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MASTER'S THESIS

Examining the Link between Financial Market Efficiency and Monetary Transmission Mechanism

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Declaration of Authorship

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Prague, July 26, 2019

Signature

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Abstract

In an effort to examine role of capital markets' efficiency in transmission of monetary policy, 28 time series of market efficiency development are estimated with use of long-term memory and fractal dimension measures and a panel of 27 inflation targeting countries is constructed to run a random effect regression. The cases of Czech Republic and Austria are thereafter more closely examined with use a vector-autoregressive and threshold vector-autoregressive frameworks on macroeconomic data spanning from 1996:Q3 to 2018:Q4. The evidence obtained through the conducted analyses support the hypothesis, that a more efficiently functioning capital market better contributes to monetary policy pass-through, or conversely, that high transaction costs, barriers to capital market entry, or poor information availability may hinder the effects of central bank's monetary policy.

JEL Classification	F12, F21, F23, H25, H71, H87
Keywords	capital market efficiency, inflation targeting, monetary transmission mechanism

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Abstrakt

Ve snaze o bližší přezkum role efektivity kapitálových trhů v transmisi měnové politiky je v práci nejdříve sestrojeno 28 časových řad míry tržní efektivity pro vybrané země cílující inflaci. To je provedeno za použití odhadu dlouhé paměti a fraktální dimenze podkladových řad odpovídajících tržních indexů. Na množině 27 z nich je provedena panelová regrese pro indikaci vztahu tržní efektivity a úspěšnosti cílování inflace. Pro období od 1996:Q3 do 2018:Q4 jsou poté za pomoci vektorové autoregrese (VAR) a režimové vektorové autoregrese (TVAR) blíže zkoumány případy Rakouska a České republiky. Výsledky provedené analýzy jsou v souladu s hypotézou, že efektivněji fungující kapitálové trhy lépe přispívají k transmisi měnové politiky dané centrální banky, respektive, že přílišná neefektivita trhů může transmisi přes ceny aktiv naopak znemožovat.

Klasifikace JEL	F12, F21, F23, H25, H71, H87
Klíčová slova	efektivita kapitalových trhů, cílovaní inflace, transmisní mechanismus měnové politiky

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Acronyms

ATX Austrian Traded Index

ADL Autoregressive Distributed Lag Model

CEESEG Central and East European Stock Exchange Group

EI Efficiency Index

EMH Efficient Market Hypothesis

FDI Foreign Direct Investment

FESE Federation of European Securities Exchanges

FWB Frankfurt Stock Exchange

IPO Initial Public Offering

IRF Impulse Response Function

LSE London Stock Exchange

MP monetary policy

MTM Monetary Transmission Mechanism

NYSE New York Stock Exchange

PSE Prague Stock Exchange

PX Prague Stock Exchange Index

TR Thomson Reuters

VAR Vector Autoregression

TVAR Threshold Vector Autoregression

WBAG Vienna Stock Exchange

Master's Thesis Proposal

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Proposed topic	Examining the Link between Financial Market Efficiency and Monetary Transmission Mechanism

Motivation Both in the developed and the developing countries, the economic dynamics is increasingly influenced by the ever growing, active, as well as qualitatively evolving capital markets. With the global stock market alone accounting for nearly the entire global GDP and the said rapid growth in the global debt markets, there is hardly a dispute over whether such markets play a role in the transmission of monetary policy implemented by a central authority. This particular MP transmission channel has already been described in the literature. Similarly, there is a variety of works concerned with broader effectiveness of monetary policy. In most cases, however, it is done for specific cases of individual countries and under specific circumstances. In a recent edition of their book Managing the Macroeconomy (2015), Rajan and Yanamandra address the question of transmission directly in a chapter entitled Effectiveness of Monetary Policy in India: The Interest Rate Pass-Through Channel. In Tai, Sek (2012), the authors evaluated the impact of financial crisis after 1997 to the functioning of transmission mechanism's interest rate channel across Asian countries and later that year Jain-Chandra and Unsal published an IMF working paper assessing the degree to which the monetary policy effectiveness in open Asian economies suffers from global interest rate drivers. As all of the above-mentioned titles together with other unincluded works find some degree of importance of the financial markets to the transmission mechanism channels, this link may be deemed well described. Nevertheless, insufficient attention is paid to the role of financial markets? quality in the matter, despite the intuition suggesting that any ill-functioning capital market is naturally also bound to be a poor instrument for policy implementation. The role of financial derivative markets has first been described on the UK case by Vrolijk (1997) who suggested a change in the transmission process as whole and as a result of the derivative market development, but found nonetheless no conclusive empirical evidence of such change at that time. Elaborating on a closely related topic with higher portion of generality is a decade later published BIS paper (Singh et. al., 2008), in which the authors compare interest rate pass-through in developed countries and developing Asian countries. In a similar tone, I hereby propose a work that would provide a closer look at the financial markets' ripeness and its role in implementation of monetary policy by given central bank. The conjecture is that the empirical part of such analysis may be prepared with the help of Krištoufek-Vošvrda Efficiency Index (2012) in combination with recorded development of inflation level deviations from their targets and by employing the structural VAR models.

Hypotheses

Hypothesis #1: Inflation targeting central banks of economies with efficient financial markets are able to operate more flexibly in terms of time span needed for the monetary transmission to take effect.

Hypothesis #2: Permeability distribution of individual channels of MTM differs significantly for countries with efficient compared to countries with inefficient financial markets.

Hypothesis #3: A presence of nonnegligible transaction costs within financial markets ultimately leads to relatively less stable macroeconomic environment

Methodology

1. Application of Krištoufek-Vošvrda Efficiency Index
2. Time-series econometrics (use of rolling window estimation to observe market efficiency development in time)
3. Use of structural VAR models to evaluate the role of market efficiency (as indicated by the EI) in sensitivity of inflation level deviation from it?s target
4. Devising measures of permeability of each individual channel of MTM to allow for subsequent use of SVAR/VECM in order to test the differences between economies with differing efficiencies of financial markets

Expected Contribution An insight into hitherto latent relationship between the efficiency of capital markets and effectiveness of policies implemented by independent central banks which is to be brought by the proposed work would generally facilitate explaining results of past policy decisions and thus allow for improvement in the decision making process. On the other hand, in case that no empirical evidence of such relationship is found for either of the examined economies, the work?s results will serve as an argument to exclude financial market ripeness or unripeness from possible causes policies? ineffectiveness.

Outline

1. Introduction and Motivation
2. Review of Related Works
3. Theoretical Background
4. Empirical Analysis
5. Presenting the Empirical Results
6. Conclusion and Discussion

Core bibliography

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Chapter 1

Introduction

Both in developed and developing countries, the economic dynamics is increasingly influenced by the ever growing, active, as well as qualitatively evolving capital markets. With the global stock market nearly matching the entire global GDP and the said rapid growth in the global equity markets, intuition suggests that next to fixed income markets, the capital market as well ought to play a role in the transmission of monetary policy implemented by a central monetary authority. This particular monetary policy (MP) transmission channel has already been described in the topical literature. Similarly, there is a variety of works concerned with broader effectiveness of monetary policy. Although a majority of such works is concerned with specific cases of individual countries and under specific circumstances, one counterexample is provided by Cottarelli & Kourelis (1994), who examine the interaction of lending rates, money market rates and discount rates with use of panel data and linear regressions to demonstrate how effectiveness of monetary policy is less hindered by the stickiness of lending rates in high inflationary environments and more so in countries with higher money market volatility. Higher levels of liquidity of commercial banks also tend to diminish the interest pass-through. Chapter *Effectiveness of Monetary Policy in India* in Rajan & Yanamandra (2015) surveys additional empirical literature and then more closely examines the Indian case to find that MP transmission can be improved by providing for a higher yield curve stability. Alternatively, in Tai *et al.* (2012a), the authors evaluated the impact of financial crisis after 1997 to the functioning of transmission mechanism's interest rate channel across Asian countries and later that year Jain-Chandra and Unsal published an IMF working paper assessing the degree to which the monetary policy effectiveness in open Asian economies suffers from global interest rate drivers. Though all of the above-mentioned works (*inter alia*) find some degree of importance of the financial markets to the transmission mechanism channels, the focus of these studies is mainly the interest rate channel of the MP and an insufficient attention is in fact paid to the role of financial markets' quality in the matter. That is despite the intuition suggesting that any poorly functioning capital market is naturally also bound to be a poor instrument for policy implementation. The impact of financial derivative markets development has first been described with concern to the UK case by Vrolijk (1997), who suggested a change in the overall transmission process and as a result of the derivative market development, but found nonetheless no conclusive empirical evidence of such change at that time. Elaborating on a closely related topic with somewhat more generality is a decade later published BIS paper Singh *et al.* (2008), interest rate pass-through in developed countries and in developing Asian countries is compared. Quoting the authors: *"The five main channels in the monetary transmission mechanism literature are the interest rate or money channel, the credit channel, the exchange rate channel, the asset price or wealth channel and the most recent addition to the literature, the expectations channel"*. A mechanism proposed by Mishkin (2001) that is derived from to the asset price channel transmits an expansionary monetary policy shock by increases in attractiveness of stock investments relative to fixed income investments, thus creating an upward pressure to stock prices and consequently also to capital formation. I hereby present a work that attempts to provide a closer look at the capital markets' degree of maturity and the role that its efficiency may have in transmission of monetary policy implemented by central banks through changes in their main policy rates. Intuitively, the asset price pass-through of monetary policy shocks to economy should be more pronounced and less lagged for a country where asset prices adjust rapidly to reflect investor preferences. Conversely, high transaction costs and informational inefficiencies might lead to market's failure to reflect investor preferences and effectively neutralize the asset price channel of transmission. The empirical part of the present work attempts to demonstrate potential differences in MP transmission caused by capital market inefficiencies. These inefficiencies are quantified by employing a version of the market efficiency measure introduced by Kristoufek & Vosvrda (2012) in combination with recorded development of inflation levels, their deviations from the corresponding targets, and other some macro-variables.

The remainder of the thesis is ordered in the following manner. The second chapter briefs the reader on the already published works that are related either to the topic of market efficiency, transmission of monetary policy, and works that may suggest a possibility of link among these two topics. Chapter 3 takes the reader through the reasoning of employed statistical frameworks — measuring the market efficiency by the Efficiency Index and evaluation of capital markets as transmission channel by different alternatives of the vector-autoregressive models. After a brief data description, Chapter 4 provides different time-series models built for the cases of Czech Republic and Austria, together with simpler analysis of wider sample of countries in a panel regression. Chapter 5 sums up the results of all the partial analyses and discusses possible implications. Modeling results are again more concisely summarized in Chapter 6, before overall conclusions and possible model limitations are described and additional research suggestions are made.

Chapter 2

Literature Overview

Providing background to the topic covered in the present thesis are works that may be split into three related, but overall separate categories. Firstly, it is the literature concerned with market efficiency alone —this includes both the works on efficient market hypothesis and more time-series oriented academic papers examining the data from capital markets. Second category is concerned with the macro-oriented studies that discuss different view of the functioning of monetary transmission mechanism as well as the appropriate framework choices. Finally, the third category summarizes the current state of literature related to the interaction of the market efficiency with transmission mechanism. While the former two areas get abundant attention in academic works that date throughout a few decades, a possible lack of resources may be encountered for the latter category.

2.1 Market Efficiency

As the notion of market efficiency is in the center of this study, I start by walking the reader through formulation and selected seminal works concerning the Efficient Market Hypothesis in an effort to provide some background and reasoning for the analysis methodology that follows. As a starting point, a notion is to be considered, stating that in an ideal setting, any capital market is determining the prices of its listed stock in an optimal way — i.e. incorporating all known and unknown information — and after an adjustment for risk, the profits by arbitrage is not possible. In other words, changes in stock prices are assumed to be random draws from a certain distribution and prices themselves are thus said to follow a random walk. In this format, the notion was initially proposed by Fama (1965), who states the assumptions and implications of the *random walk model.* After providing abundant empirical evidence for his proposition, Fama concludes that the stock prices do, in fact, approximately follow the said model. Furthermore, he supports an earlier proposition by Mandelbrot that distribution of price returns is actually only *"stable Paretian with characteristic exponent less than 2"*, rather than Gaussian distribution (which is its special case), meaning that the returns exhibit excess kurtosis. Similarly as Fama — though in more general approach — Samuelson (1965) examines the martingale process as a possible model for asset prices admitting that actual markets likely do not work as efficiently. Fama (1970) then reviews the previous literature, adds a semi-strong form of the hypothesis and proceeds to test all three forms. The weak form is tested solely by use of historical prices, while an adjustment is made for the semi-strong form, incorporating *"all obviously publicly available information"*. To test the strong form, performance of large group of mutual funds is compared to benchmark set by the S&P500 Index. The author arrives to affirmative results to the extent of weak and semi-strong form. Fama then admits limitation of empirical testing in case of the strong form and Fama (1991) further notes, that the unrealistic assumptions necessary — *i.e.* complete and costless information of all market participants and zero transaction costs — make it rather a *"clean benchmark"* to compare the two more credible versions to.

The Efficient Market Hypothesis (EMH) has been a source of controversy at least since the late 1980's as numerous works have emerged to provide evidence of price anomalies and of successful pattern-based trading strategies. The available literature discussing the critical look at EMH is thus plentiful. Most notably, professor Malkiel in his book *"Nonrandom Walk Down Wallstreet"* and then decades later in (Malkiel 2003) gathers the most prompting reasons for market inefficiencies, such as week-day-, return reversal-, and short-run momentum patterns as well as historical benefits of fundamental analysis and of anomaly exploitation. Finally, he explains how in order to attract a large enough body of market participants and analysts, certain degree of inefficiency is, in fact, a necessity. This idea is more recently confirmed by findings in Kristoufek & Vosvrda (2018). For more comprehensive literature survey, I refer the reader to Degutis & Novickytė (2014). Similarly as Malkiel, they conclude that in spite of its recently reduced popularity, the EMH remains a relevant topic in the discipline of finance with no signs of its role declining in near future.

With the relevance of the Efficient Market Hypothesis being established, let us now turn to the importance of temporary inefficiencies described by Malkiel. Recalling the *random walk theory* as proposed by Fama, it is possible to exploit the knowledge of random walk properties in evaluating the degree to which a given market exhibits inefficiencies. More specifically, Peters (1989) introduced a new approach to evaluate the departure of capital market's features from the theoretical model, by application of methods devised by hydrologist H.E. Hurst to describe the long-term dependencies of Nile water levels. Using the Hurst rescaled range, Peters finds evidence of long-memory both in stock markets and in fixed income markets, implying positive persistence in market returns. Stated in other way, Peters argues, that Stock prices follow a biased random walk, which he attributes to an impact of market sentiment. His findings are subsequently challenged in Ambrose *et al.* (1993), where the use of more sophisticated estimation techniques leads to conclusion that non-persistence in financial series may not be rejected.

More recently, the approach of Peters is augmented in Kristoufek & Vosvrda (2012) by addition of measures of time series' departure from theoretical random walk model in the value of their fractal dimension feature. They argue that although in theory, series' fractal dimension and Hurst exponent are linearly related, this is mostly not the case for financial series, implying that more precise measure may be achieved by estimating the two metrics independently. In this way, the authors circumvent the *joint hypothesis problem*, *i.e.* the possibility of rejecting market efficiency due to inappropriately set assumptions about a given market. This composite efficiency measure is thereafter appended by use of entropy in Kristoufek & Vosvrda (2014). Entropy was firstly employed by Zunino *et al.* (2010) to show that in the complexity-entropy plane, the emerging and developed financial markets will likely form distinct clusters. In order to obtain a more complete overview also in terms of possible shortcomings of the theory, the reader is also encouraged to see the publications *"Some anomalous evidence regarding market efficiency"* by Jensen and much later also the *"Efficient market hypothesis and forecasting"* by Timmermann & Granger (2004), who provide more comprehensive survey of thitherto results. They point out that the EMH is typically challenged on grounds of successful (*i.e.* profitable) model forecasts made given some informational set Ω_t, but that this is merely an issue of the very definition of Ω. Including knowledge of the particular modeling framework in the information set will then result in reestablishment of EMH as the arbitrage exploitation drives the misspricings to zero. Thus markets may still be efficient.

2.2 Road to Current Modeling of MTM Channels

First grounds for discussion of monetary transmission that may be related to this work have been laid down already in early 1970's by reactions of renown economists to a controversial work entitled "*A Theoretical Framework for Monetary Analysis*" by Friedman (1970). Linking this proposed framework back to Keynesian approach, the model assumed in Friedman's work is a closed-economy model considering dynamics of output, consumption, investment and price levels and how they respond to monetary policy (expressed in this model by the interest rate) as well as supply and demand for nominal money:

$$\frac{C}{P} = f\left(\frac{Y}{P}, r\right) \tag{2.1}$$

$$\frac{I}{P} = g(r) \tag{2.2}$$

$$\frac{Y}{P} = \frac{C}{P} + \frac{I}{P} \tag{2.3}$$

$$M^D = P \cdot l\left(\frac{Y}{P}, r\right) \tag{2.4}$$

$$M^S = h(r) \tag{2.5}$$

$$M^D = M^S \tag{2.6}$$

, with g(.) a continuous function of IR. The system is thereafter identified by an assumption added in the quantity equation approach, that the real output level is in fact determined exogenously as $\frac{Y}{P} = y_0$.

As the reader will notice further on, the ways of modeling a general equilibrium in an economy have undergone a substantial development since. As pointed out by Brunner & Meltzer (1972a) briefly after Friedman's publishing of the *Theoretical Framework*, the provided models were static and conclusions for role of money may have been insufficiently strong. Nevertheless, the simple described model stays a useful benchmark, which was later appended by many following works. Even before the break of century, a several crucial developments are recorded by Taylor (1995), including openness of the modeled economy, incorporation of rational expectations, disambiguation of changes of GDP to a *real leg* and *inflation leg*, or more importantly, an empirical quantification of the model implications.

2.2.1 Vector-Autoregressive Models

As a counterpart to large theoretical monetary models, that were becoming increasingly questioned after the 1976 *Lucas Critique*, the vector-autoregressive framework became a popular tool among econometricians for explanation of comovements among macro-variables. Prof. Christopher Sims (1980) first introduced this approach to address the accumulated objections to large-scale structural models' reliance on numerous *a priori* restrictions. The reduced form model is estimated with no assumed restrictions, *i.e.* no partial correlation among any pair of variables or their lags is assumed to be zero or otherwise. Still, the reduced form inherently produces innovations estimates that are cross-correlated. A VAR model in a structural form was presented *e.g.* in Blanchard & Watson (1986) to conclude that economic fluctuations arise due to arrivals of shocks of varying sizes to each of the relevant variables. Residuals produced by such model are uncorrelated (put in other word, the distrubances are structural). If the researcher's goal is to examine structural shocks to an economy — which for a policy maker or advisor it certainly is — there is a prevalent need to impose a number of restrictions to the structure in order to achieve a system identification. With further use of VAR models, three approaches emerged as more acceptable than the alternatives. These include the short-run restrictions imposed to the matrix of contemporaneous relations as in Gali (1992) (but also in Blanchard & Watson (1986)), restrictions to long-run impacts (see Blanchard & Quah 1988) used for retrieving the contemporaneous structure and restrictions to response functions produced by the potential model (see Uhlig 2005).

Several of the more recent works, that are concerned with policy transmission both in US and Europe, also carry useful insights for application in the present thesis (see *e.g.* Bernanke & Blinder (1992), Sims (1992), or Sims (2012)) as the primary focus here also consists of use of VAR models to examine transmission of monetary policy shocks. In more recent publication, Tai *et al.* (2012b) take a different approach and employ the seemingly unrelated regression framework to model the interest pass-through in Asian countries after the financial crisis of 1997. Somewhat more related to the topic in this work by its choice of statistical instruments and examined relations, come Jain-Chandra & Unsal (2014) as they analyze the role of global interest rate in monetary policies of selected Asian countries and conclude, that the monetary transmission mechanism may be weakened by sudden improvement in firms' access to cheap funds abroad, as they become less sensitive in response to hikes and cuts in corresponding policy rate. Similarly, if an inefficiency is present within a domestic capital market, undervalued or overvalued stocks may result in over- or insensitivity to costs of borrowing, respectively.

2.2.2 Extensions of Vector Auto-regression

As the above listed examples of Vector Autoregression (VAR) application all assume a long-run relationship among the endogenous variables, they are all subject to critique suggesting that the relationships among macro-variables are in fact ever evolving, as the fundaments of corresponding economy gradually change. Cogley & Sargent (2001) address this problem and relax the assumption of constant coefficients by treating them as random variables rather than constants. An available compromise presented by Balke (2000) and later in Atanasova (2003) assumes two possible states of the model depending on a value of a certain variable. Therefore, this Threshold Vector Autoregression (TVAR) effectively allows its coefficients to follow random process (with two possible numeric outcomes) derived from a process of threshold variable. Both of the said papers differentiate between two regimes of credit market conditions to examine asymmetries in impulse responses and both conclude affirmatively. Finally, an application that is more closely followed by the present work was recently introduced by Afonso *et al.* (2018), focusing on non-linear impulse responses caused by shifts in level of financial stress within economy — represented here by the IMF's financial stress index.

As expected, the original approach, as first advocated by Sims in 1980, was altered in multiple additional ways to better suit each researcher's goals. Taking a Bayesian approach to estimation of the VAR coefficients — first proposed by Litterman (1986) — proved to be a useful way to circumvent the data length limitation and in turn, to introduce more robust model structures. Another useful approach to incorporate the information carried by vast number of variables, which are otherwise uncontainable in the classical VAR framework, was introduced considerably later by Bernanke *et al.* in an article entitled *"Measuring the effects of monetary policy: a factor-augmented vector autoregressive (FAVAR) approach"*.

For a more comprehensive description of evolution in the literature concerned with VAR macro-modeling — ever since proposed by Sims (1980) — the reader is also encouraged to see Kilian (2011).

Despite the fact that clearly not all of the mentioned frameworks are explicitly used, the hitherto cited works are all relevant for the part of analysis presented in this work, that is concerned with the nearly purely data-oriented framework of vector auto-regression. However, in recent practice of central banking, it is the dynamic stochastic general equilibrium models (DSGE), that are becoming increasingly employed in determining the appropriate monetary policy. Combining the notion of nominal rigidities with the real business cycle — introduced by Kydland & Prescott (1982) — this way of modeling the economy's responses to exogenous shock was the New Keynesian response to the Lucas Critique from 1976.

2.3 Linking the EMH and Monetary Transmission

The topic of interaction between financial markets' efficiency and the monetary policy transmission mechanism is substantially less abundant in the related literature published to date. Moreover, such works tend to be of case specific rather than general nature and thus there seems to be a gap. This particular gap is to be partially resolved by this thesis, which aim to provide a framework that would allow a researcher to see the stated interaction for any economy of interest, provided that certain historical data of decent length are available. Still, the current section covers some works that by the examined topic fall close to the present one, in order to provide the reader with relevant background.

The link between market efficiency and MP transmission is addressed by Mishkin (1978), who — through the use of martingale model and data from the New York Stock Exchange — provides an evidence of market inefficiencies. Lags of monetary policy are concluded to stem from lengthy translation of short-term interest rates into long-term interest rates and prices of traded bonds and stocks. However, no structural model is built within the work yet.

In one of the earliest of works that do include empirical analysis, Vrolijk (1997) firstly discusses how individual channels of the monetary policy transmission are impacted by the fast growing financial markets in UK. Similarly as in the present thesis, the Vroljik exploits the above addressed framework of structural vector-autoregressive models to address the question of whether addition of derivatives to financial market accelerates the impulse responses of output and inflation levels. Although the market efficiency was shown to grow due to derivative trading, the empirical evidence did not conclusively support the said transmission acceleration at the time.

Countering the implications made by Vrolijk (1997), a number of researchers argue, that as a result of financial market completion due to inclusion of derivatives, the transmission of MP may in fact be prolonged due to declining significance of the credit channel. Both Fender *et al.* (2000) and Gómez & Vásquez (2005) arrive to conclusions, that the influence of banks to the system is weakened by grown financial market efficiency. The net implications for the speed of transmission, however, stay ambiguous.

In his later paper, Mishkin (2001) takes a rather novel approach to the issue. By examining the sensitivity of economic output to monetary policy. Concerned with asset prices, the author shows that despite their importance in monetary transmission mechanism, asset prices should not be targeted by central bankers directly. Nevertheless, the prices do remain one of the transmission channels when reacting to the policy changes properly.

Finally, the most comprehensive view of the discussed link is provided by Singh *et al.* (2008). In their article entitled *"Impact of financial market developments on the monetary transmission mechanism"*, the authors both collect insights of previously works and conduct an independent empirical study. Conclusions of both legs of this article are in line and suggest a greater interest rate pass-through for countries with developed financial markets. Unlike with the result for the asset price channel, analysis of Singh *et al.* supports some previous findings (*e.g* Fender *et al.* (2000),Gómez & Vásquez (2005)) about the bank lending channel being generally weaker in presence of more efficient financial markets.

Chapter 3

Background & Methodology

Following the summary of relevant literature on the topic, this chapter will attempt to brief the reader on the key research questions of this thesis and how the corresponding hypothesis could be addressed while taking advantage of available macroeconomic data. By the end of the introductory chapter, the reader will be aware of the thesis' proposal of possible improvement of monetary transmission mechanism functioning through raising the degree of the asset channel pass-through in a given economy. After giving the background and reasoning for the above stated proposal, I describe the two particular capital markets of primary interest (*i.e.* Prague Stock Exchange and Wiener Borse). Finally, the functioning of used market efficiency estimator is described together with choice of time-series modeling framework. It should be noted, that besides the frameworks described in detail within this chapter, additional linear regression techniques are used to complement the main analysis and are described with more brevity directly within the relevant section (see Section 4.3).

3.1 Inflation Targeting Effectivity

Though it is reasonably safe to state that each monetary policy decision's effect will always be to some degree delayed and mitigated, the questions to ask in this setting are rather : *What is the length of this delay?* and *How the response to monetary policy decision or its delay is affected by the asset price transmission channel?*. The hypothesis proposed in this work states that tools of central banks in environments of more efficient stock markets are more effective and this will in general mean a lower departure of the targeted macrovariable from its target. This work focuses on countries, where the targeted variable is inflation.

Although the topical literature agrees upon plurality of channels through which the monetary policy of CB takes effect, the opinions about importance of these channels differ. Moreover, the distribution of weights for individual channels of the transmission of MP will be without much doubt also in dependence on individual features of each examined economy. This brings up another question to be addressed, which is concerned with the potential link between efficiency of financial market and the distribution of weights across the individual channels in the given economy. The interest-rate channel, the exchange-rate channel and the credit channel are typically identified as the main three (see e.g Ehrmann *et al.* 2003). A fourth transmission channel, which is typically also deemed as significant in the mechanism is the asset prices channel. In particular Mishkin (1996; 2001) argues that other than through bonds, there are three ways, in which the asset prices work as an element of the transmission mechanism. Firstly, a positive monetary shock causes the stock prices to grow relative to bond prices and thus raising the Tobin's **q** and consequentially also the level of new investment made by firms – resulting in positive impact to GDP (see Tobin 1969). In the empirical part of the work, this influence is monitored mainly by inclusion of level of real investment in a given economy.

Secondly, in times when MP maker eases the conditions by lowering the interest rates, housing prices tend to pick up, as mortgages — with real estate acting as collateral — gradually become more affordable. As a result the direct expenditure on housing increases, thus translating to higher investment. Furthermore, households as owners of the real estate spend more because of the relative increase in their wealth and banks are able to provide more credit as the prices of collateral increase. Similarly as with housing prices, the asset price channel translates the MP shock through other kinds of investment as well. Considering an interest rate cut announced by a central bank, a reasonable expectation is an investment outflow from fixed income towards equities, as the bond yield gradually become less attractive. An intuitive result is a growth in equity securities prices, total market capitalization and conversely, of recorded economic activity.

Finally, the third leg of the asset price channel represents an effect countering the two previously mentioned. With a nominal interest rate dropping after a positive monetary shock, the domestic currency depreciates for offering a lower yield relative to foreign currency and firms whose balance sheets include a significant amount of domestic-currency-denominated assets incur fall in their net worth in terms of foreign currencies. Thus they are less likely to receive offshore financing from banks and lending in the economy may decline as a result. Therefore, for any open economy examined in Chapter 4, the exchange rate towards the EURO is also taken into consideration.

Again, though it is true that the interest channel is generally perceived as the most direct and significant of the three MP transmission channels, each channel's degree of pass-through also fluctuates with nature of the considered economy. For this reason, various other drivers that might influence the significance of transmission channels, are taken into account by including the most appropriate time-series indicator into the second stage model. Such control variables are clearly bound to be case specific and models for each examined country may therefore include slightly different variables.

3.2 Examined Markets and Indices

Of all the 29 indices of the countries included in the examined sample, there are two particular stock market indices, that receive the most attention in Chapter 4. These are the main indices of the Wiener Börse (ATX index) and of Prague Stock Exchange (PX index). In both cases, the selected stock exchange is the largest security market organizer in the country and the composite index returns may thus be regarded as the best available proxy for country's capital market performance, for which a consistent high-frequency time-series data is available.

The fact that both of the market organizers are controlled by a common holding group — CEESEG Aktiengesselschaft — very well helps to explain the unique relation of their composite returns apparent in Figure 3.1 as well as the development of the constructed efficiency measure that is later presented in section 5.1. In fact, not only are these two market organizers subsidiaries of a common holding group, but some of the traded titles and composite index constituents are indeed the same companies.

Sources of Market Imperfections

As is typically the case, the two dominant sources of market imperfection for these exchanges are related to informational costs and transaction costs. To evaluate sources of inefficiencies, we consider the costs incurred by different

Figure 3.1: ATX and PX Indices - Daily Closing Values

Source: Wiener Borse, Prague Stock Exchange

agents who take part in the exchanges' activities. The fee structures reported by both of the stock exchanges are similar and include transaction-linked fees, membership fees and emission fees. The transaction-linked costs to market participants typically do not exceed level of 10bps of the traded volume. Although they may on occasions prevent a prompt adjustment of securities' prices by arbitrage, this will more notably affect the derivatives trading, not stock trading. Furthermore, the possible misspricings that occur solely due to transaction linked costs will be of insignificant nature relative to overall asset prices' movements caused by fundamental factors.

The costs to consider are thus the membership and emission fees. The annual fees paid by the market participants vary according to the securities and market segments to be accessed — both Vienna Stock Exchange (WBAG) and Prague Stock Exchange (PSE) differentiate among foreign exchange, commodities, derivatives and stock markets and the stock markets are further divided to separate tranches. Though considerably lower than in cases of more prominent financial markets (*e.g* London Stock Exchange (LSE), New York Stock Exchange (NYSE), Frankfurt Stock Exchange (FWB), etc.), the these fees still pose a barrier to new entrants and effectively raise the cost of investment activities as the stock exchange members transfer these fees to their clients in order to preserve a certain profit margin. Moreover, charges by the market organizer for an access to a bulk of all the markets may prevent potential participants with narrower trading scope from entering, thus lowering the market's informational efficiency — as is currently the case of PSE[1]. Better price discrimination in setting the exchange membership fees thus (as is currently the case of WBAG[2]) implies higher efficiency.

Next to the membership fees, each market organizer also charges a variable fee for new stock emissions. Such fees are source of inefficiency on the opposite side of the market. As the benefit from newly issued stock is lowered for firms seeking financing through equity, so is the number of IPOs and consequently also the informational efficiency of the capital market stays significantly lower as larger number of companies remain privately owned. Misspricing of such stock is typically substantially worse and longer lasting as the company value is analyzed less frequently and based on less information available. This in turn implies lower sensitivity of perceived asset prices to economic fundamentals and thereby also a diminished wealth effect in household consumption and investment.

Wiener Börse

The Wiener Börse (or the Vienna Stock Exchange) is the sole organizer of security market in Austria. According to Federation of European Securities Exchanges (FESE) Statistics[3] for the month of December 2017, the annual volume of traded equity was €33.4bn. The market capitalization for the same month was €127.8bn with 654 listed companies traded on five different markets. According to the most recent data provided by the World Bank[4], the Austrian stock market capitalization as a percentage of the country's annual GDP equaled 36.14% in the end of 2017. For a more genuine representation of the actual capital stock, the value of mutual funds and other institutions whose sole purpose is to invest in other stock is excluded from this statistics. Considering the value of this ratio may help to see the implications of the Austrian capital market to the economy.

Though the present legal entity by the name Wiener Börse AG — which is a 100% subsidiary of CEESEG AG — only exists since 1997, the history of the

[1] Prague Stock Exchange, Exchange Rules - part XIV. : EXCHANGE FEES

[2] Wiener Börse: Schedule of Fees of Wiener Börse AG

[3] Federation of European Securities Exchanges, Monthly Statistics for December 2017, Tables 2: Market Capitalization, 3a: Listed Companies, and

[4] Market capitalization of listed domestic companies (% of GDP) - retrieved from data.worldbank.org/, database item ID: CM.MKT.LCAP.GD.ZS

exchange at hand is substantially longer than that. In fact, the Wiener Börse is arguably one of the best established exchanges worldwide as its establishment dates to 1771, when the first foreign exchanges and fixed income trades took place. Although the equity securities gained traction throughout the 19th century with the formation of legislation limiting speculation and ensuring better system stability, the trust in and turnover of the stock market later suffered in series of adverse events, including the crash of 1873, close down of the exchange during times of both world wars, and global economic downturn in the 1930's. Though briefly surpassed by the Prague Stock Exchange in terms of importance during the period after World War I, relative to other European exchanges the significance of the Wiener Börse still remained substantial before the outbreak of the World War II as multiple company shares of former Austrian-Hungarian states continued to be traded in Vienna despite the launches of independent exchanges within these successor states. The trading activities were, however, dramatically limited during the second world war, to be even temporarily closed towards the war's end. Compared to the bond market, the stock market then developed with a below average pace in the decades following its reopening in 1948 because of lack of new listings, before the explosive growth both in terms of stock prices and trading volumes took place during the 1980's with a multitude of Initial Public Offerings.

The said growth experienced within this market since the early 1980's also suggests an increasing relevance of the market's implications for the economy and its role in transmission of monetary policy via the asset prices channel as described in Mishkin (2001). For the sake of completeness, this section should also include the fact, that with the current value of the Buffet-Indicator [5] at 36.14%, Austria ranks below the world average in terms of its stock market's gravity within economy. For this reason, a more pronounced role of market efficiency should be expected in such countries as the United States, Canada, or Switzerland. Still, for Austria, this ratio has seen a long-term overall uptrend, increasing approximately elevenfold since the beginning of the observed period in 1975. This development reflects the ever growing demand for publicly provided business funding even despite the arguably adverse effects that an IPO will typically have to company's associated reporting costs. Furthermore, with advances in financial literacy of the Austrian population, new solutions of investment possibilities for wider range of households — apart from high net worth individuals with wider range of investment possibilities who have

[5] country's total stock market capitalization as a percentage of country's GDP

historically been the dominant private sector investors —, and with improved informational availability, the question of stock market's implications to Austrian economy is likely to gain even more gravity in the future. To be more specific, while reiterating the question from section 3.1: Because of the ever more relevant role of the Austrian capital market, the present work focuses on the market's fluctuating efficiency and its implications to monetary policy making. Empirically speaking, this is done with use of the market's characteristic index.

The main such index monitored by the foreign analysts in case of the Wiener Börse is the Austrian Traded Index (ATX). It was introduced in 1991 to replace the older, rather broadly defined Wiener Börse Index as the lead indicator of market returns. According to information reported by the exchange, the ATX index is free float capitalization weighted and its returns are determined based on share price movements of 20 constituent companies listed in the exchange's prime market[6], whose values are provided by the exchange in real-time. The overall weight of each individual constituent is capped at 20% on quarterly basis and the index reconstitution occurs biannually to include the most liquid traded stocks with the maximum of three titles being replaced during each reconstitution. As of June 2019, some of the main constituents (in terms of weighting) included the *Erste Group Bank,AG*, *OMV, AG*, and *Raiffeisen Bank International,AG* making the index reflect primarily the banking and natural resources industries.

Prague Stock Exchange

The second of the two CEESEG AG subsidiaries is the Prague Stock Exchange (PSE). Compared to its sister exchange in Vienna, the PSE is a security market organizer with significantly lower number of listed companies. As of May 2019, there were only 54 companies listed at PSE compared to 719 companies at the WBAG. PSE's annual equity trades volume and market capitalization at the end of 2017 only amounted to roughly one sixth and one fifth of the corresponding figure for the WBAG, respectively[7]. The difference in significance of the organized capital markets within economy is thus only partially offset by the difference in both countries' GDP values. Due to lack of recent data consistent with the World bank's figures for Austria, we estimate the relative

[6] listings in the prime market are required to meet additional criteria

[7] according to FESE statistics, the annual equity trade volumes and market capitalization at the end of 2017 equaled €5.3bn and €26.9bn, respectively.

market significance based on EUROSTAT's chain-linked GDP values and on FESE numbers for both exchanges' total market capitalization. For 2017, the WBAG's significance is approximately 2.6 times higher relative to PSE, for which the implied value is 13.9%. The PSE is nonetheless the largest and longest functioning capital market organizer in the country and thus also the best entity to be monitored when evaluating the capital market efficiency in the country.

The considerably briefer history of the Prague Stock Exchange starts with its establishment as Prague Commodities and Stock Exchange in 1871. Unlike in the case of WBAG, both commodities and stock were traded in the exchange since its founding. The focus of the initial trade was on sugar and the exchange had a major role in the global trade of this commodity, before the trading activities gradually shifted towards public companies' stock. This was the sole object of trade, before the trading activities seized completely with the World War I outbreak, only to be re-initiated in 1918, this time with a stronger government support. Despite the trading volumes experiencing strong growth throughout the 1920's — partially thanks to the newly issued independent Czechoslovakian currency — this development was reversed due to the global economic downturn in 1930's, similarly as in case of WBAG. Compared to the Viennese exchange, however, the trading in PSE was more severely limited due to the occupation of Czechoslovakia by German forces. Moreover, the transformation of the Czech economic system into planned economy which occurred as the Czechoslovakia became a Communist state of the Soviet bloc caused the PSE never to reopen until shortly after the regime reversal four decades later. The new establishment of the Prague Stock Exchange in 1992 initially awakened interest for new company listings, but the momentum did not last as majority of the companies proved not to be suitable for stock exchange trading and had to be eliminated with the few following years (1997-1999).

Two key progresses for the PSE were its addition to the list of Designated Offshore Securities Markets by the US Security and Exchange Committee in May of 2004 and its becoming a member of the Federation of European Stock Exchanges shortly after the Czech Republic's joining of the European Union in the same month. Though the primary added value of the PSE during its early years and on the break of millennium was admittedly the provision of liquidity for the existing listings (market making) rather than provision of capital source to new public offerings, the role of the exchange is arguably expanding within the Czech economy both in terms of number of new initial public offerings and regarding the qualitative range of traded securities. This development makes the question of potential future influence of monetary transmission in Czech Republic by the asset price channel even more relevant.

In line with the argument in Section 4.1, the data used in the empirical analysis (Chapter 4) to estimate the market efficiency is a time-series of daily closing values for the lead PSE index: PX. The index was firstly constituted in April of 1994 at the initial value of 1000. Similarly as in the case of the ATX, the Prague Stock Exchange Index (PX) is a free-float weighted index reflecting the price returns of the most liquid stocks traded on the PSE's prime market with much weight given to the financial industry (banking and insurance). The number of index constituents is 12 as opposed to 20 constituents for the ATX, and the reconstitution is performed quarterly, rather than biannually with a maximum weight of each individual company within the index capped at 20%. As of June 2019, this cap was effectively lowering the weight of two largest constituents within the index: a Czech based electric power distribution company CEZ Group (also traded in Warsaw and Frankfurt) and a multinational corporation Erste Group Bank AG, that also has a similar weight within the ATX index.

3.3 Market Efficiency Index

As stated in the previous section, the number of endogenous variables included in the model is augmented by the quarterly series of Efficiency Index, as the central focus of the present work is to examine the dependence of economy's response to shocks in monetary policy on the capital market efficiency. In each case, the level of market efficiency is accounted for by the Efficiency Index that closely follows the form in Kristoufek & Vosvrda (2012):

$$EI = \sqrt{\sum_{i=1}^{N} \left(\frac{\hat{M}_i - M_i^*}{R_i} \right)^2} \tag{3.1}$$

For each time series of given stock exchange index, this statistics evaluates the corresponding market's efficiency combining N main measures – $\hat{M}_i$'s , each of which is defined as a deviation from the theoretical value for fully efficient market. Each measure is then scaled by the range of its theoretically possible outcomes – denoted R_i – to keep the contribution to overall index balanced.

The considered measures are consistent with the efficient market hypothesis as proposed by Fama (1965) and with the random walk theory. As summarized in 2.1, if the stock prices and corresponding market indices truly follow the Gaussian random walk, then their past returns will have no significant explanatory power for the future returns – in this sense the process will have no memory. Even though it has been established that for finance the returns in fact tend to exhibit fatter tails, it does not affect this property.

3.3.1 Global Correlation Structure

Examining the process correlations in the long-run is achieved by estimation of the Hurst exponent. For any stationary time series, it holds that $H \in [0, 1)$. If $H = \frac{1}{2}$, then the process is fully random. The process is persistent (that is to say stationary while long-run trending) if $H > \frac{1}{2}$ and anti-persistent (or changing directions more frequently than in random case) if $H < \frac{1}{2}$. For the purposes of the present work, the value of H is estimated by two methods. Implemented with a numeric optimization algorithm, the local Whittle estimator (Robinson *et al.* 1995) obtains an estimate $\widehat{H_{LW}}$ as such value that minimizes the expression $R(H)$ defined as:

$$R(H) := log\left(\frac{1}{F}\sum_{j=1}^{F}\lambda_i^{2\hat{H}-1}I(\lambda_j) - \frac{2\hat{H}-1}{F}\sum_{j=1}^{F}log(\lambda_j)\right) \tag{3.2}$$

Where the $I(\lambda_j) = \frac{1}{T}\sum_{t=1}^{T}exp(-2\pi it\lambda_j)x_t$ is the series' periodogram (*i.e.* estimated spectral density), $F = T/2$ is the number of frequencies, $\lambda_j = \frac{2\pi}{T}$, and T is the series' length.

The Geweke & Porter-Hudak (1983) estimator regards the examined stationary series as fractional Gaussian noise, for which we have spectral density with a known theoretical specification. If the same periodogram is again used in place of spectral density, we can write:

$$\begin{aligned} log\left(I(\lambda_j)\right) &= log\left(\sigma^2 f_u(0)/2\pi\right) - (H-0.5)log\left(4sin^2(\lambda_j/2)\right) \\ &\quad + log\left(f_u(\lambda_j)/f_u(0)\right) + log\left(I(\lambda_j)/f(\lambda_j)\right) \end{aligned} \tag{3.3}$$

where the $f_u(\cdot)$ is a spectral density of a short-memory autoregressive process and $log(f_u(\lambda_j)/f_u(0))$ is negligible with the frequency approaching zero. The estimate is thus obtained by a least square regression of $log\left(I(\lambda_j)\right)$ on $log\left(4sin^2(\lambda_j/2)\right)$:

$$\begin{aligned} log\left(I(\lambda_j)\right) &= \left(log\left(\sigma^2 f_u(0)/2\pi\right) + \mu\right) \\ &+ (\widehat{H_{GPH}} - 0.5)log\left(4sin^2(\lambda_j/2)\right) + \left(log\left(I(\lambda_j)/f(\lambda_j)\right) - \mu\right) \end{aligned}$$

With $\mu := \frac{1}{F}\sum_{j=1}^{F} log\left(I(\lambda_j)/f(\lambda_j)\right)$. This can then be regarded as the following simple regression :

$$log\left(I(\lambda_j)\right) = \beta_0 + (\widehat{H_{GPH}} - 0.5)log\left(4sin^2(\lambda_j/2)\right) + \varepsilon_j \tag{3.4}$$

3.3.2 Local Correlation Structure

Clearly, next to the property of no long memory, a random walk process also exhibits no significant local correlation structure. For the purpose of Kri?toufek-Vo?vrda Efficiency Index, this property is measured by estimating the series' fractal dimension. An original idea of the related Hausdorff dimension was applied to n-dimensional mathematically defined objects – or *fractals* – and it measured the surface roughness. In theory for a self-similar one-dimensional process (having short scale patterns as a part of identical patterns on a larger scale) the theoretical relation between fractal dimension D and the Hurst exponent is : $D = 2 - H$. This is, however, not the case of financial series and for that reason, I estimate the fractal dimension separately. As in case of long-term memory estimation, two different approaches to estimation are applied. First of the two, the Hall & Wood (1993) estimator uses a box-counting technique and measures absolute changes between individual steps. For a series of cumulative logarithmic returns $\tilde{r}_t$ observed at points $t \in \{1, ..n\}$ and integers $l \in \{1, .., L\}, L \in \{2, .., n\}$ area for a box of size l is defined as[8]:

$$\widehat{A(l/n)} = \frac{l}{n}\sum_{i=1}^{\lfloor n/l \rfloor}\left|\tilde{r}_{il/n} - \tilde{r}_{(i-1)l/n}\right| \tag{3.5}$$

and the estimator itself is then defined as:

$$\widehat{D_{HW}} = 2 - \left(\sum_{l=1}^{L}(s_l - \bar{s})log\left(\widehat{A(l/n)}\right)\right)\left(\sum_{l=1}^{L}(s_l - \bar{s})^2\right)^{-1} \tag{3.6}$$

[8] r_t is a logarithm of stock return: $r_t = log(R_t) = log(S_t/S_{t-1})$. If logarithmic returns are in fact normally distributed, the underlying process of a stock price follows a random walk

with $s_l = log(l/n)$ and $\bar{s} = \frac{1}{L}\sum_{l=1}^{L} s_l$. To minimize estimator bias Hall & Wood (1993) suggest using $L = 2$, which is the value that is also used in this work. Second of the two fractal dimension estimators combines the method of moments with a variogram estimator proposed by Genton (see 1998, p.216). The methods of moments typically suffer from high sensitivity to outliers. Since Genton introduces a higly robust variogram[9] this drawback is mitigated, thus promising a superior precision for the case of financial data – where a presence of outliers is a common feature. Using the notation from (3.5), the variogram is defined as follows:

$$\widehat{V_2(l/n)} = \frac{1}{2(n-l)} \sum_{i=l}^{n} \left(\tilde{r}_{i/n} - \tilde{r}_{(i-l)/n}\right)^2 \tag{3.7}$$

and the fractal dimension estimator is then given as:

$$\widehat{D_G} = 2 - \frac{1}{2}\left(\sum_{l=1}^{L}(s_l - \bar{s})log\left(\widehat{V_2(l/n)}\right)\right)\left(\sum_{l=1}^{L}(s_l - \bar{s})^2\right)^{-1} \tag{3.8}$$

Analogically to (3.6), the number calculated variograms is 2 (*i.e.* $L = 2$).

Combining the two pairs of above described estimators, I firstly construct a composite measure of departure from a theoretical process of fully efficient market, similar to one in Kristoufek & Vosvrda (2012):

$$EI = \sqrt{\sum_{i=1}^{N}\left(\frac{\hat{M}_i - M_i^*}{R_i}\right)^2} \tag{3.9}$$

Specifically, plugging in the individual measures yields:

$$\begin{aligned} EI &= \left((\widehat{H_{LW}} - H^*)^2 + (\widehat{H_{GPH}} - H^*)^2 + (\widehat{D_{HW}} - D^*)^2 + (\widehat{D_G} - D^*)^2\right)^{1/2} \\ EI &= \left((\widehat{H_{LW}} - 0.5)^2 + (\widehat{H_{GPH}} - 0.5)^2 + (\widehat{D_{HW}} - 1.5)^2 + (\widehat{D_G} - 1.5)^2\right)^{1/2} \end{aligned} \tag{3.10}$$

[9] much as the periodogram is a sample estimate of continuous spectral density, the variogram is a sample estimate for a structure function γ_t. It gives an information about variability in pairs of data points, depending on a chosen lag length t

3.3.3 Approximate Entropy

In their later work, Kristoufek & Vosvrda (2014) also augment the previous Efficiency Index by including a bounded measure of approximate entropy (as proposed by Pincus (1991)). One feature of this measure that coincides with interests of this thesis is the fact that it is appropriate also with relatively short time series — Pincus states that *"[Approximate entropy] can classify complex systems, given at least 1000 data values.."*. As in the case of global and local correlation structure, by applying a rolling window, this originally static measure may be transformed into a time series to become dynamic. In order to achieve sufficiently low levels of variance in the above described estimators[10], the width of this sliding window was originally set to four years of daily observations. The window size corresponded to the minimum data length specified by Pincus. However, in practice, the approximate entropy estimator did not correspond to theoretically bounding conditions and exhibited high sensitivity to parameters, that are arbitrarily set by the researcher with no customary value used for financial data. For this reason, the robustness of market efficiency index would suffer by inclusion of the approximate entropy as an n^{th} efficiency measure and is therefore kept aside in this particular application.

3.4 Time Series Modeling Framework

This question of whether a market efficiency may in fact have a positive causal effect on length of delay in MP effect is to be addressed in two steps. Starting with the high-frequency data of financial markets' indices in the individual examined economies, values of market efficiency index are calculated. on sliding windows of appropriate length in order to form time series.

In the second part of analysis, the resulting time-series from the first step is employed in the macroeconometric model together with the constructed time-series of pass-through delay index and other supporting macro-indicators. The resulting relation is therefore stripped of other possible effects described in literature and thus informative for a potential policy maker.

[10]e.g. the Local Whittle Estimator or Geweke Porter-Hudak Estimator

3.4.1 Vector-Autoregressive Models

Proposed by Sims (1980), the first vector-autoregressive models appeared in response to insufficient explanatory and forecasting power of the large-scale simultaneous equations models, which were in use until then.

Reduced Form

Posing a modest amount of *a priori* restrictions, the VAR models in its simplest form treat all of the included variables as endogenous, thus circumventing the issue of whether the assumptions of exogeneity — necessary in most then employed models — are in fact credible. Clearly, next to computational intensiveness, this full orientation to information within dataset also requires a sufficient length of the used series (see e.g. Lütkepohl 2011). Consider for example a simple model:

$$\mathbf{y}_t = \mathbf{F}_0 + \mathbf{\Psi}(L)\mathbf{y}_t + \mathbf{u}_t \tag{3.11}$$

With $\mathbf{y_t}$ standing for an m-tuple of macroeconomic time-series, lag polynomial $\mathbf{\Psi(L)} = \mathbf{F_1 L} + \mathbf{F_2 L^2} + ... + \mathbf{F_p L^p}$ representing the simplified structure (that is to say non-orthogonal) of the model and $\boldsymbol{u_t}$ being again an m-dimensional vector of innovations that are serially — but not mutually — uncorrelated. Therefore, a hypothetical shock to one of the elements in $\mathbf{y}_t$ necessarily translates into a non-zero shock to the others and *vice-versa*. In order to have a reduced VAR model that is statistically relevant, the required number of observations will grow rapidly both in number of endogenous variables and in the number of lagged values we decide to use (specifically, for a model of m variables and p lags the number of coefficients that need be estimated equals m^2p+m). Indeed, also in the presented work the available datasets' lengths are of limiting nature with respect to possible number of included variables. As a result, such simplifications of the model structure must be found that will keep the model parsimonious, but will simultaneously extract as much information from the data, as possible. A simple VAR model is therefore presented first. This model follows specification used in Stock & Watson (2001), meaning that it uses inflation rate,the short-term interest rate and unemployment rate as endogenous variables. To account for the capital market efficiency, the quarterly series of Efficiency Index — constructed as presented by Kristoufek & Vosvrda

(2014) and in line with section 3.3 — is then added as a fourth variable. Already in its reduced form as in (3.11), the VAR is useful for describing the data and even for constructing quick out-of-sample forecasts. Thus, by using the Stock and Watson specification for the cases of Czech Republic and Austria, it is possible to make a first comparison of model that includes measure of market efficiency as an extra variable with a benchmark model that does not.

Structural Form

As previously stated, the task of data description and forecasting may to some degree already be achieved by the reduced form VAR in (3.11) since the agnostic approach allows for the vector elements of $\mathbf{u}_t$ to remain correlated. If the analysis is concerned with transmission of monetary policy, the model must be specified and in such way, that the innovations in individual variables are uncorrelated. This is indeed also the case for the present work.

Assuming there indeed is an underlying structure for variables at hand, it is possible to state the model in (3.11) as:

$$\begin{aligned}\mathbf{A}\mathbf{y}_t &= \mathbf{B}_0 + \boldsymbol{\Gamma}(L)\mathbf{y}_t + \boldsymbol{\varepsilon}_t \\ \mathbf{B}_0 &= \mathbf{A}\mathbf{F}_0 \\ \boldsymbol{\Gamma}(L) &= \mathbf{A}\boldsymbol{\Psi}(L) \\ \boldsymbol{\varepsilon}_t &= \mathbf{A}\mathbf{u}_t\end{aligned} \tag{3.12}$$

The innovations in vector $\boldsymbol{\varepsilon}_t$ of this model form are uncorrelated both serially and with one another, but expressing the model in this form is not possible without additional restrictions imposed by the researcher. The most straightforward way to do so is to estimate so-called recursive VAR model as do Stock & Watson (2001), which is equivalent to Choleski decomposition of the variance-covariance matrix estimated on the reduced-form residuals. This is one method initially used in this work and it can already provide some modest insights into variable interactions, but in most cases there are more meaningful ways to impose needed restrictions than the assumption of lower triangular matrix $\mathbf{A}$. As previously stated in section 2.2.1, these may concern the short-run and long-run shock impacts, or the signs of impulse responses generated by the model, the performance of the different listed approaches are discussed in chapter 5 for the cases of Czech Republic and Austria.

After obtaining a set of stationary time-series, I run a series of Granger causality tests for each pair of the included variables. I continue by estimating a VAR model in reduced form both for the basic Stock & Watson specification and for a specification augmented by the constructed series of Efficiency Index. In following steps, I firstly use the Choleski decomposition scheme to obtain a simple recursive structure and secondly estimate a long-run monetary policy rule to be used as one of the SVAR equations. Table 3.1 lists variables that are used to estimate the said models in the same order that is used for the Choleski decomposition, thus reflecting the typical behavior of the listed macro-variables in economy. Inflation rate, for example is listed as the first variable, as the shocks to other variables are unlikely to affect the price levels in the same quarter they occurred in. The short-term interest rates, on the other hand, reflect the policy decisions of central bankers and with the policy makers having a detailed forecasts at disposal, the monetary conditions typically adjust rather quickly. For the case of Czech Republic, I add the time series of quarterly averages of spot nominal exchange rate in order to account for the international flows. The efficiency index is treated as an exogenous variable to reflect the fact, that it is rather frictions in informational availability and transaction costs that are likely to cause the market inefficiencies, not the changes in macro-variables. Details of intermediate results may be found ordered by the analysis' steps in Chapter 4.

Table 3.1: Base Model Variables

denoted	variable	unit
π_t	HICP	growth rate, SPLY
Δu_t	unemployment rate	annual changes
i_t	interbank-offer rate	percentage points
q_t	spot nominal exchange rate	CZK/EUR
EI_t	Efficiency Index	estim. on 2-year window

the exchange rate q_t is only included in the VAR model for the Czech case

Bayesian Vector Autoregressive Models

As pointed out in previous sections, the number of endogenous variables that may be included in a typical VAR is limited by the length of data at econometrician's disposal. To alleviate this limitation, some techniques of introducing additional restrictions to the traditional VAR model structure were later proposed. One particularly useful extension of the basic VAR framework is provided through the combination with the Bayesian statistics (see Litterman

(1986), but also Kadiyala & Karlsson (1997) and Sims *et al.* (1998)). A second approach combines the VAR and factor-analysis (as used e.g. in Bernanke & Boivin 2003; Bernanke *et al.* 2005). Finally, combining the reduced form representation with a known economic model (*e.g.* ISLM Model) generally implies restrictions that allow for easier identification of the resulting Structural VAR model as well (used *e.g.* in Sims & Zha (2006)). In spite of these two extensions not being within a scope of the present work, I list them as possible alternative approaches for further research. Considering the potential inflation of coefficient's standard errors (and thus also the standard errors of generated forecasts and impulse responses), which is caused by estimation of the efficiency indices time series, the advantages provided by such extensions become even more pronounced.

Structural Models

The structural models are generally more useful when tackling already established issues of monetary policy. Nevertheless, they are constantly subject to calibration, which requires extensive judgment on the researcher's part. This is indeed a possibility for further examination of hypotheses stated within the presented work as it may subsequently allow for a clearer revelation of the true causal relations in the economy. When addressing the question of delay in reaction to monetary policy shock, the structural models such as real business cycle models or dynamic stochastic general equilibrium models are particularly useful, allowing for examination of variables' responses to temporary as well as permanent shocks. An additional caution is necessary before arriving to conclusions based on such analysis, since the calibrated coefficients of such models introduce even more uncertainty. For this reason, the more agnostic — less arbitrary — approach is initially chosen by using the VAR framework, to perhaps allow for a construction of structural model in a follow-up literature.

Threshold Vector Autoregressive Model

Even the simple frequentist VAR, that is initially estimated in the empirical part, may provide some comparison of monetary policy transmission depending on inclusion or omission of information about market efficiency. As the primary goal of the present thesis is to examine what are the implications of market efficiency level to monetary transmission mechanism, estimating a threshold VAR (henceforth TVAR) is a more preferable approach. At a relatively low cost in terms of additional complexity introduced, it allows me to reflect the possible nonlinearities and asymmetry in model responses to policy shocks. I extend the model in (3.11) and (3.12) by allowing for two regimes — one where market is relatively efficient and one where it is relatively inefficient. Similarly to the application in Balke (2000), I estimate the following TVAR model:

$$\mathbf{y}_t = (\mathbf{A}_0^h + \mathbf{\Gamma}^h(L)\mathbf{y}_t)I_{\{EI_{t-1}>\gamma\}} + \left(\mathbf{A}_0^l + \mathbf{\Gamma}^l(L)\mathbf{y}_t\right) I_{\{EI_{t-1}\leq\gamma\}} + \boldsymbol{\varepsilon}_t \qquad (3.13)$$

Where the $\mathbf{y}_t$ is again the vector of endogenous variables that are listed in table 3.1 and the $\mathbf{\Gamma}^i(L)$, $i \in \{h, l\}$ are lag polynomials as in 3.11, with the superscripts indicating the corresponding market efficiency regime. An indicator function $I_{\{EI_{t-d}>\gamma\}}$ is equal to one for cases when the EI_{t-d} exceeds the threshold level γ. Because the Efficiency index measures what is in fact a deviation from fully efficient market in a theoretical sense, the exceedance of threshold γ by values of the efficiency index triggers the inefficient regime.

Chapter 4

Empirical Part

Before the application of econometric methods from Chapter 3 is described, the reader is introduced to the features of employed data. Although all of the data used for purposes of this work are some form of time-series, there are two distinct types of such series. Both in the initial cross-sectional/panel regressions and in the dynamic models estimation (VAR/TVAR), the primary stage of market efficiency is conducted with help of daily closing values of local capital market indices. In the secondary stage, the constructed time-series of this market efficiency measure is put in context with quarterly macroeconomic data. Throughout the empirical part, the most attention is paid to Austria and Czech Republic for which policy inference is conducted (with use of VAR/TVAR). After estimation of market efficiency for the two countries, the resulting values are examined together with the countries' inflation, investment and unemployment data. Despite the work's focus being the interaction of market efficiency with macro-conditions, it is still interesting to see the updated values of the efficiency measures previously computed by Kristoufek & Vosvrda (2012). This is done for the inflation targeting countries listed below to allow for a small scale cross-sectional and panel analysis. The present work thus offers both cross-section/panel look and time-series look at the issue.

4.1 Financial Indices

For the estimation of market efficiency index, daily observations of 27 of financial indices were obtained from the financial database provided by *Thomson Reuters Eikon.*

Thomson Reuters in turn obtains the series directly from the corresponding

Table 4.1: List of Stock Indices

Ticker	Index Title	Country
ASX300	Australian Security Exchange Index	Australia
ATX	Austrian Stock Exchange Index	Austria
BELEX15	Belgrade Stock Exchange	Serbia
BETI	Bucharest Stock Exchange	Romania
BIST30	Instanbul Stock Exchange National 30 Index	Turkey
BSE	Bombay Stock Exchange Index	India
BUX	Budapest Stock Exchange Index	Hungary
BVSP	Bovespa Brasil Sao Paulo Stock Exchange Index	Brasil
COLCAP	Colombia COLCAP Index	Colombia
FTSE	Financial Times Stock Exchange 100 Index	UK
GSE	Ghana Stock Exchange	Ghana
IPC	Indice de Precios y Cotizaciones	Mexico
IPSA	Santiago Stock Exchange Index	Chile
JALSH	FTSE/JSE All Share Index	South Africa
JKSE	Jakarta Composite Index	Indonesia
KOSPI	Korea Stock Exchange KOSPI Index	South Korea
NI225	Nikkei heikin kabuka Index	Japan
NZX50	NZX50 Index	New Zealand
OBX	Oslo Stock Exchange Equity Index	Norway
OMX	OMX Stockholm 30 Index	Sweden
OMXIPI	OMX Iceland All-Share PI Equity Index	Iceland
PSAL	Philippine SE All Shares Index	Philippines
PX	Prague Stock Exchange Index	Czech Republic
SET	Stock Exchange of Thailand Index	Thailand
SPBLGPT	S&P Lima General Index	Peru
TA125	Tel Aviv Main 125 Index	Israel
TSX	Toronto Stock Exchange 300 Composite Index	Canada
WIG20	Warsaw Stock Exchange WIG 20 Index	Poland

providers — *i.e.* central banks, statistical bureaus and like institutions — in this case from the stock exchange entities. An exception is made for the cases of Austria and Czech Republic, where the stock market organizer (*i.e.* CEESEG) provides the full history of daily closing data for the desired composite indices, thus exceeding the size of data provided by Thomson Reuters (TR) (maximum of 20 years of observations). For each of the economies at question, the one main stock market index is selected for estimation of market efficiency. It is typically the case, that the stock market index that is most closely monitored and most frequently used as a performance benchmark will be constituted by the most liquid stocks traded at the exchange. Indeed, the appropriateness of the choice could be questioned on the grounds of incomplete nature of information carried solely by the chosen representative index. While it is true that the inefficiencies within any particular stock market will rather stem from the less liquid stocks — or their limited portion of free float — where the effective transaction costs are likely to be higher, the comparison made in this work may be justified by treating all the countries and market equally — thus preserving the level playing field. By making the assumption of similar differences between the index constituents and the rest of relevant traded companies, it possible to considerably improve the size and quality of available sample. Market indices for inflation targeting countries and for Austria are listed in Table 4.1. All of the listed indices, with the exception of ATX, are used for a simple cross-sectional analysis in Section 4.3. The data for Wiener Börse are excluded from this part of the work, because ECB, not Austrian Central Bank, sets the applicable inflation target and the main policy rate and thus Austria does meet the sample criteria.

4.2 Macroeconomic Indicators

Throughout the econometric part of this work, a range of macroeconomic indicators is utilized to either support or disprove the hypothetical notions included in the theoretical part (Chapter 3). Such variables include primarily price indices (CPI, HICP), unemployment rates and investments measured in constant prices and national currencies. Furthermore, the EURCZK exchange rate was also obtained to be used in the dynamic models. In majority of examined cases, database of Thomson Reuters reliably conveyed the needed data from their primary providers (*i.e.* national statistical bureaus etc.). Of the data were transformed from levels to either log-differences or to annual growth rates in order to avoid non-stationarity and spurious regressions. Percentage changes of the countries' price levels are depicted in Figure 4.1.

For construction of a loss measure to penalize for inflation deviation from a central bank set target, information was collected both about inflation rates and inflation targets set by the individual institutions. These constructed series were thereafter examined together with the above mentioned series of market (in)efficiencies levels.

Before diving into the econometric analysis of the economies at hand, it is important to take into account, that the examined cases are necessarily different in nature and such differences may not always be fully accounted for by a handful of macroeconomic time-series. Measures to circumvent this issue are nevertheless introduced in the following section.

Figure 4.1: Used Historical Inflation Rates

Source: OECD, Thomson Reuters

4.3 Evidence from Inflation Targeting Countries

In order to achieve a reasonable degree of homogeneity within my data in terms of measuring economy's departure from of the desired state, I restrict my sample to inflation targeting countries. With exception of Austria, the tickers listed in

Table 4.1 correspond to the selected countries. For the same reason, inflation rate will serve as the primary mean of comparing individual countries to one another and to themselves over time.

The first simple approach taken in this work to examine the possible link between the market efficiency and success with which the central bankers manage to keep the inflation close to its target is a search for linear relationships. For this purpose, a measure is devised in a form of a loss function that penalizes for deviation of realized inflation rate ($\pi_{i,t}$) from the objective value set by the central bank ($\pi^*_{i,t}$). Admittedly, the officially tolerated spreads around the set inflation targets are not completely uniform across the different central banks, but as the typical width of the target zone is $\pm 1\%$, this is also the value used by the devised penalty function:

$$pen_{i,t} = f_{pen}(\pi_{i,t}, \pi^*_{i,t}) = max[|\pi_{i,t} - \pi^*_{i,t}| - 0.01, 0] \tag{4.1}$$

The loss function values can thereafter be aggregated over some specified time period and used in a simple linear regression. Two types of cross-sectional relationship are initially sought. Firstly, the aggregated loss function values are analyzed together with market efficiency measure calculated using the data of same length and secondly, an average value is calculated for each country over the selected period. The series' length is identical for all the countries and is set to 24 quarters, *i.e.* six years. This length is selected based on the availability of capital market data for all countries in the sample. Furthermore, as the market efficiency index accounts for the four most recent years of market data, stretching the examined period prior 2013 would be likely to introduce some challenges due to extraordinary movements on capital markets during the financial turmoil prior 2010. Equation (4.2) states the initially fitted linear relationship:

$$\begin{aligned} \sum_{t=1}^{24} pen_{i,t} &= \beta_0 + \frac{\beta_1}{24} \sum_{t=1}^{24} EI_{i,t} + \varepsilon_i \\ pen_i &= \beta_0 + \beta_1 EI_i + \varepsilon_i \end{aligned} \tag{4.2}$$

Because the homogeneity of observations within the sample is still challengable despite our restriction to inflation targeting countries and because it is possible to aggregate the time-series over multiple shorter periods, panel data are constructed for the next step regression, which is to mitigate the influence of country specific effects. The 24-quarter series at hand are separated into three identical segments of 8 quarters each to construct a data panel. Difference of fixed effects and random effects regressions is thereafter tested by the Hausman (1978) test, not rejecting the null of no difference[1]. The random effects regression as in Equation (4.3) is therefore conducted with the prepared panel. This time, $t \in \{1, 2, 3\}$ and the $v_{i,t}$ is an unobservable component, which is assumed to be constant for each of the countries, *i.e.* $v_{i,t} = v_i$.

$$pen_{i,t} = \tilde{\beta}_0 + \tilde{\beta}_1 EI_{i,t} + (v_{i,t} + \varepsilon_{i,t}) \tag{4.3}$$

4.4 Evidence from Czech Republic & Austria

Apart from analyzing the Czech and Austrian financial data as a part of group of inflation targeting countries, the work also provides a closer look at the two countries in the time-domain by putting the constructed series of market efficiency indices in context with other relevant macro-variables.

As addressed in Subsection 3.4.1, this is initially done in the simplest way by devising a three-variable VAR model following the specification in Stock & Watson (2001) and then adding the measure of market efficiency as an exogenous variable.

Let us have a vector of variables $\mathbf{y}_t = (\pi_t, u_t, i_t)$ with the meaning of its elements as in Table 3.1. In order to estimate stable benchmark VAR models, I first inspect properties of the three input series for each of the cases. In most cases, non-stationary data must not be used in VAR model coefficient estimation, as it would likely lead to unstable forecasts and shock responses as a result. As is typically the case, already initial inspection of the six data series (included in an appendix B) promptly points to likely non-stationarity in HICP. Covariance-stationarity is tested by an augmented Dickey-Fuller unit-root test with an optimal lag selection determined by the Schwarz-Bayes information criterion. A drift term is only included for the two HICP series, where a long-run growth is economically justifiable. The testing results (see Table 4.2) confirm a unit root in both HICP series. Moreover, test statistics for u's and i's support stationarity only for the 3M PRIBOR rate. Still, since the interest rate in developed markets is generally deemed to be fluctuating around a natural

[1] The p-value for resulting $\chi^2 = 0.014$ and one degree of freedom is equal to 0.9.

rate of interest we keep 3M EURIBOR variable (q_t) in its level form at this stage and check the stability of produced models later on.

Table 4.2: ADF Statistics for Series in Level Form

	$HICP_{t,AT}$	$HICP_{t,CZ}$	$u_{t,AT}$	$u_{t,CZ}$	$i_{t,AT}$	$i_{t,CZ}$	q_t
lag	0.39	-0.86	0.10	-1.63	-1.41	-2.24	-1.72
drift	4.46	2.85	-	-	-	-	-

Criticals at 5% for the lag and drift coefficients are -2.89 and 4.71, for a no-drift model, the critical value for lag is -1.91

The remainder of series at hand is than transformed in order to eliminate the unit-root. Instead of $HICP_t$ and u_t levels, consider the inflation rate – *i.e.* y-o-y $HICP_t$ percentage changes – and annual unemployment increments in percentage points. The tests are now repeated for the four variables, while including neither drift nor trend term in the underlying model.

Table 4.3: ADF Statistics for Transformed Series

	$\pi_{t,AT}$	$\pi_{t,CZ}$	$\Delta u_{t,AT}$	$\Delta u_{t,CZ}$
lag	-1.45	-4.04	-2.35	-3.99

CV's at 10%,5%,1% are -1.61,-1.91,-2.6, resp.

With the exception of Austrian inflation rate, unit-root hypothesis may now be rejected in all of the employed series. While it is not possible to reject non-stationarity in $\pi_{t,AT}$, this variable is generally regarded as naturally bound and in absence of hyperinflation, it may be theoretically regarded as stationary, as well. Although it may further on raise an issue regarding VAR model stability, it is a lesser concern relative to interpretability issues and loss of carried information that would be caused by further filtration.

4.4.1 Granger Causality

As in the VAR model set up, lagged values of the listed variables are used to describe and predict the current period values of other variables, a natural next step of the analysis is to test the explanatory power herein. This concept is more generally covered in Granger (1969). As the variables at hand are now stationary, the Wald test may be conducted by comparing fits of two linear models – an unrestricted one containing lags of the explained variable itself and of another variable and a restricted one where the explanatory variable lags are omitted. If there were no evidence of causal relations among the variables,

Table 4.4: Granger Causality Testing : p-values

	Austria				Czech Republic				
	π_t	Δu_t	i_t	c_t	π_t	Δu_t	i_t	c_t	q_t
π_t	0.00	0.00	0.00	0.09	0.00	0.01	0.00	0.36	0.07
Δu_t	0.43	0.36	0.34	0.29	0.91	0.00	0.71	0.26	0.71
i_t	0.12	0.02	0.00	0.90	0.25	0.04	0.00	0.02	0.40
c_t	0.09	0.00	0.01	0.00	0.09	0.11	0.00	0.00	0.38
q_t					0.42	0.55	0.01	0.51	0.00

table lists p-values for joint significance of two lags for the regressor in RHS column
q_t stands for the EURCZK exchange rate

a series of univariate models would be more suitable for the analysis from a statistical point of view. This is, however, not the case for the variables listed above. The Table 4.4 reports results for comparison of linear models regressing on up to second lag. This is the lag order, that will be generally feasible within the analysis, as greater number of parameters would lead to overfitting, due to limited time-series length. Though in both cases, inflation is not explained by any other variable – perhaps with a exception of *EURIBOR* variable – testing for causality by the constructed Efficiency Index results in rejection of no causal relation at 5%-level for Austria. In the case of Czech inflation, additional two lags must be added to reject the null at 1%-level. This is why applying the presented approach may become more useful with several additional years of observations as the number of available degrees of freedom becomes sufficient.

4.4.2 VAR Model Estimation and Checking

With the time-series data in acceptable form and with reasonable basis to believe that the variables should be treated as a system a vector autoregressive models are initially estimated using the triplet of series $(\pi_t, \Delta u_t, i_t)$ for the Austrian case and the quadruplet $(\pi_t, \Delta u_t, i_t, q_t)$ for the case of Czech Republic as listed in Table 3.1. Having used stationary data allows for estimation of individual equations' coefficients by minimizing squared residuals. For the policy inference, a common short-run restriction identification scheme is thereafter used, decomposing the estimated covariance matrix of residuals to obtain a lower triangular matrix as a model structure. The model identification is order-sensitive as each selected ordering within the vector of variables implies restrictions on specific coefficients within matrix A from Equation (3.12). The ordering in both of the considered cases restricts the contemporaneous effects

Table 4.5: Investment Variable Description

denoted	variable	unit	ADF AT	ADF CZ
k_t	gross capital formation	annual growth	-4.55^*	-3.19^*

- the reported ADF unit-root test statistics are obtained by a linear regression of differenced series on optimal number of its lags while excluding a drift and trend terms
- the lag order is selected in accord with the Bayes-Schwarz information criterion
- (*) signifies unit-root rejection at 5% level for both of the series

of other variables to inflation, contemporaneous effects of interest rate and exchange rate to change in unemployment rate and of exchange rate to interest rate. In the case of Czech Republic the contemporaneous effects of exchange rate to all of the other variables are also assumed to be zero. The exchange rate is thus considered to be most responsive to system shocks. In practice the foreign exchange markets respond nearly immediately and short term interest rates adjust to the central bank policy rates that are set every several weeks while unemployment rate and price levels respond with a lag. Both for the model including unemployment rate and the model including the investment variable, the estimated model coefficients are included in Section A.1. After estimating the baseline model, this work follows changes in shock transmission that occur due to inclusion of the capital market efficiency measure as an exogenous regressor in each of the estimated equations.

To a large degree this first pair of models follows the variable choice in Stock & Watson (2001). Using this particular specification and identification scheme, we are able to follow the transmission of monetary policy shock both to price levels and to an economic performance variable. Initially, the unemployment rate takes place of the latter, but for a better resemblance to the mechanism described in Mishkin (2001), an additional set of models is estimated, where the unemployment rate is replaced by investment growth. As before, we are interested in the way, that the response to an orthogonal shock changes when accounting for additional information entered with the Efficiency Index.

To complete the Tables 3.1 and 4.3, we now list the investment variable details as well as the ADF test statistics for both countries. The Granger causality results for both countries are rather lopsided, as the investment does not help to explain other variables but is well explained by them. As a counterpart to Table 4.4, the summary with investment is listed in A.2.

After estimation, each of the described models is checked for stability and models' residuals for normality. The former is done by considering the determinant roots of companion matrix of the model coefficients. In Equation (3.11), the lag polynomial is of a form $\mathbf{\Psi(L)} = \mathbf{F_1L} + \mathbf{F_2L^2} + ... + \mathbf{F_pL^p}$. In case at hand (i.e. $p = 2$), this implies a companion matrix of the following form:

$$\mathbf{F} = \begin{bmatrix} \mathbf{F_1} & \mathbf{F_2} \\ \mathbf{I_k} & \mathbf{0} \end{bmatrix} \tag{4.4}$$

where the I_k is an identity matrix with a number of dimensions corresponding to number of endogenous variables. Formally the condition for stable VAR system requires that the absolute roots of the characteristic equation $|\mathbf{F} - \lambda_{2N}| = 0$ are all inside the unit circle. Equivalently, absolute values of all of the companion matrix eigenvalues must lie within the unit circle (*i.e.* the real eigenvalues must be less then one). Indeed, this is the case for all of the estimated VAR(2) models. For brevity, I summarize the results by listing only the greatest companion matrix eigenvalue for each of the estimated VAR models (see 4.6).

Table 4.6: greatest absolute values of comp. matrices

	Δu_t^*	$\Delta u_t, EI_t^{***}$	k_t^{**}	k_t, EI_t
AT	0.979	0.966	0.976	0.963
CZ	0.899	0.872	0.939	0.935

(*) models with unemployment as an economy proxy
(**) models with investment
(***) eff. index included as an explanatory variable

The attention is thereafter paid to the model residuals, which are tested for serial correlation and for distribution normality. The serial correlation is tested by determining the joint significance of lagged residuals up to second and up to fourth order as these are the orders used in the present work and typically used for macroeconomic VAR models, respectively. While the second order testing confirms no serial correlation of residuals across the board, testing for higher orders shows unaccounted for correlations are present. This is not surprising, as the macro-variables generally exhibit correlation with their previous year's value. Although no serial correlation is exhibited by the exchange rate and Austrian inflation rate, other variables' residuals are in some cases correlated with their further lags. This issue should be mitigated by extending the VAR model by the additional lags' regressor, when long enough time-series are available. The resulting p-values for each the tested residual series are listed in Tables A.13 and A.14.

To examine the residual series' normality, the visual plots of empirical distributions are complemented by the results of Jarque & Bera (1987) test for each individual series. The test first incorporates sample skewness of the data with their sample excess kurtosis in a single χ^2-distributed statistics and then compares this statistics to a critical value obtained through Monte Carlo simulations. The number of replications in this instance is set to 2000. Cases where null hypothesis of normality is rejected by the are those where both excess kurtosis and non-zero skewness is found due to outlier observations. Majority of these outlier cases occur during the period of 2006-2010.

4.4.3 Threshold VAR Model Estimation and Checking

In the final section of the empirical analysis chapter, we focus on differentiating between two regimes of capital market efficiency. For each of these regimes, a set of VAR coefficients is estimated. The framework for model's estimation stays essentially unchanged, as the parameters themselves are again obtained through minimization of squared residuals, but the market efficiency variable is now used as an external transition variable rather than an exogenous regressor, as in the linear VAR case. The optimal threshold value to divide the data is not *a priori* known and must be estimated. For this reason, the best value for threshold is deemed to be the one that minimizes determinant of model residuals' covariance matrix. Following the notation in Equation 3.13 and setting the lag polynomial order to 2 as in the previous cases, we can express this criterion more formally as follows:

$$
\begin{aligned}
\gamma^* &= argmin \left| \widehat{\Sigma}_{\hat{\varepsilon}(\gamma)} \right| \qquad (4.5) \\
\hat{\varepsilon}(\gamma) &= \mathbf{y}_t - (\mathbf{A}_0^h + \mathbf{\Gamma}_2^h(L)\mathbf{y}_t) I_{\{EI_{t-2}>\gamma\}} - \left(\mathbf{A}_0^l + \mathbf{\Gamma}_2^l(L)\mathbf{y}_t\right) I_{\{EI_{t-2}\leq\gamma\}}
\end{aligned}
$$

To test for the non-linearity, a specific form of a likelihood ratio statistics is used. Introduced for a univariate case in Hansen (1999) and then extended by Lo & Zivot (2001) for the multivariate case, the statistics essentially quantifies the additional explanatory power of the model brought by allowing for more regimes. As depicted in (4.6), this is achieved by comparing the residual covariance matrices of both model alternatives. Because the theoretical distribution of the said statistics is unknown, the critical values as well as p-values are obtained through bootstrapping by re-sampling the null-model (*i.e.* the linear model without threshold) residuals with replacement, re-estimating the model and saving the new value residual covariance matrix's determinant.

$$LR_{1,2} = T(log(|\hat{\Sigma}_1|) - log(|\hat{\Sigma_2}|)) \tag{4.6}$$

Though different versions of the test are possible, the null hypothesis in the present case is a model linearity and the alternative is an one-threshold model, using the lagged market efficiency measure as an exogenous transition variable. The results in Table 4.7 include p-values of non-linearity for the one- and two-lag model specifications for both countries. In addition, the two-lag specification is further split by the delay of the transition variable EI (*i.e.* by the d from Equation (3.13)). Linearity is rejected at 5%-level for all instances with the exception of 1-lag TVAR model estimated with Czech data and one of the 2-lag models estimated with Austrian data (only the case where transition variable is delayed by 2 quarters).

Table 4.7: Non-linearity Testing

	1-lag	2-lag, $d = 1$	2-lag, $d = 2$
AT	0.010	0.044	0.307
CZ	0.610	0.002	0.041

- p-values are bootstrapped with 2000 replications

Unlike in the linear case, the stationarity of input time series may frequently not lead model stability when threshold is recognized. As pointed out by Grynkiv & Stentoft (2018), the very threshold switching, that allows for model's closer match of the data also causes the absence of theory-based guarantee of stable model outputs. This is the case for the Czech Republic result, which prevents reasonable interpretations of asymmetric impulse responses at this stage. Nevertheless, even if one or more regime specific models are indeed locally unstable, the overall model stationarity is still not ruled out as is also the result in the above stated work.

Similarly as in the linear case of the VAR model, the resulting residual series are jointly serially correlated with their first and second lags, but the Austrian unemployment rate and Czech inflation rate exhibit serial correlation when including four lags instead. Tested normality (Jarque-Bera) of residuals slightly improves compared to the linear case. The three instances, for which the residual normality is rejected are the EURIBOR where negative skewness and excess kurtosis is caused by sharp cutting of rates during the financial crisis, the Austrian inflation rate, which rose unexpectedly in mid-2008, and the Czech unemployment rate which rose by 0.8pp in the beginning of 2009. The complete set of residuals' histogram plots for both Austria and Czech Republic is included in the appendix (see Figure B.5) as is the full list of model coefficients (Section A.5).

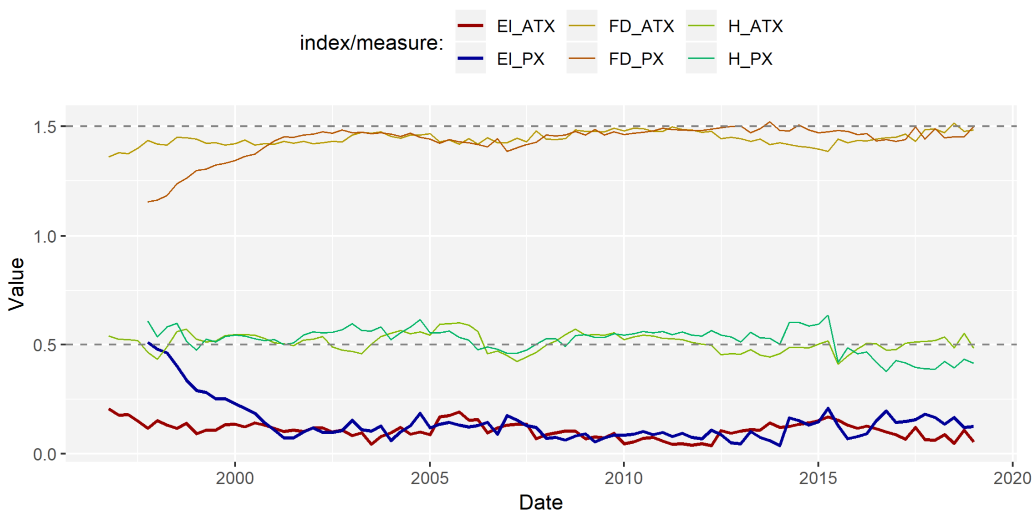
Chapter 5

Results & Discussion

5.1 Market Efficiency Measure

The initial part of the empirical study is concerned with estimation of market efficiency and its development throughout time. Although the primary focus of the analysis should be directed at the market efficiency's interaction with the rest of included variables, some observations may also be drawn from the resulting market efficiency series alone. For the inflation targeting countries, the ranking by market efficiency is included in the Table A.1, with the most market inefficiencies being present for the African and Central American countries. For the Czech Republic and Austria, the development of each country's market efficiency is based on the main composite index for the local stock exchange. To reiterate, for the two economies examined closer, these are the PX and ATX indices. The breakdown into the two distinctive index components (*i.e.* the average of the two Hurst exponent estimates and the average of the two fractal dimension estimates) is depicted in figure 5.1. Indeed, this is a particular relationship for a pair of capital markets, which by visual inspection suggests cointegration (and in fact, the Johansen eigenvalue cointegration test concludes that there truly is a cointegrated relation among the two series at 1%-significance level). This follows from the fact, that the two exchanges share an owner and that multiple traded titles are related as well. Furthermore, in line with the general theory, we observe a sharp decline in the level of inefficiency for the Prague Stock Exchange. This is observed, because the first values of the efficiency index for PX correspond to the initial years of trading at the Prague Stock Exchange and thus indicate lower levels of complexity that quickly improve in the few years prior 2000. Expectedly, both markets exhibit lower levels of predictability (or a closer resemblance of the indices to the random walk) during the time of global financial crisis as the volatility temporarily increased.

Figure 5.1: Quarterly Series of Efficiency Indices



Source: Prague Stock Exchange, Wiener Borse, own construction

Figure 5.2 appends the estimated market efficiency series by the corresponding optimal thresholds for the 2-lag TVAR models[1]. These are not interpreted as an overall measure of market efficiency for the period, but rather most appropriate threshold values (that minimize the determinant of residual covariance matrices). While approximately 41% of observed period is classified as the inefficient regime in case of Austria, this figure is substantially higher for the Czech case at roughly 70%. Furthermore, the mean value of the measured inefficiency is nearly 30% higher for the Czech case (0.14 compared to 0.11 for Austria).

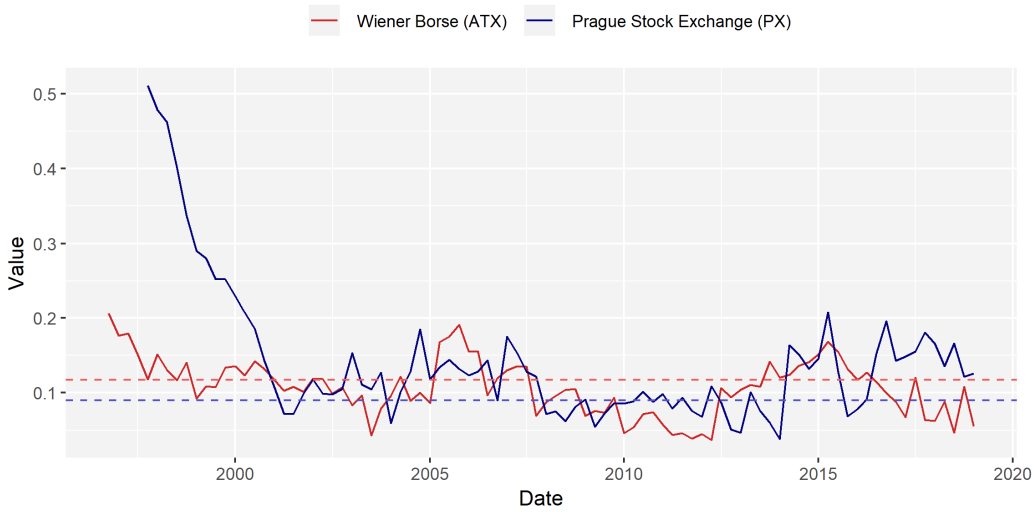
5.2 Responses to Monetary Policy Shock

Following the panel regression, whose results support the positive relationship of market efficiency and success of monetary policy[2], a more detailed analysis for two specific cases is well justified. Baseline VAR models with simple three- and four-variable specification and models extended by the efficiency index

[1] The said model specifications use threshold delay set to $d = 1$ and both of the models are significantly non-linear

[2] A positive relationship between a monetary policy loss function and market inefficiency was confirmed

Figure 5.2: Quarterly Efficiency Indices with Regime Thresholds



Source: Prague Stock Exchange, Wiener Borse, own Construction

series were therefore devised to offer a closer look at value of the additional information brought to policy inference by including the constructed time-series of market efficiencies. As confirmed in Chapter 4, these models were stable in all examined cases. Though some improvement in yielded model forecasts were recorded during out-of-sample prediction comparison, this improvement was not decisive enough to be noteworthy here as the simple VAR models struggle with the zero lower bound of the interest rates present in recent years. For this reason, the outputs of impulse response analysis are of more interest within the present's work's scope. In particular, the transmission of 1 standard deviation shock to short term interest rates is examined. Both Czech National Bank and European Central Bank set an overall price stability as a monetary policy goal, thus making the inflation rate a closely watched variable. The empirical results for price level response to interest rates uniformly exhibit the *price puzzle* phenomenon. It is a common feature of small scale multivariate models fitted on recent data, which is widely described in the literature (see *e.g.* Hanson (2004), Rusnák *et al.* (2013), Estrella (2015)) and explained by the forward looking policy rate cuts (and hikes). In expectation of economic recession, the central bank will ease the monetary conditions prior the price level adjustment. By use of frequentist approach (not Bayesian), the fitted three-variable model[3] interprets this causally as seen for the initial few quarters of inflation response

[3] or a four-variable model in case of Czech Republic

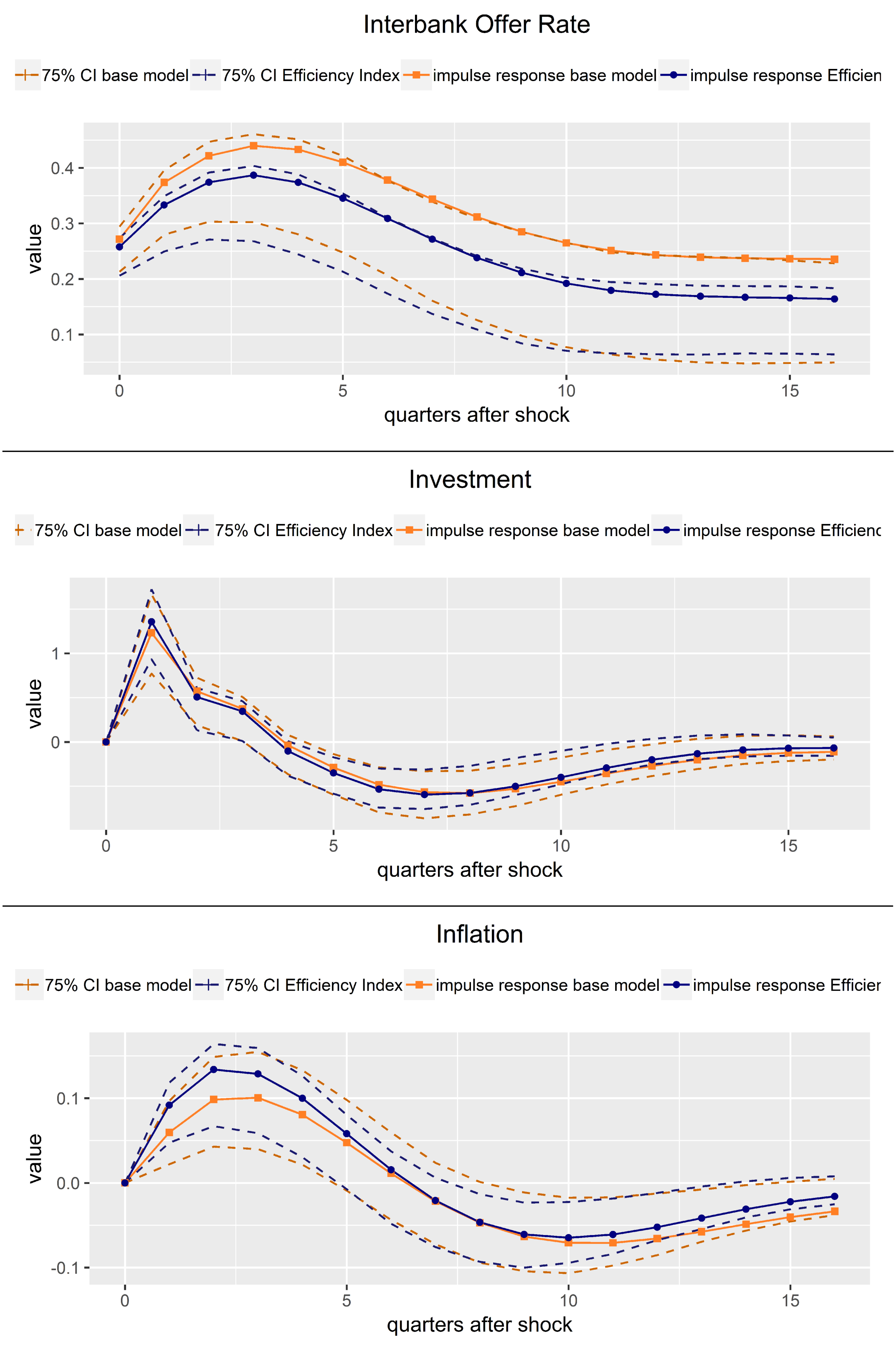
in Figure 5.3. Different kinds of commodity price indices[4] were individually tested as a proxy for the forward looking monetary policy — as the commodities typically price in the expectations immediately a thus mimic the information available to the policy makers — but the model results were little to no different from the more parsimonious benchmark and were disregarded as a result.

The inflation response is amplified by the inclusion of efficiency index in the model. Moreover, in the case of Austria the narrower confidence bands for the Efficiency Index (EI) appended model support the additional explanatory power of the variable suggested by the above stated improved forecasts. Similar amplifying effect is observed for the response of unemployment rate to policy rate hike. In line with general intuition, restrictive monetary policy results in an increase of unemployment rate (see Figure B.2), with the effect's peak approximately one year after the hike and the EI-augmented alternative yielding a significantly stronger response than the model benchmark. According to the mechanism described in Mishkin (2001), the asset prices channel transmits a monetary policy shock to economy through the wealth effect on asset owners and higher investments. Indeed, this is the effect observed in a response to an interest rate hike approximately one year after it takes place, but similarly as in the case of inflation rate, we see an initial positive response caused by additional factor excluded from the model. This time, it is the timing mismatch of Austrian economic cycle with the one of European Union. While the massive policy rate cuts introduced by the ECB arrived already in late 2008 due to sharp economic slowdown in Euro Area, the recession in Austria did not occur until the mid-2010. As in the case of price puzzle, this pattern in the data generally translates into seemingly positive causal effect of the interest rate hike to investment. In the following quarters, the Impulse Response Function (IRF) suggests significant temporary decrease of investments in line with economic theory, with the EI-augmented alternative being slightly (but not significantly) more pronounced and the benchmark response laying outside of the EI-augmented confidence bounds, thus suggesting the benchmark's significantly slower decay.

The above stated linear benchmark VAR models are thereafter generalized by allowing for two different regimes, thus forming a TVAR structure. As in the linear VAR case, the responses to orthogonal shocks are obtained by the

[4]including the Hamburg Institute of International Economics Commodity Price Index (HWWI) and different kinds of commodity prices indices supplied by the International Monetary Fund

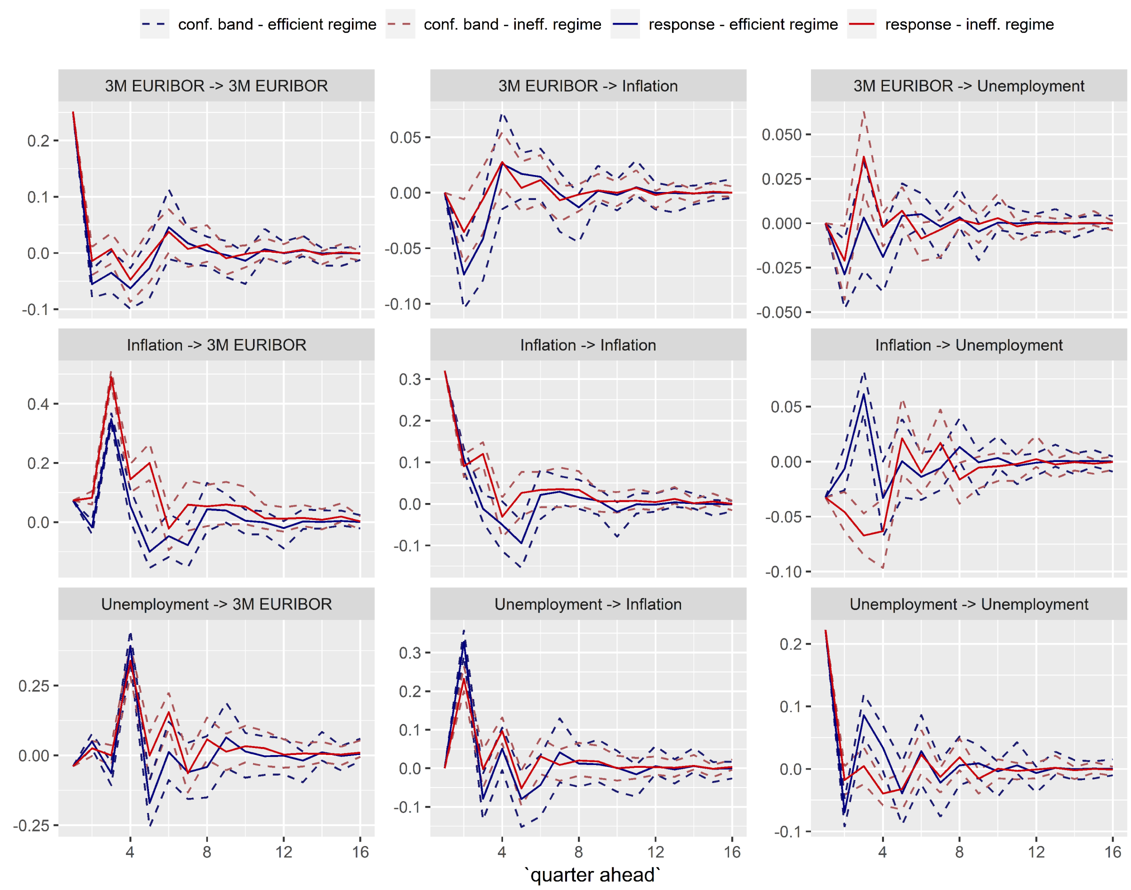
Figure 5.3: Responses to Restrictive Monetary Policy Shock - Austria



Source: Prague Stock Exchange, Wiener Borse, own Construction

Cholesky identification scheme. On one hand, the sample sizes become effectively smaller for each of the partial models as the observations are assigned to individual regimes. On the other hand, the non-linear approach is arguably more appropriate way to examine the market efficiency's influence to monetary transmission, than a simple addition of efficiency measure as an exogenous variable. Results of the TVAR analysis do in fact support the hypothesis proposed by the thesis, as for both of the examined countries, there is a significant non-linearity confirmed by the Hansen (1999) type test when using the once-lagged EI as a transition variable. The curves depicted in Figure 5.4 demonstrate responses of the three endogenous variables (*i.e.* 3M interest rates, unemployment rates and inflation rates) to all three possible shocks with the top row showing the effects of restrictive monetary policy shock (1 standard deviation interest rate hike). In line with the proposed hypothesis, observed responses indeed differ significantly for high and low efficiency regimes. For initial periods following the MP shock, the effects to Austrian inflation rate and interest rate are significantly amplified by the capital market's efficiency, while the unemployment rate's response is dampened. This in turn supports the notion, that a central bank may better target it's inflation rate with use of conventional MP tools, if the local capital market is functioning efficiently. Although it is the short-term interest rates that are typically controlled by central bank, making them the primary interest, it is worth noticing the change in price level shock transmission, as well. In particular, a positive price shock is recorded to have opposite effects for each of the two regimes. The negative supply shocks — connected typically with higher input prices (oil price shocks) — have historically led to leftward move on the aggregate demand curve, lower output, and higher unemployment. While this is suggested for the initial periods by the IRF produced by the efficient regime model, the same does not apply to the inefficient regime, where the asset channel pass-through of the transmission mechanism is limited.

Figure 5.4: Responses to 1SD Shocks - Austria



Source: Wiener Borse, OECD, EUROSTAT, own construction

Chapter 6

Concluding Remarks

In an effort to contribute to the discussion of monetary policy transmission dynamics, the present work initially surveys theoretical grounds for role of market efficiency in the transmission mechanism and then gathers empirical evidence from inflation targeting countries. While the surveyed literature suggests a role of capital markets in MP transmission, there are no prior attempts focusing directly on the relation of markets' efficiency and the way it can transmit the adjustments in MP. To shed light on this question, the present thesis firstly determines what were the market efficiency developments in selected countries over time. This is achieved by implementation of specific version of the market efficiency index introduced in Kristoufek & Vosvrda (2012). By combining estimates of long-term memory and fractal dimension, the index effectively measures a departure of market returns' underlying process from the theoretical random walk model. Desired narrowness of index's confidence bands is achieved through use of large time-series samples of high-frequency market data. By series of estimation with a rolling window of 1000 market returns observations, quarterly time series of market efficiency values are constructed for a sample of inflation targeting countries. This sample is thereafter used to form a panel, which next to the market efficiency series contains information about central banks' success in inflation targeting. In the performed panel regression, evidence is found, that the market efficiency indeed should be relevant for monetary policy makers. Nevertheless, the results are rather regarded as an indication of an underlying relationship due to the regression's limited robustness. For conclusive findings, specific economies should be examined in more detail as is done in this work for the Czech Republic and Austria cases. For these two economies, the estimated market efficiencies' developments are examined in context with common macroeconomic variables including inflation rate, unemployment rate and others. By a comparison with a benchmark small-scale VAR model, the information about market efficiency within the relevant economy is found to have an additional explanatory value, altering the ways an economy is predicted to respond to changes in MP. More specifically, movements in selected macro-variables that are not in line with economic theory, were explained by presence of higher levels of market inefficiencies, thus leaving the impulse responses clearer and more pronounced. A slight out-of-sample error improvement is achieved as well. In a similarly structured TVAR analysis it is confirmed, that an economy's response to MP shock differs for periods of high and periods of low market inefficiencies. Aligning with the aforementioned theoretical argument, claiming that the asset price channel is better functioning for efficient markets, the responses to an MP and price shocks exhibit more coherence with economic theory for high-efficiency regime. As an example, consider an inflation rate's negative response to restrictive MP shock, which is significantly more pronounced in the high-efficiency regime compared to the low-efficiency regime.

As described in Mishkin (2001), the asset channel of monetary transmission mechanism is achieved through asset pricing response to monetary conditions. An interest rate hike (cut) introduced by a central bank makes an investment to fixed income instruments relatively more (less) attractive than an investment to equities, presumably making the stock prices fall (rise) and causing a drag (boost) to economic activity through a wealth effect to stock owners, *i.e.* households. By following this mechanism, if a presence of market inefficiencies prevents the policy changes from being properly priced in, the MP effect is hindered. While this is indeed, what the empirical results of the present work support for the examined cases, the author makes no claim, that the work's scope is sufficient to apply universally to all developed economies, let alone the emerging economies. Still, both the theory and the cross-sectional part of the analysis suggest, that similar findings can be expected when applying the introduced framework to other cases. In particular, economies with higher proportion of annually traded volume of stock to GDP may even better reflect the discovered effects of market efficiency. Furthermore, an omnipresent issue throughout the work's empirical part was the limited length of available time-series data. As the countries with more developed and liquid capital markets typically also hold longer records of macroeconomic series, obtained empirical results are less likely to suffer from imbalances caused by the recent financial crisis. For such cases, a better (meaning less restricted) separation of high and low market efficiency regimes is therefore possible. Clearly, the same is true for the two cases examined within this work, if revisited in the future, as having additional data available, will require less constraints of model specification and regime separation to avoid over-fitting. Next to the improved length of macroeconomic series, better interpretability of the model can be achieved by an application of more sophisticated frameworks, such as utilization of coefficient priors in Bayesian estimation. For the issue at hand, comparison of responses to MP impulse obtained in the present work (*i.e.* through use of frequentist VAR) with those obtained through Bayesian estimation, would indeed be interesting and as such pose an opportunity for further research.

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Appendix A

Table A.1: Indices by Efficiency during 2013Q1-2018Q4

Rank	Country	Ticker	Efficiency Index
1	Brazil	BVSP	0.05138777
2	Norway	OBX	0.06252092
3	Serbia	BELEX15	0.06918189
4	Hungary	BUX	0.08982261
5	Indonesia	JKSE	0.10111893
6	Philippines	PSAL	0.11459433
7	Australia	ASX300	0.12042627
8	Czech Republic	PX	0.12048828
9	Iceland	OMXIPI	0.12350904
10	Turkey	BIST30	0.12383259
11	Japan	NIKKEI225	0.13175957
12	Thailand	SETI	0.13200918
13	Sweden	OMX30	0.13893284
14	Korea	KOSPI	0.13956428
15	Uganda	ALSIUG	0.14189027
16	Israel	TA125	0.14537779
17	Romania	BETI	0.1478642
18	Colombia	COLCAP	0.14810649
19	Mexico	IPC	0.15132139
20	New Zealand	NZ50	0.1555818
21	Canada	TSX	0.15989061
22	Chile	IPSA	0.17143167
23	United Kingdom	FTSE	0.17604963
24	Poland	WIG	0.18626338
25	South Africa	JALSH	0.21281142
26	Peru	SPBLGPT	0.32411976
27	Ghana	GSE	0.7214259

Table A.2: Granger Causality Testing with Investment: p-values

	Austria				Czech Republic				
	π_t	k_t	i_t	c_t	π_t	k_t	i_t	c_t	q_t
π_t	0.00	0.01	0.00	0.09	0.00	0.10	0.00	0.36	0.07
k_t	0.26	0.00	0.37	0.65	0.43	0.00	0.33	0.15	0.83
i_t	0.12	0.00	0.00	0.90	0.25	0.31	0.00	0.02	0.40
c_t	0.09	0.10	0.01	0.00	0.09	0.02	0.00	0.00	0.38
q_t					0.42	0.20	0.01	0.51	0.00

table lists p-values for joint significance of two lags for the regressor in RHS column

q_t stands for the EURCZK exchange rate

A.1 Baseline VAR Coefficients with Unemployment

$$\mathbf{y}_t = \mathbf{F}_0 + \mathbf{\Psi}_p(L)\mathbf{y}_t + \mathbf{u}_t, \quad \mathbf{y}_t = (\pi_t, \Delta u_t, i_t), \quad p = 2 \tag{A.1}$$

Table A.3: Baseline VAR Coefficients - Austria

	Inflation		Unemployment		3M EURIBOR	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
π_{t-1}	1.150	0.115	-0.139	0.073	0.122	0.087
Δu_{t-1}	-0.148	0.179	-0.129	0.113	-0.149	0.135
i_{t-1}	0.242	0.143	-0.147	0.091	1.389	0.108
π_{t-2}	-0.358	0.112	0.192	0.071	-0.215	0.085
Δu_{t-2}	0.053	0.175	0.054	0.110	-0.053	0.132
i_{t-2}	-0.260	0.144	0.157	0.091	-0.412	0.109
interc.	0.422	0.107	-0.120	0.068	0.184	0.081

Table A.4: Baseline VAR Coefficients - Czech Republic

	Inflation		Unemployment		3M PRIBOR	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
π_{t-1}	1.157	0.116	-0.016	0.034	0.186	0.047
Δu_{t-1}	-0.059	0.402	0.415	0.119	0.062	0.163
i_{t-1}	0.383	0.282	0.054	0.084	1.209	0.115
q_{t-1}	0.156	0.152	0.081	0.045	0.145	0.062
π_{t-2}	-0.456	0.111	0.024	0.033	-0.170	0.045
Δu_{t-2}	-0.194	0.371	0.133	0.110	-0.153	0.151
i_{t-2}	-0.291	0.247	-0.007	0.073	-0.321	0.100
q_{t-2}	-0.143	0.149	-0.105	0.044	-0.111	0.061
interc.	0.090	1.141	0.536	0.339	-0.782	0.464

A.2 EI-Augmented VAR with Unemployment

$$\mathbf{y}_t = \mathbf{F}_0 + \mathbf{\Psi}_p(L)\mathbf{y}_t + EI_t + \mathbf{u}_t, \quad \mathbf{y}_t = (\pi_t, \Delta u_t, i_t), \quad p = 2 \tag{A.2}$$

Table A.5: EI-Augmented VAR Coefficients - Austria

	Inflation		Unemployment		3M EURIBOR	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
π_{t-1}	1.056	0.119	-0.111	0.077	0.190	0.090
Δu_{t-1}	-0.078	0.176	-0.150	0.114	-0.201	0.133
i_{t-1}	0.397	0.154	-0.193	0.100	1.275	0.116
π_{t-2}	-0.306	0.111	0.177	0.072	-0.253	0.084
Δu_{t-2}	0.080	0.170	0.046	0.111	-0.073	0.129
i_{t-2}	-0.404	0.153	0.200	0.099	-0.306	0.116
interc.	0.820	0.198	-0.239	0.129	-0.108	0.150
EI_t	-3.211	1.363	0.960	0.884	2.354	1.029

Table A.6: EI-Augmented VAR Coefficients - Czech Republic

	Inflation		Unemployment		3M PRIBOR	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
π_{t-1}	1.157	0.117	-0.019	0.034	0.186	0.048
Δu_{t-1}	-0.068	0.413	0.365	0.119	0.069	0.168
i_{t-1}	0.386	0.286	0.073	0.083	1.207	0.116
q_{t-1}	0.157	0.154	0.092	0.044	0.144	0.063
π_{t-2}	-0.458	0.113	0.015	0.033	-0.169	0.046
Δu_{t-2}	-0.191	0.375	0.152	0.108	-0.156	0.152
i_{t-2}	-0.289	0.249	0.002	0.072	-0.322	0.101
q_{t-2}	-0.145	0.152	-0.118	0.044	-0.110	0.062
interc.	0.113	1.172	0.674	0.338	-0.801	0.477
EI_t	-0.184	1.816	-1.083	0.524	0.144	0.738

A.3 Baseline VAR with Investment

$$\mathbf{y}_t = \mathbf{F}_0 + \mathbf{\Psi}_p(L)\mathbf{y}_t + \mathbf{u}_t, \quad \mathbf{y}_t = (\pi_t, k_t, i_t), \quad p = 2 \tag{A.3}$$

Table A.7: Baseline VAR (Investment) - Austria

	Inflation		Unemployment		3M EURIBOR	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
π_{t-1}	1.11	0.116	0.285	1.242	0.114	0.087
k_{t-1}	0.0103	0.010	0.180	0.105	0.007	0.007
i_{t-1}	0.219	0.143	4.538	1.529	1.376	0.107
π_{t-2}	-0.347	0.112	-1.539	1.203	-0.215	0.0846
k_{t-2}	-0.001	0.01	0.239	0.101	0.005	0.007
i_{t-2}	-0.234	0.145	-5.014	1.550	-0.397	0.109
const	0.415	0.107	4.367	1.140	0.175	0.080

Table A.8: Baseline VAR (Investment) - Czech Republic

	Inflation		Unemployment		3M PRIBOR	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
π_{t-1}	1.160	0.114	0.121	0.759	0.185	0.046
k_{t-1}	0.013	0.016	0.797	0.109	-0.002	0.007
i_{t-1}	0.376	0.281	1.949	1.875	1.213	0.114
q_{t-1}	0.150	0.147	-0.854	0.985	0.150	0.060
π_{t-2}	-0.449	0.109	-0.914	0.728	-0.168	0.044
k_{t-2}	-0.002	0.016	-0.136	0.107	0.006	0.007
i_{t-2}	-0.291	0.242	-1.619	1.617	-0.323	0.099
q_{t-2}	-0.144	0.144	1.132	0.962	-0.119	0.059
const	0.265	1.179	-5.775	7.875	-0.693	0.480

A.4 EI-Augmented VAR with Investment

$$\mathbf{y}_t = \mathbf{F}_0 + \mathbf{\Psi}_p(L)\mathbf{y}_t + EI_t + \mathbf{u}_t, \quad \mathbf{y}_t = (\pi_t, k_t, i_t), \quad p = 2 \tag{A.4}$$

Table A.9: EI-Augmented VAR (Investment) - Austria

	Inflation		Unemployment		3M EURIBOR	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
π_{t-1}	1.020	0.121	-0.308	1.333	0.182	0.092
k_{t-1}	0.011	0.010	0.182	0.105	0.007	0.007
i_{t-1}	0.356	0.149	5.268	1.641	1.293	0.114
π_{t-2}	-0.282	0.112	-1.187	1.235	-0.256	0.085
k_{t-2}	0.000	0.009	0.242	0.101	0.004	0.007
i_{t-2}	-0.361	0.149	-5.690	1.644	-0.320	0.114
const	0.829	0.196	6.581	2.159	-0.078	0.149
EI_t	-3.318	1.335	-17.737	14.704	2.027	1.017

Table A.10: EI-Augmented VAR (Investment) - Czech Republic

	Inflation		Unemployment		3M PRIBOR	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
π_{t-1}	1.160	0.114	0.145	0.739	0.185	0.047
k_{t-1}	0.013	0.017	0.738	0.110	-0.002	0.007
i_{t-1}	0.382	0.284	1.473	1.838	1.209	0.116
q_{t-1}	0.152	0.149	-1.016	0.961	0.148	0.061
π_{t-2}	-0.452	0.111	-0.691	0.715	-0.167	0.045
k_{t-2}	-0.002	0.016	-0.088	0.106	0.007	0.007
i_{t-2}	-0.289	0.244	-1.773	1.576	-0.324	0.099
q_{t-2}	-0.147	0.146	1.325	0.940	-0.118	0.059
const	0.310	1.207	-9.009	7.798	-0.717	0.491
EI_t	-0.366	1.824	26.708	11.786	0.203	0.743

A.5 Threshold VAR Coefficients

$$\mathbf{y}_t = (\mathbf{A}_0^h + \mathbf{\Gamma}_p^h(L)\mathbf{y}_t) I_{\{EI_{t-1}>\gamma\}} + \left(\mathbf{A}_0^l + \mathbf{\Gamma}_p^l(L)\mathbf{y}_t\right) I_{\{EI_{t-1}\leq\gamma\}} + \boldsymbol{\varepsilon}_t, \quad p = 2 \quad \text{(A.5)}$$

Table A.11: TVAR Coefficient Estimates - Austria

Inefficient (h)	Inflation		Unemployment		3M EURIBOR	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
interc.	0.0079	0.2046	0.1465	0.1379	-0.1825	0.1606
π_{t-1}	0.8342	0.2309	-0.1523	0.1556	0.2371	0.1812
Δu_{t-1}	0.2935	0.3326	-0.2147	0.2242	0.1276	0.2610
i_{t-1}	0.9971	0.3627	0.1533	0.2444	1.3225	0.2846
π_{t-2}	0.1176	0.2153	0.0837	0.1451	-0.0968	0.1689
Δu_{t-2}	0.0362	0.3331	0.0664	0.2245	0.0509	0.2613
i_{t-2}	-1.0138	0.3827	-0.1993	0.2579	-0.3152	0.3002
Efficient (l)	Inflation		Unemployment		3M EURIBOR	
interc.	0.6101	0.1314	-0.2031	0.0886	0.2118	0.1031
π_{t-1}	1.1950	0.1343	-0.1251	0.0905	0.1434	0.1053
Δu_{t-1}	-0.2454	0.1970	-0.1140	0.1327	-0.2523	0.1545
i_{t-1}	0.2052	0.1918	-0.1248	0.1293	1.1750	0.1505
π_{t-2}	-0.4579	0.1244	0.1975	0.0838	-0.2470	0.0976
Δu_{t-2}	0.2392	0.2025	0.0939	0.1365	-0.1997	0.1589
i_{t-2}	-0.2339	0.1840	0.1589	0.1240	-0.2332	0.1444

Table A.12: TVAR Coefficient Estimates - Czech Republic

Inefficient (h)	Inflation		Unemployment		3M PRIBOR	
	Estimate	Std. Error	Estimate	Std. Error	Estimate	Std. Error
interc.	-0.0873	1.5873	0.7106	0.4267	-1.2797	0.5353
π_{t-1}	1.1693	0.1701	-0.0446	0.0457	0.1424	0.0574
Δu_{t-1}	0.0858	0.5280	0.4328	0.1419	-0.0197	0.1781
i_{t-1}	0.5304	0.3673	0.0687	0.0987	1.4150	0.1239
q_{t-1}	0.3073	0.2122	0.0152	0.0571	0.3900	0.0716
π_{t-2}	-0.4134	0.1488	0.0109	0.0400	-0.1123	0.0502
Δu_{t-2}	-0.0470	0.4914	0.1536	0.1321	-0.3223	0.1657
i_{t-2}	-0.4731	0.3152	-0.0023	0.0847	-0.5158	0.1063
q_{t-2}	-0.2855	0.2028	-0.0438	0.0545	-0.3396	0.0684
Efficient (l)	Inflation		Unemployment		3M PRIBOR	
interc.	0.2137	2.2571	1.1148	0.6067	-1.3170	0.7611
π_{t-1}	1.0545	0.1966	0.0579	0.0529	0.1199	0.0663
Δu_{t-1}	-0.3171	0.7880	0.3540	0.2118	-0.2843	0.2657
i_{t-1}	0.1178	1.1330	-0.3355	0.3046	0.3276	0.3821
q_{t-1}	-0.2846	0.3135	0.3249	0.0843	-0.1844	0.1057
Δu_{t-2}	-0.4013	0.2123	-0.0150	0.0571	-0.1046	0.0716
Δu_{t-2}	-0.5307	0.8527	0.2570	0.2292	-0.1841	0.2875
i_{t-2}	-0.0696	1.2022	0.4770	0.3232	0.5618	0.4054
q_{t-2}	0.2957	0.3283	-0.3823	0.0883	0.2349	0.1107

Table A.13: VAR - Serial Correlation - 2^{nd} lag

		Δu_t^*	$\Delta u_t, EI_t^{***}$	k_t^{**}	k_t, EI_t
AT	π	0.969	0.778	0.836	0.746
	Δu	0.802	0.773	0.852	0.761
	i	0.985	0.887	0.955	0.915
CZ	π	0.910	0.892	0.787	0.790
	Δu	0.959	0.950	0.869	0.991
	i	0.370	0.342	0.236	0.265
	q	0.665	0.634	0.609	0.599

- p-values for joint significance up to the 2^{th} lag
- first row depicts the various models
(*) models with unemployment as an economy proxy
(**) models with investment
(***) eff. index included as an explanatory variable

Table A.14: VAR - Serial Correlation - 4^{th} lag

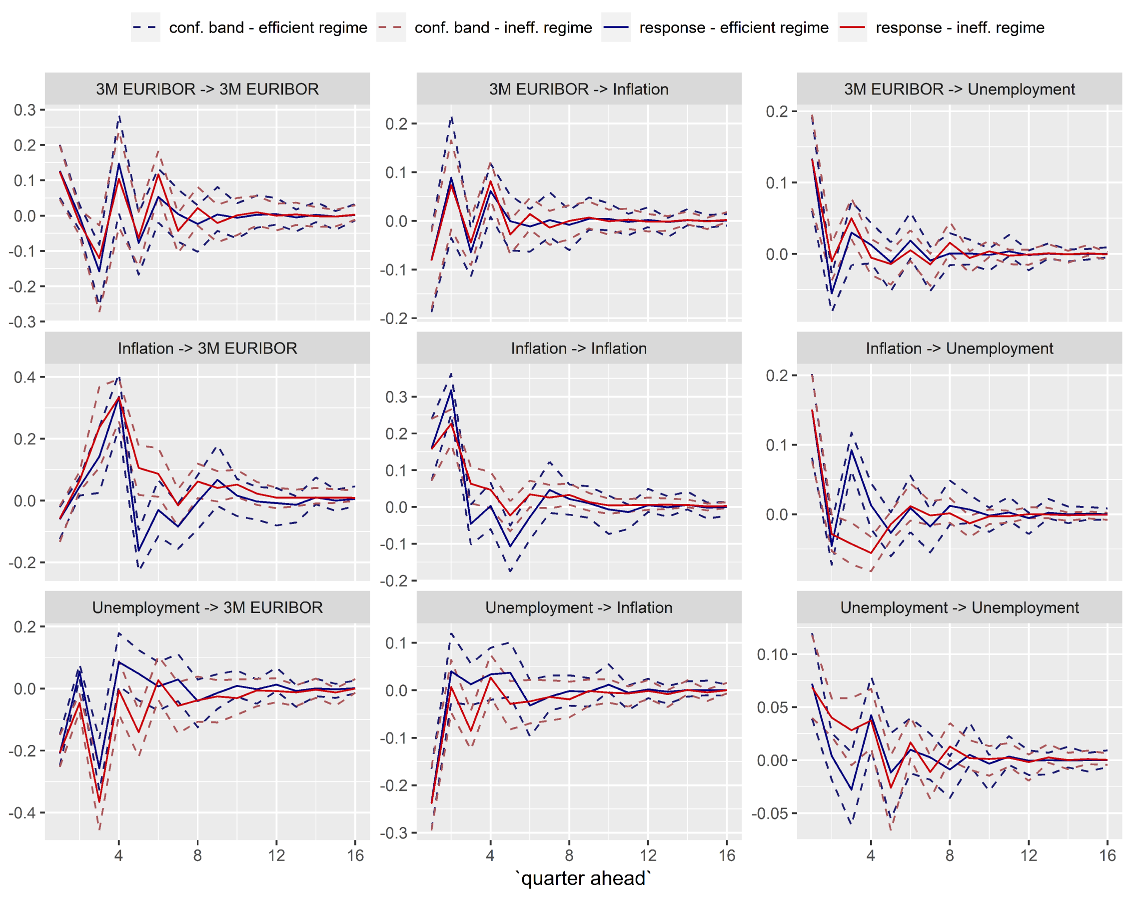
		Δu_t^*	$\Delta u_t, EI_t^{***}$	k_t^{**}	k_t, EI_t
AT	π	0.141	0.109	0.168	0.118
	Δu	0.003	0.004	0.013	0.011
	i	0.193	0.354	0.169	0.233
CZ	π	0.006	0.006	0.009	0.010
	Δu	0.965	0.994	0.012	0.029
	i	0.103	0.111	0.041	0.044
	q	0.790	0.799	0.689	0.699

- p-values for joint significance up to the 4^{th} lag

Appendix B

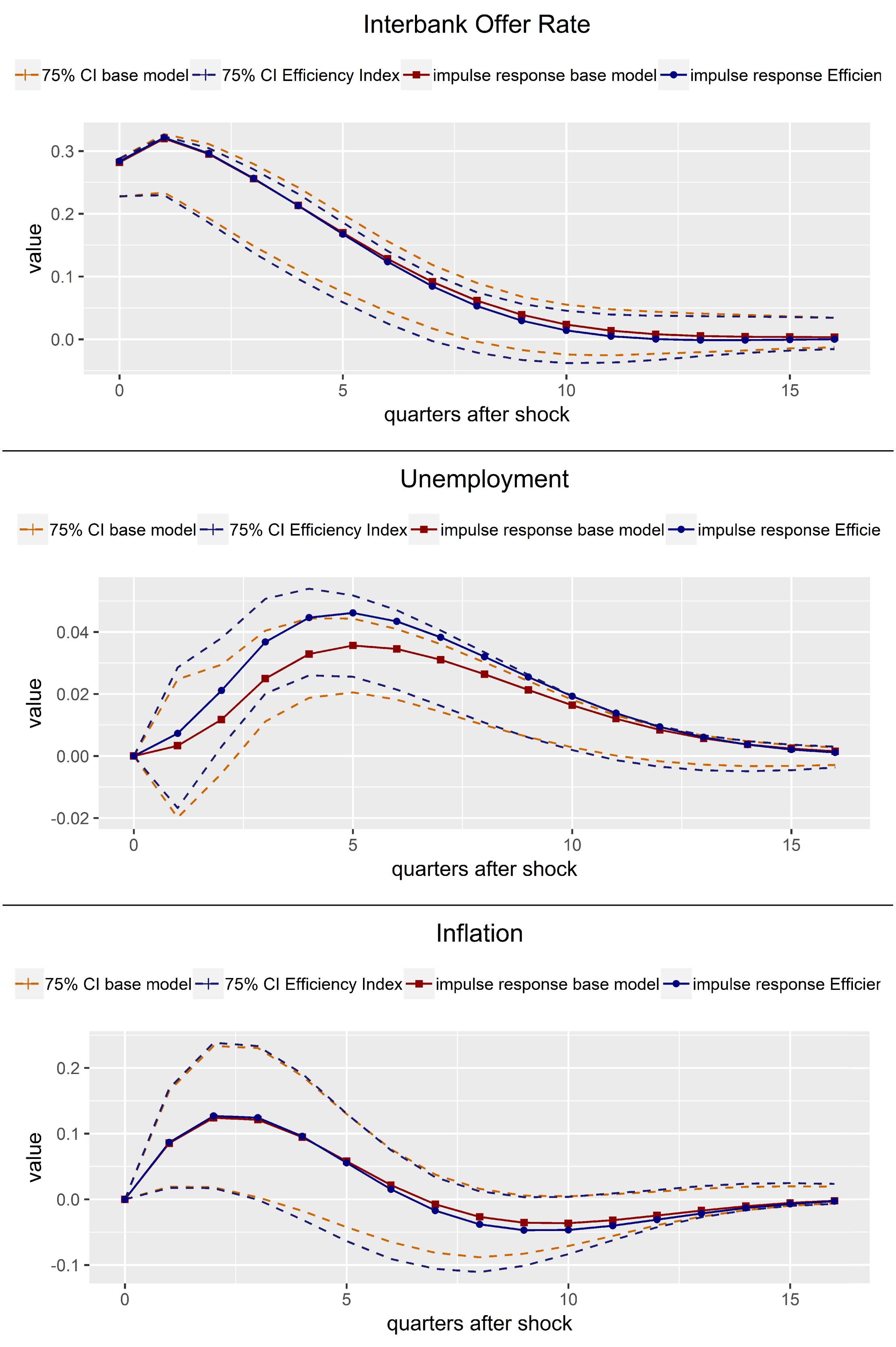
Supplementary Figures

Figure B.1: Orthogonal Shock Responses with sign Restriction - Austria



Source: Wiener Borse, OECD, EUROSTAT, own Construction

Figure B.2: Responses to Restrictive Monetary Policy Shock - Czechia



Source: Prague Stock Exchange, Wiener Borse, own Construction

Figure B.3: Eff. Index - RW vs. RW with switch to White Noise

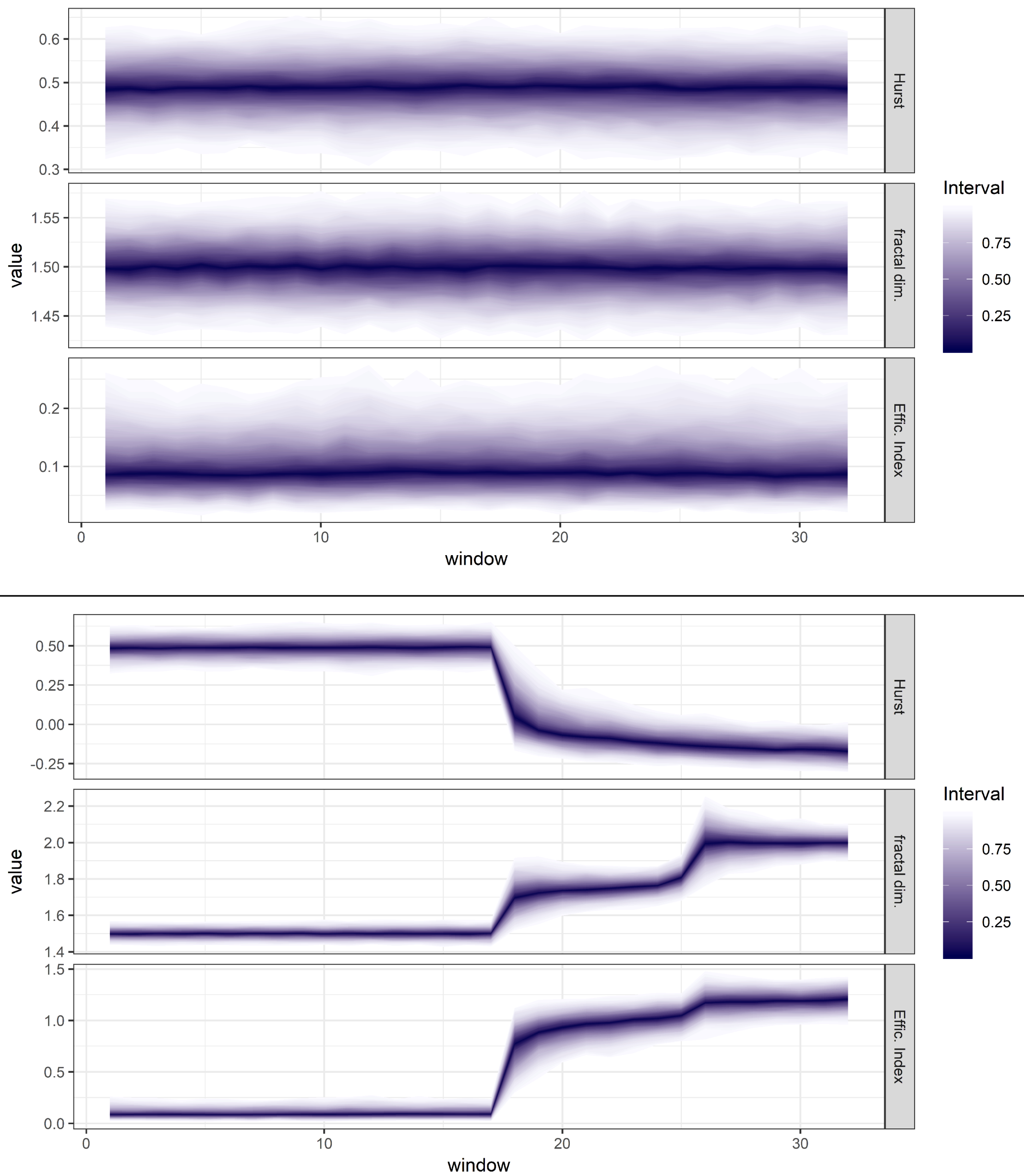


Figure B.4: MP Loss Function vs. Market Efficiency

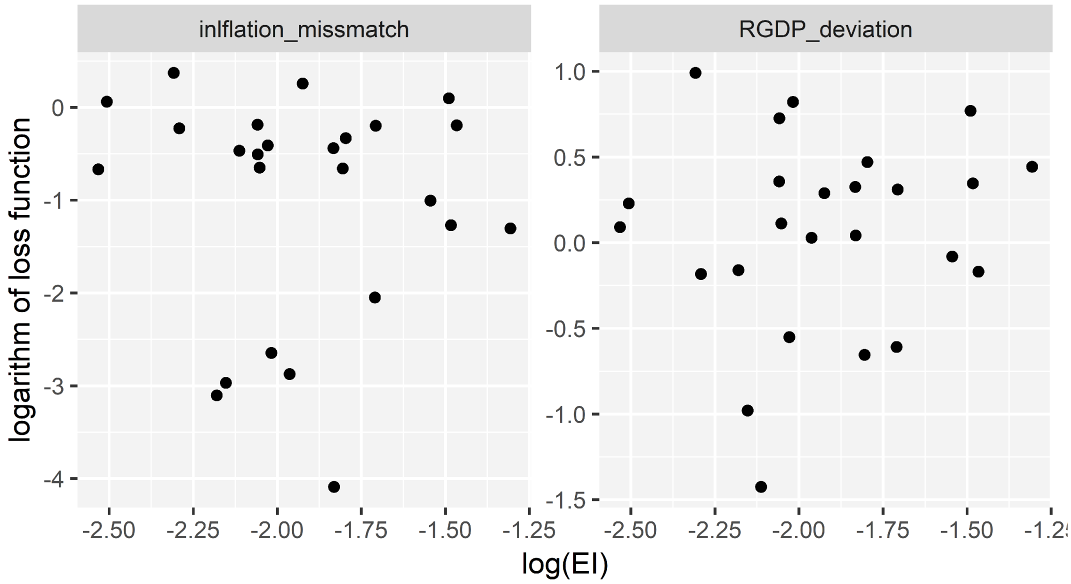


Figure B.5: TVAR Residuals' Empirical Distribution