve factors and macroeconomic variables changed after the implementation of the QE, predominantly in terms of their strength.

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APPENDICES

Appendix 1: Povzetek (Summary in Slovene language)

Krivulja donosnosti prikazuje razmerje med obrestnimi merami različnih ročnosti in je eden najpomembnejših konceptov v finančnem svetu. Krivulja donosnosti je zaradi svoje informativne narave mnogokrat uporabljena kot orodje za napovedovanje prihodnje gospodarske klime. Stock in Watson (1999), Mishkin (1990a, 1990b) ter drugi avtorji so namreč odkrili, da razpon med obrestnimi merami poseduje pojasnjevalne informacije glede prihodnjega gibanja obrestnih mer, ekonomske aktivnosti in inflacije. Krivulja donosnosti predstavlja tudi osnovo pri sprejemanju naložbenih odločitev, odločitev glede prihrankov in samega ravnanja tako podjetij, posameznikov kot oblikovalcev politike. Krivulja donosnosti je ključni del transmisijskega mehanizma monetarne politike in obenem vpliva na njeno učinkovitost. Monetarna politika lahko s svojimi ukrepi vpliva le na najkrajši del krivulje donosnosti, potem pa se učinki ukrepov monetarne politike prenesejo prek celotne krivulje donosnosti in posledično vplivajo na obnašanje ekonomskih agentov ter makroekonomske agregate. Monetarna politika s svojimi ukrepi vpliva prek krivulje donosnosti na cene sredstev, finančne pogoje in odločitve ter inflacijo, zato je ključno za oblikovalce politik, da razumejo, na kakšen način se monetarni šok prenese na krivuljo donosnosti in posledično v gospodarstvo. Krivulja donosnosti je v uporabi tudi pri upravljanju tveganj pri implementaciji raznovrstnih strategij. Cene obveznic in izvedenih finančnih instrumentov, kot so zamenjave (angl. *swaps*), terminske pogodbe (angl. *futures*) in opcije (angl. *options*) na obrestne mere, so odvisne od krivulje donosnosti. Poleg tega je krivulja donosnosti pomemben koncept tudi v bančništvu pri upravljanju bilance banke in njenih tokov. Skratka, krivulja donosnosti je v povezavi z makroekonomskimi agregati izjemno pomembno orodje, kar potrjujejo tudi mnoge študije, ki obravnavajo to področje. Prve študije, ki so proučevale razmerja med krivuljo donosnosti in makroekonomskimi spremenljivkami, so se osredotočale na obrestni razmik (angl. *yield curve spread*) oziroma naklon krivulje donosnosti in njegovo sposobnost napovedovanja inflacije in proizvodnje. Obrestni razmik se je pri tem izkazal kot precej dober napovedovalec poslovnega cikla. Sčasoma so študije začele uporabljati kompleksnejše metode pri proučevanju razmerij med krivuljo donosnosti in makroekonomskimi spremenljivkami. Študije so se raziskovalnega problema lotevale s skupnim modeliranjem dinamike krivulje donosnosti in makroekonomskih spremenljivk, vendar z različnimi pristopi. Določen delež študij je pokazal, da se razmerje med krivuljo donosnosti in makroekonomskimi spremenljivkami spremeni ob spremembi delovanja monetarne politike. Slednje odpira pomembno vprašanje, ki se tiče mojega magistrskega dela, in sicer kaj se je zgodilo s povezavo med krivuljo donosnosti in monetarno politiko po uvedbi kvantitativnega sproščanja. Slednje in pa razmerje med krivuljo donosnosti in ostalimi makroekonomskimi spremenljivkami je predmet magistrskega dela.

Namen magistrskega dela je določiti, kako monetarna politika vpliva na krivuljo donosnosti, in preveriti, ali se je vpliv monetarne politike na krivuljo donosnosti spremenil po implementaciji kvantitativnega sproščanja in drugih nekonvencionalnih ukrepih. Magistrsko delo se ukvarja tudi s povezavo med krivuljo donosnosti in ostalimi makroekonomskimi spremenljivkami. Cilj je dodatno osvetliti študije povezave med krivuljo donosnosti in monetarno politiko ter ostalimi makroekonomskimi spremenljivkami. Poleg tega je cilj magistrskega dela preveriti morebitno spremembo v omenjenih povezavah.

Magistrsko delo je, gledano z vidika metodologije, sestavljeno iz dveh delov. In sicer prvi del magistrskega dela je opisni del, v katerem sta uporabljeni metodi opisovanja in kompilacije. V opisnem delu je pregled literature in raziskovalnih člankov ter odkritij, povezanih z raziskovanjem povezave med krivuljo donosnosti in makroekonomskimi spremenljivkami. Predstavljena sta tudi najbolj razširjena modela krivulje donosnosti in izsledki raziskav vpliva kvantitativnega sproščanja na krivuljo donosnosti. V drugem delu magistrskega dela je uporabljena metodologija ekonometričnega modeliranja. V drugem delu predstavim in ocenim makrofinančni model, v katerem združim Svenssonovo (1994) funkcijsko obliko krivulje donosnosti in FAVAR model, ki so ga predstavili Bernanke, Boivin in Eliasz (2004). V metodološko gledano drugem delu magistrskega dela predstavitvi in oceni modela sledita predstavitev in diskusija rezultatov.

V svojem magistrskem delu odgovorim na naslednja raziskovalna vprašanja:

- Kako šok monetarne politike vpliva na krivuljo donosnosti prek latentnih faktorjev krivulje donosnosti?
- Ali se je povezava med monetarno politiko in krivuljo donosnosti spremenila od implementacije kvantitativnega sproščanja naprej?
- Ali je morebitna sprememba povezave med monetarno politiko in krivuljo donosnosti vplivala na odzive makroekonomskih spremenljivk na šok monetarne politike?
- Katere so glavne makroekonomske spremenljivke, ki poganjajo krivuljo donosnosti prek faktorjev krivulje donosnosti?
- Ali je povezava med krivuljo donosnosti in makroekonomskimi spremenljivkami dvosmerna in ali se je povezava spremenila od implementacije kvantitativnega sproščanja naprej?

V prvem poglavju magistrskega dela predstavim dve najbolj razširjeni funkcijski obliki krivulje donosnosti. Nelson in Siegel (1987) sta predstavila enostaven parametrični trifaktorski model, ki predstavlja krivuljo donosnosti in njene stilizirane značilnosti. Predstavljeni model krivulje donosnosti je funkcija treh latentnih faktorjev krivulje donosnosti, nivoja (angl. *level*), naklona (angl. *slope*) in ukrivljenosti (angl. *curvature*). V osnovi naj bi bila krivulja donosnosti dekompozicija omenjenih latentnih finančnih faktorjev. Poleg omenjenih latentnih faktorjev je Nelson-Sieglov model tudi funkcija dospelosti (angl. *maturity*) in parametra razpada (angl. *decay parameter*). Dospelost in parameter razpada s svojimi vrednostmi določata faktorski naložbeni koeficient (angl. *factor loadings*). Imena faktorjev povzemajo njihov vpliv na obliko krivulje donosnosti, medtem ko parameter razpada določa položaj in obliko grbe (angl. *hump*) krivulje donosnosti. Svensson (1994) je trifaktorski model Nelsona in Siegla (1987) razširil z dodatnim četrtim faktorjem, ki predstavlja drugi faktor ukrivljenosti in ima svoj parameter razpada. Razširjeni model omogoča večjo prilagodljivost funkcijske oblike krivulje donosnosti in zaradi dodatnega faktorja ukrivljenosti omogoča drugo grbo pri krivulji donosnosti.

V drugem poglavju magistrsko delo obravnava povezavo med krivuljo donosnosti in makroekonomskimi spremenljivkami ter agregati z vidika preteklih raziskav na to temo. Na začetku so se študije ukvarjale predvsem s povezavo med krivuljo donosnosti, proizvodom in inflacijo. Predmet proučevanja, tako teoretičnega kot empiričnega, je predstavljala sposobnost krivulje donosnosti za napovedovanje prihodnjega proizvoda in inflacije. Harvey (1988) je prek modela za določanje cen sredstev na podlagi potrošnje (angl. *consumption-based asset pricing model*) pokazal povezavo med realno krivuljo donosnosti in prihodnjo proizvodnjo. Stock in Watson (1989) sta leto pozneje odkrila, da se obrnjena krivulja donosnosti pojavlja pred vsako upočasnitvijo gospodarske aktivnosti. Slednjemu je sledil razmah študij, ki so se ukvarjale z napovedovanjem gospodarske aktivnosti in verjetnosti recesije s strani krivulje donosnosti in razmika med donosnostmi na dolžniške vrednostne papirje različnih ročnosti. Estrella in Hardouvelis (1991), Plosser in Rouwenhorst (1994), Estrella in Mishkin (1997) ter drugi potrdijo precejšnjo sposobnost in uspešnost razmika krivulje donosnosti (angl. *yield curve spread*) pri napovedovanju prihodnje gospodarske rasti in recesije. Zmanjšanje razmika krivulje donosnosti se s temi študijami uveljavi kot močan indikator zmanjšanja prihodnje gospodarske aktivnosti in je neodvisen od države, za katero je bila študija izvedena. Velja tudi obratno, in sicer da se s povečanjem razmika oziroma naklona krivulje donosnosti zmanjša verjetnost recesije in poveča gospodarska rast. Razlag za tovrstno povezavo je kar nekaj, najpogostejša pa temelji na monetarni politiki. Estrella (2004) namreč ugotovi, da je moč povezave med krivuljo donosnosti in prihodnjo gospodarsko aktivnostjo v veliki meri odvisna od parametrov oziroma uteži v reakcijski funkciji monetarne politike. Slednje pomeni, da je povezava odvisna od režima monetarne politike. Sočasno s študijami glede sposobnosti razmika krivulje donosnosti za napovedovanje prihodnje gospodarske aktivnosti so se pojavile tudi študije, čeprav v manjšem obsegu, ki so proučevale povezavo med inflacijo in krivuljo donosnosti. Mishkin (1990a, 1990b, 1990c) je bil na tem področju neke vrste pionir. Povezava med razmikom krivulje donosnosti in inflacijo je osnovana na Fisherjevi dekompoziciji obrestne mere, kjer je nominalna obrestna mera izražena s pričakovano realno obrestno mero in pričakovano inflacijo. Poleg tega je v primeru racionalnih pričakovanj realizirano inflacijo mogoče razdeliti na pričakovano inflacijo in na določeno odstopanje od pričakovane inflacije. Združitev opisanih principov in upoštevanje razlike v času da enačbo, ki opiše povezavo med inflacijo in krivuljo donosnosti. Z ocenjevanjem slednje in ocenjevanjem binarnih modelov, Mishkin (1990a, 1990b, 1990c), Estrella in Mishkin (1997) in Estrella, Rodrigues in Schich (2003) odkrijejo, da je povečan naklon krivulje donosnosti signal za prihodnje povečanje inflacije, nasprotno pa je manjši naklon signal za prihodnje zmanjšanje inflacije. V osnovi je daljši konec krivulje donosnosti tisti, ki vsebuje več informacij glede prihodnje inflacije. Krajši konec vsebuje večinoma informacije o gibanju realnih obrestnih mer. Tako kot v primeru gospodarske aktivnosti je povezava močno odvisna od režima monetarne politike, saj drži Estrellova (2004) ugotovitev o odvisnosti moči povezave od parametrov reakcijske funkcije monetarne politike.

Na podlagi opogumljajočih rezultatov študij, ki se ukvarjajo s sposobnostjo krivulje donosnosti glede napovedovanja prihodnje gospodarske aktivnosti in inflacije, so se pojavile raziskave, ki se ukvarjajo s sočasnim modeliranjem dinamike krivulje donosnosti in makroekonomskih spremenljivk, tako imenovani makrofinančni modeli. Temelj pri tovrstnem obravnavanju povezave med krivuljo donosnosti in makroekonomskimi spremenljivkami predstavlja študija, ki sta jo predstavila Ang in Piazzesi (2003). Ang in Piazzesi (2003) skupno dinamiko krivulje donosnosti in makroekonomskih spremenljivk predstavita kot afin terminski strukturni model (angl. *affine term structure model*), ki vključuje dva makroekonomska faktorja, pridobljena iz podatkov za inflacijo in realno gospodarsko aktivnost z analizo glavnih komponent (angl. *principal component analysis*). Pridobljena faktorja sta Ang in Piazzesi (2003) implementirala v specifikacijo kratkoročne obrestne mere v obliki Taylorjevega pravila kot afino funkcijo opazovanih in makroekonomskih ter neopazovanih faktorjev krivulje donosnosti. Za razliko od avtorjev, ki so sledili raziskovalnemu zgledu Anga in Piazzesijeve (2003), le-ta v svojem modelu dovolita le enosmerno povezavo med makroekonomskimi spremenljivkami in faktorji krivulje donosnosti. Slednje pomeni, da makroekonomske spremenljivke lahko vplivajo na donosnost, medtem ko krivulja donosnosti ne more vplivati na makroekonomske spremenljivke. Inflacija in realna gospodarska aktivnost vplivata na krivuljo donosnosti, vendar z različno amplitudo. Inflacija vpliva na krivuljo donosnosti predvsem na območju krajše dospelosti, medtem ko realna gospodarska aktivnost vpliva na celotno krivuljo donosnosti. Pozitiven inflacijski šok ali šok realne gospodarske aktivnosti povzročita izravnavanje krivulje donosnosti (angl. *flattening*). Poleg tega Ang in Piazzesi (2003) odkrijeta, da so gibanja krivulje donosnosti v območju daljših ročnosti posledica latentnih faktorjev krivulje donosnosti, medtem ko makroekonomski faktorji poganjajo krajši del krivulje donosnosti. Omenjeni študiji metodološko sledijo drugi avtorji. Mönch (2005) upošteva večji nabor makroekonomskih spremenljivk ter združi FAVAR in terminski strukturni model krivulje donosnosti. Prav vsi makroekonomski faktorji značilno vplivajo na krivuljo donosnosti, kljub temu pa po vplivu izstopajo kratkoročna obrestna mera, makroekonomski faktor, povezan s poslovnim ciklom, in faktor, povezan z inflacijo. Izsledki so podobni kot pri Bomfimu (2003) in Dewachterju in Lyriu (2006), in sicer da spremembe v kratkoročni obrestni meri pod vplivom centralne banke vplivajo primarno na faktor naklona tako, da povečanje obrestne mere vodi v zmanjšanje faktorja in posledično izravnavanje krivulje donosnosti. Faktor nivoja krivulje donosnosti se v glavnem povezuje z inflacijo in inflacijskimi pričakovanji, tako da povečanje inflacije vodi v dvig obrestnih mer tekom celotnega spektra dospelosti. Kljub temu obstajajo določene razlike med ugotovitvami različnih študij glede povezave med inflacijo in nivojem krivulje donosnosti. Dewachter in Lyrio (2006) z malenkost drugačno zasnovo modela uspeta interpretirati tudi faktor ukrivljenosti, in sicer ga povežeta s poslovnim ciklom. Posledično zaključita, da poslovni cikel prek vpliva na faktor ukrivljenosti primarno vpliva na kratkoročne in srednjeročne obrestne mere. Ker obstaja možnost mednarodne transmisije makrofinančnih šokov, so se nekateri avtorji, kot so Diebold, Li in Yue (2008) ter ostali, ki so jim sledili, odločili, da v koncept makrofinančnih modelov implementirajo globalne faktorje in faktorje, ki so specifični za posamezno državo. Ocenjevanje tovrstnih modelov privede do ugotovitev, da globalna faktorja naklona in nivoja globalne krivulje donosa izražata gibanja v globalni inflaciji in gospodarski aktivnosti. Poleg tega so gibanja faktorja nivoja v posamezni državi zelo odvisna od gibanja v globalnem faktorju nivoja in globalne inflacije, medtem ko je odvisnost faktorja naklona od globalnega faktorja naklona in poslovnega cikla svetovnega gospodarstva odvisna od posamezne države. V splošnem je ugotovitev takšna, da globalni faktorji v veliki meri vplivajo na krivulje donosnosti posameznih držav. Bikbov in Chernov (2010) metodološko sledita ostalim, modelu pa dodata specifikacijo, ki omogoča tudi identifikacijo novih informacij pri krivulji donosnosti, ki ni pojasnjena s strani inflacije in realne gospodarske aktivnosti. Posledično Bikbov in Chernov (2010) ugotovita, da poleg monetarne politike na krivuljo donosnosti pri daljših ročnostih vpliva tudi fiskalna politika, ki je skupaj z monetarno politiko po moči vpliva enako pomembna kot inflacija in realna gospodarska aktivnost. Dewachter, Iania in Lyrio (2011) podobno kot ostali pred njimi ocenijo makrofinančni model, temelječ na modelu brezarbitražne terminske strukture, vendar za razliko od ostalih dinamiko faktorjev krivulje donosnosti in makroekonomskih spremenljivk modelirajo kot VECM (Vector Error Correction Model). Prav tako razdelijo krivuljo donosnosti na komponenti pričakovanj in terminske premije. Posledično ugotovijo, da so pričakovanja glede krivulje donosnosti pri krajših ročnostih v glavnem odvisna od monetarne politike, medtem ko so pri daljših ročnostih odvisna od dolgoročnih inflacijskih pričakovanj. Mnoge študije poleg interpretacije latentnih faktorjev krivulje donosnosti zaznajo precejšnjo odvisnost vpliva makroekonomskih spremenljivk na krivuljo donosnosti od monetarne politike in režima monetarne politike.

Nekateri avtorji so poskrbeli za rahel odklon od makrofinančnih modelov, ki implementirajo makroekonomske spremenljivke v afine brezarbitražne terminske modele, in sicer so uporabili bolj strukturni pristop pri združevanju dinamike makroekonomskih spremenljivk in krivulje donosnosti. Rudebusch in Wu (2004) ocenita makrofinančni model, ki vključuje dvofaktorski brezarbitražni strukturni terminski model in strukturno specifikacijo makrofinančnih faktorjev. V standardnem afinem brezarbitražnem terminskem modelu, ki vključuje makroekonomske faktorje, je kratkoročna obrestna mera izražena z reakcijsko funkcijo monetarne politike, po navadi v obliki Taylorjevega pravila. Rudebusch in Wu (2004) trdita, da je kratkoročno obrestno mero mogoče zapisati tudi z dvema latentnima faktorjema krivulje donosnosti iz modela. Posledično združita finančno reprezentacijo kratkoročne obrestne mere, ki je zapisana z latentnima faktorjema, in makroekonomsko reprezentacijo, ki je zapisana s Taylorjevim pravilom. Povezava med obema zapisoma obrestnih mer temelji na identifikaciji faktorja nivoja kot inflacijskega cilja v Taylorjevem pravilu in identifikaciji faktorja naklona kot del cikličnih prilagoditev v Taylorjevem pravilu. Ocena obeh specifikacij kratkoročne obrestne mere potrdi, da dekompozicija Taylorjevega pravila na dolgoročni nivo kratkoročne obrestne mere in ciklične komponente sovpada z dekompozicijo kratkoročne obrestne mere na faktor nivoja in naklona. Posledični model, ki ga predstavita Rudebusch in Wu (2004), združuje afin brezarbitražni terminski model in mali novokeynesijanski (angl. *New-Keynesien*) makroekonomski model. Ocena tovrstnega modela pokaže odvisnost faktorja nivoja od srednjeročnega inflacijskega cilja monetarne politike ter odvisnost faktorja naklona od cikličnih nihanj inflacijske in proizvodne vrzeli. Hördahl, Tristani in Vestin (2004) ter ostali avtorji, ki so se osredotočili na bolj strukturni pristop, metodološko bolj ali manj sledijo študiji, ki sta jo predstavila Rudebusch in Wu (2004), in dobijo podobne rezultate.

Tretji metodološki del makrofinančnih modelov, ki družno modelirajo dinamiko krivulje donosnosti in makroekonomskih spremenljivk, predstavljajo modeli, ki namesto standardnega afinega brezarbitražnega terminskega strukturnega modela uporabljajo enostaven terminski strukturni model, ki sta ga predstavila Nelson in Siegel (1987). Diebold, Rudebusch in Aruoba (2006) predstavijo makrofinančni model, v katerem družno modelirajo dinamiko latentnih faktorjev krivulje donosnosti in opazovanih makroekonomskih spremenljivk. Faktorji krivulje donosnosti so pridobljeni na podlagi dinamične implementacije Nelson-Sieglovega modela krivulje donosnosti, ki sta jo predstavila Diebold in Li (2006). Po sami zasnovi makrofinančnega modela, za razliko od modela Anga in Piazzesijeve (2003), le-ta dovoljuje dvosmerno povezavo med krivuljo donosnosti in makroekonomskimi spremenljivkami. Rezultati implicirajo, da naklon krivulje vpliva na instrument monetarne politike (federal funds rate) in da spremembe v nivoju krivulje vplivajo na vse obravnavane makroekonomske spremenljivke (realna gospodarska aktivnost, inflacija, federal funds rate). Poleg tega vse obravnavane makroekonomske spremenljivke vplivajo na naklon krivulje donosnosti. Restriktivna monetarna politika posledično povzroči izravnavanje krivulje donosnosti (angl. *flattening*). Podoben, vendar zapoznel vpliv na naklon imata tudi pozitiven inflacijski šok in šok realne gospodarske aktivnosti. Spremembe v inflaciji se kažejo tudi v nivoju krivulje donosnosti. Inflacija naj bi na nivo krivulje donosnosti vplivala prek spremenjenih prihodnjih inflacijskih pričakovanj. Diebold, Rudebusch in Aruoba (2006) potrdijo dvosmerno makrofinančno povezavo, vendar odkrijejo, da je vpliv makroekonomskih spremenljivk na krivuljo donosnosti večji, kot pa je vpliv krivulje donosnosti na makroekonomske spremenljivke. Ang, Dong in Piazzesi (2005) dodajo, da so rezultati glede dvosmerne povezave odvisni od same zasnove modela, ki tovrstno povezavo dovoljuje ali pa ne. Afonso in Martins (2010) v predstavljenem metodološkem okviru razširita makrofinančni model z vključitvijo spremenljivk fiskalne politike. Njuni rezultati priznavajo, da fiskalna politika vpliva na krivuljo donosnosti in da je sam vpliv fiskalne politike na krivuljo donosnosti odvisen od posamezne države. Odziv krivulje donosnosti na spremembe v fiskalni politiki je odvisen od nivoja državnega dolga glede na BDP, pri čemer je vpliv državnega dolga glede na BDP na krivuljo manjši od vpliva proračunskega primanjkljaja. Povečan dolg glede na BDP dviguje dolgoročne obrestne mere, medtem ko jih povečan proračunski primanjkljaj zmanjšuje. Obe fiskalni spremenljivki vplivata na krivuljo predvsem prek njenega nivoja in naklona. Mönch (2012) uspe dodati makroekonomsko interpretacijo tudi faktorju ukrivljenosti. In sicer faktor ukrivljenosti poveže z gospodarsko rastjo na način, da povečanje faktorja ukrivljenosti, ki mu ne sledi prilagoditev s strani faktorjev nivoja in naklona, pomeni upad gospodarske aktivnosti.

V splošnem je inverzna krivulja donosnosti indikator upada gospodarske aktivnosti, vendar tovrstna povezava vedno ne drži. Takšne nestabilnosti je zaznal Hamilton (2010), izpostavljene pa so bile tudi že v študijah precej prej. Mishkin (1990a) opazi in empirično potrdi spremembe v koeficientih pri napovedovanju inflacije s strani obrestnega razmika v določenih obdobjih. Tovrstne spremembe Mishkin (1990a) poveže s spremembami v režimu monetarne politike. Podobna opažanja zaznajo tudi Haubrich in Dombrosky (1996) ter Dotsey (1998) v primeru napovedovanja gospodarske aktivnosti. Estrella (2004) izpelje makroekonomski model, ki implicira stabilnejšo povezavo med naklonom krivulje donosnosti, proizvodom in inflacijo v primeru stabilne monetarne politike. Slednje pomeni, da spremembe v režimu monetarne politike vplivajo na opisane povezave. Giacomini in Rossi (2006) ter mnogo drugih študij odvisnost povezave med krivuljo donosnosti in makroekonomskimi spremenljivkami od režima monetarne politike tudi empirično potrdijo. Nestabilnost glede povezave med krivuljo donosnosti in makroekonomskimi spremenljivkami je mogoče zaznati tudi v določenih študijah, ki se obravnavanja tovrstnih povezav lotijo z implementacijo makrofinančnih modelov. Halberstadt (2015) kot možnost za nestabilnosti v povezavi med krivuljo donosnosti in makroekonomijo navaja tudi obnašanje ekonomskih agentov in njihovo prilagoditev različnim makroekonomskim šokom in informacijam.

V tretjem poglavju magistrskega dela predstavim vpliv količinskega sproščanja (angl. *quantitative easing*) na krivuljo donosnosti in transmisijske kanale količinskega sproščanja. Količinsko sproščanje vpliva na krivuljo donosnosti in gospodarstvo prek kanala uravnoteženja portfeljev (angl. *portfolio balance sheet channel*), signalizacijskega kanala (angl. *signaling channel*), kanala bančnega kapitala in bilance (angl. *bank capital and balance sheet channel*) ter prek kanala deviznega tečaja (angl. *exchange rate channel*). Količinsko sproščanje je v glavnem vplivalo na krivuljo donosnosti z znižanjem dolgoročnih donosnosti in izravnavanjem krivulje donosnosti.

V četrtem poglavju predstavim makrofinančni model, ki konceptualno predstavlja izjemno pomemben del magistrskega dela za poznejšo empirično analizo. V prvem delu četrtega poglavja predstavim del makrofinančnega modela, ki se nanaša na modeliranje krivulje donosnosti. Naslonim se na Diebolda in Lija (2006), Diebolda, Rudebuscha in Aruobo (2006) ter Christensena, Diebolda in Rudebuscha (2011), ki obravnavajo Nelson-Sieglovo funkcijsko obliko krivulje donosnosti kot dinamični latentni faktorski model, v katerem so parametri $\beta_{0,t}$, $\beta_{1,t}$ in $\beta_{2,t}$ obravnavani kot parametri, ki se spreminjajo v času in jih je mogoče interpretirati kot nivo, naklon in ukrivljenost krivulje donosnosti. Ker so omenjeni parametri obravnavani kot dinamični faktorji, vsakemu od njih pritiče tudi naložbeni koeficient (angl. *factor loading*), ki je odvisen od parametra razpada $\lambda_{1,t}$ in je prav tako odvisen od časovne komponente. Apliciranje njihovih ugotovitev na Svenssonovo funkcijsko obliko krivulje donosnosti samega dinamičnega modela krivulje donosnosti ne spremeni veliko. Dodan je le še en faktor ukrivljenosti $\beta_{3,t}$ s pripadajočim faktorskim naložbenim koeficientom in svojim koeficientom razpada $\lambda_{2,t}$. Dinamični model krivulje donosnosti je posledično sestavljen iz meritvene enačbe (angl. *measurement equation*), ki ustreza Svenssonovi funkcijski obliki krivulje donosnosti in enačbe stanja ali prehoda (angl. *state or transition equation*), ki sledi VAR. Namen in cilji magistrskega dela narekujejo implementacijo makroekonomskih spremenljivk v dinamični model krivulje donosnosti, za kar je treba opisani model razširiti. Makrofinančni model je tako osnovan na FAVAR modelu, ki so ga predstavili Bernanke, Boivin in Eliasz (2004), kar omogoča vključitev širokega spektra makroekonomskih spremenljivk. V FAVAR modelu namreč dinamiko makroekonomskih spremenljivk poganjajo nekateri skupni faktorji in določene opazovane makroekonomske spremenljivke. Posledično je makrofinančni model sestavljen iz dveh meritvenih enačb, pri čemer prva temelji na funkcijski obliki Svenssonovega modela krivulje donosnosti kot v samem primeru dinamičnega faktorskega modela krivulje, medtem ko druga predstavlja povezavo faktorjev krivulje donosnosti in skupnih ekonomskih faktorjev z gospodarstvom. Enačbo stanja ali prehoda predstavlja FAVAR, v katerega so implementirani tudi dinamični faktorji krivulje donosnosti, ki so obravnavani kot opazovane spremenljivke.

V petem poglavju na kratko predstavim makroekonomske podatke in podatke, ki omogočajo oceno parametrov Svenssonovega modela krivulje donosnosti. Pridobljeni so bili mesečni makroekonomski podatki in podatki o dolžniških vrednostnih papirjih za Združene države Amerike za obdobje od januarja 1998 do decembra 2018. Ker so parametri krivulje donosnosti ocenjeni na podlagi brezkuponskih donosnosti dolžniških vrednostnih papirjev je posledično treba pridobiti tovrstne donosnosti iz cen dolžniških vrednostnih papirjev. Makroekonomski podatki so za potrebe ocenjevanja FAVAR transformirani, pomensko pa so razdeljeni v osem skupin, in sicer: proizvod in dohodek, trg dela, nastanitev, potrošnja, naročila in zaloge, denar in kredit, obrestne mere in devizni tečaji, cene in delniški trg.

Šesto poglavje je namenjeno predstavitvi ocene makrofinančnega modela. Strukturni terminski model brezkuponskih donosnosti se lahko oceni na več načinov. Konceptualno sledim študiji, ki jo je predstavil De Pooter (2007), ki pravi, da ocenjevanje dinamičnega modela krivulje donosnosti v dveh korakih, pri katerem sta parametra razpada ocenjena, in ne vnaprej determinirana, ne zaostaja bistveno za ocenjevanjem modela v enem koraku. V prvem koraku ocenim Svenssonov model z uporabo metode največje verjetnosti (angl. *maximum likelihood estimation*), pri tem pa upoštevam pomisleke glede kalibracije modela, ki so jih izpostavili tako Gilli, Große in Schumann (2010) kot De Pooter (2007). Svenssonov model ocenim z restrikcijo glede parametrov razpada $\lambda_{1,t}$ in $\lambda_{2,t}$, in sicer za omenjena parametra dovolim vrednosti na različnih intervalih, da se izognem potencialnemu problemu multikolinearnosti in dobim faktorje, ki spominjajo na časovno serijo. Slednje je ključno za modeliranje njihove dinamike v FAVAR. Ocenjeni faktorji krivulje donosnosti dokaj dobro posnemajo numerične faktorje krivulje donosnosti, ki jih je mogoče izračunati iz donosnosti konstantnih dospelosti. Ocenjeni parametri Svenssonovega modela ustrezajo najrazličnejšim oblikam krivulje donosnosti, ki so se pojavile v proučevanem obdobju. Obenem ocenjene donosnosti konstantnih dospelosti na podlagi ocenjenih parametrov Svenssonovega modela dobro sledijo donosnostim konstantnih dospelosti, ki jih je poročala centralna banka Združenih držav Amerike. Drugi korak v dvokoračnem ocenjevanju makrofinančnega modela je ocena FAVAR modela. Pri oceni FAVAR modela uporabim dvokoračni pristop, ki so ga predstavili Bernanke, Boivin in Eliasz (2004), kar pomeni, da iz nabora makroekonomskih spremenljivk izluščim skupne faktorje z uporabo PCA (angl. *principal component analysis*). Slednje potem očistim vplivov počasnih faktorjev, faktorjev krivulje donosnosti in opazovane spremenljivke (federal funds rate). Pri določitvi števila potrebnih faktorjev se oprem na merila, ki sta jih razvila Bai in Ng (2002), medtem ko si pri specifikaciji modela pomagam z informacijskimi merili. V šestem poglavju predstavim tudi ključne elemente za analizo združene dinamike krivulje donosnosti in makroekonomskih spremenljivk v primeru šoka monetarne politike, in sicer predstavim izračun impulznih odzivov na šok in dekompozicijo variance napovednih napak (angl. *forecast error variance decomposition*).

V sedmem poglavju magistrskega dela predstavim in interpretiram dobljene rezultate empiričnega analize. Monetarna politika na krivuljo donosnosti v glavnem vpliva prek faktorja naklona oziroma β_1 faktorja. Posledično se restriktivni šok monetarne politike kaže v položnejši krivulji donosnosti. Ker lahko na faktor naklona oziroma β_1 faktor gledamo kot na negativen razmik krivulje donosnosti (angl. *yield curve spread*), povečanje faktorja naklona in posledično položnejša krivulja donosnosti ter v skladu s tem ožji razmik krivulje donosnosti sovpadajo s splošnim prepričanjem, da zožitev razmika krivulje donosnosti napoveduje prihajajočo gospodarsko recesijo. Razmerje med krivuljo donosnosti in monetarno politiko se je po implementaciji količinskega sproščanja (angl. *quantitative easing*) spremenilo. Na splošno drži, da monetarna politika s spremembami ključne obrestne mere vpliva na krivuljo donosnosti prek faktorja naklona. V obdobju po implementaciji količinskega sproščanja se vpliv monetarne politike spremeni, saj le-ta značilno vpliva na krivuljo donosnosti prek obeh faktorjev ukrivljenosti (angl. *curvature factors*) oziroma faktorjev β_2 in β_3. Slednje pomeni, da se oblika krivulje donosnosti, kot odziv na restriktivno monetarno politiko oziroma dvig ključne obrestne mere, spremeni po implementaciji količinskega sproščanja. V tem obdobju se, kot odgovor na dvig ključne obrestne mere, razmik krivulje donosnosti še vedno zmanjša, podobno kot pred implementacijo, spremeni pa se oblika krivulje donosnosti. Tako krivulja donosnosti kot odziv na restriktivno monetarno politiko dobi nekakšno grbasto obliko (angl. *hump shape*), ki napoveduje samo inverzijo krivulje donosnosti. Poleg tega monetarna politika bolj vpliva na krivuljo donosnosti v obdobju po implementaciji količinskega sproščanja kot v obdobju pred tem. Rezultati kažejo, da je transmisija monetarnega šoka v krivuljo donosnosti hitrejša in da se pojavlja večja negotovost glede prihajajočega gospodarskega ohlajanja v primeru dviga ključne obrestne mere. Poleg spremenjenega vpliva na krivuljo donosnosti se je z implementacijo količinskega sproščanja spremenil tudi vpliv monetarne politike na makroekonomske indikatorje, vendar so večinoma spremembe vezane le na magnitudo vpliva. Rezultati kažejo, da je monetarna politika eden glavnih in najpomembnejših gonilnikov krivulje donosnosti. Dejansko je najpomembnejši gonilnik faktorja naklona, so pa tudi druge makroekonomske spremenljivke, ki vplivajo na krivuljo donosnosti. Kot glavni gonilnik faktorja nivoja krivulje donosnosti se pokaže inflacija, medtem ko sta oba faktorja ukrivljenosti povezana s poslovnim ciklom. Prvi faktor ukrivljenosti oziroma β_2 faktor je neke vrste prehitevajoči indikator gospodarskega cikla, medtem ko ima drugi faktor ukrivljenosti oziroma β_3 faktor določene lastnosti zaostajajočega indikatorja gospodarskega cikla. Rezultati kažejo, da je povezava med krivuljo donosnosti, njenimi faktorji in makroekonomskimi spremenljivkami dvosmerna, kljub temu pa makroekonomske spremenljivke bolj vplivajo na faktorje krivulje donosnosti kot pa slednji vplivajo na makroekonomske spremenljivke. Obenem rezultati kažejo tudi, da so se povezave med makroekonomskimi spremenljivkami in krivuljo donosnosti ter njenimi latentnimi faktorji večinoma spremenile po implementaciji količinskega sproščanja. Magistrsko delo sklenem s sklepom, v katerem povzamem glavne ugotovitve, podkrepljene z empirično analizo. Sklep temelji na podlagi raziskovalnih vprašanj, postavljenih v uvodu magistrskega dela, in odgovorov nanje, pri čemer se naslonim na rezultate empiričnega dela magistrskega dela.

Appendix 2: Macroeconomic dataset description

The macroeconomic dataset is classified into eight categories following McCracken and Ng (2015). The TCODE column denotes the data transformation for a particular time series x. The data transformations are as follows: 1 – no transformation, 2 – Δx_t, 4 – $\log(x_t)$ and 5 – $\Delta \log(x_t)$. The FRED column contains notation of each particular time series in the FRED database and the column DESCRIPTION contains a short description of the time series following McCracken and Ng (2015). The TYPE column contains information regarding whether a particular time series data is treated as slow-moving or fast-moving in FAVAR estimation.

Table 1: Output and income

	TCODE	FRED	DESCRIPTION	TYPE
1	5	RPI	Real Personal Income	Slow
2	5	W875RX1	Real Personal Income Ex Transfer Receipts	Slow
3	5	INDPRO	IP Index	Slow
4	5	IPFPNSS	IP: Final Products and Nonindustrial Supplies	Slow
5	5	IPFINAL	IP: Final Products (Market Group)	Slow
6	5	IPCONGD	IP: Consumer Goods	Slow
7	5	IPDCONGD	IP: Durable Consumer Goods	Slow
8	5	IPNCONGD	IP: Nondurable Consumer Goods	Slow
9	5	IPBUSEQ	IP: Business Equipment	Slow
10	5	IPMAT	IP: Materials	Slow
11	5	IPDMAT	IP: Durable Materials	Slow
12	5	IPNMAT	IP: Nondurable Materials	Slow
13	5	IPMANSICS	IP: Manufacturing (SIC)	Slow
14	5	IPB51222S	IP: Residential Utilities	Slow
15	5	IPFUELS	IP: Fuels	Slow
16	2	CUMFNS	Capacity Utilization: Manufacturing	Slow

Table 2: Labour market

	TCODE	FRED	DESCRIPTION	TYPE
1	2	HWI	Help Wanted Index for United States	Slow
2	2	HWIURATIO	Ratio of Help Wanted/No. Unemployed	Slow
3	5	CLF16OV	Civilian Labor Force	Slow
4	5	CE16OV	Civilian Employment	Slow
5	2	UNRATE	Civilian Unemployment Rate	Slow
6	2	UEMPMEAN	Average Duration of Unemployment (Weeks)	Slow
7	5	UEMPLT5	Civilians Unemployed – Less Than 5 Weeks	Slow
8	5	UEMP5TO14	Civilians Unemployed for 5-14 Weeks	Slow
9	5	UEMP15OV	Civilians Unemployed – 15 Weeks & Over	Slow
10	5	UEMP15T26	Civilians Unemployed for 15-26 Weeks	Slow
11	5	UEMP27OV	Civilians Unemployed for 27 Weeks and Over	Slow
12	5	CLAIMSx	Initial Claims	Slow
13	5	PAYEMS	All Employees: Total Nonfarm	Slow
14	5	USGOOD	All Employees: Goods-Producing Industries	Slow
15	5	CES1021000001	All Employees: Mining and Logging: Mining	Slow
16	5	USCONS	All Employees: Construction	Slow
17	5	MANEMP	All Employees: Manufacturing	Slow
18	5	DMANEMP	All Employees: Durable goods	Slow
19	5	NDMANEMP	All Employees: Nondurable goods	Slow
20	5	SRVPRD	All Employees: Service-Providing Industries	Slow
21	5	USTPU	All Employees: Trade, Transportation & Utilities	Slow
22	5	USWTRADE	All Employees: Wholesale Trade	Slow
23	5	USTRADE	All Employees: Retail Trade	Slow
24	5	USFIRE	All Employees: Financial Activities	Slow
25	5	USGOVT	All Employees: Government	Slow
26	1	CES0600000007	Avg Weekly Hours: Goods-Producing	Slow
27	2	AWOTMAN	Avg Weekly Overtime Hours: Manufacturing	Slow
28	1	AWHMAN	Avg Weekly Hours: Manufacturing	Slow
29	5	CES0600000008	Avg Hourly Earnings: Goods-Producing	Slow
30	5	CES2000000008	Avg Hourly Earnings: Construction	Slow
31	5	CES3000000008	Avg Hourly Earnings: Manufacturing	Slow

Table 3: Housing

	TCODE	FRED	DESCRIPTION	TYPE
1	4	HOUST	Housing Starts: Total New Privately Owned	Fast
2	4	HOUSTNE	Housing Starts, Northeast	Fast
3	4	HOUSTMW	Housing Starts, Midwest	Fast
4	4	HOUSTS	Housing Starts, South	Fast
5	4	HOUSTW	Housing Starts, West	Fast
6	4	PERMIT	New Private Housing Permits (SAAR)	Fast
7	4	PERMITNE	New Private Housing Permits, Northeast (SAAR)	Fast
8	4	PERMITMW	New Private Housing Permits, Midwest (SAAR)	Fast
9	4	PERMITS	New Private Housing Permits, South (SAAR)	Fast
10	4	PERMITW	New Private Housing Permits, West (SAAR)	Fast

Table 4: Consumption, orders and inventories

	TCODE	FRED	DESCRIPTION	TYPE
1	5	DPCERA3M086SBEA	Real Personal Consumption Expenditures	Slow
2	5	CMRMTSPLx	Real Manufacturing and Trade Industries Sales	Slow
3	5	RETAILx	Retail and Food Services Sales	Slow
4	5	AMDMNOx	New Orders for Durable Goods	Fast
5	5	ANDENOx	New Orders for Nondefense Capital Goods	Fast
6	5	AMDMUOx	Unfilled Orders for Durable Goods	Slow
7	5	BUSINVx	Total Business Inventories	Slow
8	2	ISRATIOx	Total Business: Inventories to Sales Ratio	Slow
9	2	UMCSENTx	Consumer Sentiment Index	Fast

Table 5: Money and credit

	TCODE	FRED	DESCRIPTION	TYPE
1	5	M1SL	M1 Money Stock	Fast
2	5	M2SL	M2 Money Stock	Fast
3	5	M2REAL	Real M2 Money Stock	Fast
4	5	AMBSL	St. Luis Adjusted Monetary Base	Fast
5	5	BUSLOANS	Commercial and Industrial Loans	Fast
6	5	REALLN	Real Estate Loans at All Commercial Banks	Fast
7	5	NONREVSL	Total Nonrevolving Credit	Fast
8	2	CONSPI	Nonrevolving Consumer Credit to Personal Income	Fast
9	5	MZMSL	MZM Money Stock	Fast
10	5	DTCOLNVHFNM	Consumer Motor Vehicle Loans Outstanding	Fast
11	5	DTCTHFNM	Total Consumer Loans and Leases Outstanding	Fast
12	5	INVEST	Securities in Bank Credit at All Commercial Banks	Fast

Table 6: Interest and exchange rates

	TCODE	FRED	DESCRIPTION	TYPE
1	1	*FEDFUNDS	Effective Federal Funds Rate Complemented by Wu and Xia Shadow Federal Funds Rate	Fast
2	2	CP3Mx	3-Month AA Financial Commercial Paper Rate	Fast
3	2	AAA	Moody’s Seasoned Aaa Corporate Bond Yield	Fast
4	2	BAA	Moody’s Seasoned Baa Corporate Bond Yield	Fast
5	1	COMPAPFFx	3-Month Commercial Paper Minus FEDFUNDS	Fast
6	1	AAAFFM	Moody’s Aaa Corporate Bond Minus FEDFUNDS	Fast
7	1	BAAFFM	Moody’s Baa Corporate Bond Minus FEDFUNDS	Fast
8	5	TWEXMMTH	Trade Weighted U.S. Dollar Index: Major Currencies	Fast
9	5	EXSZUSx	Switzerland / U.S. Foreign Exchange Rate	Fast
10	5	EXJPUSx	Japan / U.S. Foreign Exchange Rate	Fast
11	5	EXUSUKx	U.S. / U.K. Foreign Exchange Rate	Fast
12	5	EXCAUSx	Canada / U.S. Foreign Exchange Rate	Fast

NOTE: *The Effective Federal Funds Rate provided by FRED-MD and described by McCracken and Ng (2015) is complemented by Wu and Xia Shadow Federal Funds Rate when the Effective Federal Funds Rate hits the zero lower bound. The complemented time series data is used as a monetary policy stance variable.

Table 7: Prices

	TCODE	FRED	DESCRIPTION	TYPE
1	5	WPSFD49207	PPI: Finished Goods	Slow
2	5	WPSFD49502	PPI: Finished Consumer Goods	Slow
3	5	WPSID61	PPI: Intermediate Goods	Slow
4	5	WPSID62	PPI: Crude Materials	Slow
5	5	OILPRICEx	Crude Oil, Spliced WRI and Cushing	Slow
6	5	PPICMM	PPI: Metals and Metal Products	Slow
7	5	CPIAUCSL	CPI: All Items	Slow
8	5	CPIAPPSL	CPI: Apparel	Slow
9	5	CPITRNSL	CPI: Transportation	Slow
10	5	CPIMEDSL	CPI: Medical Care	Slow
11	5	CUSR0000SAC	CPI: Commodities	Slow
12	5	CUSR0000SAD	CPI: Durables	Slow
13	5	CUSR0000SAS	CPI: Services	Slow
14	5	CPIULFSL	CPI: All Items Less Food	Slow
15	5	CUSR0000SA0L2	CPI: All Items Less Shelter	Slow
16	5	CUSR0000SA0L5	CPI: All Items Less Medical Care	Slow
17	5	PCEPI	Personal Consumption Expenditures: Chain Index	Slow
18	5	DDURRG3M086SBEA	Personal Consumption Expenditures: Durable Goods	Slow
19	5	DNDGRG3M086SBEA	Personal Consumption Expenditures: Nondurable Goods	Slow
20	5	DSERRG3M086SBEA	Personal Consumption Expenditures: Services	Slow

Table 8: Stock market

	TCODE	FRED	DESCRIPTION	TYPE
1	5	S&P 500	S&P's Common Stock Price Index: Composite	Fast
2	5	S&P: indust	S&P's Common Stock Price Index: Industrials	Fast
3	2	S&P div yield	S&P's Composite Common Stock: Dividend Yield	Fast
4	5	S&P PE ratio	S&P's Composite Common Stock: Price-Earnings Ratio	Fast
5	1	VXOCLSx	VXO	Fast

Appendix 3: Descriptive statistics of estimated yield curve factors and constant maturity yields discrepancies

Table 9: Descriptive statistics of estimated yield curve factors

Factor	Mean	Stdev	Min	Max	$\rho(1)$	$\rho(12)$	ADF	KPSS (4)	KPSS (12)
β_0	4.5040	1.0187	1.7284	6.5702	0.9260	0.5362	-2.7240 (0.2710)	1.7440 (*0.01)	0.7653 (*0.01)
β_1	-2.6913	1.9065	-5.8478	2.5332	0.9257	0.6082	-1.6324 (0.7305)	1.0805 (*0.01)	0.4557 (0.0532)
β_2	-2.6777	3.7062	-25.7383	5.6298	0.7386	0.1222	-3.3589 (0.0618)	0.1921 (**0.1)	0.1043 (**0.1)
β_3	1.3335	5.7112	-9.4661	22.3156	0.8471	0.2835	-3.1519 (0.0964)	1.1740 (*0.01)	0.5664 (0.0267)

NOTE: This table reports descriptive statistics, autocorrelation coefficients and stationarity tests for estimated yield curve factors over the period from January 1998 to December 2018. The table reports the mean, standard deviation (Stdev), minimum and maximum values of the estimated yield curve factors. It is important to note that for calculations of the descriptive statistics displayed in the table that the slope factor β_1 values are taken as estimated, contrary to the figures presented in the master's thesis where the negative of the slope factor β_1 is presented (the negative of the yield curve factor β_1 coincides with the slope of the yield curve as presented by Diebold and Li (2006)). Furthermore, the table reports autocorrelation coefficients ρ where the number in parentheses represents the number of lags considered. The table reports Augmented Dickey-Fuller test statistics (ADF) with corresponding p-values in parentheses and KPSS test statistics (KPSS) derived by Kwiatkowski, Phillips, Schmidt and Shin (1992). The reported values of KPSS test statistics correspond to the lag truncation parameter being equal to 4 and 12. KPSS tests are performed for level stationarity. In the case of ADF test statistics, a maximum number of six lags is considered. ADF and KPSS tests p-values are written in parenthesis. Moreover, * denotes that the p-value is lower than the p-value presented in the table and ** denotes that the p-value is greater than the p-value presented in the table.

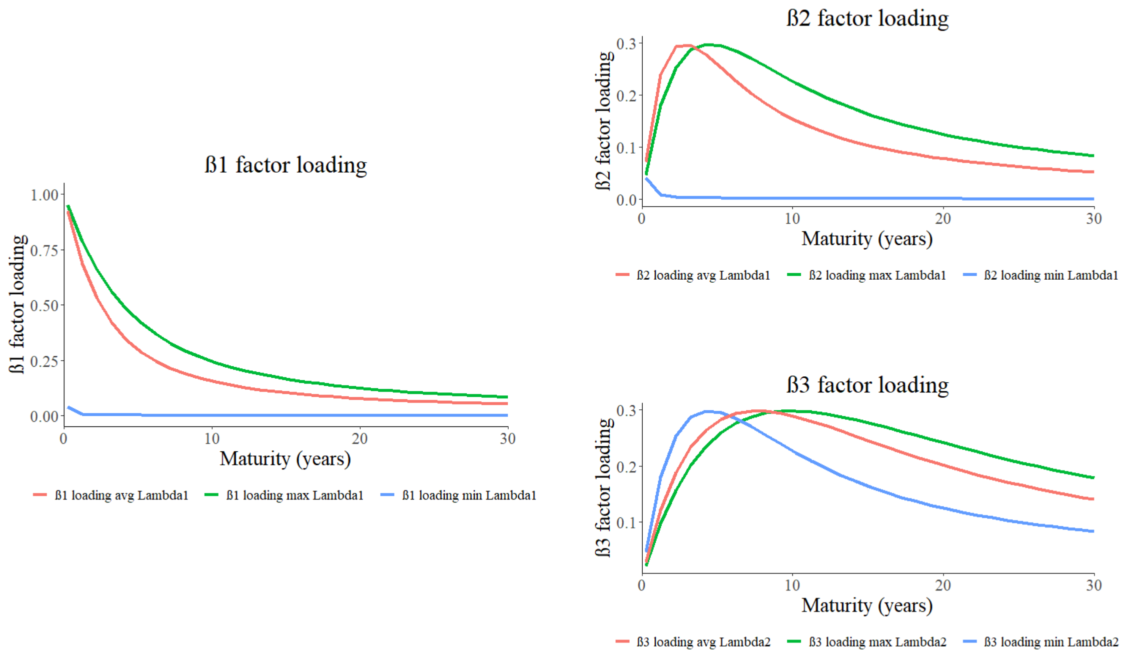
Table 10: Descriptive statistics of constant maturity yields errors/discrepancies

Maturity	Mean	Stdev	Minimum	Maximum	MAE	RMSE
3 months	0.0098	0.1124	0.0002	0.8706	0.0676	0.1126
6 months	-0.0212	0.1145	0.0002	0.9103	0.0666	0.1163
1 year	-0.0010	0.1426	0.0001	0.7740	0.0926	0.1424
2 years	-0.0235	0.1303	0.0001	0.5460	0.0990	0.1321
3 years	0.0039	0.1403	0.0001	0.4171	0.1080	0.1400
5 years	0.0578	0.2075	0.0022	0.8089	0.1481	0.2150
7 years	0.1056	0.2398	0.0001	0.9637	0.1740	0.2616
10 years	0.2442	0.3018	0.0028	1.3013	0.2702	0.3878
30 years	0.1388	0.2656	0.6847	0.7360	0.2514	0.2991

NOTE: This table reports descriptive statistics of constant maturities yields errors/discrepancies over the period from January 1998 to December 2018. Errors/discrepancies are calculated as the difference between the estimated constant maturities yields and constant maturities yields reported by the Federal Reserve. Errors/discrepancies representing the basis for descriptive statistics calculations are in percentage points. The table reports the mean, standard deviation (Stdev) or the tracking error, minimum absolute error, maximum absolute error, mean-absolute-error (MAE), and root-mean-square-error (RMSE).

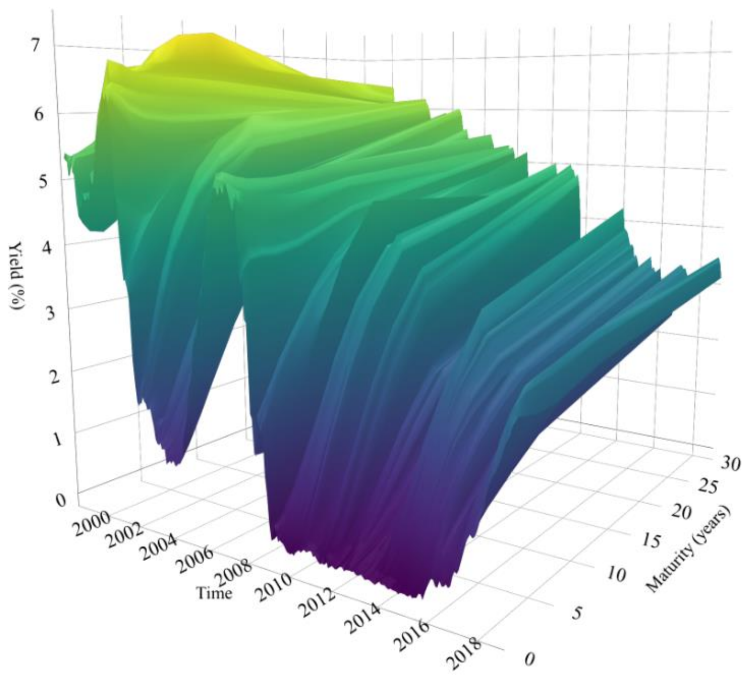
Appendix 4: Yield curve estimation results

Figure 1: Factor loadings for different maturities



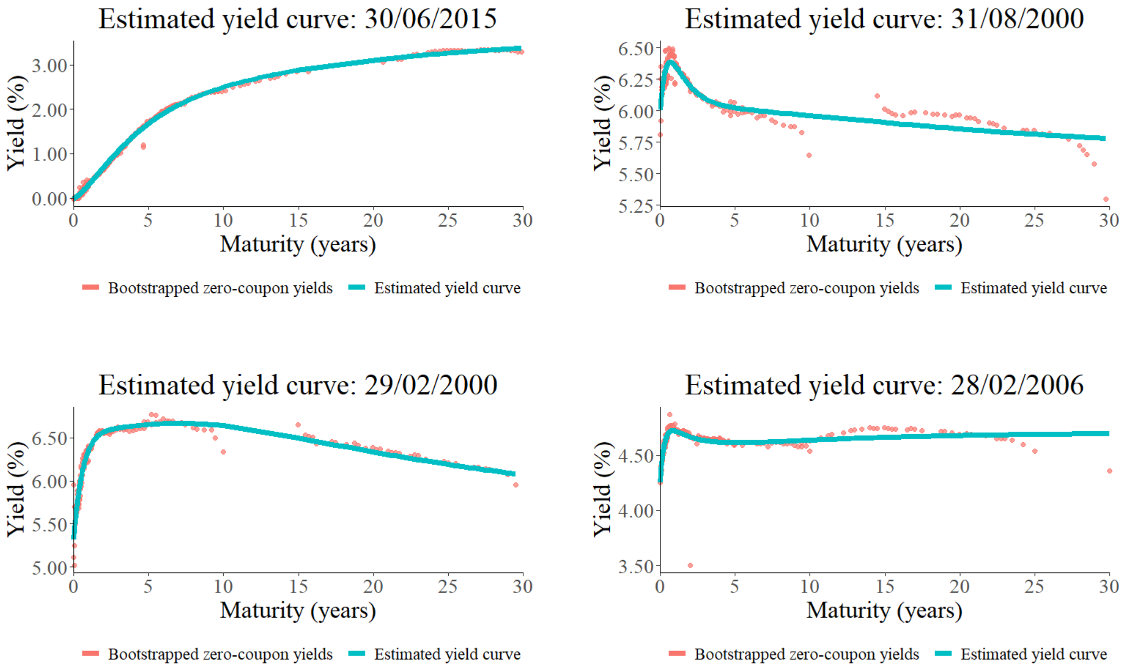
Source: Own work

Figure 2: A plane of estimated zero coupon yield curves



Source: Own work

Figure 3: Different shapes of estimated yield curves



Source: Own work

Appendix 5: Determining the number of factors using Bai and Ng (2002) criteria

Bai and Ng (2002) propose some criteria to enable consistent estimation of the number of factors. Bai and Ng (2002) criteria are developed under the assumption of large cross-sections N and large time dimensions T. Bai and Ng (2002) set up the determination of number of factors as a model selection problem and therefore the proposed criteria rely on the trade-off between goodness of fit and parsimony. Bai and Ng (2002) assert that when treating all potentially informative factors as observable and factor loadings as non-observable, the problem is simplified to determining the number of factors k that optimally explain variations in X (the macroeconomic dataset) and estimate the respective factor loadings. Furthermore, as factors are observed and the model is linear, the factor loadings λ_i can be estimated by the use of least squares for each equation $X_{it} = \lambda_i' F_t + e_{it}$. This makes the problem of determining the number of factors, as aforementioned, a model selection problem, since a model with $k+1$ factors cannot fit worse than a model with k factors. There is only a loss of efficiency as more factor loadings needs to be estimated. The optimization problem for factor loading estimation is expressed as

$$V(k, F^k) = \min_{\lambda} \frac{1}{NT} \sum_{i=1}^{N} \sum_{t=1}^{T} \left(X_{it} - \lambda_i^{k\prime} F_t^k\right)^2$$

where F^k is a matrix of k factors and $V(k, F^k)$ is the sum of squared residuals divided by NT from time-series regressions of X_i on k factors for all i. Bai and Ng (2002) claim that a loss function in a form of $V(k, F^k) + kg(N, T)$ can be used to determine k where $g(N, T)$ denotes the penalty part of the loss function for overfitting. Since factors are not actually observed because they are estimated, Bai and Ng (2002) aim to find penalty functions $g(N, T)$ such that the criteria of the following form

$$PC(k) = V\left(k, \hat{F}^k\right) + kg(N, T)$$

enable consistent estimations of r, i.e. a true number of factors. Moreover, Bai and Ng (2002) also present an alternative class of criteria formed as

$$IC(k) = \ln\left(V\left(k, \hat{F}^k\right)\right) + kg(N, T)$$

which enables consistent estimations of r, i.e. true number of factors as well. As a result, Bai and Ng (2002), assuming that factors are estimated by the usage of principal components, developed the following forms of penalty functions $g(N, T)$ in criteria $PC(k)$ and $IC(k)$.

$$PC_{p1}(k) = V\left(k, \hat{F}^k\right) + k\hat{\sigma}^2 \left(\frac{N+T}{NT}\right) \ln\left(\frac{NT}{N+T}\right)$$

$$PC_{p2}(k) = V(k, \hat{F}^k) + k\hat{\sigma}^2 \left(\frac{N+T}{NT}\right) \ln C_{NT}^2$$

$$PC_{p3}(k) = V(k, \hat{F}^k) + k\hat{\sigma}^2 \left(\frac{\ln C_{NT}^2}{C_{NT}^2}\right)$$

$$IC_{p1}(k) = \ln\left(V(k, \hat{F}^k)\right) + k\left(\frac{N+T}{NT}\right) \ln\left(\frac{NT}{N+T}\right)$$

$$IC_{p2}(k) = \ln\left(V(k, \hat{F}^k)\right) + k\left(\frac{N+T}{NT}\right) \ln C_{NT}^2$$

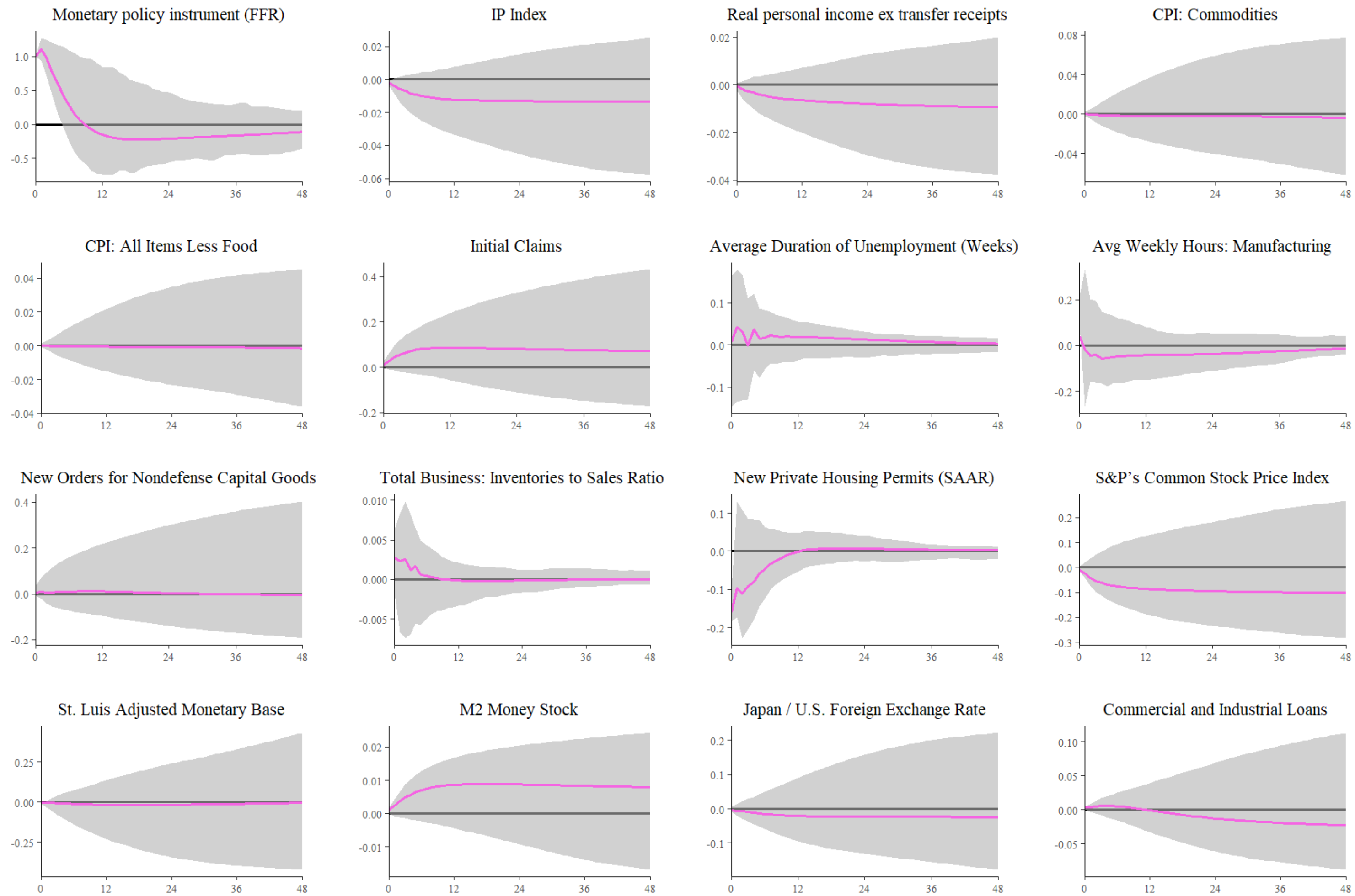
$$IC_{p3}(k) = \ln\left(V(k, \hat{F}^k)\right) + k\left(\frac{\ln C_{NT}^2}{C_{NT}^2}\right)$$

In the criteria $PC(k)$ and $IC(k)$, $C_{NT}^2 = min\{N, T\}$, $V(k, \hat{F}^k) = N^{-1} \sum_{i=1}^{N} \hat{\sigma}_i^2$ and $\hat{\sigma}_i^2 = \hat{e}_i'\hat{e}_i/T$, from equation $X_{it} = \lambda_i' F_t + e_{it}$ represents the cornerstone of the formulation of the problem of determining the number of factors as the model selection problem through factor loadings estimation. In applications, $\hat{\sigma}^2$ can be replaced by $V(kmax, \hat{F}^{kmax})$. The aforementioned criteria developed by Bai and Ng (2002) have several advantages over other methods of determining the number of factors. They do not rely on sequential limits and there is no restriction imposed between N and T. Furthermore, the results hold under heteroscedasticity in both cross-section and time dimensions. The results also hold under weak serial and cross-section correlation and simulations run by Bai and Ng (2002), which demonstrates that the criteria have good finite sample properties.

Appendix 6: Impulse responses to monetary policy shock

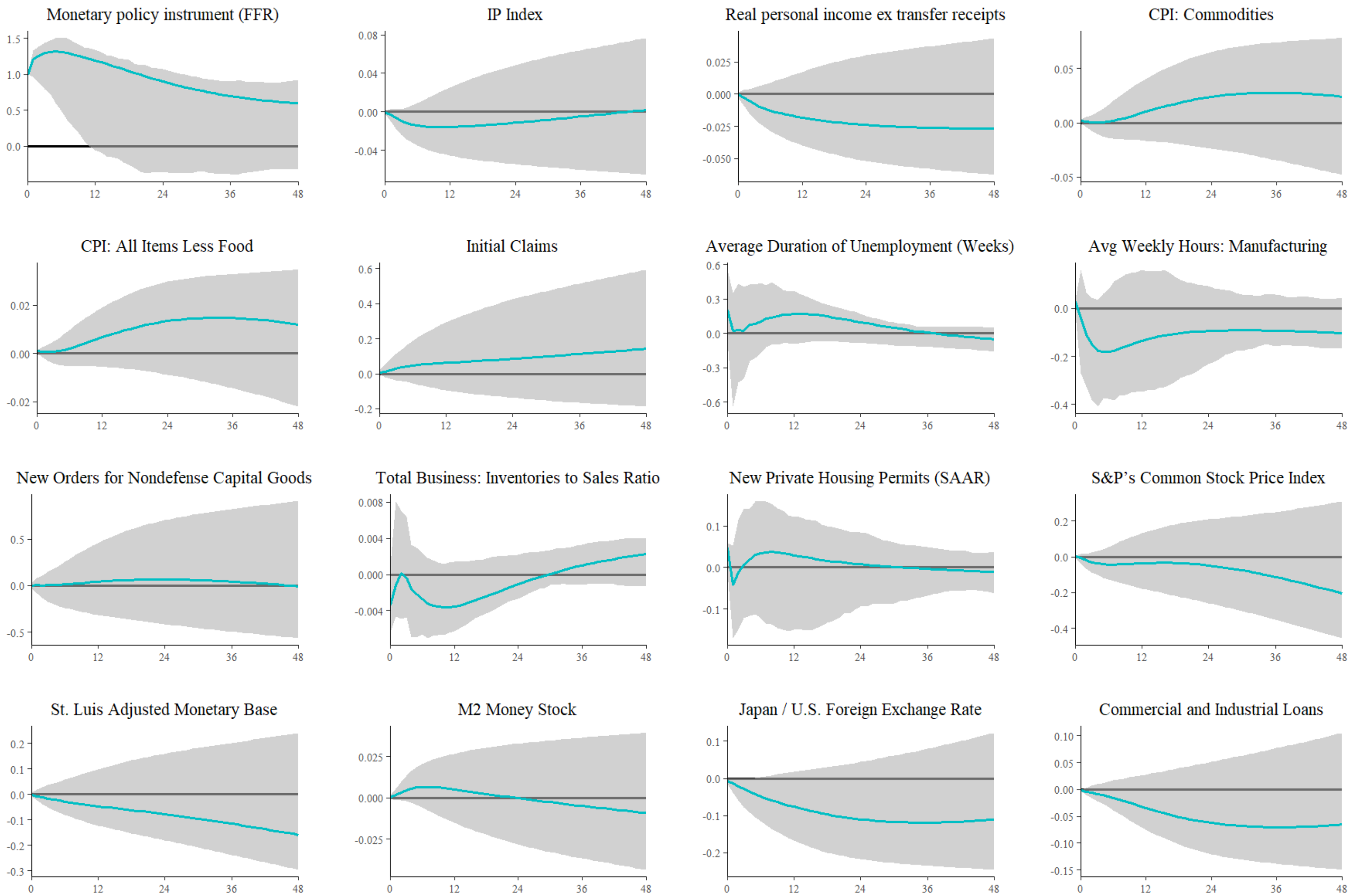
The following figures report 48-month horizon orthogonal impulse responses of several macroeconomic variables to the restrictive monetary policy shock and the corresponding 90% bootstrapped confidence intervals (grey shaded area). A monetary policy shock represents a shock to the Effective Federal Funds Rate complemented by Wu and Xia Shadow Federal Funds Rate in periods when the Effective Federal Funds Rate hits the zero lower bound. The Pre-QE period impulse responses correspond to the time period spanning from January 1998 to November 2008 inclusive. The Post-QE period impulse responses correspond to the time period spanning from December 2008 to December 2018. The Pre-QE period coincides with the part of the total sample corresponding to the period before the implementation of the QE and the Post-QE period coincides with the part of the total sample that corresponds to period after the implementation of the QE. The breaking point for the division of the total sample period into two sub-samples is the Federal Reserve's announcement of QE1 on 25 November 2008. The QE1 was launched in December 2008.

Figure 4: Impulse responses of macroeconomic variables – Pre-QE period



Source: Own work

Figure 5: Impulse responses of macroeconomic variables – Post-QE period



Source: Own work

Appendix 7: Forecast error variance decomposition

Table 11: Forecast error variance decomposition

	Total			Pre-QE			Post-QE		
	FEVD	*R squared*	*Product*	*FEVD*	*R squared*	*Product*	*FEVD*	*R squared*	*Product*
Monetary Policy Instrument (FFR)	0.1692	1*	0.1692	0.0141	1*	0.0141	0.1898	1*	0.1898
β_0	0.0207	1*	0.0207	0.0006	1*	0.0006	0.0241	1*	0.0241
β_1	0.0359	1*	0.0359	0.0109	1*	0.0109	0.0654	1*	0.0654
β_2	0.0167	1*	0.0167	0.0073	1*	0.0073	0.0779	1*	0.0779
β_3	0.0142	1*	0.0142	0.0008	1*	0.0008	0.0582	1*	0.0582
IP Index	0.0619	0.1534	0.0095	0.0083	0.1958	0.0016	0.0398	0.2826	0.0113
Real Personal Income ex Transfer Receipts	0.0654	0.0976	0.0064	0.0079	0.1505	0.0012	0.0524	0.1092	0.0057
CPI: Commodities	0.0392	0.1446	0.0057	0.0019	0.1675	0.0003	0.0768	0.2599	0.0200
CPI: All Items Less Food	0.0557	0.1687	0.0094	0.0019	0.2133	0.0004	0.1105	0.1989	0.0220
Initial Claims	0.0610	0.0915	0.0056	0.0071	0.1798	0.0013	0.0717	0.0773	0.0055
Average Duration of Unemployment (Weeks)	0.0659	0.1217	0.0080	0.0033	0.0770	0.0003	0.0889	0.1820	0.0162
Avg. Weekly Hours: Manufacturing	0.0097	0.8919	0.0087	0.0052	0.8284	0.0043	0.0070	0.9797	0.0069
New Orders for Nondefense Capital Goods	0.0422	0.0213	0.0009	0.0055	0.0536	0.0003	0.0369	0.0268	0.0010
Total Business: Inventories to Sales Ratio	0.0541	0.1393	0.0075	0.0042	0.1862	0.0008	0.0774	0.2452	0.0190
New Private Housing Permits (SAAR)	0.0288	0.6229	0.0179	0.0058	0.4768	0.0028	0.0082	0.9013	0.0074
S&P's Common Stock Price Index: Composite	0.0239	0.3349	0.0080	0.0069	0.4077	0.0028	0.0649	0.3381	0.0219
St. Luis Adjusted Monetary Base	0.0408	0.1990	0.0081	0.0023	0.6446	0.0015	0.0624	0.1133	0.0071
M2 Money Stock	0.0237	0.1770	0.0042	0.0098	0.2195	0.0022	0.0671	0.2667	0.0179
Japan / U.S. Foreign Exchange Rate	0.0791	0.1137	0.0090	0.0049	0.1265	0.0006	0.0857	0.1402	0.0120
Commercial and Industrial Loans	0.0403	0.4028	0.0162	0.0026	0.5099	0.0013	0.0680	0.7844	0.0533

NOTE: This table reports the contribution of the monetary policy shock to the variance of the latent yield curve factors and several macroeconomic variables for the 48-month horizon for the Total period (from January 1998 to December 2018), Pre-QE period (from January 1998 to including November 2008) and Post-QE period (from December 2008 to December 2018). Columns entitled "FEVD" report the fraction of the variance of the forecast error corresponding to the common component and the columns entitled "R squared" report the fraction of the variance of a particular variable explained by common factors ($\hat{F}_t, Y_t, f_t^y$). The product (columns "Product") of the corresponding "FEVD" and "R squared" columns is equivalent to the standard VAR forecast error variance decomposition. Therefore, it represents the fraction of the variance of the forecast error of the respective variables and yield curve factors explained by the monetary policy shock. * denotes that the fraction of the variance explained by common factors is imposed by construction.

Appendix 8: Relationships between yield curve factors and macroeconomic variables

The following tables report the results of regressing respective yield curve factors on the respective lagged macroeconomic variables (one lag) and regressing respective macroeconomic variables on the respective lagged yield curve factors (one lag) in order to examine the bi-directional relationships between the latent yield curve factors and the macroeconomic variables. Note that the results are reported only for the macroeconomic variables where the F statistic's p-value for the Total period is lower or equal to 0.05 and R-squared for the Total period exceeds 0.05. Results are reported for the Total period (from January 1998 to December 2018) as well as both sub-periods, i.e. Pre-QE period (from January 1998 to including November 2008) and Post-QE period (from December 2008 to December 2018). They are denoted as "total", "pre" and "post" respectively in the column "Period". Columns entitled as "Rho" report the Pearson correlation coefficient, "R-squared" reports coefficients of determination, "F stat" reports a particular regression's F statistic and "p-value" reports its corresponding p-value. Columns entitled "Chow test" report the Chow test statistic following Greene (2012) with a corresponding p-value reported in the parentheses. In addition, * denotes that the p-value is lower than the p-value presented in the table and ** denotes that the p-value is greater than the p-value presented in the table.

Table 12: Regression of Beta0 factor on lagged macroeconomic variables

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
All Employees: Mining and Logging: Mining	total	0.3296	0.1086	30.3470	*0.01	80.6824 (*0.01)
	pre	0.3764	0.1417	21.1246	*0.01	
	post	0.3776	0.1426	19.6219	*0.01	
All Employees: Nondurable Goods	total	-0.2899	0.0840	22.8451	*0.01	58.1976 (*0.01)
	pre	-0.1034	0.0107	1.3834	**0.1	
	post	-0.0594	0.0035	0.4183	**0.1	
Avg Weekly Hours: Goods-Producing	total	-0.4848	0.2350	76.4968	*0.01	60.1174 (*0.01)
	pre	-0.4695	0.2204	36.1949	*0.01	
	post	-0.2658	0.0707	8.9709	*0.01	
Avg Weekly Hours: Manufacturing	total	-0.4799	0.2303	74.4966	*0.01	55.1052 (*0.01)
	pre	-0.4284	0.1835	28.7732	*0.01	
	post	-0.2578	0.0665	8.4015	*0.01	
Housing Starts: Total New Privately Owned	total	0.3966	0.1573	46.4748	*0.01	75.359 (*0.01)
	pre	0.2891	0.0836	11.6722	*0.01	
	post	-0.6318	0.3992	78.3970	*0.01	
Housing Starts, Northeast	total	0.4079	0.1664	49.7037	*0.01	55.8449 (*0.01)
	pre	0.2504	0.0627	8.5642	*0.01	
	post	-0.3887	0.1511	20.9983	*0.01	
Housing Starts, Midwest	total	0.4411	0.1946	60.1671	*0.01	49.2605 (*0.01)
	pre	0.1632	0.0266	3.5022	0.0636	
	post	-0.4908	0.2409	37.4381	*0.01	
Housing Starts, South	total	0.3721	0.1385	40.0192	*0.01	78.095 (*0.01)
	pre	0.2805	0.0787	10.9343	*0.01	
	post	-0.6214	0.3862	74.2336	*0.01	
Housing Starts, West	total	0.3518	0.1237	35.1585	*0.01	90.9397 (*0.01)
	pre	0.3243	0.1052	15.0442	*0.01	
	post	-0.6725	0.4522	97.4123	*0.01	

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
New Private Housing Permits (SAAR)	total	0.3999	0.1599	47.3946	*0.01	80.0016 (*0.01)
	pre	0.3356	0.1126	16.2482	*0.01	
	post	-0.6324	0.3999	78.6291	*0.01	
New Private Housing Permits, Northeast (SAAR)	total	0.4292	0.1842	56.2354	*0.01	65.1913 (*0.01)
	pre	0.3700	0.1369	20.2983	*0.01	
	post	-0.4321	0.1867	27.0847	*0.01	
New Private Housing Permits, Midwest (SAAR)	total	0.4474	0.2002	62.3291	*0.01	54.3329 (*0.01)
	pre	0.1925	0.0370	4.9237	0.0283	
	post	-0.5784	0.3345	59.3134	*0.01	
New Private Housing Permits, South (SAAR)	total	0.3742	0.1400	40.5478	*0.01	86.5899 (*0.01)
	pre	0.3355	0.1125	16.2329	*0.01	
	post	-0.6530	0.4263	87.6987	*0.01	
New Private Housing Permits, West (SAAR)	total	0.3645	0.1329	38.1576	*0.01	88.723 (*0.01)
	pre	0.3510	0.1232	17.9863	*0.01	
	post	-0.6342	0.4023	79.4083	*0.01	
Unfilled Orders for Durable Goods	total	0.2784	0.0775	20.9154	*0.01	65.1931 (*0.01)
	pre	0.1824	0.0333	4.4035	0.0378	
	post	0.2331	0.0543	6.7773	0.0104	
Real Estate Loans at All Commercial Banks	total	0.2376	0.0565	14.9016	*0.01	74.2641 (*0.01)
	pre	0.0144	0.0002	0.0265	**0.1	
	post	-0.4843	0.2345	36.1535	*0.01	
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	total	0.2992	0.0895	24.4848	*0.01	82.7696 (*0.01)
	pre	-0.3286	0.1080	15.4949	*0.01	
	post	-0.4476	0.2004	29.5703	*0.01	
3-Month Commercial Paper Minus FEDFUNDS	total	-0.3215	0.1033	28.6977	*0.01	73.4837 (*0.01)
	pre	-0.2779	0.0772	10.7130	*0.01	
	post	-0.4278	0.1830	26.4302	*0.01	
PPI: Finished Goods	total	0.2545	0.0648	17.2396	*0.01	69.0854 (*0.01)
	pre	0.1809	0.0327	4.3314	0.0394	
	post	0.2833	0.0803	10.3008	*0.01	
PPI: Finished Consumer Goods	total	0.2537	0.0643	17.1221	*0.01	69.2822 (*0.01)
	pre	0.1855	0.0344	4.5615	0.0346	
	post	0.2788	0.0777	9.9432	*0.01	
PPI: Intermediate Goods	total	0.3447	0.1188	33.5733	*0.01	66.2582 (*0.01)
	pre	0.2730	0.0745	10.3085	*0.01	
	post	0.3491	0.1219	16.3788	*0.01	
PPI: Metals and Metal Products	total	0.2563	0.0657	17.5054	*0.01	70.9319 (*0.01)
	pre	0.2565	0.0658	9.0178	*0.01	
	post	0.1617	0.0261	3.1672	0.0777	
CPI: All Items	total	0.2917	0.0851	23.1644	*0.01	62.7888 (*0.01)
	pre	0.1704	0.0290	3.8263	0.0526	
	post	0.2224	0.0495	6.1420	0.0146	
CPI: Medical Care	total	0.2603	0.0678	18.1033	*0.01	67.3188 (*0.01)
	pre	0.2314	0.0535	7.2416	*0.01	
	post	-0.0242	0.0006	0.0694	**0.1	
CPI: Commodities	total	0.2421	0.0586	15.5042	*0.01	68.4655 (*0.01)
	pre	0.1216	0.0148	1.9214	**0.1	
	post	0.3078	0.0948	12.3532	*0.01	
CPI: Services	total	0.2985	0.0891	24.3606	*0.01	68.673 (*0.01)
	pre	0.2361	0.0558	7.5574	*0.01	
	post	-0.3205	0.1027	13.5112	*0.01	
CPI: All Items Less Food	total	0.2718	0.0739	19.8559	*0.01	64.6793 (*0.01)
	pre	0.1786	0.0319	4.2163	0.0421	
	post	0.1838	0.0338	4.1273	0.0444	
CPI: All Items Less Shelter	total	0.2829	0.0800	21.6604	*0.01	65.2879 (*0.01)
	pre	0.1549	0.0240	3.1475	0.0784	
	post	0.3032	0.0919	11.9462	*0.01	

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
CPI: All Items Less Medical Care	total	0.2852	0.0813	22.0421	*0.01	63.3864 (*0.01)
	pre	0.1659	0.0275	3.6221	0.0593	
	post	0.2243	0.0503	6.2503	0.0138	
Personal Consumption Expenditures: Chain Index	total	0.3133	0.0982	27.1035	*0.01	63.5477 (*0.01)
	pre	0.2168	0.0470	6.3145	0.0132	
	post	0.2572	0.0662	8.3623	*0.01	
Personal Consumption Expenditures: Nondurable Goods	total	0.2499	0.0625	16.5864	*0.01	67.4874 (*0.01)
	pre	0.1248	0.0156	2.0259	**0.1	
	post	0.2979	0.0888	11.4953	*0.01	
Personal Consumption Expenditures: Services	total	0.2820	0.0795	21.5042	*0.01	65.0106 (*0.01)
	pre	0.2290	0.0524	7.0816	*0.01	
	post	-0.0731	0.0053	0.6338	**0.1	

Table 13: Regression of macroeconomic variables on lagged Beta0 factor

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
All Employees: Mining and Logging: Mining	total	0.3675	0.1351	38.8784	*0.01	9.2151 (*0.01)
	pre	0.4463	0.1992	31.8322	*0.01	
	post	0.4258	0.1813	26.1246	*0.01	
All Employees: Nondurable goods	total	-0.2437	0.0594	15.7177	*0.01	39.5514 (*0.01)
	pre	-0.1142	0.0130	1.6902	**0.1	
	post	0.1478	0.0218	2.6353	**0.1	
Avg Weekly Hours: Goods-Producing	total	-0.4647	0.2159	68.5615	*0.01	18.1607 (*0.01)
	pre	-0.5013	0.2513	42.9655	*0.01	
	post	-0.1061	0.0113	1.3426	**0.1	
Avg Weekly Hours: Manufacturing	total	-0.4670	0.2181	69.4526	*0.01	20.3782 (*0.01)
	pre	-0.4592	0.2108	34.1953	*0.01	
	post	-0.1209	0.0146	1.7506	**0.1	
Housing Starts: Total New Privately Owned	total	0.3994	0.1595	47.2671	*0.01	180.5901 (*0.01)
	pre	0.2273	0.0517	6.9749	*0.01	
	post	-0.5385	0.2900	48.1924	*0.01	
Housing Starts, Northeast	total	0.4281	0.1832	55.8587	*0.01	108.8382 (*0.01)
	pre	0.2798	0.0783	10.8742	*0.01	
	post	-0.3167	0.1003	13.1540	*0.01	
Housing Starts, Midwest	total	0.4364	0.1904	58.5627	*0.01	173.7293 (*0.01)
	pre	0.1058	0.0112	1.4489	**0.1	
	post	-0.4374	0.1913	27.9174	*0.01	
Housing Starts, South	total	0.3773	0.1423	41.3278	*0.01	155.4427 (*0.01)
	pre	0.2199	0.0484	6.5068	0.0119	
	post	-0.5211	0.2715	43.9787	*0.01	
Housing Starts, West	total	0.3539	0.1252	35.6402	*0.01	150.3216 (*0.01)
	pre	0.2622	0.0687	9.4491	*0.01	
	post	-0.5687	0.3235	56.4168	*0.01	
New Private Housing Permits (SAAR)	total	0.3926	0.1541	45.3750	*0.01	165.6475 (*0.01)
	pre	0.2566	0.0658	9.0195	*0.01	
	post	-0.5519	0.3046	51.6885	*0.01	
New Private Housing Permits, Northeast (SAAR)	total	0.4001	0.1601	47.4615	*0.01	123.8778 (*0.01)
	pre	0.2362	0.0558	7.5620	*0.01	
	post	-0.4115	0.1693	24.0522	*0.01	
New Private Housing Permits, Midwest (SAAR)	total	0.4415	0.1949	60.2894	*0.01	185.1603 (*0.01)
	pre	0.1283	0.0165	2.1416	**0.1	
	post	-0.4961	0.2461	38.5141	*0.01	
New Private Housing Permits, South (SAAR)	total	0.3725	0.1387	40.1044	*0.01	147.5009 (*0.01)
	pre	0.2830	0.0801	11.1410	*0.01	
	post	-0.5636	0.3177	54.9431	*0.01	

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
New Private Housing Permits, West (SAAR)	total	0.3608	0.1302	37.2714	*0.01	142.4741 (*0.01)
	pre	0.2719	0.0739	10.2174	*0.01	
	post	-0.5461	0.2982	50.1431	*0.01	
Unfilled Orders for Durable Goods	total	0.2683	0.0720	19.3148	*0.01	2.6457 (0.073)
	pre	0.1177	0.0138	1.7969	**0.1	
	post	0.3323	0.1104	14.6495	*0.01	
Real Estate Loans at All Commercial Banks	total	0.2561	0.0656	17.4832	*0.01	42.3552 (*0.01)
	pre	0.0375	0.0014	0.1805	**0.1	
	post	-0.4444	0.1975	29.0451	*0.01	
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	total	0.2873	0.0826	22.4101	*0.01	237.0575 (*0.01)
	pre	-0.3472	0.1205	17.5408	*0.01	
	post	-0.4981	0.2481	38.9445	*0.01	
3-Month Commercial Paper Minus FEDFUNDS	total	-0.2630	0.0692	18.5050	*0.01	7.4546 (*0.01)
	pre	-0.2016	0.0407	5.4250	0.0214	
	post	-0.5539	0.3068	52.2141	*0.01	
PPI: Intermediate Goods	total	0.2648	0.0701	18.7710	*0.01	10.3962 (*0.01)
	pre	0.2349	0.0552	7.4761	*0.01	
	post	0.2365	0.0559	6.9891	*0.01	
CPI: Medical Care	total	0.2657	0.0706	18.9190	*0.01	6.0784 (*0.01)
	pre	0.2349	0.0552	7.4745	*0.01	
	post	-0.0087	0.0001	0.0088	**0.1	
CPI: Services	total	0.2922	0.0854	23.2523	*0.01	16.1137 (*0.01)
	pre	0.2182	0.0476	6.3999	0.0126	
	post	-0.2428	0.0590	7.3929	*0.01	
Personal Consumption Expenditures: Chain Index	total	0.2456	0.0603	15.9867	*0.01	5.3099 (*0.01)
	pre	0.2353	0.0554	7.5050	*0.01	
	post	0.1238	0.0153	1.8354	**0.1	
Personal Consumption Expenditures: Services	total	0.2879	0.0829	22.4999	*0.01	2.3907 (0.0937)
	pre	0.2265	0.0513	6.9248	*0.01	
	post	0.0393	0.0015	0.1828	**0.1	

Table 14: Regression of Beta1 factor on lagged macroeconomic variables

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
All Employees: Service-Providing Industries	total	0.2917	0.0851	23.1647	*0.01	47.4549 (*0.01)
	pre	0.4820	0.2324	38.7448	*0.01	
	post	0.0555	0.0031	0.3644	**0.1	
Housing Starts: Total New Privately Owned	total	0.4043	0.1635	48.6626	*0.01	12.1084 (*0.01)
	pre	-0.1088	0.0118	1.5337	**0.1	
	post	0.6590	0.4342	90.5607	*0.01	
Housing Starts, Northeast	total	0.3521	0.1240	35.2334	*0.01	11.6399 (*0.01)
	pre	-0.0944	0.0089	1.1508	**0.1	
	post	0.3686	0.1359	18.5575	*0.01	
Housing Starts, Midwest	total	0.3886	0.1510	44.2959	*0.01	9.1544 (*0.01)
	pre	-0.0491	0.0024	0.3092	**0.1	
	post	0.5053	0.2553	40.4579	*0.01	
Housing Starts, South	total	0.3997	0.1598	47.3522	*0.01	12.1041 (*0.01)
	pre	-0.0985	0.0097	1.2532	**0.1	
	post	0.6472	0.4189	85.0479	*0.01	
Housing Starts, West	total	0.3924	0.1540	45.3189	*0.01	16.232 (*0.01)
	pre	-0.1369	0.0187	2.4440	**0.1	
	post	0.7142	0.5100	122.8395	*0.01	
New Private Housing Permits (SAAR)	total	0.3857	0.1487	43.5038	*0.01	15.4626 (*0.01)
	pre	-0.1410	0.0199	2.5948	**0.1	
	post	0.6572	0.4319	89.7266	*0.01	

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
New Private Housing Permits, Northeast (SAAR)	total	0.3316	0.1100	30.7630	*0.01	16.4555 (*0.01)
	pre	-0.1617	0.0262	3.4372	0.066	
	post	0.4025	0.1620	22.8191	*0.01	
New Private Housing Permits, Midwest (SAAR)	total	0.3971	0.1577	46.6245	*0.01	10.3247 (*0.01)
	pre	-0.0554	0.0031	0.3935	**0.1	
	post	0.5984	0.3581	65.8304	*0.01	
New Private Housing Permits, South (SAAR)	total	0.3746	0.1403	40.6492	*0.01	18.0696 (*0.01)
	pre	-0.1566	0.0245	3.2192	0.0751	
	post	0.6779	0.4595	100.3278	*0.01	
New Private Housing Permits, West (SAAR)	total	0.3840	0.1474	43.0602	*0.01	16.0483 (*0.01)
	pre	-0.1372	0.0188	2.4562	**0.1	
	post	0.6741	0.4545	98.3011	*0.01	
M1 Money Stock	total	-0.2424	0.0587	15.5378	*0.01	22.9941 (*0.01)
	pre	-0.1989	0.0396	5.2737	0.0233	
	post	-0.1437	0.0207	2.4885	**0.1	
Commercial and Industrial Loans	total	0.3263	0.1065	29.6675	*0.01	37.4466 (*0.01)
	pre	0.4426	0.1959	31.1788	*0.01	
	post	0.0952	0.0091	1.0783	**0.1	
Real Estate Loans at All Commercial Banks	total	0.2295	0.0527	13.8445	*0.01	22.4192 (*0.01)
	pre	-0.0695	0.0048	0.6215	**0.1	
	post	0.3888	0.1512	21.0190	*0.01	
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	total	0.7778	0.6050	381.4191	*0.01	85.4458 (*0.01)
	pre	0.8684	0.7541	392.5742	*0.01	
	post	0.7107	0.5051	120.4210	*0.01	
Moody’s Aaa Corporate Bond Minus FEDFUNDS	total	-0.8179	0.6689	503.1481	*0.01	10.2224 (*0.01)
	pre	-0.7895	0.6233	211.8125	*0.01	
	post	-0.8121	0.6595	228.5905	*0.01	
Moody’s Baa Corporate Bond Minus FEDFUNDS	total	-0.7684	0.5905	359.0250	*0.01	25.161 (*0.01)
	pre	-0.7859	0.6176	206.7353	*0.01	
	post	-0.6427	0.4131	83.0432	*0.01	

Table 15: Regression of macroeconomic variables on lagged Beta1 factor

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
Capacity Utilization: Manufacturing	total	-0.2317	0.0537	14.1227	*0.01	12.3427 (*0.01)
	pre	-0.1811	0.0328	4.3413	0.0392	
	post	-0.1891	0.0358	4.3775	0.0386	
All Employees: Service-Providing Industries	total	0.2525	0.0638	16.9620	*0.01	13.6015 (*0.01)
	pre	0.4586	0.2103	34.0821	*0.01	
	post	-0.0800	0.0064	0.7602	**0.1	
Avg Hourly Earnings: Goods-Producing	total	0.2351	0.0553	14.5675	*0.01	8.2231 (*0.01)
	pre	0.0969	0.0094	1.2125	**0.1	
	post	0.3207	0.1029	13.5316	*0.01	
Housing Starts: Total New Privately Owned	total	0.3805	0.1448	42.1442	*0.01	195.874 (*0.01)
	pre	-0.1203	0.0145	1.8787	**0.1	
	post	0.5901	0.3482	63.0415	*0.01	
Housing Starts, Northeast	total	0.3192	0.1019	28.2414	*0.01	127.8959 (*0.01)
	pre	-0.1482	0.0220	2.8734	0.0925	
	post	0.3178	0.1010	13.2525	*0.01	
Housing Starts, Midwest	total	0.3767	0.1419	41.1788	*0.01	193.0554 (*0.01)
	pre	-0.0490	0.0024	0.3087	**0.1	
	post	0.4582	0.2099	31.3544	*0.01	
Housing Starts, South	total	0.3753	0.1409	40.8314	*0.01	167.6581 (*0.01)
	pre	-0.1111	0.0124	1.6011	**0.1	
	post	0.5812	0.3378	60.1820	*0.01	

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
Housing Starts, West	total	0.3632	0.1319	37.8395	*0.01	159.7654 (*0.01)
	pre	-0.1493	0.0223	2.9198	0.0899	
	post	0.6269	0.3930	76.3975	*0.01	
New Private Housing Permits (SAAR)	total	0.3648	0.1331	38.2315	*0.01	180.3868 (*0.01)
	pre	-0.1436	0.0206	2.6936	**0.1	
	post	0.6014	0.3617	66.8611	*0.01	
New Private Housing Permits, Northeast (SAAR)	total	0.3230	0.1044	29.0104	*0.01	131.9369 (*0.01)
	pre	-0.1466	0.0215	2.8107	0.0961	
	post	0.3792	0.1438	19.8132	*0.01	
New Private Housing Permits, Midwest (SAAR)	total	0.3799	0.1443	41.9893	*0.01	206.2987 (*0.01)
	pre	-0.0576	0.0033	0.4262	**0.1	
	post	0.5230	0.2735	44.4181	*0.01	
New Private Housing Permits, South (SAAR)	total	0.3480	0.1211	34.3150	*0.01	161.9026 (*0.01)
	pre	-0.1716	0.0294	3.8832	0.0509	
	post	0.6198	0.3841	73.6029	*0.01	
New Private Housing Permits, West (SAAR)	total	0.3628	0.1316	37.7491	*0.01	155.0234 (*0.01)
	pre	-0.1371	0.0188	2.4508	**0.1	
	post	0.6155	0.3789	71.9709	*0.01	
Commercial and Industrial Loans	total	0.2556	0.0653	17.4021	*0.01	2.3216 (**0.1)
	pre	0.3570	0.1275	18.7014	*0.01	
	post	0.0435	0.0019	0.2233	**0.1	
MZM Money Stock	total	0.3254	0.1059	29.4931	*0.01	12.721 (*0.01)
	pre	0.3303	0.1091	15.6758	*0.01	
	post	-0.0982	0.0096	1.1492	**0.1	
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	total	0.7876	0.6203	406.8235	*0.01	276.1531 (*0.01)
	pre	0.8701	0.7570	398.8147	*0.01	
	post	0.7385	0.5454	141.5513	*0.01	
Moody's Aaa Corporate Bond Minus FEDFUNDS	total	-0.8027	0.6442	450.9286	*0.01	8.0244 (*0.01)
	pre	-0.7715	0.5953	188.2558	*0.01	
	post	-0.7672	0.5885	168.7721	*0.01	
Moody's Baa Corporate Bond Minus FEDFUNDS	total	-0.7451	0.5552	310.8147	*0.01	11.5572 (*0.01)
	pre	-0.7543	0.5690	168.9658	*0.01	
	post	-0.5899	0.3480	62.9778	*0.01	

Table 16: Regression of Beta2 factor on lagged macroeconomic variables

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
All Employees: Total Nonfarm	total	0.3030	0.0918	25.1727	*0.01	5.2498 (*0.01)
	pre	0.3642	0.1327	19.5799	*0.01	
	post	0.2677	0.0717	9.1102	*0.01	
All Employees: Goods-Producing Industries	total	0.2549	0.0650	17.2961	*0.01	7.3893 (*0.01)
	pre	0.3476	0.1208	17.5917	*0.01	
	post	0.2461	0.0606	7.6102	*0.01	
All Employees: Construction	total	0.2307	0.0532	13.9946	*0.01	3.6248 (*0.01)
	pre	0.1515	0.0230	3.0079	0.0853	
	post	0.2645	0.0700	8.8768	*0.01	
All Employees: Manufacturing	total	0.2323	0.0540	14.1997	*0.01	9.7057 (*0.01)
	pre	0.3726	0.1388	20.6359	*0.01	
	post	0.2358	0.0556	6.9500	*0.01	
All Employees: Durable Goods	total	0.2354	0.0554	14.6012	*0.01	8.207 (*0.01)
	pre	0.3612	0.1305	19.2057	*0.01	
	post	0.2149	0.0462	5.7120	0.0184	
All Employees: Service-Providing Industries	total	0.3016	0.0910	24.9175	*0.01	3.5112 (0.0314)
	pre	0.3265	0.1066	15.2724	*0.01	
	post	0.2626	0.0690	8.7404	*0.01	

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
All Employees: Trade, Transportation & Utilities	total	0.2249	0.0506	13.2679	*0.01	5.6501 (*0.01)
	pre	0.3288	0.1081	15.5157	*0.01	
	post	0.1508	0.0227	2.7450	**0.1	
Avg Weekly Hours: Goods-Producing	total	0.2514	0.0632	16.8026	*0.01	15.7908 (*0.01)
	pre	0.3477	0.1209	17.6002	*0.01	
	post	0.3976	0.1581	22.1607	*0.01	
Avg Weekly Hours: Manufacturing	total	0.2400	0.0576	15.2216	*0.01	15.5814 (*0.01)
	pre	0.3371	0.1136	16.4107	*0.01	
	post	0.3903	0.1523	21.2036	*0.01	
Housing Starts: Total New Privately Owned	total	0.3681	0.1355	39.0291	*0.01	6.0723 (*0.01)
	pre	0.1784	0.0318	4.2101	0.0422	
	post	0.4930	0.2430	37.8871	*0.01	
Housing Starts, Northeast	total	0.3075	0.0945	25.9989	*0.01	0.9741 (**0.1)
	pre	0.1721	0.0296	3.9062	0.0503	
	post	0.3235	0.1047	13.7942	*0.01	
Housing Starts, Midwest	total	0.3167	0.1003	27.7580	*0.01	9.305 (*0.01)
	pre	0.0864	0.0075	0.9617	**0.1	
	post	0.4892	0.2393	37.1219	*0.01	
Housing Starts, South	total	0.3808	0.1450	42.2247	*0.01	5.2095 (*0.01)
	pre	0.1970	0.0388	5.1656	0.0247	
	post	0.4940	0.2440	38.0937	*0.01	
Housing Starts, West	total	0.3673	0.1349	38.8240	*0.01	3.608 (0.0286)
	pre	0.1669	0.0278	3.6664	0.0578	
	post	0.4637	0.2150	32.3227	*0.01	
New Private Housing Permits (SAAR)	total	0.3719	0.1383	39.9655	*0.01	5.2406 (*0.01)
	pre	0.1917	0.0368	4.8841	0.0289	
	post	0.4838	0.2340	36.0517	*0.01	
New Private Housing Permits, Northeast (SAAR)	total	0.3135	0.0983	27.1457	*0.01	1.076 (**0.1)
	pre	0.2279	0.0519	7.0104	*0.01	
	post	0.3079	0.0948	12.3565	*0.01	
New Private Housing Permits, Midwest (SAAR)	total	0.3029	0.0917	25.1511	*0.01	7.9618 (*0.01)
	pre	0.0903	0.0082	1.0532	**0.1	
	post	0.4555	0.2075	30.8909	*0.01	
New Private Housing Permits, South (SAAR)	total	0.3923	0.1539	45.2937	*0.01	5.0222 (*0.01)
	pre	0.2087	0.0436	5.8319	0.0172	
	post	0.5040	0.2540	40.1734	*0.01	
New Private Housing Permits, West (SAAR)	total	0.3758	0.1412	40.9406	*0.01	3.9507 (0.0205)
	pre	0.1793	0.0322	4.2520	0.0412	
	post	0.4767	0.2273	34.7067	*0.01	
St. Luis Adjusted Monetary Base	total	-0.2362	0.0558	14.7145	*0.01	4.3555 (0.0138)
	pre	-0.2171	0.0472	6.3340	0.0131	
	post	-0.2545	0.0648	8.1724	*0.01	
Commercial and Industrial Loans	total	0.2747	0.0754	20.3171	*0.01	3.2838 (0.0391)
	pre	0.2481	0.0616	8.3979	*0.01	
	post	0.2728	0.0744	9.4844	*0.01	
Real Estate Loans at All Commercial Banks	total	0.2253	0.0507	13.3092	*0.01	9.0328 (*0.01)
	pre	0.0300	0.0009	0.1151	**0.1	
	post	0.3932	0.1546	21.5744	*0.01	
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	total	0.3595	0.1293	36.9648	*0.01	7.2661 (*0.01)
	pre	0.3844	0.1478	22.1923	*0.01	
	post	0.3889	0.1512	21.0215	*0.01	
3-Month AA Financial Commercial Paper Rate	total	0.2960	0.0876	23.9127	*0.01	8.6587 (*0.01)
	pre	0.3980	0.1584	24.0886	*0.01	
	post	0.2927	0.0857	11.0564	*0.01	
Moody’s Aaa Corporate Bond Minus FEDFUNDS	total	-0.4705	0.2214	70.7918	*0.01	17.6652 (*0.01)
	pre	-0.3540	0.1253	18.3426	*0.01	
	post	-0.6599	0.4355	91.0210	*0.01	

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
Moody's Baa Corporate Bond Minus FEDFUNDS	total	-0.4724	0.2231	71.5158	*0.01	6.2242 (*0.01)
	pre	-0.3939	0.1551	23.5037	*0.01	
	post	-0.5484	0.3008	50.7624	*0.01	
CPI: Services	total	0.2402	0.0577	15.2448	*0.01	2.4245 (0.0906)
	pre	0.1460	0.0213	2.7860	0.0975	
	post	0.2511	0.0630	7.9374	*0.01	
VXO	total	-0.3180	0.1011	28.0166	*0.01	10.9054 (*0.01)
	pre	-0.4982	0.2482	42.2499	*0.01	
	post	-0.2498	0.0624	7.8529	*0.01	

Table 17: Regression of macroeconomic variables on lagged Beta2 factor

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
All Employees: Total Nonfarm	total	0.2789	0.0778	21.0040	*0.01	8.8067 (*0.01)
	pre	0.3209	0.1030	14.6963	*0.01	
	post	0.2578	0.0665	8.3998	*0.01	
All Employees: Goods-Producing Industries	total	0.2461	0.0606	16.0558	*0.01	14.1747 (*0.01)
	pre	0.3818	0.1458	21.8393	*0.01	
	post	0.2099	0.0440	5.4365	0.0214	
All Employees: Manufacturing	total	0.2286	0.0522	13.7253	*0.01	27.3178 (*0.01)
	pre	0.4300	0.1849	29.0318	*0.01	
	post	0.1924	0.0370	4.5370	0.0352	
All Employees: Durable Goods	total	0.2264	0.0513	13.4562	*0.01	17.8901 (*0.01)
	pre	0.4270	0.1823	28.5396	*0.01	
	post	0.1525	0.0233	2.8114	0.0962	
All Employees: Service-Providing Industries	total	0.2683	0.0720	19.3205	*0.01	5.3762 (*0.01)
	pre	0.2519	0.0634	8.6710	*0.01	
	post	0.2665	0.0710	9.0218	*0.01	
All Employees: Trade, Transportation & Utilities	total	0.2239	0.0501	13.1400	*0.01	11.5149 (*0.01)
	pre	0.3281	0.1076	15.4375	*0.01	
	post	0.1461	0.0214	2.5744	**0.1	
Avg Weekly Hours: Goods-Producing	total	0.2331	0.0543	14.3080	*0.01	57.9457 (*0.01)
	pre	0.3709	0.1376	20.4158	*0.01	
	post	0.3693	0.1364	18.6304	*0.01	
Avg Weekly Hours: Manufacturing	total	0.2269	0.0515	13.5179	*0.01	62.6836 (*0.01)
	pre	0.3586	0.1286	18.8837	*0.01	
	post	0.3734	0.1395	19.1228	*0.01	
Housing Starts: Total New Privately Owned	total	0.3674	0.1350	38.8611	*0.01	175.0498 (*0.01)
	pre	0.1164	0.0135	1.7578	**0.1	
	post	0.5015	0.2515	39.6478	*0.01	
Housing Starts, Northeast	total	0.3165	0.1002	27.7205	*0.01	126.4638 (*0.01)
	pre	0.2533	0.0642	8.7789	*0.01	
	post	0.2756	0.0760	9.7017	*0.01	
Housing Starts, Midwest	total	0.2878	0.0828	22.4801	*0.01	212.0105 (*0.01)
	pre	-0.0033	0.0000	0.0014	**0.1	
	post	0.4437	0.1969	28.9253	*0.01	
Housing Starts, South	total	0.3823	0.1461	42.6128	*0.01	147.0062 (*0.01)
	pre	0.1394	0.0194	2.5363	**0.1	
	post	0.5038	0.2538	40.1357	*0.01	
Housing Starts, West	total	0.3809	0.1451	42.2593	*0.01	123.5546 (*0.01)
	pre	0.1160	0.0134	1.7450	**0.1	
	post	0.5059	0.2560	40.5942	*0.01	
New Private Housing Permits (SAAR)	total	0.3664	0.1342	38.6102	*0.01	151.0058 (*0.01)
	pre	0.1230	0.0151	1.9666	**0.1	
	post	0.4871	0.2372	36.7011	*0.01	

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
New Private Housing Permits, Northeast (SAAR)	total	0.2938	0.0863	23.5270	*0.01	125.1012 (*0.01)
	pre	0.1351	0.0182	2.3791	**0.1	
	post	0.2871	0.0824	10.6010	*0.01	
New Private Housing Permits, Midwest (SAAR)	total	0.2980	0.0888	24.2627	*0.01	217.1713 (*0.01)
	pre	0.0330	0.0011	0.1392	**0.1	
	post	0.4635	0.2148	32.2885	*0.01	
New Private Housing Permits, South (SAAR)	total	0.3912	0.1530	44.9915	*0.01	123.8626 (*0.01)
	pre	0.1661	0.0276	3.6333	0.0589	
	post	0.5040	0.2540	40.1843	*0.01	
New Private Housing Permits, West (SAAR)	total	0.3718	0.1382	39.9308	*0.01	120.9728 (*0.01)
	pre	0.0996	0.0099	1.2822	**0.1	
	post	0.4892	0.2393	37.1294	*0.01	
Unfilled Orders for Durable Goods	total	0.2294	0.0526	13.8310	*0.01	7.7489 (*0.01)
	pre	0.3353	0.1124	16.2139	*0.01	
	post	0.0453	0.0021	0.2426	**0.1	
M1 Money Stock	total	-0.2603	0.0678	18.1038	*0.01	22.5705 (*0.01)
	pre	-0.2693	0.0725	10.0063	*0.01	
	post	-0.1584	0.0251	3.0350	0.0841	
Commercial and Industrial Loans	total	0.3259	0.1062	29.5911	*0.01	3.1573 (0.0443)
	pre	0.4224	0.1784	27.7945	*0.01	
	post	0.2091	0.0437	5.3956	0.0219	
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	total	0.4142	0.1716	51.5734	*0.01	223.9954 (*0.01)
	pre	0.4715	0.2223	36.5931	*0.01	
	post	0.4484	0.2010	29.6912	*0.01	
3-Month AA Financial Commercial Paper Rate	total	0.2965	0.0879	23.9963	*0.01	13.3001 (*0.01)
	pre	0.3917	0.1534	23.2002	*0.01	
	post	0.3103	0.0963	12.5688	*0.01	
Moody's Aaa Corporate Bond Minus FEDFUNDS	total	-0.5220	0.2724	93.2444	*0.01	22.4683 (*0.01)
	pre	-0.4401	0.1937	30.7549	*0.01	
	post	-0.6656	0.4431	93.8720	*0.01	
Moody's Baa Corporate Bond Minus FEDFUNDS	total	-0.5175	0.2678	91.0741	*0.01	22.2827 (*0.01)
	pre	-0.4718	0.2226	36.6460	*0.01	
	post	-0.5567	0.3099	52.9918	*0.01	
VXO	total	-0.2900	0.0841	22.8658	*0.01	26.2094 (*0.01)
	pre	-0.4314	0.1861	29.2693	*0.01	
	post	-0.2565	0.0658	8.3098	*0.01	

Table 18: Regression of Beta3 factor on lagged macroeconomic variables

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
All Employees: Total Nonfarm	total	-0.2518	0.0634	16.8621	*0.01	14.652 (*0.01)
	pre	0.0107	0.0001	0.0146	**0.1	
	post	-0.4477	0.2004	29.5783	*0.01	
All Employees: Goods-Producing Industries	total	-0.3382	0.1144	32.1607	*0.01	7.6898 (*0.01)
	pre	-0.1194	0.0143	1.8520	**0.1	
	post	-0.4388	0.1926	28.1444	*0.01	
All Employees: Manufacturing	total	-0.3612	0.1305	37.3617	*0.01	5.0765 (*0.01)
	pre	-0.1661	0.0276	3.6308	0.059	
	post	-0.4177	0.1745	24.9366	*0.01	
All Employees: Durable Goods	total	-0.3395	0.1153	32.4358	*0.01	6.4996 (*0.01)
	pre	-0.1716	0.0294	3.8827	0.0509	
	post	-0.4006	0.1605	22.5552	*0.01	
All Employees: Nondurable Goods	total	-0.3496	0.1222	34.6756	*0.01	4.038 (0.0188)
	pre	-0.0949	0.0090	1.1627	**0.1	
	post	-0.4016	0.1613	22.6950	*0.01	

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
All Employees: Trade, Transportation & Utilities	total	-0.2333	0.0544	14.3281	*0.01	11.5968 (*0.01)
	pre	-0.0386	0.0015	0.1906	**0.1	
	post	-0.3705	0.1373	18.7746	*0.01	
All Employees: Wholesale Trade	total	-0.2494	0.0622	16.5091	*0.01	12.775 (*0.01)
	pre	-0.0816	0.0067	0.8589	**0.1	
	post	-0.4056	0.1645	23.2329	*0.01	
Avg Weekly Hours: Goods-Producing	total	-0.3135	0.0983	27.1355	*0.01	25.7029 (*0.01)
	pre	0.2856	0.0816	11.3706	*0.01	
	post	-0.5633	0.3173	54.8308	*0.01	
Avg Weekly Hours: Manufacturing	total	-0.3186	0.1015	28.1384	*0.01	18.8512 (*0.01)
	pre	0.2073	0.0430	5.7473	0.018	
	post	-0.5333	0.2844	46.8929	*0.01	
Unfilled Orders for Durable Goods	total	-0.3031	0.0919	25.1931	*0.01	17.3582 (*0.01)
	pre	-0.4620	0.2134	34.7302	*0.01	
	post	-0.2445	0.0598	7.5030	*0.01	
Total Business Inventories	total	-0.2399	0.0576	15.2084	*0.01	10.6175 (*0.01)
	pre	-0.2591	0.0671	9.2102	*0.01	
	post	-0.2400	0.0576	7.2123	*0.01	
St. Luis Adjusted Monetary Base	total	0.2402	0.0577	15.2488	*0.01	10.3844 (*0.01)
	pre	0.2619	0.0686	9.4282	*0.01	
	post	0.2299	0.0528	6.5841	0.0115	
Commercial and Industrial Loans	total	-0.2823	0.0797	21.5616	*0.01	19.0147 (*0.01)
	pre	-0.1234	0.0152	1.9798	**0.1	
	post	-0.5234	0.2740	44.5280	*0.01	
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	total	0.2421	0.0586	15.5084	*0.01	3.5389 (0.0305)
	pre	0.1429	0.0204	2.6679	**0.1	
	post	-0.0351	0.0012	0.1458	**0.1	
3-Month AA Financial Commercial Paper Rate	total	-0.2404	0.0578	15.2727	*0.01	9.6743 (*0.01)
	pre	-0.2181	0.0476	6.3928	0.0127	
	post	-0.2560	0.0655	8.2760	*0.01	
VXO	total	0.5063	0.2563	85.8309	*0.01	5.4585 (*0.01)
	pre	0.5734	0.3288	62.6916	*0.01	
	post	0.3508	0.1231	16.5608	*0.01	

Table 19: Regression of macroeconomic variables on lagged Beta3 factor

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
All Employees: Total Nonfarm	total	-0.2392	0.0572	15.1181	*0.01	15.9658 (*0.01)
	pre	0.0501	0.0025	0.3218	**0.1	
	post	-0.4553	0.2073	30.8591	*0.01	
All Employees: Goods-Producing Industries	total	-0.3207	0.1028	28.5443	*0.01	12.7268 (*0.01)
	pre	-0.0995	0.0099	1.2802	**0.1	
	post	-0.4067	0.1654	23.3903	*0.01	
All Employees: Manufacturing	total	-0.3277	0.1074	29.9657	*0.01	17.7945 (*0.01)
	pre	-0.1213	0.0147	1.9113	**0.1	
	post	-0.3683	0.1357	18.5191	*0.01	
All Employees: Durable Goods	total	-0.2931	0.0859	23.4010	*0.01	10.5817 (*0.01)
	pre	-0.1198	0.0144	1.8636	**0.1	
	post	-0.3310	0.1095	14.5168	*0.01	
All Employees: Nondurable Goods	total	-0.3617	0.1308	37.4751	*0.01	42.8419 (*0.01)
	pre	-0.0896	0.0080	1.0352	**0.1	
	post	-0.4218	0.1780	25.5443	*0.01	
All Employees: Wholesale Trade	total	-0.2386	0.0569	15.0275	*0.01	8.136 (*0.01)
	pre	-0.0647	0.0042	0.5382	**0.1	
	post	-0.3783	0.1431	19.7087	*0.01	

Variable	Period	Rho	R-squared	F stat	p-value	Chow test
Avg Weekly Hours: Goods-Producing	total	-0.3107	0.0965	26.6024	*0.01	74.6236 (*0.01)
	pre	0.2912	0.0848	11.8620	*0.01	
	post	-0.5588	0.3123	53.5888	*0.01	
Avg Weekly Hours: Manufacturing	total	-0.3143	0.0988	27.2855	*0.01	69.2326 (*0.01)
	pre	0.2230	0.0497	6.7007	0.0108	
	post	-0.5303	0.2813	46.1747	*0.01	
Unfilled Orders for Durable Goods	total	-0.2757	0.0760	20.4760	*0.01	11.6391 (*0.01)
	pre	-0.3943	0.1555	23.5701	*0.01	
	post	-0.2465	0.0608	7.6360	*0.01	
Commercial and Industrial Loans	total	-0.3379	0.1142	32.0880	*0.01	5.9893 (*0.01)
	pre	-0.2529	0.0639	8.7440	*0.01	
	post	-0.4803	0.2307	35.3782	*0.01	
Effective Federal Funds Rate and Shadow Short Rate (Wu and Xia)	total	0.2076	0.0431	11.2097	*0.01	194.7049 (*0.01)
	pre	0.1080	0.0117	1.5107	**0.1	
	post	-0.0819	0.0067	0.7966	**0.1	
3-Month AA Financial Commercial Paper Rate	total	-0.2365	0.0559	14.7460	*0.01	3.6117 (0.0284)
	pre	-0.2258	0.0510	6.8763	*0.01	
	post	-0.2532	0.0641	8.0827	*0.01	
VXO	total	0.5049	0.2549	85.1837	*0.01	12.6753 (*0.01)
	pre	0.5434	0.2952	53.6200	*0.01	
	post	0.3538	0.1252	16.8853	*0.01	