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Samu Kärkkäinen

Essays on Monetary Policy

JYVÄSKYLÄ UNIVERSITY
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ABSTRACT

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This doctoral dissertation studies questions related to monetary policy and its economic effects. Particularly, the focus is on questions that have been relevant from the point of view of both practical policymaking as well as academic research in the recent decades. The dissertation consists of an introductory chapter and three distinct research essays. The two first essays are empirical, while the third one is more theoretical in nature.

The first essay examines the role of stock and currency market information in the monetary policy rules of 14 OECD countries during the period of 1999–2016. The results show that both the stock market as well as currency market variables have been statistically significant predictors in the monetary policy rules of several OECD countries. Additionally, the results indicate that stock and currency market variables have had significance for monetary policy through their potential role in providing information about future economic activity.

The second essay examines the influence of United States monetary policy on the monetary policies of four small open economies. The results indicate that US monetary policy has systematically influenced the monetary policies especially in Canada and the UK. Moreover, surprise developments in US monetary policy are shown to affect the interest rates in Canada, Norway, and Sweden, although the strength of this result is somewhat dependent on the empirical method used. In addition, the essay studies whether the small open economies have utilised foreign exchange interventions to enhance their monetary policy autonomy. This hypothesis is not supported in light of the empirical results of the study.

The third essay builds a theoretical general equilibrium model that analyses the extent to which the economic effects of the central bank's quantitative easing are dependent on the fiscal policy conducted by the government. It is shown that the effectiveness of quantitative easing depends on whether the government adjusts its budget constraint through changes in taxation or by issuing debt. In the latter scenario, it is shown that quantitative easing is more effective when the government is issuing bonds of long maturity.

Keywords: Monetary policy, stock market, currency market, international macroeconomics, unconventional monetary policy, quantitative easing, fiscal policy

TIIVISTELMÄ

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Väitöskirjassa tutkitaan rahapolitiikkaan ja sen taloudellisiin vaikutuksiin liittyviä kysymyksiä. Painopiste on erityisesti kysymyksissä, jotka ovat olleet viime vuosikymmenten aikana keskeisiä niin käytännön rahapolitiikan harjoittamisen kuin akateemisen tutkimuksenkin kannalta. Väitöskirja koostuu johdantoluvusta seka kolmesta tutkimuksesta. Kaksi ensimmäistä tutkimusta ovat empiirisiä, kun taas kolmas on luonteeltaan teoreettisempi.

Ensimmäinen tutkimus tarkastelee osake- ja valuuttamarkkinainformaation roolia 14 OECD-maan rahapolitiikkasäännöissä vuosina 1999–2016. Tutkimuksessa havaitaan, että niin osake- kuin valuuttamarkkinamuuttujatkin ovat olleet tilastollisesti merkitseviä selittäjiä usean OECD-maan rahapolitiikkasäännöissä. Lisäksi osoitetaan, että osake- ja valuuttamarkkinamuuttujilla on ollut potentiaalinen epäsuora rooli tulevan kokonaistaloudellisen kehityksen ennustajina, ja sitä kautta merkitysta rahapolitiikkapäätösten kannalta.

Toisessa tutkimuksessa arvioidaan Yhdysvaltojen rahapolitiikan vaikutusta neljän pienen avotalouden rahapolitiikkaan. Tulokset viittaavat siihen, että Yhdysvaltojen rahapolitiikalla on ollut systemaattinen rooli erityisesti Kanadan ja Ison-Britannian harjoittamassa rahapolitiikassa. Lisäksi Yhdysvaltojen rahapolitiikkasokkien todetaan vaikuttaneen korkoihin Kanadassa, Norjassa ja Ruotissa, joskin tuloksen vahvuuden osoitetaan olevan riippuvainen käytettävästä tutkimusmenetelmästä. Tutkimuksessa tarkastellaan myös, ovatko pienet avotaloudet käyttäneet valuuttainterventioita lisätäkseen rahapolitiikkansa autonomiaa. Tälle hypoteesille ei löydetä tukea.

Kolmannessa tutkimuksessa kehitetään teoreettinen yleisen tasapainon malli, jonka avulla tutkitaan, missä määrin keskuspankin suorittaman määrällisen keventämisen talousvaikutukset riippuvat valtion harjoittamasta finanssipolitiikasta. Osoitetaan, että määrällisen keventämisen tehokkuus riippuu siitä, sopeuttaako valtio budjettirajoitteensa muuttamalla verotusta vai laskemalla liikkeeseen valtionlainoja. Jälkimmäisessä tapauksessa määrällisen keventämisen osoitetaan olevan tehokkaimmillaan silloin, kun valtio laskee liikkeeseen juoksuajaltaan pitkiä velkakirjoja.

Asiasanat: Rahapolitiikka, osakemarkkinat, valuuttamarkkinat, kansainvälinen makrotaloustiede, epätavanomainen rahapolitiikka, määrällinen keventäminen, finanssipolitiikka

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CONTENTS

1 INTRODUCTION

1.1 Background

Broadly speaking, monetary policy can be defined as the actions taken by the central bank to achieve the economic objectives stated in its mandate. Most often, these objectives include price stability, low unemployment, and securing conditions for sustainable growth of the real economy—concepts that are important for welfare and social stability.

It is thus no surprise that research on monetary policy remains vibrant. Can monetary policy affect prices and real economic activity? What is the mechanism behind monetary policy transmission? Should monetary policy target a monetary aggregate, or should policy be instead implemented by specifying a target for the overnight interbank rate that the central bank then tries to achieve through various policy tools? Should low and stable inflation be the primary objective of monetary policy, or should central banks pay attention to other factors as well? These are some of the fundamental questions that researchers have attempted to answer over the years, and around which a vast literature has emerged.

The aim of this doctoral thesis is to provide insights on various issues that the research on monetary policy has faced in recent decades. Especially, the aim of this work is to shed light on the issues that are relevant from both academic as well as policymaking perspectives. The following research questions are explored in this thesis: have the central banks in various advanced economies assigned importance to stock prices and exchange rates; to what extent are the central banks of inflation-targeting small open economies following the policy decisions of the Federal Reserve (i.e., the central bank of the United States); and how is the transmission and macroeconomic effectiveness of quantitative easing altered under different fiscal policies pursued by the central government. These questions will be addressed from both an empirical and theoretical perspective. In the following subsections, a brief overview of the topics addressed in this dissertation.

1.1.1 Research topics and related literature

1.1.1.1 Monetary policy rules and the role of financial market information

Kydland and Prescott (1977) made a path-breaking contribution to macroeconomics by showing that in macroeconomic models where the dynamics of the economy depend on private sector expectations about the evolution of endogenous variables, discretionary policy, that is, a policy that at each point in time chooses the policy instrument so as to maximise some given objective, could lead to time inconsistency. A policy commitment that is optimal from today's perspective might turn out to be suboptimal in the future, and the policymaker will be tempted to renege on its promise when the time to implement the policy arrives. If expectations are rational, agents will anticipate this, and hence policy is unable to influence the private sector behaviour in the intended way. A classic example of time-inconsistent policymaking in the context of monetary policy is presented by Barro and Gordon (1983), who showed, using a simple macroeconomic model, that if a policymaker does not pre-commit to future policy choices by following an appropriate policy rule but instead optimises every period, higher than socially optimal inflation will occur.

The time inconsistency result of Kydland and Prescott (1977) led to an attention shift towards the design of optimal *policy rules*, that is, contingency plans that describe how the policy instrument should be adjusted given the past, current, and expected future state of the economy. In terms of monetary policy, early contributions to the literature specified policy rules related to the money supply, over which the central bank has control. Examples of articles considering properties of money supply rules are McCallum (1988) and Meltzer (1989). However, in practice monetary policy has, at least in recent decades before the global financial crisis of 2007–2008, been characterised by an operating target for an overnight interest rate. Apparently, there has been, at least to a certain extent, a disconnect between the theoretical treatment of monetary policy rules and the actual policy practice of central banks.

In an influential study, Taylor (1993) proposed a simple theoretical formulation of a policy rule whereby the central bank sets its target interest rate as a function of the deviation of inflation from its target and the output gap:

$$i_t = \pi_t + \alpha_y y_t + \alpha_\pi \left(\pi_t - \pi_t^*\right) + r_t^*, \tag{1}$$

where i_t denotes the federal funds rate, the main policy instrument of the Federal Reserve, at time t; π_t denotes inflation and π_t^* its target value; y_t is the percentage deviation of output from its long-term trend; and r_t^* is the equilibrium real rate, that is, the real interest rate that would prevail when inflation is at its target value and output at its long-run trend.[1]

Taylor found that for certain values of the coefficients α_y and α_π, such prescription of interest rate policy fit the actual US data rather well for the period

[1] The reader should note that the notation employed here differs somewhat from the original notation used in Taylor (1993).

of 1987–1992. Taylor thus concluded that the Federal Reserve's monetary policy had been, during that time period, conducted as if the central bank was following a policy rule of the form described in Equation (1). Subsequent research papers studying the monetary policy of the US and other countries estimated the parameters of such "Taylor rules" using econometric methods. For example, seminal papers by Clarida et al. (1998, 2000) found that monetary policy in several important economies could be described by a similar policy reaction function. In addition, Clarida et al. (2000) pointed out that there was a notable difference in the estimated inflation response coefficient across the regimes of different Federal Reserve chairmen. In particular, their estimates implied that the Fed was reacting to the changes in inflation much less aggressively during the period before the appointment of Paul Volcker in 1979. Further, the authors attributed the high and volatile inflation observed in the US during the 1960's and 70's precisely to the failure of the Fed to react aggressively enough to developments in inflation.

The original Taylor rule assumed that the central bank was reacting to inflation and output, which seems reasonable given that the Federal Reserve announces the stability of prices and maximum sustainable employment as its collective goal in its dual mandate. More generally, the inclusion of the inflation rate in the reaction function seems especially well grounded because several advanced economies have since the early 1990's been following a policy regime known as inflation targeting when pursuing their price stability goals. Under an inflation targeting regime, the central bank publicly announces a transparent numerical target (or a target range) for the inflation rate, seeking to achieve this target by using the policy tools at its disposal (Bernanke and Mishkin, 1997). The inflation targeting framework is often characterised by accountability, as the central bank is obliged to explain its policy decisions and how these decisions will help in bringing the inflation rate to its target (Svensson, 2010).

The presence of the output gap in the central bank reaction function can be rationalised, even if the central bank does not have a direct goal related to the stabilization of the real economy, through some kind of Phillips curve relation that links inflation and real economic activity. This kind of relation is often found in theoretical macroeconomic models.[2] This kind of "hybrid" setting, in which the central bank might also be reacting directly to other variables than inflation, is sometimes called flexible inflation targeting (Svensson 2000).

One of the questions arising in the context of monetary policy reaction functions, such as the one in Equation (1), is whether the central bank should also respond (or whether it in fact has historically responded) to the information regarding financial markets. This question was partly motivated by the stock market bubble of the late 1990's that, upon bursting, dragged the US economy into a recession. Some economists argued that a "leaning against the wind" policy,

2 The Phillips curve, originating in the study of Phillips (1958), is an inverse relation between the unemployment rate and inflation. Modern macroeconomic models often formulate the Phillips curve in terms of expected inflation and the deviation of output from its trend or potential value; see, for example, Roberts (1995) and the exhaustive treatment of New Keynesian economics given in Woodford (2003).

that is, the central bank reacting to misalignments between stock prices and their fundamental values, could be beneficial because it would rein in the stock market bubbles that, when bursting, could affect the real economy and price stability. Moreover, even if a direct response would not be warranted, the literature has found that asset prices may have some predictive value for inflation and real activity, as reviewed by Stock and Watson (2003).

On a related note, some studies have asked whether the exchange rate should be included in the monetary policy rule. This question seems especially relevant from the point of view of an open economy, as the fluctuations in the exchange rate may at least partly transmit to import prices (Campa and Goldberg, 2005). This, in turn, may have an effect on inflation if the changes in the prices of imports are reflected in consumer prices.

Moreover, as emphasised by Svensson (2000), changes in relative prices between domestic and foreign goods induced by exchange rate movements affect both domestic and foreign demand for domestic goods. This, in turn, influences aggregate demand and inflation. Ball (1999) examines the issue in a simple small open economy model and finds that a monetary policy rule entailing a direct response to the changes in the real exchange rate would yield a better outcome, measured in terms of output gap and inflation fluctuations, than a rule that only places importance on inflation and real activity. However, Ball finds the improvement to be quite small.

Svensson (2000) studies a similar model, assuming rational expectations and more explicit microfoundations, and finds that a policy rule involving a direct reaction to the exchange rate would, in fact, while reducing the inflation volatility, increase the variability of output. Taylor (2001), summarizing these findings, argues that the observation that direct reactions to the exchange rate lead to only small improvements may stem from the fact that it is more preferable to respond indirectly—that is, not adjusting the policy rate directly in response to swings in the real exchange rate but rather in response to inflation and output gap developments they might produce—since this would minimise the potentially harmful swings of the interest rate. In a more recent study, Lubik and Schorfheide (2007) estimate structural general equilibrium models for Australia, Canada, New Zealand, and the UK. They find that the central banks of Australia and New Zealand did not respond directly to exchange rates during the sample period of 1983–2004 (1988–2004 for New Zealand), while the central banks of Canada and the UK did.

The issues concerning financial market stability and exchange rates as central banks' potential policy objectives seem relevant in the post-financial crisis world. The global financial crisis of 2007–2008 clearly showed that, in practice, monetary policy should probably place importance on policy goals above and beyond low and stable inflation. The crisis originated in the US housing markets, soon spreading to other sectors of financial markets and ultimately into the real economy.

Before the crisis, few macroeconomists thought that house prices and other asset prices played an important role in macroeconomic fluctuations, although there were some notable exceptions (Bernanke et al., 1999; Iacoviello, 2005; Kiyotaki and Moore, 1997). Consequently, from a purely academic perspective, there was no strong case for a central bank reacting to developments in asset prices, at least beyond their effects on inflation expectations (Bernanke and Gertler, 2000). However, as is often the case, theory and practice may differ. For this reason, it is interesting to take a historical perspective and study whether the central banks have actually considered asset market information important when deciding on monetary policy. Chapter 2 of this dissertation will explore this particular topic.

1.1.1.2 The era of financial globalisation: The influence of the Federal Reserve monetary policy on a small open economy and additional tools to enhance monetary autonomy

Since the mid-1980's, capital flows among industrial countries and between industrial and developing countries have grown rapidly (Prasad et al., 2005). As a result of financial globalisation, there is a stronger chance of monetary policy spillovers from globally important economies to the rest of the world. Rey (2015, 2016) documents the existence of the "global financial cycle"—a significant comovement of gross capital flows, credit growth, leverage, and asset prices across the world. Miranda-Agrippino and Rey (2015) find that the global financial cycle is partly driven by US monetary policy. An implication of this finding is that, through these international linkages of the global financial cycle, monetary policy decisions of the Federal Reserve might transmit to other economies as well.

The "Trilemma" result originating in the independent works of Mundell (1963) and Fleming (1962) is a fundamental result in international macroeconomics. It states that, under free capital movements, a country cannot simultaneously have a fixed exchange rate and an autonomous monetary policy. An implication of the result is that a country with perfect capital movements that lets its exchange rate float freely should be able to exert monetary policy independent of foreign influences. Recently, the validity of the Trilemma has been questioned by some authors. For example, Rey (2015) argues that a floating exchange rate might not be enough to guarantee monetary policy autonomy even under full capital mobility because financial interlinkages effectively transmit the monetary conditions of the center country (the United States) to the small open economies. She proposes that for a country to be able to exert autonomous monetary policy, capital movements should be restricted. Klein and Shambaugh (2015) find that, for advanced economies, a floating exhange rate regime, on average, implies a milder response of the local interest rate to the base country interest rate than a fixed exchange rate or a soft peg regime. However, Klein and Shambaugh's estimated regression coefficient on the base country interest rate in advanced economies exercising a float is still statistically significant, raising some concerns regarding the validity of Trilemma.

However, it is not entirely clear whether the results brought forth by Rey and others in fact imply the loss of monetary autonomy. For example, Nelson (2020) argues that the mere empirical fact that monetary policy developments in the US have an effect on small open economies' financial conditions is not inconsistent with monetary autonomy. According to Nelson, the problem with Rey's logic lies in the characterisation of monetary policy autonomy. Nelson's definition states that monetary policy autonomy means that the open economy's central bank has a decisive influence on the nominal value of economic activity. This definition, in fact, stems from the work of Friedman (1953). Friedman argues that the central bank's control over nominal economic activity follows from its ability to set the country's monetary instruments—taken by Friedman to mean the economy's monetary quantities. Rey, on the other hand, argues that the evidence regarding the movement of domestic financial variables in response to US monetary policy shocks conflicts the notion of monetary autonomy. According to Nelson, this finding could simply result from financial integration and should not be taken to indicate a loss of monetary autonomy.

Furthermore, Nelson argues that the fact that the domestic policy rate correlates with the base country policy rate does not in itself imply a loss of monetary autonomy either. The reason for this is twofold: First, international shocks that affect the central banks' target variables like inflation and the output gap could induce procyclical movements in both policy rates. Second, domestic spending and production might depend on a global component that correlates with shocks elsewhere.

Nevertheless, one would still expect a central bank enjoying monetary autonomy not to adjust its primary policy instrument one-to-one with that of the center country central bank. Undoubtedly, a zero correlation between the local and foreign policy rate could be seen as undisputed evidence in favour of monetary autonomy. Intermediate cases are more challenging since, as argued by Nelson (2020), a non-zero correlation between policy rates is not sufficient evidence of a loss of monetary autonomy.

An interesting related question is whether the central bank could provide some leeway for its main policy instrument through the adjustment of alternative instruments. As stated by Calvo and Mishkin (2003, p.101), a floating exchange rate regime does not preclude the use of monetary policy tools other than the short-term interest rate. Indeed, a small open economy central bank concerned with an inflation objective might worry about exchange rate movements even if the *de jure* exchange rate regime is a float, especially if the country in question has a large export sector or relies heavily on imports. Moreover, based on the work of Cravino and Levchenko (2017), changes in relative prices brought about by large exchange rate fluctuations may affect the cost of living of especially low-income households. Monetary policy decisions abroad may induce pressures on the exchange rate, and a purely floating exchange rate regime would call for all of these pressures to be relieved through the appreciation or depreciation of the currency. However, this might sometimes contradict the goals of domestic monetary policy. Curbing the exchange rate pressures through changes in the policy rate might likewise contradict domestic objectives of the central bank and induce undesirable volatility in domestic interest rates. In addition, it might hamper the credibility of the inflation target of the central bank.

A sterilised foreign exchange intervention (i.e. an intervention that leaves the monetary base unchanged) could be seen as a potential tool that would provide an additional independent monetary instrument that could be used to smooth exchange rate movements and relax the Trilemma constraint. For example, in emerging market economies, foreign exchange interventions have been an important tool of monetary policy, often utilised to avoid excessive movements of the exchange rate (Neely, 2000; Canales-Kriljenko, 2003). In principle, there is no reason why advanced countries with a flexible exchange rate regime could not use it as well.

Recently, a body of literature related to this questions has emerged. Steiner (2017) builds a simple portfolio balance model and shows that foreign exchange interventions can serve as a substitute for capital controls, relaxing the Trilemma and making it possible for the central bank to pursue independent monetary and exchange rate policies under free capital mobility. Deviating from the standard portfolio balance framework, Steiner's model assumes that, instead of being determined entirely by market forces, the exchange rate is affected by the foreign exchange interventions of the central bank. The effectiveness stems from the existence of the portfolio–balance channel, which posits that foreign and home assets are imperfect substitutes and, therefore, the central bank can affect the exchange rate by varying the relative supplies and demands of assets through interventions. Cavallino (2019) studies a theoretical small open economy model and shows that optimal foreign exchange interventions should lean against the wind, or in other words, stabilise the exchange rate movements induced by shocks to capital inflows.

Although exposures to capital inflows and outflows have traditionally been thought to predominantly concern emerging and developing economies, recent evidence presented by Rey (2015, 2016) supports the view that they might be important for advanced economies as well. Moreover, her empirical finding that US monetary policy is an important driver of global capital flows has potential implications for monetary policy in small open economies in light of the result of Cavallino (2019)

Fanelli and Straub (2020) develop a theory for foreign exchange interventions. In their model the central bank can affect the interest rate spread, i.e., the difference between domestic and foreign interest rates, by conducting foreign interventions. However, interventions are costly because interest rate spreads open up profit opportunities for foreign carry traders. Similar to Cavallino (2019), one of the Fanelli and Straub's main insights is that an optimal intervention policy should lean against the wind.

As the preceding discussion shows, the increasing financial integration of the last few decades and the ensuing prevalence of cross-border capital flows have made the question regarding monetary policy autonomy under floating exchange rates relevant again. Chapter 3 takes an econometric view on the issue, focusing on a selected group of inflation-targeting, small open economies with an announced floating exchange rate. First, the chapter aims to shed light on the potential effects that the monetary policy decisions in the centre country, the

US, have on monetary policies in our selected small open economies. Second, it considers whether the central banks in our countries of interest have utilised foreign exchange interventions as an additional tool of monetary policy in order to mitigate the potential constraints on the policy rate posed by external monetary policy developments.

1.1.1.3 The financial crisis, quantitative easing, and fiscal policy interactions

The global financial crisis of 2007–2008 has fundamentally shaped macroeconomists' thinking on how to conduct monetary policy. As Blanchard et al. (2010) note, before the crisis, monetary policy was in advanced economies largely thought as a pursuit of a single objective, price stability, using a single instrument, the central bank policy rate. The post-financial crisis policy environment has been drastically different compared to the era of Great Moderation, a term coined by Stock and Watson (2002) to describe the period of relatively stable macroeconomic conditions from the mid-1980's until 2007. Most notably, several prominent central banks around the world introduced unconventional policy measures in the aftermath of the financial crisis as well as during the ongoing COVID-19 pandemic.

Quantitative easing (QE) has undoubtedly been the most visible and debated of such unconventional policy tools. QE refers to the large-scale purchases of long-term government debt and other long-maturity securities and has been employed by practically every major central bank since the beginning of the financial crisis of 2007–2008.[3] The introduction of QE has arguably made the size and composition of the central bank's balance sheet the main instrument of monetary policy, instead of the short-term interest rate.

Following the introduction of QE policies, there has been a growing academic interest in their effects as well. Although policymakers have been convinced that these policies work, macroeconomists have struggled to reach a consensus on the theoretical justification for why QE works, as pointed out by the former Federal Reserve chairman Ben Bernanke.[4] Perhaps the most common rationale for the working of QE is the so-called *portfolio balance* effect: When a central bank buys assets in exchange of newly created central bank reserves, it changes the supply of assets available to the private sector and affects the relative prices of assets, and hence, their relative yields. If the assets being purchased are not perfect substitutes with central bank reserves, the private sector investors then attempt to rebalance their portfolios towards assets that are similar to those that the central bank purchased. This process brings down the yields of these other assets as well.

The portfolio balance effect is, however, inconsistent with the standard asset pricing theory, as discussed in Woodford (2012). According to the standard

[3] QE was, in fact, already used in Japan in the early 2000's by the Bank of Japan; for a review of quantitative easing policies used by several prominent central banks, see, e.g., Fawley et al. (2013)

[4] "The problem with QE is it works in practice, but it doesn't work in theory." (Bernanke, 2014, p. 14)

consumption-based asset pricing framework, assets are priced based on their state-contingent payoffs in different states of the world. To the extent that a simple reshuffling of assets between the central bank and the private sector does not affect the real resources available for consumption in each state of the world, the representative agent's stochastic discount factor, which is used to price different assets, should not change.[5] Consequently, the prices of assets should not change in response to central bank purchases, given that the risky payoffs associated with those assets do not change (Woodford, 2012, p. 61). This echoes the well-known result of Wallace (1981), who showed that, under certain conditions, central bank open-market operations would be irrelevant for equilibrium allocations and prices in a certain class of macroeconomic models.

Several articles have proposed modifications to the standard theory in order to make quantitative easing relevant in dynamic general equilibrium models. Harrison (2012, 2017) assumes that the representative household regards long- and short-term government bonds as imperfect substitutes, making it possible for the central bank to affect the interest rate spread and hence aggregate demand through asset purchases. The idea is similar to that in Andres et al. (2004), who in turn formalise the idea presented in Tobin (1969) that returns on different assets should depend on their relative supplies. Chapter 4 of this dissertation follows a similar approach by assuming imperfect substitution between short- and long-term government bonds, from the point of view of asset-market participating households.

The large-scale asset purchase operations of central banks have stirred controversy on several fronts. For example, some have argued that by inflating the asset prices across the board, the asset purchase programmes have contributed to the increasing wealth inequality; others have pointed out that, by engaging in such massive operations, the central banks have distorted the financial markets.

One of the points of controversy, perhaps not as discernible as the two previously mentioned examples, is centred on the fiscal implications of the large-scale asset purchase operations. Monetary policy operations of such scope have inevitable consequences for fiscal policy as well. For example, extensive monetary easing may decrease the interest rates, therefore decreasing the government's debt servicing costs as well, thus having direct implications for public finances. In addition, when a central bank holds large amounts of risky assets in its balance sheet, potential losses on these assets may ultimately have consequences for central bank solvency (Hall and Reis, 2015). This, in turn, can lead to a central bank recapitalisation by the treasury, putting the operational independence of the central bank under threat, or monetary financing of losses, potentially threatening the price stability goal (Stella, 1997).

5 In the consumption-based model of asset pricing, the stochastic discount factor, or pricing kernel, is given by the formula $p_t = \beta \, \mathbb{E}_t \frac{u'(c_{t+1})}{u'(c_t)} x_{t+1}$, where p_t is the price of the asset, β is a parameter measuring the impatience of the representative agent with regards to consumption over time, $\mathbb{E}_t$ denotes a mathematical expectation conditional on information at time t, $u'(c_t)$ is the marginal utility of consumption, and x_{t+1} is the payoff of the asset. Cochrane (2009) gives a detailed exposition of consumption-based asset pricing theory.

Furthermore, not only the fiscal consequences of QE are of potential interest but also its interplay with the government's fiscal policy. QE aims to decrease the amount of long-term (government) securities in the hands of the private sector. However, low interest rates, a consequence of extensive monetary easing, can create an incentive for the government to issue more long-term debt, thus potentially offsetting the intended effect of QE. For example, Greenwood et al. (2015) document that in the United States the stock of debt with a maturity over five years held by the private sector in fact rose between 2008 and 2014, despite several rounds of large-scale asset purchases by the Fed. In light of this evidence, what kind of policy the fiscal authority conducts in response to the central bank's quantitative easing operations could turn out to be important for the overall macroeconomic effects of these unconventional monetary policies. This also raises the question of policy coordination between the fiscal and monetary authorities in a situation where unconventional policy tools are employed.

It could be argued that, before the global financial crisis of 2007–2008, the fiscal aspects of monetary policy and its interaction with fiscal policy were not given a prominent role in the macroeconomic literature, although there had been some important previous studies. An early contribution by Sargent and Wallace (1981) shows that when it comes to the ability of the central bank to control inflation, it matters a great deal what the fiscal policy does. In subsequent work, Leeper (1991) studies the issue of fiscal-monetary interactions in a stochastic setting where, instead of controlling the supply of money, the central bank sets the interest rate. Following the contributions of Sims (1994), Woodford (1995), and others on this topic, the fiscal theory of the price level emerged. This branch of literature sought to explain the determination of the price level resulting from fiscal policy and government debt rather than from monetary factors, contrary to what the conventional monetarist narrative suggested.

Chapter 4 of this dissertation studies the effects of QE in a business cycle model of the New Keynesian tradition, as outlined in, for example, Woodford (2003) and Galí (2015), with a focus on the implications of different fiscal policy regimes on the macroeconomic effectiveness of quantitative easing.

1.2 Outline of the thesis

1.2.1 Research questions

The research questions presented in thesis are related to the issues that were discussed in the previous section. The list below summarises the main research questions of each thesis chapter. A more detailed overview of the chapters and their contributions are given in subsection 1.2.3.

Chapter 2:

– What is the role of stock market and currency market information in the monetary policy reaction function, estimated for 14 OECD countries over the period of 1999–2016?

– Does the stock and currency market information have a direct role (i.e., as explicit explanatory variables) in the policy reaction function or an indirect role (as a part of the central bank's information set)?

Chapter 3:

– Does the the federal funds rate, the primary policy instrument of the Federal Reserve, play a significant role in the monetary policy reaction functions estimated for a group of small open economies with a floating exchange rate and an inflation-targeting central bank?
– Do unanticipated developments in United States monetary policy (i.e., monetary policy shocks) affect the interest rates of these small open economies?
– Have the small open economies in question used foreign exchange interventions in order to buffer some of the external pressures induced by US monetary policy shocks?

Chapter 4:

– What are the implications of different fiscal policies for macroeconomic effects of QE?

1.2.2 Research methods

This thesis contains studies that are both empirical and theoretical in nature. Chapters 2 and 3 are more empirically driven and use applied econometric methods without much formal theory, although Chapter 2 does present a simple non-microfounded partial equilibrium model, based on Junttila and Korhonen (2011), that rationalises the use of financial market variables in a monetary policy rule. The study presented in Chapter 2 utilises a simple ordinary least squares method to estimate contemporaneous Taylor rules, which assume that the central bank reacts to current inflation and output gap values. Forward-looking policy rules, which in turn assume that the central bank reacts to expected future values of inflation and output gap, are estimated using the generalised method of moments, as in Clarida et al. (2000).

Chapter 3 uses several macroeconomic methods to study the effects of US monetary policy on the monetary policies of small open economies. Like in Chapter 2, ordinary least squares and the generalised method of moments are used to estimate Taylor rule regressions. Moreover, the study also aims to uncover the dynamic causal effect of US monetary policy shocks on small open economies. To do so, as a primary method, we use the local projections approach, developed by Jordà (2005). Local projections are a way to estimate dynamic responses, commonly referred to as impulse response functions, of endogenous variables to exogenous shocks. In recent years, they have become an alternative to structural vector autoregressions (VARs) in the literature attempting to estimate the effects of fiscal policy (Auerbach and Gorodnichenko, 2013; Ramey and Zubairy, 2018) as well as monetary policy (Miranda-Agrippino and Ricco, 2018; Swanson, 2020); because they are arguably more robust to model misspecification than VARs. As a robustness check, we also estimate impulse responses based on a structural VAR model.

One major challenge in estimating the effects of policy shocks lies in their identification. Loosely speaking, in the present context, identification means extracting the variation in monetary policy that is exogenous, or in other words, not influenced by endogenous variables of the model. This often turns out to be difficult, as central banks carefully base their policy decisions on a massive amount of macroeconomic data. The structural VAR literature has proposed several ways to identify policy shocks. We use a "narrative" method, where a proxy for US monetary policy shocks is constructed from information that is external to the model we estimate. Specifically, we use two candidate monetary policy shock proxies. The primary proxy we use is the shock series constructed following Romer and Romer (2004). The method of Romer and Romer identifies exogenous variation in US monetary policy by regressing the intended changes in the federal funds rate around Federal Open Market Committee (FOMC) meeting dates on the Federal Reserve's internal Greenbook forecasts.[6] To the extent that these internal forecasts accurately summarise the relevant information about the future economic outlook that the FOMC utilises in its monetary policy decisions, the obtained regression residual can be interpreted as the exogenous variation in policy.

As a second alternative, we utilise the high-frequency surprises around Federal Reserve monetary policy announcements. To be more precise, these surprises are measured as movements in three-month federal funds futures within short windows around FOMC announcements. Such movements can be interpreted as reflecting the information about monetary policy that was not already anticipated by the financial market participants prior to the policy committee meeting. Furthermore, because changes in Fed fund futures are measured within small windows around the announcement, they can be seen as caused exclusively by the Federal Reserve policy announcements. Our two candidate shock proxies thus lend themselves to an interesting comparison: While one is constructed on the basis of the information available only to the Fed, the other implicitly assumes that all forecastable information about the future economic conditions is correctly reflected in the expectations of the financial market participants.

Compared to Chapters 2 and 3, the article in Chapter 4 is more theoretically oriented. It uses a New Keynesian dynamic stochastic general equilibrium (DSGE) model in order to disentangle the transmission mechanisms of unconventional monetary policy. Arguably, DSGE models are well suited for policy

[6] Greenbook forecasts refer to projections of several important macroeconomic variables for the US economy. The forecast is produced by the Federal Reserve Board before each meeting of the FOMC. Greenbook forecasts are made public with a five-year lag, which suggests that they can be regarded as private information of the Federal Reserve at the time of FOMC meetings.

analysis since they address the famous critique of Lucas (1976). Lucas argued that policy evaluation using reduced-form econometric models would yield biased results, as they do not take into account that rational and forward-looking private agents may change their behaviour as a response to the policy change. Put in a more technical manner, the coefficients in agents' decision rules may depend on policy, and when policy changes, the decision rule coefficients change accordingly. An econometrician estimating the effects of a macroeconomic policy using a reduced-form model fitted to historical data would fail to take this into account. DSGE models address this issue by starting from microeconomic foundations. That is, the relationships between aggregate variables in the model are derived as a solution to individual agents' decision problems, and they are thus consistent with individual optimisation.

Chapter 4 aspires to take the Lucas critique seriously by using a simple New Keynesian DSGE model to analyse the macroeconomic effects of QE policies. Instead of estimating the model parameters, I follow the calibration approach, popularised by Kydland and Prescott (1982), that is often used in the DSGE literature. Most of the model parameters are set in accordance with conventional values used in the literature; other parameter values are chosen to match some of the model moments with data. The model is solved using a first-order linear approximation around the deterministic steady state, and dynamic responses of endogenous variables to exogenous policy shocks are then examined.

1.2.3 Overview of the research articles

In addition to the introductory chapter, this dissertation features three independent research articles that all study issues related to monetary policy. In what follows, I will provide a short overview of the research articles presented in each chapter.

Two of the three research articles presented in this dissertation are jointly authored. The article in Chapter 2 is co-authored with professors Kari Heimonen and Juha Junttila. I have contributed to the article by collecting and preparing the data and carrying out all the econometric estimations presented in the article. I have also contributed by writing Sections 3 and 4, in which the data are described and the results analysed, jointly with professor Junttila.

The research article presented in Chapter 3 is co-authored with professor Kari Heimonen. I have contributed to the article by collecting and preparing the data and carrying out all the econometric estimations presented in the article. I have written Sections 3 and 5 of the article and most of Sections 4, 6, and 7 with some additions from professor Heimonen. Sections 1 and 2 are written jointly with professor Heimonen.

The research article in Chapter 4 is single-authored, and I have done all the writing, modelling, data collection, computation and analysis presented in the article.

1.2.3.1 Chapter 2: Stock market and exchange rate information in the Taylor rule: Evidence from OECD countries

Chapter 2 presents an empirical study scrutinising the role of stock market and exchange rate information in the monetary policy reaction function of 14 OECD countries over the period of 1999–2016, jointly authored with Kari Heimonen and Juha Junttila. The research theme of the chapter relates to the lively debate on whether central banks should take asset prices into account when deciding on their monetary policies. The article presented in Chapter 2 thus relates to the literature examining the significance of financial market information for monetary policy. More specifically, the article does not take a stance on whether the central bank should or should not respond, for example, to asset price booms. Instead, its primary aim is to study whether there has been a significant statistical connection between asset price information and monetary policy in a multitude of advanced economies over a sample period that includes spells of both calm and turmoil in the global financial markets.

The literature on the relationship between asset market information and monetary policy is quite extensive. In a seminal paper, Bernanke and Gertler (2000) address the issue from a more normative perspective, asking how the central bank should react to asset price volatility. Bernanke and Gertler's conclusion is that central banks should not target asset prices *per se* but rather consider them as a useful indicator of the underlying inflationary or deflationary pressures. Cecchetti et al. (2000) arrive at a different conclusion: They argue that a central bank that is concerned with achieving its inflation target would benefit from adjusting its policy instrument directly in response to the expectations about future inflation and the output gap *as well as* asset prices. Fuhrer and Tootell (2008), using the Greenbook forecasts, find little evidence that the Federal Reserve has historically responded directly to the developments in stock prices. Castro (2011) confirms the finding that the Fed does not directly respond to asset prices, but on the other hand his findings suggest that the European Central Bank may have taken the financial conditions into account in its monetary policy.

A seminal paper by Clarida et al. (1998) studies forward-looking augmented Taylor rules for the US, Japan, and large European economies (Italy, France, Germany, and the UK). The paper considers the real exchange rate as one of the additional variables in the monetary policy reaction function. The authors find that the real exchange rate enters the monetary policy reaction function statistically significantly in most of the countries they analyse, although the estimated coefficient is, in most cases, quantitatively small. Further discussion of the inclusion of the exchange rate in the monetary policy rule is provided by Taylor (2001), who considers, from a normative perspective, whether an open-economy central bank should directly respond to developments in the exchange rate. Taylor notes that the existing evidence does not provide much support for the view that a central bank responding directly to the exchange rate would fare better, in terms of stabilizing the macroeconomy, than a central bank that responds only to inflation and the output gap. He argues that this observation may stem from the fact that it is preferable to respond indirectly to the exchange rate, since this would minimise harmful swings of the interest rate.

The article in Chapter 2 approaches the issue through a monetary policy reaction function framework. In our study, various specifications of a Taylor (1993)-type monetary policy rule are estimated: contemporaneous specifications, in which the central bank is assumed to react to the current values of relevant target variables, as well as forward-looking specifications, in which the central bank is assumed to react to the expected inflation and output gap values.

Our article entertains the idea that the central banks of the OECD countries in question might have taken financial market information *directly* into account by not only having them as target variables in the monetary policy rule but also considered them as useful indicators of future macroeconomic conditions, thus giving them a more *indirect* role. We test the former possibility by including stock and currency market information variables (more specifically, the dividend yield and the real exchange rate) in the contemporaneous Taylor rule and examining their statistical significance. The latter possibility is tested by estimating forward-looking monetary policy rules—where the central bank is assumed to react to the expected inflation and output gap—using the generalised method of moments and including additional financial market variables into the set of instrumental variables. The resulting estimates are then compared to those obtained from the model in which the instrument set does not include financial market variables. If the inclusion of financial market variables increases the p-value associated with Hansen's J-test and/or improves the model fit, we conclude that the financial market information is indirectly taken into account by the central banks when setting their interest rate. This method of testing the relevance stock and currency market variables as additional information in the GMM estimation is, according to our knowledge, a new contribution to the existing literature.

Our study also provides a novel contribution to the literature by offering an extensive examination of the role of stock and currency market information in the Taylor rules of a multitude of advanced economies. While there are several studies examining the role of asset prices in US monetary policy and the role of the exchange rate in monetary policy in open economies, our study is, to the best of our knowledge, the first to do it on such an extensive scale. We also address the potential issues emerging from estimating monetary policy reaction functions using historical data by utilising real-time data on inflation and real economic activity instead, as recommended by Orphanides (2001).

The results indicate that, for most of the countries analysed, the role of stock and currency market information seems to be important both in the contemporaneous Taylor rule, where the additional variables are included as direct regressors, as well as in the forward-looking specification, where they enter indirectly as instrumental variables. However, it should be stressed that our results do not necessarily suggest that the central banks in our sample countries have in fact directly reacted to the financial market information during the observed time period. Rather, the analysis establishes a clear connection between the financial market indicators and the monetary policy stance. Our interpretation of the estimates from the forward-looking monetary policy rules also points to an indirect role of financial market information in the monetary policy decisions of several OECD countries.

1.2.3.2 Chapter 3: Fed hurts: The exposure to the US monetary policy in inflation targeting economies

Chapter 3 presents a study, coauthored with professor Kari Heimonen, that examines the influence of United States monetary policy on a set of small open economies with an inflation-targeting monetary policy framework and a flexible exchange rate arrangement. Specifically, we aim to determine the extent to which United States monetary policy influenced the monetary policy in our sample countries during their inflation-targeting regime before the start of the financial crisis of 2007–2008. Our focus is on the pre-financial crisis period because, since then, monetary policy in most advanced economies has been characterised by a range of unconventional policy tools that have, in most countries, been employed simultaneously. Identifying the effects of policy shocks during the post-financial crisis period thus becomes challenging, as arguably it is difficult to establish a single indicator, such as the policy interest rate, that could efficiently be used to summarise the overall stance of monetary policy.

The famous Trilemma result, most often attributed to the works of Mundell (1963) and Fleming (1962), states that a country can simultaneously achieve only two out of the three objectives of exchange rate stability, monetary policy autonomy, and free capital movements. The topic has attracted renewed attention recently, and the validity of the trilemma has been questioned by some authors. For example, Rey (2015) has argued that the global financial cycle, that is, the strong comovement of asset prices, capital flows, and credit growth across countries, has transformed the trilemma into a dilemma. She presents evidence that one important determinant of the global financial cycle is the monetary policy in the centre country. Effectively, monetary policy decisions in a globally important financing centre, like the United States, transmit the monetary conditions to other countries via the global financial cycle, regardless of the exchange rate regime. Thus, even a country with a floating exchange rate may not achieve monetary autonomy as long as capital movements are not restricted.

From the point of view of an inflation-targeting small open economy, this is an important issue since credible inflation targeting would most likely require the central bank to be able to exert monetary policy independently of foreign developments. Arguably, a central bank announcing an inflation target would not be perceived as credible by the public if it had to adjust its policy instruments in response to external factors instead of domestic inflation and economic activity.

Rey (2016) provides evidence that even inflation-targeting countries' monetary policy is influenced by that of the US. Our study examines the extent to which developments in US monetary policy affected monetary policies in a few selected small open economies prior to the financial crisis of 2007–2008. The economies we analyse are those of Canada, Norway, Sweden, and the UK. Our choice of countries in this study is guided by the fact that each of these countries, apart from Norway[7], has adopted a floating exchange rate regime and inflation targeting in the early-to-mid 90's, after the collapse of the European Exchange Rate Mechanism I (ERM I). This provides us with a relatively long time series before the start of the period of unconventional monetary policy.

In addition to examining the exposure of the small open economies' monetary policies to the monetary policy of the US, we consider whether the central banks of our countries of interest have employed additional policy tools in order to curb the potential exposure to US policy. Rey (2015) argues that in order to regain monetary policy autonomy and deal with the "dilemma", a country should, for example, employ macroprudential policies that directly monitor leverage and credit growth and potentially use targeted capital controls. We entertain the idea that foreign exchange management could serve as a tool to mitigate the constraints posed by the US monetary policy. To this end, we extend the work of Steiner (2017), who argues, using a simple portfolio balance model framework, that foreign exchange interventions may effectively be used as a substitute for capital controls, thus providing a small open economy central bank some leeway in pursuing independent monetary policy in the presence of free capital movements. Therefore, our primary research question is twofold: First, whether the developments in US monetary policy have spilled over to the monetary policies in our sample economies; and second, whether the central banks in question have employed foreign reserve interventions in response to monetary policy developments in the US.

Our results lend some tentative support to the view that monetary policy in a small open economy with a floating exchange rate regime and an inflation target is not completely free of foreign influence. Our empirical analysis shows that, when included in a Taylor (1993)-type monetary policy reaction function, the estimated long-run response coefficient on the federal funds rate is statistically significant for Canada and the UK both in contemporaneous as well as forward-looking policy rules. We also estimate the dynamic effects of US monetary policy shocks, identified by narrative methods as in Romer and Romer (2004) and Gertler and Karadi (2015). The results obtained using the local projections approach, developed by Jordà (2005), indicate that US monetary policy shocks identified with the Romer–Romer method have significant effects on the interest rates of Canada, Sweden, and Norway; however, the evidence is less clear when the Gertler–Karadi monetary policy shocks are considered. We do not find robust evidence that the central banks of our sample countries would have responded to US monetary policy shocks by engaging in foreign reserve interventions.

In sum, Chapter 3 contributes to the existing literature on monetary policy autonomy and flexible exchange rates by conducting a careful econometric analysis of the effects of US monetary policy on the interest rates in the aforementioned economies. Although several previous studies have examined the effects of US monetary policy shocks on interest rates and macroeconomic variables in other economies, to the best of the authors' knowledge, this is the first study to first

[7] Norway announced inflation targeting in March 2001.

explicitly focus on a few small open economies that are known to have practiced inflation targeting before the financial crisis and the Great Recession, our sample period being determined by the duration of that particular policy regime in each country. In addition, our study contributes to the literature on foreign exchange interventions by employing state-of-the-art macroeconometric methods to estimate the potential responses of central banks' foreign exchange interventions to US monetary policy shocks.

1.2.3.3 Chapter 4: The fiscal channel of quantitative easing: Insights from a two-agent New Keynesian model

Finally, Chapter 4 of the dissertation studies the effects of QE and the role of the government's fiscal policy in its transmission and effectiveness. The analysis is conducted using a simple New Keynesian business cycle model with a stylised form of household heterogeneity and portfolio frictions. The chapter is single-authored. In the model, a fraction of households do not participate in the asset market and consumer their disposable income each period. In this sense, the article follows the lead of, for example, Galí et al. (2007) and Bilbiie (2008), who analyse the effects of government policies when such "hand-to-mouth" households are present. The presence of hand-to-mouth households breaks the well-known Ricardian equivalence result, which states that, essentially, it makes no difference whether the government budget is financed through taxes or debt.

The main research objective of the paper is to investigate how different fiscal policy configurations affect the overall macroeconomic effects of the central bank's asset purchase operations. Three alternative fiscal policy scenarios are considered: i) "tax-financing", where the government adjusts lump-sum taxes to ensure that its budget constraint holds while keeping the issuance of debt constant, ii) "short-term debt financing", where the government sets the lump-sum taxes as a function of outstanding government debt and closes the budget constraint by adjusting short-term debt issuance, and iii) "long-term debt financing", which is otherwise similar to the previous scenario, except that the government budget constraint is closed by adjusting long-term debt.

The article is related to several studies on the workings of QE in dynamic general equilibrium models. Some examples of earlier papers include Gertler and Karadi (2011), Chen et al. (2012), and Carlstrom et al. (2017). While the literature on the effects of QE on financial markets and the economy has burgeoned in the aftermath of the financial crisis of 2007–2008, and several articles have incorporated quantitative easing into New Keynesian DSGE models, academic contributions regarding the interaction between QE and the government's fiscal policy remain, for the time being, rather scarce.[8] This study aims to provide some insights on this question. The question is particularly interesting because some economists have expressed concerns about fiscal policy potentially offsetting the

[8] A recent influential study by Kaplan et al. (2018) analyses, among other things, the fiscal channel of monetary policy in a business cycle model with nominal rigidites and rich heterogeneity in the household sector, but more or less on a side note.

intended effect of QE, which is to reduce the amount of long-term debt in the hands of the private sector. Regarding this issue, Borio and Disyatat (2010) note that

> "The objectives of debt management, such as minimizing the cost of government debt, may sometimes conflict with those of monetary policy, notably when this is seeking to stimulate aggregate demand. For example, debt managers have a strong temptation to lengthen the maturity of the outstanding debt by issuing long when long-term rates look low by historical standards. By doing so, they can lock in a low financing cost. But this may be precisely the time when the central bank is seeking to buy long-term debt to boost economic activity. In addition, the government balance sheet generally dwarfs that of the central bank. Marginal adjustments to its debt management policies can easily swamp central bank actions." (Borio and Disyatat, 2010, p. 83)

In itself, the idea of fiscal–monetary interaction is not new. In a classic paper, Sargent and Wallace (1981) demonstrated that the central bank's ability to control inflation depends greatly on the coordination between fiscal and monetary policies. Perhaps the most influential result of Sargent and Wallace was that, if fiscal policy dominates monetary policy, or in other words, if the fiscal authority is the "first mover" and sets the path for current and future primary surpluses, then the central bank is constrained in its policy decisions because, in equilibrium, the government must remain intertemporally solvent, or to use a more common term, the government debt must be sustainable. In a regime of fiscal dominance, according to Sargent and Wallace, tighter monetary policy now can mean higher inflation in the future. The fiscal theory of the price level literature, advocated by Leeper (1991), Sims (1994), and Woodford (1995) among others, offers a more recent take on the matter of monetary and fiscal interaction. While this branch of literature provides an alternative explanation for the determination of the price level, my aim is not to delve into that question. Rather, I am interested in simply documenting what kind of implications different fiscal policies could have for the conduct of QE.

Turning to the results of my study, the model simulations suggest that, on impact, the effects of QE on aggregate output are the largest under tax financing, that is, when the government adjusts lump-sum taxes to close the budget constraint while keeping the debt issuance constant. The result stems from the fact that hand-to-mouth households' consumption is very sensitive to lump-sum taxes, and therefore, when the accommodation in the government budget constraint comes entirely from changes in taxes, hand-to-mouth households' consumption is strongly altered, leading to a strong response in aggregate demand. Meanwhile, positive responses of the economy are more prolonged under long-term debt financing compared to the other two fiscal policy scenarios. Additionally, the results suggest that when the government adjusts long-term debt, the positive macroeconomic response is stronger than in the case where short-term debt adjusts.

In the light of the previously mentioned concerns by, for example, Borio and Disyatat (2010) about fiscal policy offsetting the intended effects of QE, it seems interesting that a fiscal policy that closes the government budget constraint by adjusting long-term debt would, in fact, boost the macroeconomic effectiveness of QE compared to a policy in which short-term debt is adjusted. In the model, the effectiveness of QE stems from the fact that households that can participate in the asset market are so-called "preferred habitat" investors, that is, they have a preference for a certain mix of long-term and short-term securities in their portfolios. A QE operation by the central bank raises the price of long-term bonds that the government issues, effectively boosting government revenue and loosening the government budget constraint. Whether the government accommodates its budget by lowering the issuance of short-term or long-term debt implies a differing equilibrium ratio of long-term to short-term bonds in the hands of the representative saver households, leading to changes in the term premium of differing magnitudes. This in turn yields differing responses in aggregate demand.

The results presented in Chapter 4 clearly indicate that the interaction of unconventional monetary policy and fiscal policy should be taken seriously. At the same time, it should be kept in mind that the model outlined in Chapter 4 is merely a first approximation to the interaction of QE and fiscal policy. It abstracts from some important aspects, such as distorting taxation and optimal debt management policy of the fiscal authority, given the quantitative easing operations of the central bank. In addition, welfare properties of different policies are not considered. All these are issues could prove to be fruitful avenues of future research.

REFERENCES

Andres, J., López-Salido, J. D., and Nelson, E. (2004). Tobin's imperfect asset substitution in optimizing general equilibrium. *Journal of Money, Credit and Banking*, pages 665–690.

Auerbach, A. J. and Gorodnichenko, Y. (2013). Fiscal multipliers in recession and expansion. In Alesina, A. and Giavazzi, F., editors, *Fiscal Policy After the Financial Crisis*, chapter 2, pages 63–98. University of Chicago Press.

Ball, L. M. (1999). Policy rules for open economies. In Taylor, J. B., editor, *Monetary Policy Rules*, chapter 3, pages 127–156. University of Chicago Press.

Barro, R. J. and Gordon, D. B. (1983). A positive theory of monetary policy in a natural rate model. *Journal of Political Economy*, 91(4):589–610.

Bernanke, B. (2014). Central banking after the Great Recession: Lessons learned and challenges ahead. A discussion with Federal Reserve chairman Ben Bernanke on the Fed's 100th anniversary. Technical report, The Brookings Institution, 16 January.

Bernanke, B. and Gertler, M. (2000). Monetary policy and asset price volatility. Working Paper 7559, National Bureau of Economic Research.

Bernanke, B. S., Gertler, M., and Gilchrist, S. (1999). The financial accelerator in a quantitative business cycle framework. *Handbook of Macroeconomics*, 1:1341–1393.

Bernanke, B. S. and Mishkin, F. S. (1997). Inflation targeting: A new framework for monetary policy? *Journal of Economic Perspectives*, 11(2):97–116.

Bilbiie, F. O. (2008). Limited asset markets participation, monetary policy and (inverted) aggregate demand logic. *Journal of Economic Theory*, 140(1):162–196.

Blanchard, O., Dell'Ariccia, G., and Mauro, P. (2010). Rethinking macroeconomic policy. *Journal of Money, Credit and Banking*, 42:199–215.

Borio, C. and Disyatat, P. (2010). Unconventional monetary policies: an appraisal. *The Manchester School*, 78:53–89.

Calvo, G. A. and Mishkin, F. S. (2003). The mirage of exchange rate regimes for emerging market countries. *Journal of Economic Perspectives*, 17(4):99–118.

Campa, J. M. and Goldberg, L. S. (2005). Exchange rate pass-through into import prices. *Review of Economics and Statistics*, 87(4):679–690.

Canales-Kriljenko, J. I. (2003). Foreign exchange intervention in developing and transition economies: results of a survey.

Carlstrom, C. T., Fuerst, T. S., and Paustian, M. (2017). Targeting long rates in a model with segmented markets. *American Economic Journal: Macroeconomics*, 9(1):205–42.

Castro, V. (2011). Can central banks' monetary policy be described by a linear (augmented) Taylor rule or by a nonlinear rule? *Journal of Financial Stability*, 7(4):228–246.

Cavallino, P. (2019). Capital flows and foreign exchange intervention. *American Economic Journal: Macroeconomics*, 11(2):127–70.

Cecchetti, S. G., Genberg, H., Lipsky, J., and Wadhwani, S. (2000). *Asset Prices and Central Bank Policy*. Centre for Economic Policy Research.

Chen, H., Cúrdia, V., and Ferrero, A. (2012). The macroeconomic effects of large-scale asset purchase programmes. *The Economic Journal*, 122(564):289–315.

Clarida, R., Galı, J., and Gertler, M. (1998). Monetary policy rules in practice: Some international evidence. *European Economic Review*, 42(6):1033–1067.

Clarida, R., Gali, J., and Gertler, M. (2000). Monetary policy rules and macroeconomic stability: Evidence and some theory. *The Quarterly Journal of Economics*, 115(1):147–180.

Cochrane, J. H. (2009). *Asset pricing: Revised edition*. Princeton University Press.

Cravino, J. and Levchenko, A. A. (2017). The distributional consequences of large devaluations. *American Economic Review*, 107(11):3477–3509.

Fanelli, S. and Straub, L. (2020). A theory of foreign exchange interventions. Working Paper 27872, National Bureau of Economic Research.

Fawley, B. W., Neely, C. J., et al. (2013). Four stories of quantitative easing. *Federal Reserve Bank of St. Louis Review*, 95(1):51–88.

Fleming, J. M. (1962). Domestic financial policies under fixed and under floating exchange rates. *Staff Papers*, 9(3):369–380.

Friedman, M. (1953). The case for flexible exchange rates. In Friedman, M., editor, *Essays in Positive Economics*, pages 157–203. University of Chicago Press.

Fuhrer, J. and Tootell, G. (2008). Eyes on the prize: How did the Fed respond to the stock market? *Journal of Monetary Economics*, 55(4):796–805.

Galí, J. (2015). *Monetary policy, inflation, and the business cycle: an introduction to the new Keynesian framework and its applications*. Princeton University Press.

Galí, J., López-Salido, J. D., and Vallés, J. (2007). Understanding the effects of government spending on consumption. *Journal of the European Economic Association*, 5(1):227–270.

Gertler, M. and Karadi, P. (2011). A model of unconventional monetary policy. *Journal of Monetary Economics*, 58(1):17–34.

Gertler, M. and Karadi, P. (2015). Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics*, 7(1):44–76.

Greenwood, R., Hanson, S. G., Rudolph, J. S., and Summers, L. (2015). Debt management conflicts between the U.S. Treasury and the Federal Reserve. In Wessel, D., editor, *The $13 Trillion Question: How America Manages its Debt*, chapter 2, pages 43–89. Brookings Institution Press.

Hall, R. E. and Reis, R. (2015). Maintaining central-bank financial stability under new-style central banking. Working Paper 21173, National Bureau of Economic Research.

Harrison, R. (2012). Asset purchase policy at the effective lower bound for interest rates. Working Paper 444, Bank of England.

Harrison, R. (2017). Optimal quantitative easing. Working Paper 678, Bank of England.

Iacoviello, M. (2005). House prices, borrowing constraints, and monetary policy in the business cycle. *American Economic Review*, 95(3):739–764.

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *American Economic Review*, 95(1):161–182.

Junttila, J. and Korhonen, M. (2011). Utilizing financial market information in forecasting real growth, inflation and real exchange rate. *International Review of Economics & Finance*, 20(2):281–301.

Kaplan, G., Moll, B., and Violante, G. L. (2018). Monetary policy according to HANK. *American Economic Review*, 108(3):697–743.

Kiyotaki, N. and Moore, J. (1997). Credit cycles. *Journal of Political Economy*, 105(2):211–248.

Klein, M. W. and Shambaugh, J. C. (2015). Rounding the corners of the policy trilemma: Sources of monetary policy autonomy. *American Economic Journal: Macroeconomics*, 7(4):33–66.

Kydland, F. E. and Prescott, E. C. (1977). Rules rather than discretion: The inconsistency of optimal plans. *Journal of Political Economy*, 85(3):473–491.

Kydland, F. E. and Prescott, E. C. (1982). Time to build and aggregate fluctuations. *Econometrica: Journal of the Econometric Society*, pages 1345–1370.

Leeper, E. M. (1991). Equilibria under ’active’ and ’passive’ monetary and fiscal policies. *Journal of Monetary Economics*, 27(1):129–147.

Lubik, T. A. and Schorfheide, F. (2007). Do central banks respond to exchange rate movements? a structural investigation. *Journal of Monetary Economics*, 54(4):1069 – 1087.

Lucas, R. E. (1976). Econometric policy evaluation: A critique. In *Carnegie-Rochester Conference Series on Public Policy*, volume 1, pages 19–46.

McCallum, B. T. (1988). Robustness properties of a rule for monetary policy. In *Carnegie-Rochester Conference Series on Public Policy*, volume 29, pages 173–203. Elsevier.

Meltzer, A. H. (1989). On monetary stability and monetary reform. In *Dollars Deficits & Trade*, pages 63–85. Springer.

Miranda-Agrippino, S. and Rey, H. (2015). US monetary policy and the global financial cycle. Working Paper 21722, National Bureau of Economic Research.

Miranda-Agrippino, S. and Ricco, G. (2018). The transmission of monetary policy shocks. Discussion Paper DP13396, Centre for Economic Policy Research.

Mundell, R. A. (1963). Capital mobility and stabilization policy under fixed and flexible exchange rates. *The Canadian Journal of Economics and Political Science/Revue canadienne d'Economique et de Science politique*, 29(4):475–485.

Neely, C. J. (2000). The practice of central bank intervention: Looking under the hood. Working Paper 2000-028A, Federal Reserve Bank of St. Louis.

Nelson, E. (2020). The continuing validity of monetary policy autonomy under floating exchange rates. *The International Journal of Central Banking*, 16(2):81–123.

Orphanides, A. (2001). Monetary policy rules based on real-time data. *American Economic Review*, 91(4):964–985.

Phillips, A. W. (1958). The relation between unemployment and the rate of change of money wage rates in the United Kingdom, 1861-1957. *Economica*, 25(100):283–299.

Prasad, E., Rogoff, K., Wei, S.-J., and Kose, M. A. (2005). Effects of financial globalization on developing countries: Some empirical evidence. In *India's and China's recent experience with reform and growth*, pages 201–228. Springer.

Ramey, V. A. and Zubairy, S. (2018). Government spending multipliers in good times and in bad: Evidence from US historical data. *Journal of Political Economy*, 126(2):850–901.

Rey, H. (2015). Dilemma not Trilemma: The global financial cycle and monetary policy independence. Working Paper 21162, National Bureau of Economic Research.

Rey, H. (2016). International channels of transmission of monetary policy and the Mundellian trilemma. *IMF Economic Review*, 64(1):6–35.

Roberts, J. M. (1995). New Keynesian economics and the Phillips curve. *Journal of Money, Credit and Banking*, 27(4):975–984.

Romer, C. D. and Romer, D. H. (2004). A new measure of monetary shocks: Derivation and implications. *American Economic Review*, 94(4):1055–1084.

Sargent, T. J. and Wallace, N. (1981). Some unpleasant monetarist arithmetic. *Federal Reserve Bank of Minneapolis Quarterly Review*, 5(3):1–17.

Sims, C. A. (1994). A simple model for study of the determination of the price level and the interaction of monetary and fiscal policy. *Economic Theory*, 4(3):381–399.

Steiner, A. (2017). Central banks and macroeconomic policy choices: Relaxing the trilemma. *Journal of Banking & Finance*, 77:283–299.

Stella, P. (1997). Do central banks need capital? Working Paper No. 97/83, International Monetary Fund.

Stock, J. H. and Watson, M. W. (2002). Has the business cycle changed and why? *NBER Macroeconomics Annual*, 17:159–218.

Stock, J. H. and Watson, M. W. (2003). Forecasting output and inflation: The role of asset prices. *Journal of Economic Literature*, 41(3):788–829.

Svensson, L. E. (2000). Open-economy inflation targeting. *Journal of International Economics*, 50(1):155 – 183.

Svensson, L. E. (2010). Inflation targeting. volume 3 of *Handbook of Monetary Economics*, pages 1237 – 1302. Elsevier.

Swanson, E. T. (2020). Measuring the effects of Federal Reserve forward guidance and asset purchases on financial markets. *Journal of Monetary Economics*.

Taylor, J. B. (1993). Discretion versus policy rules in practice. In *Carnegie-Rochester conference series on public policy*, volume 39, pages 195–214. Elsevier.

Taylor, J. B. (2001). The role of the exchange rate in monetary-policy rules. *American Economic Review*, 91(2):263–267.

Tobin, J. (1969). A general equilibrium approach to monetary theory. *Journal of Money, Credit and Banking*, 1(1):15–29.

Wallace, N. (1981). A Modigliani-Miller theorem for open-market operations. *The American Economic Review*, 71(3):267–274.

Woodford, M. (1995). Price-level determinacy without control of a monetary aggregate. In *Carnegie-Rochester conference series on public policy*, volume 43, pages 1–46. Elsevier.

Woodford, M. (2003). *Interest and prices: Foundations of a theory of monetary policy*. Princeton University Press.

Woodford, M. (2012). Methods of Policy Accommodation at the Interest-Rate Lower Bounds. In *Jackson Hole Symposium, August, Federal Reserve Bank of Kansas City*.

2 STOCK MARKET AND EXCHANGE RATE INFORMATION IN THE TAYLOR RULE: EVIDENCE FROM OECD COUNTRIES

Abstract.
We analyze the effects of stock market and exchange rate information in a forward-looking Taylor rule for monthly data from 14 OECD countries during the years 1999–2016. Especially the stock market information in the form of dividend but also the currency market information in the form of real exchange rate are revealed to be relevant in Taylor rule for many of the countries examined by helping to strengthen the role of inflation and real economic activity deviations in the policy rule. In many cases the rule also seems to be opportunistic, i.e., the inflation target has been time-varying.

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Stock market and exchange rate information in the Taylor rule: Evidence from OECD countries

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ABSTRACT

We analyze the effects of stock market and exchange rate information in a forward-looking Taylor rule for monthly data from 14 OECD countries during the years 1999–2016. Especially the stock market information in the form of dividend but also the currency market information in the form of real exchange rate are revealed to be relevant in Taylor rule for many of the countries examined by helping to strengthen the role of inflation and real economic activity deviations in the policy rule. In many cases the rule also seems to be opportunistic, i.e., the inflation target has been time-varying.

1. Introduction

There is ample evidence that many of the modern central banks would seem to have followed the Taylor (1993) rule as the rule of thumb in their monetary policy actions, in one form or the other. From the point of view of the central banks' monetary policy target functions e.g. the role of financial markets is especially connected to the question of whether the financial market performance is or should be an actual policy target variable, or whether it merely reflects the future performance of the macroeconomy, and hence, the behaviour of the more traditional policy variables in the Taylor rule, i.e. the real economic activity and inflation. The set of papers attempting to scrutinize the role of financial and also currency market (that is the second focus in this paper[1]) information in the formulation of the Taylor rule is somewhat limited. One of the most recent attempts is the paper by Castro (2011), who, compared to our approach, introduces a much more complicated financial market indicator variable to the traditional Taylor rule. Some details of the Castro (2011) approach are given in section 2, but there are also some other previous papers that have attempted to use more simple measures for the market performance, like Chadha, Sarno, and Valente (2004) and Fuhrer and Tootell (2008).

After the studies by Taylor (2001) and Clarida (2001) there has been a long debate whether and how the stock and other financial market information and exchange rates should explicitly be taken into account in formulating the monetary policy. While presumably asset prices should be used as indicator variables for the real economy, during the last two decades it has been actually more or less obvious that the central banks have started to take into account the apparent increase in financial instability, and in many studies asset booms and busts have been found to be important factors in macroeconomic fluctuations in both developing and industrial countries.[2]

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[1] See for example Molodtsova, Nikolsko-Rzhevskyy, and Papell (2011), who implicitly study whether using the real exchange rate in the Taylor rule helps to outperform the random walk model in out-of-sample forecasting attempts.

[2] For an early contribution on these findings see Borio, Kennedy, and Prowse (1994), and for similar conclusions on the role of exchange rates in central banks' reaction functions see Clarida et al. (1998) and Taylor (2001).

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Chadha et al. (2004) introduced empirically both the asset prices and exchange rates to the standard interest rate rule for the United States, the United Kingdom and Japan since 1979. In the empirical analysis they used GMM estimation and without any theoretical, model based derivations, specified the monetary policy rule as a forward-looking Taylor rule augmented by the dividend-price ratio calculated using the Datastream composite stock price indices for each country, and the log-real effective exchange rate. Their main findings on the role of asset prices and exchange rate were that monetary policy makers may have used asset prices and exchange rates not only as part of their information set for setting interest rates, but also to set interest rates to offset deviations of asset prices or exchange rates from their equilibrium levels.

Also Fuhrer and Tootell (2008) examined the role of financial market information, specifically equity prices, in affecting the U.S. monetary policy steering rate directly. Alternatively, they considered financial market information as an instrument for forming the forecasts of the traditional policy variables, which were in their study a vector of variables consisting of quarterly percentage changes in real GDP, a gap variable measured by either the unemployment rate or a Hodrick-Prescott detrended real GDP gap, and a four-quarter moving average of inflation, measured in three different ways. They also estimated a forward-looking Taylor rule using Generalized Method of Moments (GMM). More specifically, they distinguished the Federal Open Market Committee's (FOMC) reaction to forecasts of traditional goal variables, which may depend on equity prices, from the FOMC's independent reaction to changes in equity prices. They used actual forward-looking variables examined by the FOMC before each action (the ”Greenbook” forecasts) and found little evidence to support the proposition that the FOMC responds to stock values, except as filtered through a forecast of accepted monetary policy goal variables.

Finally, according to Castro (2011) the Taylor rule type monetary policy rules might be nonlinear for the part of financial market effects. He analyzed whether the rule can be augmented with a financial conditions index containing information from some asset prices and financial variables. His results indicated that the monetary policy behaviour of the European Central Bank and Bank of England is best described by a nonlinear rule, but the behaviour of the Federal Reserve can be best described by a linear rule. In addition, his findings indicated that only the European Central Bank is reacting to financial conditions.

First, our analysis will focus the standard linear representation similar to the original Taylor rule, but we will allow for the interest rate smoothing and also for the possibility of opportunistic rules with a time-varying inflation target, as has been found in some of the recent studies on monetary policy rules. Second, the main new contribution in our study is to introduce two very simple forms of information from the stock and currency markets, i.e., the dividend yield and the real exchange rate as *additional information* variables that may have affected the monetary policy decisions of central banks, especially in turbulent time periods in the overall economies. In the first stage, this is based on adding these information as additional regressors to the regression analysis of the standard Taylor rule containing also the interest rate smoothing (i.e. lagged values of the interest rate) and time-varying inflation target. Third, we will use real-time data for the aggregate economic target variables in the policy rule, and based on the previous findings in the literature, the financial market information contains forecasting power for these variables. Hence, we are able to examine whether the role of these additional stock and currency market information is actually more of the 'instrument type', i.e., does their inclusion to the set of instrument variables in a GMM regression of the Taylor rule improve or strengthen the role of original economic target variables. Using real-time data from 1999 to 2016 for 14 OECD countries we clearly find that for all the other countries except the three big countries (in terms of their role in the global economy) outside the euro area – i.e. Japan, the UK and the U.S. – especially the role of stock but also of the currency market information seems to be essential when analysing the responsiveness of the interest rate on real activity and inflation deviations from their target values.[3] Furthermore, for many countries the inclusion of financial market information to the estimation of the Taylor rule reveals that for the part of inflation effects the rule has been opportunistic, i.e., the inflation target has been time-varying.

The structure of this paper is the following. In section 2 we give the theoretical motivation for the role of stock and currency market information in the Taylor rule. Section 3 gives the description of the data, some descriptive statistics and finally, the proposed specifications of the Taylor rule that we empirically analyze. Section 4 reports our empirical results based on real-time data from 14 OECD countries, and finally, section 5 gives conclusions.

2. The theoretical model

2.1. Stock market performance and currency market information as additional explicit policy targets

Usually in macroeconomic modelling the stock market performance has in many cases been treated as a forward looking variable that is able to forecast the future real economic activity or other aggregate variables out of sample. However, in some of the previous studies e.g. the performance of stock market has been introduced to the Taylor rule simply as an additional policy variable. For example Castro (2011) starts from a linear representation of the Taylor rule (later abbreviated as TR) in the form

$$i_t^* = \overline{r} + \pi^* + \beta(\pi_t - \pi^*) + \gamma(y_t - y_t^*),$$

that gives the nominal short-term target interest rate (i^*) as the sum of equilibrium real interest rate $(\overline{r})$ and target inflation (π^*) and the policy reactions (β and γ) to inflation deviations $(\pi_t - \pi^*)$ and deviations of output (y_t) from its (time-varying) trend or potential value (y_t^*),respectively. In addition, many of the modern studies scrutinizing the policy relevant representations of the original TR use the

[3] Actually in the forward looking opportunistic Taylor rule the financial market information proved to be important also for the case of Japan.

Clarida, Galí, and Gertler (1998) and Clarida, Galí, and Gertler (2000) suggestion that the rule should actually be forward looking. This allows the central bank to take various other variables (like stock and/or currency market prices and/or returns) into account when forming its inflation forecasts. Hence, Clarida et al. argue that the desired level of the nominal interest rate depends actually on the deviation of expected inflation k periods ahead (in annual terms) from its target value and the expected output gap p periods ahead, resulting the TR to be given as

$$i_t^* = \overline{r} + \pi^* + \beta\left[E(\pi_{t+k}|\Omega_t) - \pi^*)\right] + \gamma E\left[\left(y_{t+p} - y_{t+p}^*\right)|\Omega_t\right], \tag{1}$$

where E denotes the expectations operator and Ω_t is a vector of other relevant information for the central bank at the time of interest rate decision making. When inflation expectations rise, and if the monetary policy is supposed to be stabilizing in terms of affecting actually the real rate of interest (that affects the rate of inflation via its effects on economic activity in general), the coefficient on the inflation gap (β) should be greater than one and the coefficient on the output gap (γ) should be positive. Furthermore, nowadays the usual procedure in examining the monetary policy reaction functions is to try to control also for the observed serial correlation in the actual interest rates. This indicates that the central banks are assumed to practise so called interest rate smoothing, and hence, the lagged values of the instrument rate are added to the TR, implying that the central bank adjusts the interest rate gradually towards the desired level. In this case the dynamics of the adjustment of the current level of interest rate towards its target is given by

$$i_t = \left(1 - \sum_{j=1}^{n} \rho_j\right) i_t^* + \sum_{j=1}^{n} \rho_j i_{t-j}, \quad \text{where } 0 < \sum_{j=1}^{n} \rho_j < 1. \tag{2}$$

Here the sum of ρ_j captures the degree of interest rate smoothing and n the number of lags. After defining $\alpha = \overline{r} - (\beta - 1)\pi^*$ and $\overline{y} = y_{t+p} - y_{t+p}^*$ and inserting equation (2) into (1) with an assumption that the central bank is able to control interest rates only up to an independent and identically distributed stochastic error (u_t) yields the following equation:

$$i_t = \left(1 - \sum_{j=1}^{n} \rho_j\right)\left[\alpha + \beta E(\pi_{t+k}|\Omega_t) + \gamma E(\overline{y}_{t+p}|\Omega_t\right] + \sum_{j=1}^{n} \rho_j i_{t-j} + u_t. \tag{3}$$

Castro (2011) uses this form of the TR and extends it to include an additional vector of other explanatory variables ($\boldsymbol{x}$) that might have a role to play in interest rate setting by introducing a general term $\theta' E(\boldsymbol{x}_{t+q}|\Omega_t)$ to the set of terms in square brackets in (3). Here θ is a vector of coefficients associated with the additional variables targeted by the monetary policy actions. After eliminating the unobserved forecast variables, the extended policy rule can be written in terms of realized variables as

$$i_t = \left(1 - \sum_{j=1}^{n} \rho_j\right)\left[\alpha + \beta\pi_{t+k} + \gamma_{t+p}\overline{y} + \theta' \boldsymbol{x}_{t+q}\right] + \sum_{j=1}^{n} \rho_j i_{t-j} + \varepsilon_t, \tag{4}$$

where the error term ε_t is a linear combination of the forecast errors of inflation, output, the vector of additional exogenous variables and the disturbance term u_t. Like e.g. Castro (2011), Chadha et al. (2004), Clarida et al. (1998), Clarida et al. (2000), Fuhrer and Tootell (2008) and Quin and Enders (2008) all stress out, these kind of regression equations should be estimated by the generalized method of moments (GMM), because they involve unobserved values for some of the variables in the equation. For central banks, actually none of the variables in square brackets in equation (4) are observed at the time of interest rate decision making. To implement the GMM procedure, the following orthogonality conditions are imposed regarding the variables in (4):

$$E\left\{i_t - \left(1 - \sum_{j=1}^{n} \rho_j\right)\left[\alpha + \beta\pi_{t+k} + \gamma\overline{y}_{t+p} + \theta' \boldsymbol{x}_{t+q}\right] + \sum_{j=1}^{n} \rho_j i_{t-j}\middle| v_t\right\} = 0, \tag{5}$$

where v_t is a vector of (instrumental) variables that the central bank has in its information set at the time it chooses the interest rate, and that are orthogonal to the ε_t term. As Castro (2011), among others notes, the set of instruments has usually included for example lagged variables that help predict inflation, the output gap, and the additional exogenous variables, together with other contemporary variables that should not be correlated with the disturbance term u_t. In practice, the estimation of equation (5) involves the reduced form

$$i_t = \phi_0 + \phi_1\pi_{t+k} + \phi_2\overline{y}_{t+p} + \varphi' \boldsymbol{x}_{t+q} + \sum_{j=1}^{n} \rho_j i_{t-j} + \varepsilon_t, \tag{6}$$

where the regression parameter vector is related to the parameter vector in (5) via a representation $(\phi_0, \phi_1, \phi_2, \varphi)' = (1 - \sum_{j=0}^{n} \rho_j)(\alpha, \beta, \gamma, \theta)'$, so the original parameter vector and the standard errors related to equation (5) can be recovered based on the delta method.

In what follows in the empirical analyses of this paper, we will consider only the role of stock and currency market information supposed to be contained in the variable (vector) x in the augmented Taylor rule. Put it more precisely, we want to analyze the role of these additional variables either as direct policy variables, referring to the vector x in equation (6) above, or alternatively, as merely instrumental variables, and hence, belonging to the information vector v in equation (5). First of all, the role of stock market performance is measured by the dividend yield.[4] Furthermore, we also examine the potential role of currency market infromation in the form of real exchange rate. Because in addition to the traditional TR variables (inflation and real activity deviations) it clearly is a possible macroeconomic policy target variable, too, we analyze its role either as a strict target variable or an instrumental variable in the estimation of TR representations. Details of the background for the potential role of stock and currency market information specifically in the form of dividend yield and real exchange rate are given next.

2.2. Adding the stock and currency market information to the Taylor rule

One possibility to scrutinize the role of additional variables in the original standard Taylor (1993) rule is to introduce them as potential instrumental variables affecting indirectly the interest rate decision via their effect on inflation and output gap as predictive (leading indicator) variables. In some of the previous studies regarding the augmentation of the Taylor rule the dividend yield[5] has been considered as a potential information variable for the macro variables in the right hand side of the TR, but in none of them have the author(s) explicitly attempted to derive an actual regression equation for the analysis of its effects. In this paper, we utilize a recent paper by Junttila and Korhonen (2011) that explicitly derives a forecasting model for inflation, real economic activity and real exchange rate, where in addition to the short-term interest rate the main forecasting variable is the dividend yield for future inflation and real economic activity, and the relative (in relation to the foreign market) dividend yield for the real exchange rate. Their forecasting model starts from the traditional Gordon (1962) growth model that gives the fundamental value of equity (stock price, P_t^S) based on

$$P_t^S = \frac{D_t}{i_t - g_t^e - \pi_t^e}, \tag{7}$$

where the current stock price is dependent on the dividend stream (D_t) realized at time t, the nominal interest rate (i_t) at time t, the expected growth rate of economy (g_t^e, reflecting also the growth possibilities of future real yields on stock investments), and the expected inflation rate (π_t^e) at time t. It is straight forward to write equation (7) in terms of the dividend yield $(d_t = D_t/P_t^S)$ i.e., in the form[6] $d_t = i_t - g_t^e - \pi_t^e$. The next step is to use some relevant partial equilibrium conditions for the macroeconomic and financial market variables (that are at least partly referred to also in e.g. Stock & Watson, 2003), that is, the Fisher (1930) equation, the Euler equation for the real interest rates, and the purchasing power parity (PPP) together with the uncovered interest rate parity (UIP) condition in a two-country context that enable to construct a three-equation model for the relevant three asset market related variables, i.e., the dividend yield, nominal interest rate and the real exchange rate.[7] The final forecasting system in Junttila and Korhonen (2011) for expected values of the main interesting macro variables in the current study, that is, the real growth and inflation, and for the real exchange rate is comprised of,

$$\begin{aligned} g_t^e &= \frac{\rho}{1-\lambda} - \frac{d_t}{1-\lambda} \\ \pi_t^e &= i_t - \frac{\rho}{1-\lambda} + \frac{\lambda d_t}{1-\lambda} \\ q_t &= \alpha - \lambda\left(\frac{d_t^* - d_t}{1-\lambda}\right). \end{aligned} \tag{8}$$

The system of equations (8) gives us the background to include specifically the dividend yield and also the real exchange rate as additional variables to the empirical analysis of the augmented Taylor rule in this paper. However, at this point it is worth to mention some other studies that yield similar kinds of outcomes as (8) especially in terms of the predicted signs for the correlations between the dividend yield and the two most relevant macro variables regarding the augmentation of the standard Taylor rule, i.e., inflation and real growth.[8] As one can see from the above forecasting system (8), the proposed relationships here are a negative correlation between the (expected) economic growth and dividend yield and a positive correlation between the (expected) inflation and dividend yield.

Empirical research on the so called 'Fed model' (see Asness, 2000; Asness, 2003) has previously also found a clearly positive correlation between inflation and dividend yield, but a recent paper by Wei (2010) gives also an elegant theoretical background for the proposed positive relationship. Prior to her study, three hypotheses had been put forward to explain the positive correlation between inflation and dividend yield. The first one states that the monetary authority's tightening response to inflation damages the real

[4] Note that even though we have otherwise followed the paper by Castro (2011) closely in deriving the augmented representation of the Taylor rule, especially for this part we depart strongly from one of the main ideas in his paper. He uses a much more complex measure for the financial market performance, that is, a financial conditions index (FCI) designed to capture misalignments in the financial markets more generally. More specifically, he constructs a new and extended FCI from the weighted average of the real effective exchange rate, real share prices and real property prices plus credit spread and futures interest rate spread. Furthermore, he uses a Kalman filter procedure for the purposes of calculating the time varying weights of each of the asset components in the FCI. We are more interested in revealing the roles of a simple (single) stock market performance measure and the real exchange rate in affecting monetary policy decisions.

[5] See, e.g. Chadha et al. (2004).

[6] This valuation formula already includes all the main relevant variables for our stock market extension of the Taylor rule analysis, i.e., the dividend yield $\frac{D_t}{P_t^S}$(obtained dividing equation (7) by P_t^S), nominal interest rate i_t, expected growth of economy g_t^e and expected inflation π_t^e..

[7] The complete derivation of this system is given in Junttila and Korhonen (2011). Basically the first equation in the system resembles one simple form of a stock market valuation model, the second one a standard Taylor rule (stacking the target values for inflation and real growth to a single constant term, that originally describes only the rate of time preference in a Euler equation for the real interest rate), and finally, the third equation is the standard representation of the real interest rate parity.

[8] Our main reference paper by Junttila and Korhonen (2011) does not discuss these other studies in details, and most of them are connected to the analysis of monetary policy effects, so to our mind it is essential to take a look at these results at this point in the current study.

economy, and especially lowers the corporate profits. Hence, the growth rate of real dividends declines in response to inflation, driving up the dividend yields. On the other hand, Brandt and Wang (2003) have presented a model in which inflation makes investors more risk averse, and this drives up the required equity premium, and hence, the real discount rate. Finally, already Modigliani and Cohn (1979) have proposed a concept of so called inflation illusion,[9] according to which the stock market investors fail to understand the effect of inflation on nominal dividend growth rates and extrapolate historical nominal growth rates in periods of higher inflation. From the perspective of a rational investor, this implies that stock prices are undervalued when inflation is high and overvalued when it is low. The model presented by Wei (2010) is based on a modern structural, dynamic stochastic general equilibrium (DSGE) approach, and she finds that this kind of fully rational model can also theoretically generate a positive correlation between dividend yields and inflation as observed in the data. The main idea there is that a technology shock to an economy moves both inflation and dividend yields in the same direction, resulting in a positive correlation between the two.

The proposed negative correlation between the real growth of economy and dividend yield has not been discovered in many papers prior to Junttila and Korhonen (2011). In addition to his own theoretical and empirical findings in favor of this alleged relationship e.g. Ritter (2005) refers to papers by Dimson, Marsh, and Staunton (2002) and Siegel (1998), too. Ritter finds in his calculations for 16 countries over the 1900–2002 period that the simple correlation coefficient between total real return (including the dividend yield) on equities and the GDP growth rate is −0.37 (with a p-value of 0.16) rather than the −0.27 value that Dimson et al. (2002) reported. Siegel (1998) has argued that part of the negative correlation between real stock returns and real economic growth might be due to the fact that high economic growth may have been impounded into prices at the start of the analyzed periods. However, Ritter (2005) states perhaps more intuitively, that there is a general tendency for markets to assign higher price per earnings and price per dividend multiples (and hence, lower dividend yields) when economic growth is expected to be high, which has the effect of lowering realized returns because more capital must be committed by investors to receive the same dividends. More recently, Bekaert and Engstrom (2010) have performed an in-depth vector autoregressive analysis regarding the above mentioned 'Fed model' and received as a side product also some implications in favor of the proposed negative correlation between real economic growth and the dividend yield. They use a dynamic version of the Gordon (1962) growth model and the VAR approach building on the seminal work of Campbell and Shiller (1988), and find that the high correlation between expected inflation and the dividend yield is almost entirely due to the positive correlation between expected inflation and two plausible proxies for rational time-varying risk premiums, i.e., a measure of economic uncertainty (the uncertainty among professional forecasters regarding real GDP growth) and a consumption-based measure of risk aversion. When the economic uncertainty is high, the real economic activity is typically low (see also Ritter, 2005), so at least part of the negative correlation between the expected future real growth and the dividend yield comes from this channel. Furthermore, the analysis and empirical results of Bekaert and Engstrom (2010) actually indicate that the examination of the relationship between the dividend yield and future inflation and future economic activity should be conducted based on a system approach, and this is also the idea behind the derivation of the three-equation system given in (8).

The third alleged correlation in system (8) is the one between the contemporaneous values of the real exchange rate and the difference between the foreign and domestic dividend yields. Based on previous studies, this is perhaps the most difficult to connect to any kind of modern general equilibrium models theoretically, so in addition to the obtained partial equilibrium result, the main motivation for this proposed relationship comes from previous purely empirical findings. By definition, the dividend yield variable is comprised of the (somewhat constant) dividend stream in the numerator and much more volatile equity price in the denominator of the definition, so the main differences in domestic and foreign dividend yields have to stem from the differences in domestic and foreign stock market valuations at each point of time. In a recent, purely empirical study regarding the transmission of the ongoing financial and sovereign debt crises to the EMU countries for the part of stock, fixed income and currency markets, Grammatikos and Vermeulen (2012) find that the correlation between stock market values and exchange rates is very much dependent on the tranquility of the general economic conditions. They also point out that the early theoretical literature on this relationship does not actually agree on the sign of the correlation between the stock prices and the exchange rate. One stream of the literature represents the view that developments in the current account determine more or less exclusively the exchange rates (see e.g. Dornbusch & Fisher, 1980), and according to the so called 'harmful to exports' hypothesis exchange rate movements have an effect on firm competitiveness, that affects the stock prices through the future profitability of firms. In this case, e.g. when the euro exchange rate appreciates, this makes European products more expensive to foreign customers, so both exports and profits decrease. Hence, this theory predicts a negative relationship between stock prices and exchange rates, and in terms of the dividend yield analysis, a positive relationship between the domestic dividend yield and exchange rate. Correspondingly, in view of the main interesting variable, that is, the difference between the foreign and domestic dividend yields in the third equation of (8), this fits to our hypothesized negative relationship between the dividend yield spread and the real exchange rate, when the dividend yield spread is defined as the foreign dividend yield minus the domestic dividend yield.

The second view on the stock vs. currency market relationship is based on the portfolio balance models (see originally Branson, 1983; Frankel, 1983), proposing that the exchange rate is a variable equating the supply and demand of financial assets. Hence, these models predict a positive relationship between stock prices and exchange rates, because exchange rate appreciations are correlated with positive stock market returns. In this case rising stock prices increase the value of the equity market, which is associated with an exchange rate appreciation, and this view has generally been termed the 'signal of economic strength' hypothesis.

Grammatikos and Vermeulen (2012) use daily data from 15 EMU countries from 2003 to 2010 and analyze the relationship between stock market returns and exchange rate separately for Northern and Southern, big and small countries, and also separately for financial and non-financial firms' stock returns. Their main findings are that during tranquil times the coefficient of European financial firms'

[9] See more recently e.g. Campbell and Vuolteenaho (2004) for a VAR analysis on inflation illusion.

stock returns on euro-dollar exchange rate changes is in line with the 'harmful to exports' hypothesis. The effect is the strongest for North countries and the weakest for small Euro area countries. For both the North and South country groups the effect is also economically large. However, during the crisis period this relationship changes drastically. For all country groups the coefficient on exchange rate changes to positive and the result is equally strong for both the financial and non-financial firms' stock returns. Hence, in sum, the role of a strong euro during the crisis period appears to have changed from 'harmful to exports' to a 'signal of economic growth'.

3. Description of the data, descriptive statistics and the proposed specifications

We started our empirical analyses from descriptive statistics and a set of unit root tests. The original and transformed set of data that we are interested in is comprised of the 3-month money market interest rate [10] (i), deviation of real economic activity, measured by the deviation of the log of industrial production index in levels $(\overline{y})$ or as an annual growth rate $(\tilde{y})$ from the time varying trend value, deviation of annual CPI-inflation from trend value $(\tilde{\pi})$, actual CPI-inflation (π), log of the real effective exchange rate index (q), deviation of the log of real effective exchange rate index from its trend value $(\overline{q})$, the domestic dividend yield (d), deviation of the domestic dividend yield from its trend value $(\tilde{d})$, and finally, the difference between the foreign (d^*) and domestic dividend yield $(d^* - d)$, where the foreign market is the U.S. market for all the other analyzed 13 OECD countries.

One point that is much emphasized in the literature related to the estimation of monetary policy rules is the possible bias following from the use of revised data. Typically, macroeconomic variables such as industrial production and consumer price index are not observed immediately, but with some lag. In addition, these variables are often subject to subsequent revisions. Orphanides (2001) points out that the monetary policy rules estimated from revised data may provide misleading results, since the revised data do not correctly reflect the information that the central bankers have at the time they are making the monetary policy decisions. Instead, he argues that real-time data on macroeconomic variables should be used when evaluating monetary policy based on, for example, a Taylor rule.

In our analysis, we have used real-time series of industrial production index and consumer price index obtained from OECD's Main Economic Indicators real-time database .[11] The database contains monthly vintages of industrial production index and consumer price index starting from February 1999. The real-time series of industrial production index is constructed by extracting the latest value of each vintage corresponding to the observation period. Hence, for example the latest value in the data vintage of February 2004 corresponds to the February 2004 observation in our real-time series. The real-time series for inflation is constructed by subtracting from the log of the most recent value in each vintage the log of the value 12 months earlier in the same vintage, and multiplying the obtained number by 100. The growth rate for industrial production index, where it is used, is constructed in a similar manner. Typically, the publication lag for industrial production index is three months, and for consumer price index one month. Obviously, since the financial market variables are not subject to publication lag or subsequent revisions, there is no need to consider any real-time adjustments. The time series of nominal 3-month money market interest rate, dividend yield and real effective exchange rate index were obtained from Thomson Reuters Datastream.

Since in our empirical analysis we use the deviations of variables from their trend values, a some kind of detrending method is required. A popular way of detrending macroeconomic time series is the Hodrick-Prescott filter. However, according to Hamilton (2016), using the Hodrick-Prescott filter may induce spurious dynamic relations that have no basis in the underlying data generating processes. Hamilton (2016) proposes a simple alternative: In each period, four most recent observations are used to form a h-period linear forecast of the variable in question. The resulting series serves as a proxy for the trend. We apply this detrending procedure to the constructed real-time series of inflation and industrial production index to obtain the trends of these variables. We also apply the procedure to the log of the real effective exchange rate, since we consider the deviation of that variable from its trend value in our analysis, too.

Hamilton (2016) suggests that one should use $h = 8$ for quarterly data and $h = 24$ for monthly data. Although the data we use is of monthly frequency, we decided to use $h = 8$ since our sample is relatively short, and using $h = 24$ would discard a big number of observations from the beginning of the sample. We did some robustness checks using also $h = 24$, but this did not change the main results significantly. Hence, in obtaining the time-varying trend values of each variable, we have used this simple linear projection method proposed by Hamilton (2016). The countries in our data set are Austria, Belgium, Canada, Denmark, Finland, France, Germany, Italy, Japan, the Netherlands, Norway, Sweden, the UK, and finally, the U.S. The original full sample of data are monthly observations from 1999:2–2016:9. It is worth noting that, because of the detrending method that we use, a total of 11 observations are discarded from the beginning of the sample in each country.

From Table 1 we see that in terms of stationarity/nonstationarity properties there are clearly some problems in the time series data of the Taylor rule variables. First of all, like observed among others also in Enders, Im, Lee, and Strazicich (2010), the interest rate series in all countries seem to behave like unit root processes, and this might indicate that further analyses of the Taylor rule (TR) should be executed using differenced values of the interest rate series. However, it is well known that the power of unit root tests in small samples

[10] Most of the studies that estimate Taylor rules use an overnight interbank rate, such as EONIA or the effective Federal funds rate, as the policy instrument. However, for example Castro (2011) conducts robustness tests using 3-month money market rates, and finds that results are not significantly altered. Sauer and Sturm (2007) do similar robustness checks for the Eurozone, and come to the same conclusion. Also Belke and Klose (2011), Belke and Polleit (2007) and Surico (2003) use 3-month money market rate as the policy instrument. These previous studies lend support to our choice to use the 3-month money market interest rate as the dependent variable in the estimation of the Taylor rules for the OECD countries, too.

[11] http://stats.oecd.org/mei/.

Table 1
Descriptive statistics.

Country/Variable	i	$\tilde{y}$	$\tilde{\pi}$	$\bar{y}$	π	q	$\bar{q}$	d	$\tilde{d}$	$d^* - d$
Austria										
Mean	2.13	0.00	0.00	0.00	1.83	4.65	0.00	2.36	0.00	−0.46
Stdev	1.64	5.31	0.73	5.04	0.88	0.02	1.45	0.86	0.72	0.67
ADF	−1.16	−5.34***	−5.35***	−4.07***	−2.63*	−2.96**	−2.8*	−2.48	−2.96**	−2.28
KPSS	2.74**	0.36*	0.24	0.27	0.16	0.48**	0.21	1.34***	0.45*	0.33
Belgium										
Mean	2.13	0.00	0.00	0.00	1.92	4.59	0.00	3.29	0.00	−1.39
Stdev	1.64	5.47	1.04	6.65	1.23	0.04	2.07	1.78	1.63	1.63
ADF	−1.16	−3.85***	−2.51	−3.50***	−2.90**	−1.93	−3.73***	−4.76***	−2.63*	−3.85***
KPSS	2.74***	0.09	0.37*	0.51**	0.26	1.68***	0.20	0.23	0.14	0.39
Canada										
Mean	2.33	0.00	0.00	0.00	1.91	4.48	0.00	2.43	0.00	−0.54
Stdev	1.57	4.12	0.88	3.63	0.90	0.11	5.33	0.62	0.40	0.20
ADF	−1.59	−3.90***	−3.06**	−3.52***	−2.73*	−1.78	−3.84***	−1.87	−3.76***	−3.13**
KPSS	2.85***	0.20	0.97***	0.22	0.73**	2.32***	0.29	3.20***	0.42*	1.28***
Denmark										
Mean	2.39	0.00	0.00	0.00	1.86	4.59	0.00	1.78	0.00	0.12
Stdev	1.78	5.33	0.72	4.70	0.90	0.03	2.02	0.48	0.43	0.42
ADF	−0.86	−4.89***	−3.05**	−4.62***	−1.68	−1.95	−4.17***	−2.23	−3.21**	−2.74*
KPSS	2.67***	0.23	0.61**	0.59**	1.32***	1.09***	0.20	0.76***	0.44*	2.29***
Finland										
Mean	2.13	0.00	0.00	0.00	1.61	4.63	0.00	3.46	0.00	−1.56
Stdev	1.64	6.94	0.97	5.55	1.29	0.03	2.35	1.30	0.95	0.95
ADF	−1.16	−4.74***	−3.26**	−3.72***	−2.62*	−2.77*	−4.14***	−2.36	−4.64***	−2.31
KPSS	2.74***	0.55**	0.23	0.21	0.27	1.63***	0.43*	1.77***	0.32	0.91***
France										
Mean	2.13	0.00	0.00	0.00	1.40	4.60	0.00	3.23	0.00	−1.33
Stdev	1.64	3.64	0.72	3.73	0.85	0.04	2.10	0.79	0.62	0.53
ADF	−1.16	−4.37***	−1.95	−3.89***	−1.86	−1.20	−3.72***	−2.56	−3.98***	−2.53
KPSS	2.74***	0.32	0.96***	0.68**	0.91***	1.15***	0.49**	1.49***	0.31	0.38*
Germany										
Mean	2.13	0.00	0.00	0.00	1.46	4.62	0.00	2.54	0.00	−0.64
Stdev	1.64	5.39	0.65	4.96	0.80	0.04	2.46	0.76	0.54	0.42
ADF	−1.16	−3.15**	−2.73*	−3.74***	−2.44	−1.84	−1.97	−2.38	−3.58***	−2.32
KPSS	2.74***	0.09	0.64**	0.51**	0.50**	1.79***	0.51**	2.25***	0.43**	0.57**
Italy										
Mean	2.13	0.00	0.00	0.00	1.70	4.60	0.00	3.55	0.00	−1.65
Stdev	1.64	5.05	2.55	4.17	2.50	0.04	2.25	1.33	1.06	1.15
ADF	−1.16	−3.54***	−12.34***	−3.83***	−12.49***	−1.90	−3.62***	−2.50	−3.45**	−2.25
KPSS	2.74***	0.29	0.83***	0.47**	1.00***	0.81***	0.28	0.78***	0.20	0.58**
Japan										
Mean	0.27	0.00	0.00	0.00	0.04	4.56	0.00	1.47	0.00	0.42
Stdev	0.25	8.26	0.89	6.80	1.04	0.16	7.67	0.61	0.33	0.30
ADF	−2.14	−3.37**	−2.37	−3.96***	−2.53	−1.53	−3.26**	−1.32	−3.96***	−2.10
KPSS	0.50**	0.15	0.58**	0.36*	0.87***	2.74***	0.29	3.27***	0.34	0.71**
Netherlands										
Mean	2.13	0.00	0.00	0.00	1.95	4.61	0.00	3.17	0.00	−1.27
Stdev	1.64	4.25	0.78	3.87	1.04	0.04	2.22	0.97	0.86	0.77
ADF	−1.16	−4.81***	−4.42***	−5.42***	−1.69	−2.15	−3.94***	−3.03**	−3.33**	−2.70*
KPSS	2.74***	0.31	0.56**	0.45*	1.39***	0.67**	0.23	0.48**	0.14	0.66**
Norway										
Mean	3.67	0.00	0.00	0.00	2.01	4.55	0.00	3.26	0.00	−1.36
Stdev	2.15	4.61	1.04	3.65	1.10	0.05	4.25	1.13	0.90	0.77
ADF	−1.91	−8.01***	−3.75***	−5.79***	−4.35***	−2.53	−3.54***	−2.54	−3.47***	−2.82**
KPSS	2.54***	0.28	0.17	0.34	0.18	0.55**	0.33	2.31***	0.64	1.21***
Sweden										
Mean	2.30	0.00	0.00	0.00	1.17	4.65	0.00	2.90	0.00	−1.00
Stdev	1.61	6.12	1.01	4.83	1.20	0.05	4.11	0.89	0.72	0.56
ADF	−1.15	−3.71***	−3.94***	−3.11**	−2.66*	−2.10	−2.75**	−2.81*	−3.92***	−3.09*
KPSS	2.68***	0.25	0.42*	0.64**	0.48**	1.50***	0.48**	1.80***	0.50**	0.48**
UK										
Mean	3.10	0.00	0.00	0.00	2.40	4.75	0.00	3.34	0.00	−1.45
Stdev	2.21	2.67	0.96	2.49	1.11	0.10	4.90	0.61	0.48	0.38
ADF	−0.93	−4.85***	−2.60*	−4.10***	−1.70	−1.26	−2.63*	−2.51	−3.62***	−2.15
KPSS	3.21***	0.22	0.46	0.38*	0.57**	2.79***	0.27	1.05***	0.38*	0.98***

Table 1 (*continued*)

Country/Variable	i	$\tilde{y}$	$\tilde{\pi}$	$\bar{y}$	π	q	$\bar{q}$	d	$\tilde{d}$	$d^* - d$
US										
Mean	1.82	0.00	0.00	0.00	2.16	4.68	0.00	1.90	0.00	NA
Stdev	2.02	3.35	1.24	3.10	1.29	0.08	4.40	0.50	0.31	NA
ADF	−1.75	−3.71***	−2.18	−4.12***	−1.52	−1.49	−2.81*	−1.59	−3.73***	NA
KPSS	2.44***	0.11	0.79***	0.39*	0.88***	2.41***	0.31	3.40***	0.45*	NA

Notes: Table 1 presents sample means, standard deviations and the results from the augmented Dickey-Fuller-tests (ADF, H_0: unit root) and Kwiatkowski-Phillips-Schmidt-Shin-tests (KPSS, H_0: stationarity), and the significance levels for both these test statistics are denoted by * = 10%, ** = 5%, and *** = 1%. The analyzed variables are: i = the nominal 3-month money market interest rate, $\tilde{y}$ = deviation of the real growth (measured by annual change of the industrial production index) from its trend value, $\tilde{\pi}$ = deviation of annual CPI-inflation from its trend value, $\bar{y}$ = deviation of the level of real economic activity (log of industrial production index) from its trend value, π = actual CPI-inflation, q = log of the real effective exchange rate index, $\bar{q}$ = deviation of the log of real effective exchange rate index from its trend value, d = the domestic dividend yield, $\tilde{d}$ = deviation of the domestic dividend yield from its trend value, and d^* = the foreign (US) dividend yield. The trends of the variables in question have been obtained by Hamilton (2016)'s linear projection method with $h = 8$ and $p = 4$.

is rather weak. Furthermore, almost all the deviation (i.e., gaps calculated against the time-varying trend values) series seem stationary. This is simply due to the fact that the detrending method extracts the stationary component of the series. So basically, the Taylor rule regression equation would seem to contain a mixture of stationary and nonstationary time series right from the beginning, and this is problematic, as we know from the vast amount of unit root and cointegration literature starting from the Engle and Granger (1987) and Johansen (1988) presentations. However, in our analyses part of the effects of the permanent component in the interest rate will be taken into account by using a smoothing version of the TR, that is, by introducing the lagged value(s) of the interest rate to the regression equation. Obviously, the more permanent the interest rate time series is, the closer will be the coefficient on lagged interest rate be to one in the right-hand-side of the TR regression equation.

Furthermore, from Table 1 we also see that in addition to the unit root properties of actual inflation series, especially in the time series of the proposed new variables (dividend yields and real exchange rates) there also seems to be indications that they might actually behave like unit root processes, so in this respect, too, we had to introduce and test various forms of transformations regarding the proposed augmented version of the Taylor rule right from the beginning of our empirical analyses. First of all, as already mentioned, we always included the lagged value of the interest rate to the equation. Second, we considered the real activity variable either as a deviation of the log level of industrial production from its trend value, or as the deviation of the annual change in the monthly value (growth) of that same index. Third, we analyzed the role of actual annual inflation and its deviation from the trend value separately, so in the latter case, we wanted to allow for the possibility of the so called 'opportunistic' monetary policy in terms of inflation reactions, like e.g. in Bunzel and Enders (2010). Also the possibility that the actual inflation process might be nonstationary was considered in the model transformations. Finally, the potential role for the new alleged financial market variables, namely the dividend yield and real exchange rate, had to be taken into account in view of their possible unit root properties, too. Hence, we considered the following main set of possibilities when seeking for the best possible (in terms of econometric 'performance') form of the augmented Taylor rule[12] for each of the analyzed countries:

1) The original, simple Taylor rule without additional variables:

$$i_t = \alpha_0 + \alpha_1 \pi_t + \alpha_2 \bar{y}_t + \rho i_{t-1} + \varepsilon_t,$$

where in addition to the notations given above, α_0 is the constant term, α_1 and α_2 are regression parameters for the actual inflation and real activity deviation from its trend value, ρ is the regression coefficient (smoothing parameter[13]) for the lagged interest rate, and ε_t is the error term. Furthermore, for the inflation variable we alternatively considered the difference of it and for the real activity variable we scrutinized also the deviation of annual growth rate from its trend;

2) An 'opportunistic' Taylor rule with a time-varying inflation target:

$$i_t = \alpha_0 + \alpha_1 \pi_t + \alpha_2 \bar{y}_t + \alpha_3 \tilde{\pi}_t + \rho i_{t-1} + \varepsilon_t,$$

where in addition to the notations given above, $\tilde{\pi}_t$ describes the deviation of inflation from its trend value, and α_3 is its regression coefficient. Also for this representation we considered the other possibilities for measuring the real activity and inflation variables as in case 1);

[12] This form has been analyzed for example in Bunzel and Enders (2010), and the first empirical results reported in Table 2 were obtained from simple OLS estimations with heteroscedasticity and autocorrelation consistent (Newey-West) standard errors. The next stage of our analysis will utilize forward-looking TR formulations and GMM estimation, but the potential role for the new additional variables in the TR will be revealed to a degree already from these simple first stage estimations.

[13] Based on obtained parameter estimates the actual policy response coefficients regarding inflation (g_π) and real activity deviation (g_y) can be calculated from $(1-\rho)g_\pi = \alpha_1$ and $(1-\rho)g_y = \alpha_2$, and based on this same idea it would be possible to calculate the 'policy response coefficients' for the potential additional new variables in the TR, too.

3) An augmented (and possibly 'opportunistic') Taylor rule, where the augmentation considers the currency and stock market information as additional policy variables;

$$i_t = \alpha_0 + \alpha_1 \pi_t + \alpha_2 \overline{y}_t + \alpha_3 \tilde{\pi}_t + \alpha_4 q_t + \alpha_5 d_t + \rho i_{t-1} + \varepsilon_t,$$

where the new notations denote q_t as the log of real effective exchange rate, d_t as the dividend yield, and α_4, α_5 are their regression coefficients, respectively. We also considered the role of these additional information in the form of deviations from their trend values and also by replacing the exchange rate variable by the difference between foreign and domestic dividend yields, as suggested by the system of equation (8) given in section 2. In addition, in the empirical analyses we will especially focus on the role of additional financial market information as instrument variables in the GMM estimation of the forward looking Taylor rule.

Empirical results

4.1. Results for the contemporaneous Taylor rule using real time data

Table 2 reports the results from OLS regressions with Newey-West standard errors for the real-time values of the policy variables in the Taylor rule. For each country we report the best (in terms of the goodness of fit) obtained form of the regression equation, where the selection criteria were based on the significance of the obtained parameter estimates, and the Schwarz information criterion. The results in Table 2 give us the first-stage indication on the role of stock and currency market information in the Taylor rule. It seems that only in the cases of Japan and the U.S. the information from financial markets is not relevant in the contemporaneous Taylor rule when the simple currency and stock market information are included as actual additional policy variables. In all the other cases the dividend yield and/or the log of real exchange rate and/or the dividend yield spread is/are relevant in terms of improving the econometric fit of the Taylor rule, as measured by the Schwarz information criterion. Both the currency and stock market information would seem to have an important role in Belgium, Canada, France, Italy, the Netherlands, Sweden and the UK. In addition, only the stock market information is relevant in Austria, Denmark, Finland, Germany, and Norway.

Perhaps the most striking finding in these results is that the sign of the estimated coefficient on dividend yield is negative in all cases where the aforementioned variable enters the Taylor rule, that is, for all the other countries except Japan and the U.S. This indicates a loosening monetary policy reaction as the prices in the stock market decrease, i.e., when the dividend yield increases. According to our results, the monetary policy for example in Norway and the UK has not followed the Taylor rule principle, because the traditional policy variables would seem to have no role to play in affecting the short-term interest rate at all. Also, in small EMU countries like Austria, Belgium, and the Netherlands, the estimated coefficients of the traditional Taylor rule policy variables are not statistically significant. However, this is true for the core EMU economies like Italy and France, too. For Germany, the parameter estimate on the real growth deviation is significant at 5% level, but on the differenced inflation it is not significant. This seems somewhat strange considering the historically hawkish attitude of German policymakers towards high inflation, and the allegedly big influence of Germany's economic outlook in the monetary policy of the European Central Bank. These results might indicate that central banks simply do not consider contemporaneous values of policy variables when making monetary policy decisions, but are rather forward-looking. For the part of all the Euro area countries we naturally have to remember that the common monetary policy from the beginning of 1999 has most likely not been guided by the development of smaller union countries, but more likely it has been based on the economic performance of the big core countries like France, Germany and Italy in our data set. Hence, in what follows when we discuss the results based on a forward-looking TR representation, it is useful to divide the reporting of results into subgroups of the analyzed countries based on viewing e.g. the smaller and larger members of the Euro area separately. But already from these first-stage results we clearly see that the information from currency and stock markets might have a strong role to play in the empirical analysis of the Taylor rule for these countries.

Finally, one thing worth to mention already from these results is the strong influence of the lagged interest rate in the estimated Taylor rules. In our sample, as seen from the unit root tests reported in Table 1, the short-term rates seem to exhibit unit root behaviour. This in turn clearly shows up in the values of the estimates for the coefficient on the lagged interest rate (ρ) which is very close to one in all countries, and for Belgium, the estimated coefficient is in fact above one. This is not surprising, since high values of the estimated smoothing parameter have also been found in the earlier literature. Moreover, we have to keep in mind that in monthly data, the role of sluggish interest rate adjustment tends to be even more apparent than for example in quarterly data. Furthermore, our sample covers the period when the short-term nominal interest rates have more or less been stuck at zero or below it, which partly contributes to the dominating role of the lagged interest rate in the estimated Taylor rules.[14]

[14] Note that we analyzed also the role of stock and currency market information in a model, where we controlled for the effects of zero lower bound interest rate era after the 2008–2009 crisis by introducing a dummy variable to all the OLS regressions for the country-specific Taylor rules. For most countries the dummy variable proved not to be statistically significant in the contemporaneous Taylor rule regressions. However, in the case of the forward looking rules discussed in the next section the coefficient on the zero interest rate era dummy was negative and statistically significant for most countries. This indicates that it captured well the more or less permanently lower mean (zero) value of the short-term interest rates since the onset of 2008–2009 crisis (after the Lehman Brothers bankruptcy in September 2008). However, more importantly, its inclusion to the regression model did not have almost any role on either the significance or signs of the parameter estimates for our main interesting additional regressors, i.e., the dividend yield and the real exchange rate. These additional results not reported in this paper are available from the authors upon request.

Table 2
Results from the estimation of the linear Taylor rule using real-time data.

Variables/Country	Aus	Bel	Can	Den	Fin	Fra	Ger	Ita	Jap	Net	Nor	Swe	UK	US
Traditional policy variables in the Taylor rule														
Constant	0.255	−3.342	0.149	0.245	0.339	−3.776	0.330	−4.823	0.004	−4.739	0.556	0.430	−4.059	0.045
	(0.006)	(0.111)	(0.021)	(0.027)	(0.000)	(0.014)	(0.002)	(0.034)	(0.214)	(0.013)	(0.004)	(0.000)	(0.028)	(0.093)
π_t	–	–	–	–	–	0.024	–	−0.001	0.002	−0.016	−0.021	0.054	0.014	−0.025
						(0.250)		(0.701)	(0.485)	(0.277)	(0.331)	(0.002)	(0.367)	(0.144)
$\Delta\pi_t$	0.051	0.035	0.036	0.171	0.042	–	0.061	–	–	–	–	–	–	–
	(0.148)	(0.242)	(0.038)	(0.078)	(0.194)		(0.225)							
$\overline{y}_t$	0.005	−0.002	0.007	0.013	0.009	0.005	–	0.003	0.002	–	–	0.009	–	–
	(0.112)	(0.471)	(0.090)	(0.000)	(0.000)	(0.177)		(0.451)	(0.000)			(0.010)		
$\tilde{\pi}_t$	–	–	–	–	–	–	–	–	–	–	–	–	–	–
$\Delta\overline{y}_t$	–	–	–	–	–	–	0.007	–	–	0.002	0.009	–	0.001	0.014
							(0.029)			(0.274)	(0.106)		(0.932)	(0.005)
i_{t-1}	0.982	1.013	0.973	0.973	0.966	0.957	0.973	0.998	0.977	1.000	0.963	0.935	0.949	0.991
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Variables in the augmented Taylor rule														
q_t	–	0.762	–	–	–	0.927	–	1.104	–	1.120	–	–	0.969	–
		(0.097)				(0.021)		(0.011)		(0.007)			(0.020)	
$\overline{q}_t$	–	–	0.008	–	–	–	–	–	–	–	–	0.011	–	–
			(0.005)									(0.016)		
d_t	−0.099	−0.061	–	−0.114	−0.080	−0.138	−0.112	−0.075	–	−0.127	−0.122	−0.125	−0.131	–
	(0.002)	(0.000)		(0.018)	(0.000)	(0.000)	(0.001)	(0.001)		(0.000)	(0.001)	(0.000)	(0.027)	
$d_t^* - d_t$	–	–	0.197	–	–	–	–	–	–	–	–	–	–	–
			(0.032)											
Model Statistics														
R^2	0.993	0.994	0.987	0.991	0.994	0.994	0.993	0.993	0.973	0.994	0.988	0.991	0.994	0.987
SIC	−1.026	−1.065	−0.574	−0.587	−1.108	−1.048	−1.053	−0.946	−3.388	−1.199	0.012	−0.806	−0.510	−0.118
LM-test	30.688	25.550	5.477	10.742	18.922	28.336	28.392	32.530	17.086	14.708	8.282	26.978	21.818	7.926
	(0.000)	(0.000)	(0.019)	(0.001)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.004)	(0.000)	(0.000)	(0.005)

Notes: The results are based on OLS estimation with Newey-West HAC standard errors. The dependent variable is the nominal 3-month interest rate (i_t), and the fundamental regression equation (for the augmented model, that nests the original simple Taylor rule rule, too), is $i_t = \alpha_0 + \alpha_1\pi_t + \alpha_2\overline{y}_t + \alpha_3\tilde{\pi}_t + \alpha_4 q_t + \alpha_5 d_t + \rho i_{t-1} + \varepsilon_t$, where α_0 is the constant term, $\alpha_1, \alpha_2, \alpha_3, \alpha_4, \alpha_5$ are the regression parameters for the actual inflation (π_t), real activity deviation from its trend value ($\overline{y}_t$), the deviation of inflation from its trend value (indicating the 'opportunistic' Taylor rule) ($\tilde{\pi}_t$), the log of real effective exchange rate (q_t), and the dividend yield (d_t), respectively. ρ is the regression coefficient (smoothing parameter) for the lagged interest rate, and ε_t is the error term. For the part of augmentation variables (the stock and currency market information), we also tested for versions involving the deviation of the log of real effective exchange rate from its trend value ($\overline{q}_t$), the deviation of the dividend yield from its trend value ($\tilde{d}_t$), and the difference between foreign and domestic dividend yields ($d_t^* - d_t$). Δ refers to the use of differenced values of the variable in question, except for the real activity variable, where it indicates the annual growth rate of the monthly index value. For the variables in question, the trend value is obtained by Hamilton (2016)'s linear projection method with $h = 8$ and $p = 4$. For each country we report the best fitting Taylor rule, in terms of the econometric fit, i.e., based on the Schwarz information criterion, and the significance of the estimated regression parameters. The Newey-West procedure uses six lags in the Bartlett lag window. The reported goodness of fit statistics are the values for the Schwarz information criteria (SIC), the coefficient of determination (R^2) and the Breusch-Godfrey LM-test value (with p-value in parentheses) for testing general form of autocorrelation in the residuals. Below the values for regression coefficients we give the p-values for the null of zero coefficient in parentheses.

Table 3a
Results from the estimation of the forward looking Taylor rule for the core EMU countries.

Variables/Country	Fra		Ger		Ita	
Horizon (k, p in months)	3	12	3	12	3	12
Traditional forward looking TR without additional instruments from the stock and currency markets						
Constant	−0.014 (0.634)	−0.024* (0.061)	−0.076*** (0.006)	−0.169** (0.0187)	0.015 (0.744)	0.024 (0.141)
π_{t+k}	0.001 (0.988)	–	−0.007 (0.859)	0.179*** (0.000)	0.020 (0.775)	−0.002 (0.782)
$\Delta\pi_{t+k}$	–	−0.228* (0.052)	–	–	–	–
$\overline{y}_{t+p}$	0.033*** (0.000)	−0.001 (0.816)	0.026*** (0.000)	−0.008 (0.167)	0.045*** (0.000)	−0.027*** (0.000)
i_{t-1}	1.007*** (0.000)	1.003*** (0.000)	1.033*** (0.000)	0.945*** (0.000)	0.970*** (0.000)	0.978*** (0.000)
J-statistics	11.686** (0.039)	12.580 (0.961)	3.7927 (0.579)	16.652 0.952	6.292 (0.279)	13.180 (0.948)
SSR-value	4.742	5.456	4.327	5.148	6.180	6.145
Forward looking TR with additional instruments from the stock and currency markets						
Constant	−0.015 (0.562)	−0.020** (0.041)	−0.075*** (0.007)	−0.219*** (0.000)	0.002 (0.942)	0.016 (0.104)
π_{t+k}	0.034 (0.147)	–	−0.005 (0.904)	0.196*** (0.000)	−0.004 (0.943)	0.006 (0.212)
$\Delta\pi_{t+k}$	–	−0.230** (0.045)	–	–	–	–
$\overline{y}_{t+p}$	0.032*** (0.000)	−0.002 (0.629)	0.026*** (0.000)	−0.008** (0.032)	0.036*** (0.000)	−0.010*** (0.000)
i_{t-1}	0.981*** (0.000)	0.998*** (0.000)	1.031*** (0.000)	0.957*** (0.000)	0.995*** (0.000)	0.975*** (0.000)
J-statistics	12.316 (0.091)	13.596 (0.968)	3.7839 (0.706)	18.655 (0.985)	6.463 (0.486)	15.786 (0.997)
Best set of addit. instrum.	d_t and q_t	d_t	$\tilde{q}_t$	d_t	d_t and $\tilde{q}_t$	d_t
SSR-value	4.426	5.396	4.276	5.405	4.702	4.899

Notes: We report the results from GMM estimation with Newey-West HAC standard errors. The fundamental regression equation is now $i_t = \alpha_0 + \alpha_1\pi_{t+k} + \alpha_2\overline{y}_{t+p} + \rho i_{t-1} + \varepsilon_t$, where the dependent variable is the nominal 3-month interest rate (i_t), α_0 is the constant term, and α_1, α_2 are the regression parameters for the actual future inflation (π_{t+k}) and future real activity deviation from its trend value ($\overline{y}_{t+p}$). ρ is the regression coefficient (smoothing parameter) for the lagged interest rate, and ε_t is the error term. We analyze two forward looking horizons ($k, p = 3$ and 12 months), and use actual realized future values in place of e.g. generated, or questionnaire based expected values for the traditional policy variables. The upper panel reports the GMM-results for the standard TR, where the set of instruments includes a constant, 3 lags (for 3-month horizon) or 12 lags (for 12 months horizon) of the policy variables (inflation and real activity deviation), and always two lags of differenced values of the interest rate. In the lower panel we report the effects of additional instruments in the GMM estimation, where the possibilities for the form of additional information are the contemporaneous values of the domestic dividend yield (d_t), the dividend yield difference against the US market ($d_t^* - d_t$), the log of real effective exchange rate (q_t), and the deviation of the log of effective exchange rate from its trend values ($\tilde{q}_t$). In addition to the role of individual variables from the stock or currency markets, we also scrutinized their joint effects, i.e., including e.g. the domestic dividend yield and the log of real effective exchange rate together into the set of instruments. We also examined the role of using differenced values of inflation in the rule, and report the parameter estimates if that specification proved better in terms of econometric fit. In the lower panel the reported results on additional stock and currency market instruments are based on the best fitting Taylor rule in terms of the significance of the estimated regression parameters, the value of the test statistics and its p-value for the Hansen's J-test regarding the validity of overidentifying restrictions on the set of instruments, and the value of the sum of squared residuals (SSR). The Newey-West procedure uses again always six lags in the Bartlett lag window. Below the values for regression coefficients we give the p-values for the null of zero coefficient in parentheses, and the significance levels for the parameter estimates are denoted by * = 10%, ** = 5%, and *** = 1%.

4.2. Results for the forward looking Taylor rule

4.2.1. The core EMU countries

In Table 3a we report the results from GMM estimation[15] of a forward looking Taylor rule for the core EMU countries France, Germany and Italy. We used two forward looking time horizons, i.e., 3 and 12 months. In contrast to the results reported in section 4.1, here we especially wanted to focus on the role of stock and currency market variables as additional instruments in the GMM estimation of the forward looking Taylor rule, because the forward-looking specification is the more relevant one in case of including the financial market information to the Taylor rule analysis based on our background model (8)[16]. In the standard Taylor rule the set of instruments always includes a constant, 3 lags (for 3-month horizon) or 12 lags (for 12 months horizon) of the policy variables (inflation and real activity deviation), and always two lags of differenced values of the interest rate. In the lower panel of all Tables 3a–3d we report the effects of additional instruments in the GMM estimation, where the possibilities for the form of additional financial market based information are the contemporaneous values of the domestic dividend yield (d_t), the dividend yield difference against the US market ($d_t^* - d_t$), the log of real effective exchange rate (q_t), and the deviation of the log of effective exchange rate from its time-varying trend values ($\tilde{q}_t$). In addition to the role of individual variables from the stock or currency markets, we also scrutinized their joint effects, i.e., including e.g. the domestic dividend yield and the log of real effective exchange rate together into the set of instruments.

Based on the results reported in Table 3a we see that there clearly is a role for the financial market information in the formulation of the forward looking Taylor rule already for the three big core countries of the Euro area. The parameter estimates for the policy variables remain more or less the same in terms of their statistical significance, but in 5 out of 6 cases (the exception being the 12-month horizon rule for Germany) the sum of squared residuals value improves, so there is at least marginal improvement in these cases when the financial market information is included as additional instrumental variable information to the GMM regressions. Furthermore, according to the Hansen J-test statistics the inclusion of financial market variables improves the validity of the instrument set in terms of

[15] We acknowledge that the GMM estimation with HAC standard errors does not control for contemporaneous correlation in the error terms across countries, but because most of the previous studies analyzing the forward-looking Taylor rules have used this estimation procedure, we will use it also in our analysis.

[16] Here we follow the usual practice in most of the previous studies (see e.g. Castro, 2011) by estimating all the forward looking Taylor rule regressions using the Generalized Method of Moments (GMM) approach.

increasing the p-values associated with the test statistics, although only marginally in some cases. A three-month horizon rule for France is the only case for which the null hypothesis of instrument validity is rejected at 10% significance level, even after including the financial market variables as instruments.

Regarding the interpretation of the policy variable parameter estimates, the change in future inflation would seem to have been informative for the 12-month horizon in France at 10% percent significance level, whereas the future level of inflation has been relevant in Germany at 12-month horizon at 1% significance level. Future deviations of real activity from its time varying trend have been important in the Taylor rule at the short horizon in every core country at 1% level. However, the important new finding is here that in all cases the best fitting Taylor rule requires the inclusion of some form of financial market information, either in the form of dividend yield, log of real exchange rate, or both the dividend yield and the log of real exchange rate or its deviation from the time-varying trend value.

4.2.2. The small EMU countries

The GMM estimation results for the forward-looking rules in small EMU countries (Austria, Belgium, Finland and the Netherlands) are presented in Table 3b. Again, adding financial market variables into the instrument set reduces the value of the sum of squared residuals in all but one case, this being the 12-month horizon rule for the Netherlands. Also, the p-values associated with the J-test statistics increase for all countries except Finland. An interesting finding is now that the set of best additional instruments includes here the difference between the US and domestic dividend yields in most countries.

When looking at the estimated coefficients on policy variables in the rules without additional financial market instruments, we can see that inflation (in levels or in first differences) is a statistically significant regressor at least at 10% level at some horizon in every country except the Netherlands. The same applies for the output gap. This result is quite interesting in the light of the fact that the ECB has stated that its main policy goal is to maintain steady inflation in the Euro area, and it has not explicitly announced to be targeting the real economy growth or fluctuations. As a whole, our results for the small euro area countries indicate that also their real activity has been targeted to a degree in the conduct of the ECB interest rate policies.

When the financial market variables are added into the set of instruments, the magnitudes of the estimated coefficients stay more or less the same. However, in many cases the estimated coefficients become more precise, i.e. their associated p-values become smaller. Furthermore, with additional instruments, the coefficient on output gap is significant at least at 10% level now also for the Netherlands for both horizons. For Finland, the sign of the coefficient of output gap changes to positive, which seems theoretically more reasonable. Of course, when analyzing these results, one must remember that none of the countries reported in Table 3b has conducted autonomous monetary policy during the sample period. Hence, it might not be meaningful to talk about economically reasonable coefficient signs, since it is likely that the monetary policy of ECB has been conducted more in terms of the big economies than the small economies

Table 3b
Results from the estimation of the forward looking Taylor rule for the small EMU countries.

Variables/Country	Aus		Bel		Fin		Net	
Horizon (k,p in months)	3	12	3	12	3	12	3	12
Traditional forward looking TR without additional instruments from the stock and currency markets								
Constant	−0.015	−0.284***	−0.058*	−0.051	0.110	−0.105*	−0.003	−0.002
	(0.831)	(0.000)	(0.052)	(0.155)	(0.307)	(0.081)	(0.962)	(0.925)
π_{t+k}	−0.056	0.175***	−0.000	–	0.103	0.124***	−0.094	−0.009
	(0.442)	(0.000)	(0.994)		(0.347)	(0.001)	(0.387)	(0.717)
$\Delta\pi_{t+k}$	–	–	–	−0.122*	–	–	–	–
				(0.083)				
$\overline{y}_{t+p}$	0.027***	−0.007	0.010**	0.015**	0.019*	0.000	0.007	0.007
	(0.007)	(0.300)	(0.016)	(0.012)	(0.065)	(0.979)	(0.638)	(0.121)
i_{t-1}	1.059***	0.973***	1.025***	1.010***	0.855***	0.954***	1.077***	0.998***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
J-statistics	2.029	14.549	4.242	13.919	4.249	12.865	4.658	12.950
	(0.845)	(0.910)	(0.515)	(0.929)	(0.514)	(0.955)	(0.459)	(0.953)
SSR-value	6.158	6.309	5.142	5.484	10.548	5.770	6.991	5.126
Forward looking TR with additional instruments from the stock and currency markets								
Constant	−0.004	−0.173***	−0.055**	−0.077***	0.011	−0.113**	0.022	−0.051
	(0.949)	(0.000)	(0.023)	(0.000)	(0.586)	(0.046)	(0.510)	(0.134)
π_{t+k}	−0.052	0.091***	0.006	–	−0.006	0.078***	−0.035*	0.038
	(0.355)	(0.000)	(0.724)		(0.768)	(0.001)	(0.090)	(0.185)
$\Delta\pi_{t+k}$	–	–	–	−0.175***	–	–	–	–
				(0.000)				
$\overline{y}_{t+p}$	0.029***	0.008*	0.010***	0.012***	0.018***	0.007*	0.013*	0.013**
	(0.000)	(0.051)	(0.008)	(0.000)	(0.000)	(0.063)	(0.072)	(0.017)
i_{t-1}	1.046***	0.995***	1.017***	1.023***	0.996***	0.992***	1.021***	0.984***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
J-statistics	2.852	14.977	5.214	20.015	7.365	12.309	6.487	10.688
	(0.898)	(0.941)	(0.634)	(0.980)	(0.392)	(0.976)	(0.485)	(0.994)
Best set of addit. instrum.	d_t and $d_t^* - d_t$	d_t and $d_t^* - d_t$	d_t and $d_t^* - d_t$	d_t and $d_t^* - d_t$	d_t and $d_t^* - d_t$	q_t	d_t and $d_t^* - d_t$	d_t and $d_t^* - d_t$
SSR-value	5.816	5.360	4.980	5.340	4.687	5.056	5.375	5.619

Notes: For the notations and explanations see Table 3a.

analyzed in this section.

All in all, from these results we can conclude that for the small EMU countries, the role of additional financial market information in the set of instrumental variables is clearly even more important than for the big countries. Again, we have to note that it would be somewhat mysterious to claim that the ECB monetary policy actions would have so much taken into account the behaviour of the stock market returns or real exchange rates of the small EMU member countries. Nevertheless, in general in our sample the financial market information from the small union countries has had some role to play in determining the level of short-term interest rates during the analyzed time period of 1999:2–2016:9.

4.2.3. The big countries outside the EMU

Results for the big OECD countries outside the EMU (Japan, the UK and the U.S.) are reported in Table 3c. For these countries the main conclusions regarding the role of financial market information are more or less the same than for the big core EMU countries. Including financial market variables improves the validity of the GMM instrument set as measured by the p-value associated with the Hansen J-test in all cases except for the Japanese 3-month horizon Taylor rule, and both 3 and 12-month horizon rules for the U.S. The result regarding the U.S. is in line with e.g. the results of Fuhrer and Tootell (2008) who found that the Fed has not reacted to financial market information as measured by equity prices. Instead, the Fed seems to have reacted to future levels of the traditional Taylor rule variables, that is, inflation and output gap especially at 12-month horizon.

Japan is a somewhat problematic country in our sample, since the Bank of Japan has conducted zero interest rate policy during more or less the whole of our sample period, and therefore the variation in the short-term rates has been minimal. This can also be seen from the sum of squared residuals computed from the estimated Taylor rules that incorporate interest rate smoothing. Nevertheless, we obtain statistically significant parameter estimates for output gap in the 3-month horizon rule, and for both the output gap and differenced inflation in the 12-month horizon rule. The estimated negative signs of the coefficients on the differenced inflation in the 12-month rule could perhaps be motivated by the fact that during our sample period, Japan has experienced deflation while the short-term rates have already been stuck at zero level, making the relationship between inflation and short-term rate rather perverse. Adding financial market variables into the instrument set improves the J-test statistic for both the 3- and 12-month horizon rules, but the sum of squared residuals is in fact marginally higher for the 3-month rule.

For the UK data the results remain pretty much the same after including the financial market information to the instrument set. In other words, the main interest in short-term interest rate policy has been in focusing on future output gap at short-term horizon. Future inflation does not seem significant in explaining the current short-term rate, which is somewhat puzzling since the Bank of England has publicly announced an inflation targeting policy. Again, as in the case of Japan, this result could be possibly motivated by noting that the Bank of England has kept the policy rates essentially at zero from 2009 onwards, which might in part distort the conventional relationship between inflation and monetary policy.

It is worth to note that although the inclusion of financial market variables into the instrument set improves the J-test statistic, the sum of squared residuals actually increases in 3 out of 6 estimated rules, implying a worse fit. Hence, in the case of big countries outside the EMU, it might be not straightforward to claim that including financial market information in the instrument set better explains the monetary policy decisions.

4.2.4. The small countries outside the EMU

In our data set the small OECD countries (in terms of their international role in the global economy in general) outside the EMU are Canada, Denmark, Norway and Sweden. In these data the role of additional financial market information in view of affecting also to the

Table 3c
Results from the estimation of the forward looking Taylor rule for the big countries outside the EMU.

Variables/Country	Jap		UK		US	
Horizon (k,p in months)	3	12	3	12	3	12
Traditional forward looking TR without additional instruments from the stock and currency markets						
Constant	−0.011 (0.452)	−0.009** (0.018)	−0.003 (0.929)	0.030 (0.615)	−0.070 (0.445)	−0.209*** (0.000)
π_{t+k}	–	–	0.006 (0.661)	−0.007 (0.709)	–	0.097*** (0.000)
$\Delta\pi_{t+k}$	−0.017 (0.726)	−0.025* (0.054)	–	–	0.195 (0.611)	–
$\bar{y}_{t+p}$	0.002* (0.071)	0.002** (0.020)	0.041*** (0.000)	−0.013 (0.221)	0.030* (0.079)	0.017** (0.017)
i_{t-1}	1.040*** (0.000)	1.034*** (0.000)	0.990*** (0.000)	0.991*** (0.000)	1.027*** (0.000)	0.982*** (0.000)
J-statistics	6.174 (0.290)	9.710 (0.993)	2.516 (0.774)	11.144 (0.982)	2.995 (0.701)	12.423 (0.963)
SSR-value	0.342	0.329	7.010	8.698	11.793	9.736
Forward looking TR with additional instruments from the stock and currency markets						
Constant	−0.007 (0.547)	−0.007** (0.047)	−0.003 (0.925)	−0.077 (0.400)	−0.057 (0.220)	−0.129*** (0.000)
π_{t+k}	–	–	0.004 (0.769)	0.021 (0.435)	–	0.061*** (0.000)
$\Delta\pi_{t+k}$	−0.042 (0.162)	−0.025** (0.049)	–	–	0.234 (0.247)	–
$\bar{y}_{t+p}$	0.003*** (0.001)	0.002** (0.013)	0.044*** (0.000)	0.004 (0.825)	0.032*** (0.004)	0.021*** (0.000)
i_{t-1}	1.028*** (0.000)	1.027*** (0.000)	0.991*** (0.000)	1.007*** (0.000)	1.019*** (0.000)	0.976*** (0.000)
J-statistics	6.557 (0.476)	9.918 (0.995)	2.769 (0.905)	9.072 (0.997)	5.114 (0.529)	14.137 (0.944)
Best set of addit. instrum.	d_t and q_t	$\tilde{q}_t$	d_t and q_t	d_t	q_t	d_t
SSR-value	0.350	0.321	7.113	8.466	12.064	8.605

Notes: For the notations and explanations see Table 3a.

Table 3d
Results from the estimation of the forward looking Taylor rule for the small countries outside the EMU.

Variables/Country	Can		Den		Nor		Swe	
Horizon (k,p in months)	3	12	3	12	3	12	3	12
Traditional forward looking TR without additional instruments from the stock and currency markets								
Constant	0.087	0.009	0.066	−0.045	−0.016	−0.141*	0.101*	−0.107*
	(0.083)	(0.805)	(0.153)	(0.623)	(0.829)	(0.312)	(0.060)	(0.052)
π_{t+k}	−0.079	–	0.029	0.017	–	0.087***	0.091	0.102***
	(0.245)		(0.541)	(0.764)		(0.000)	(0.121)	(0.005)
$\Delta\pi_{t+k}$	–	−0.133***	–	–	0.101	–	–	–
		(0.006)			(0.257)			
$\overline{y}_{t+p}$	0.038***	0.034***	0.025***	0.028***	0.001	−0.004	0.032***	0.018**
	(0.001)	(0.000)	(0.003)	(0.001)	(0.961)	(0.580)	(0.000)	(0.036)
i_{t-1}	1.019***	0.977***	0.933***	0.997***	1.009***	0.987***	0.899***	0.979***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
J-statistics	6.145	15.676	4.217	9.890	6.485	14.794	4.059	9.735
	(0.292)	(0.869)	(0.519)	(0.991)	(0.262)	(0.902)	(0.541)	(0.993)
SSR-value	8.510	7.736	6.326	7.555	14.084	13.298	7.419	8.070
Forward looking TR with additional instruments from the stock and currency markets								
Constant	0.082	0.016	0.065	−0.018	−0.070	−0.206***	0.085**	−0.032
	(0.270)	(0.367)	(0.144)	(0.471)	(0.259)	(0.002)	(0.017)	(0.395)
π_{t+k}	−0.082	–	0.024	0.008	–	0.085***	0.061**	0.039**
	(0.220)		(0.512)	(0.609)		(0.000)	(0.027)	(0.018)
$\Delta\pi_{t+k}$	–	−0.125***	–	–	0.119	–	–	–
		(0.001)			(0.274)			
$\overline{y}_{t+p}$	0.035***	0.028***	0.026***	0.018***	−0.001	0.021**	0.035***	0.025***
	(0.000)	(0.000)	(0.002)	(0.000)	(0.966)	(0.029)	(0.000)	(0.001)
i_{t-1}	1.024***	0.973***	0.938***	0.993***	1.025***	1.009***	0.921***	0.985***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
J-statistics	6.082	15.974	4.300	13.762	6.544	14.898	3.881	10.225
	(0.530)	(0.915)	(0.636)	(0.966)	(0.478)	(0.924)	(0.793)	(0.996)
Best set of addit. instrum.	d_t and $d_t^* - d_t$	d_t and $d_t^* - d_t$	$d_t^* - d_t$	d_t and $d_t^* - d_t$	d_t and q_t	d_t	d_t and q_t	d_t and q_t
SSR-value	8.426	6.954	6.171	6.295	14.887	13.819	7.471	7.631

Notes: For the notations and explanations see Table 3a.

role of fundamental policy variables in the Taylor rule is also rather strong. Additional financial market variables in the instrument set improve the J-test statistics in all cases. In addition, the sum of squared residuals decreases in most cases. In the estimated rules without financial information in the instrument set, it seems that in all countries except Denmark, the future inflation or its difference at 12-month horizon has had a significant role in central banks' monetary policy decisions. Also, it is worth mentioning that in all countries except Norway, the future output gap has a notable role according to our results. When we add the financial market information into the set of instruments, the parameter estimate on the output gap becomes significant at 5% level also in Norway at 12-month horizon.

Excluding Denmark, all the central banks of the countries analyzed in Table 3d have declared publicly to have been low inflation targeters during the analyzed time period. Our results partly verify these claims. For Canada, the estimated sign of the coefficient on the future change in inflation is negative, which does not seem reasonable.

4.3. *Results for the forward looking opportunistic Taylor rule*

Tables 4a–4d report the empirical results from GMM estimation with Newey-West HAC standard errors for the forward-looking opportunistic Taylor rule, again at 3- and 12-month horizons. The fundamental regression equation is now $i_t = \alpha_0 + \alpha_1\pi_{t+k} + \alpha_2\tilde{\pi}_{t+k} + \alpha_3\overline{y}_{t+p} + \rho i_{t-1} + \varepsilon_t$, where α_0 is the constant term, α_1, α_2 are the regression parameters for the actual future inflation (π_{t+k}), and its deviation from the time-varying trend value $(\tilde{\pi}_{t+k})$, indicating the opportunistic monetary policy rule regarding the inflation target, and α_3 is the regression parameter on the future real activity deviation from its trend value $(\overline{y}_{t+p})$. In Tables 4a–4d we consider only the version of the TR where the actual inflation is in levels on the RHS of regression equation. ρ is the regression coefficient (smoothing parameter) for the lagged interest rate, and ε_t is the error term. For all the other notations and explanations see Table 3a.

Table 4a reports the results for the core EMU countries (France, Germany and Italy). Based on viewing the statistical significance of the parameter estimates on the standard policy variables, the opportunistic Taylor rule, i.e., a rule reacting on the deviations of the perceived future inflation from its time-varying trend, has been valid for 12-month horizon in Germany and Italy. The estimated coefficient is negative for Germany, implying that when the German inflation has exceeded its target level (the proxy of which we take to be the time-varying trend of inflation), the ECB's policy stance has actually been more passive regarding inflation. Again, this is a result that is difficult to justify on the grounds of the ECB's announced mandate and the overall role of Germany in originally formulating the European Monetary System (EMS). For Italy, the estimated coefficient is positive, which seems more reasonable.

However, the results for the TR without financial market instruments change quite a bit when the information from stock and currency markets is included to the estimation of the opportunistic Taylor rule. With added financial market information, the

Table 4a
Results from the estimation of the forward looking opportunistic Taylor rule for the core EMU countries.

Variables/Country	Fra		Ger		Ita	
Horizon (k,p in months)	3	12	3	12	3	12
Traditional forward looking TR without additional instruments from the stock and currency markets						
Constant	0.007 (0.955)	−0.413*** (0.001)	−0.041 (0.609)	−0.239*** (0.003)	−1.410 (0.412)	0.134** (0.035)
π_{t+k}	−0.020 (0.922)	0.413*** (0.000)	−0.043 (0.481)	0.210*** (0.000)	0.981 (0.386)	−0.079* (0.058)
$\tilde{\pi}_{t+k}$	0.023 (0.890)	−0.085 (0.176)	0.028 (0.733)	−0.087* (0.089)	−0.933 (0.414)	0.074* (0.060)
$\overline{y}_{t+p}$	0.032*** (0.002)	−0.031*** (0.003)	0.027*** (0.000)	−0.005 (0.486)	0.078*** (0.008)	−0.026*** (0.000)
i_{t-1}	1.013*** (0.000)	0.895*** (0.000)	1.043*** (0.000)	0.951*** (0.000)	0.873*** (0.000)	0.987*** (0.000)
J-statistics	11.635** (0.020)	12.878 (0.937)	5.278 (0.260)	15.515 (0.839)	3.126 (0.537)	13.482 (0.919)
SSR-value	4.794	12.559	4.483	4.818	23.175	6.100
Forward looking TR with additional instruments from the stock and currency markets						
Constant	−0.039 (0.636)	−0.391*** (0.000)	−0.051 (0.531)	−0.343*** (0.000)	−1.364 (0.414)	1.129 (0.359)
π_{t+k}	0.053 (0.473)	0.344*** (0.000)	−0.045 (0.435)	0.233*** (0.000)	0.950 (0.389)	−0.779 (0.355)
$\tilde{\pi}_{t+k}$	−0.026 (0.786)	−0.121** (0.013)	0.019 (0.813)	−0.107** (0.046)	−0.901 (0.415)	0.769 (0.342)
$\overline{y}_{t+p}$	0.034*** (0.001)	−0.020*** (0.014)	0.028*** (0.000)	0.001 (0.901)	0.077*** (0.007)	−0.036* (0.078)
i_{t-1}	0.979*** (0.000)	0.932*** (0.000)	1.050*** (0.000)	0.981*** (0.000)	0.875*** (0.000)	1.080*** (0.000)
J-statistics	12.044* (0.061)	15.641 (0.901)	4.710 (0.581)	14.623 (0.908)	3.163 (0.675)	3.915 (0.562)
Best set of addit. instrum.	d_t and q_t	d_t and $\tilde{q}_t$	d_t and q_t	d_t	q_t	q_t
SSR-value	4.517	8.067	4.646	5.524	22.377	14.464

Notes: We report the results from GMM estimation with Newey-West HAC standard errors. The fundamental regression equation is now $i_t = \alpha_0 + \alpha_1\pi_{t+k} + \alpha_2\tilde{\pi}_{t+k} + \alpha_3\overline{y}_{t+p} + \rho i_{t-1} + \varepsilon_t$, where α_0 is the constant term, α_1, α_2 are the regression parameters for the actual future inflation (π_{t+k}), and its deviation from the trend value ($\tilde{\pi}_{t+k}$, indicating the opportunistic monetary policy rule regarding the inflation target), and α_3 is the regression parameter on the future real activity deviation from its trend value $(\overline{y}_{t+p})$. Here we consider only the version of the TR where the actual inflation is in levels on the RHS of regression equation. ρ is the regression coefficient (smoothing parameter) for the lagged interest rate, and ε_t is the error term. For all the other notations and explanations see Table 3a.

opportunism is still observed for Germany (with a more precise estimate) but not for Italy. Instead, the deviation of inflation from its time-varying trend is now significant for France at 12-month horizon, too. As in the case of forward-looking rules without the inflation deviation term, the role of future output gap is prominent at both shorter and longer horizons. An exception is Germany, for which the output gap is significant only at the short horizon.

In Table 4b we present the estimation results of the opportunistic rule for the small EMU countries (Austria, Belgium, Finland, and the Netherlands). For some of these countries there are clear signs of opportunistic rule already for the standard version without the financial market information, too. The inclusion of financial market information does not considerably change the results, except perhaps for the Netherlands, where the estimated coefficient on inflation gap becomes more precise after the inclusion of financial market variables into the instrument set. Regarding the signs and magnitudes of the estimated coefficients, it is rather striking that the absolute values of the estimates of the inflation gap term for Austria and Belgium are quite large. Furthermore, it is curious that the ECB's monetary policy stance towards inflation in Austria seems to be linked only to the longer-term inflation, while the opposite is true for Belgian inflation. For Finland and the Netherlands, the inflation gap is significant at 12-month horizon. Again, as in the case of estimated forward-looking rules without the inflation deviation term, adding financial market variables into the instrument set improves the validity of instruments in almost all cases. Also the fit as measured by the SSR is enhanced in all but one case, this being the 3-month horizon rule for Finland.

Table 4c gives the empirical results from analyzing the opportunistic rule for the big countries outside the EMU, i.e. Japan, the UK and the U.S. For these countries, there is only little evidence of opportunistic monetary policy rules. For the standard case without additional financial market information, none of the countries seem to have followed an opportunistic monetary policy rule. The results suggest that the monetary policy has focused on the future inflation at 12-month horizon in Japan and the U.S., but not in the U.K., as also implied by the results in Table 3c. When adding the financial market variables into the set of GMM instruments, we obtain some evidence that the Bank of Japan might have conducted opportunistic monetary policy at 12-month horizon, as the coefficient on the inflation gap becomes statistically significant at 10% level. Also, the inclusion of financial market information makes the coefficients on the output gap statistically significant at both horizons. This might imply that the Bank of Japan has indeed utilized financial market information, in the form of dividend yield and real exchange rate, to forecast the future real economic activity when making its monetary policy decisions. For the U.K. and the U.S., the inclusion of financial market information does not seem to change the results notably. Again, it needs to be stressed out that obviously the extreme actions of quantitative easing, and the almost zero-level of steering rates in all the countries here, too, during the global financial market turmoil, might adverse the obtained results strongly. Hence, the inclusion of money supply variable to the analysis, or alternatively, controlling of this extreme period by sub-sample analysis or an estimation procedure utilizing time varying parameters would be an appropriate solution in the future analyses of these data.

Table 4d reports the results for the small countries outside the EMU. Without the additional financial market variables in the instrument set, there is some evidence for an opportunistic monetary policy rule in Denmark and Norway at 12-month horizon. However, it is worth noting that the estimated coefficient on the actual inflation in levels, is not significant for Denmark. This makes the result difficult to interpret. When we add the financial market variables into the set of instruments, the results change quite drastically. With added instruments, the estimated rules suggest that the central banks of Denmark and Norway have followed an opportunistic rule

Table 4b
Results from the estimation of the forward looking opportunistic Taylor rule for the small EMU countries.

Variables/Country	Aus		Bel		Fin		Net	
Horizon (k,p in months)	3	12	3	12	3	12	3	12
Traditional forward looking TR without additional instruments from the stock and currency markets								
Constant	−0.012	−0.516***	0.291**	−0.177	0.057	−0.146***	0.074	0.088
	(0.932)	(0.000)	(0.035)	(0.181)	(0.542)	(0.002)	(0.586)	(0.087*)
π_{t+k}	−0.066	0.312***	−0.203**	0.090	−0.004	0.150***	−0.124	−0.097
	(0.309)	(0.000)	(0.014)	(0.103)	(0.979)	(0.000)	(0.201)	(0.188)
$\tilde{\pi}_{t+k}$	0.001	−0.201***	0.283***	0.010	0.059	−0.079***	0.113	0.087*
	(0.992)	(0.000)	(0.005)	(0.816)	(0.514)	(0.001)	(0.416)	(0.053)
$\overline{y}_{t+p}$	0.031***	−0.010**	0.017***	−0.006	0.017*	0.003	0.003	−0.003
	(0.001)	(0.046)	(0.000)	(0.507)	(0.057)	(0.512)	(0.852)	(0.674)
i_{t-1}	1.066***	0.958***	1.050***	0.985***	0.969***	0.949***	1.077***	1.033***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
J-statistics	2.898	13.326	5.386	6.360	4.951	13.574	4.174	13.513
	(0.575)	(0.924)	(0.250)	(0.999)	(0.292)	(0.916)	(0.383)	(0.918)
SSR-value	6.620	6.199	8.297	6.273	4.737	4.958	6.925	5.700
Forward looking TR with additional instruments from the stock and currency markets								
Constant	−0.031	−0.527***	0.283**	−0.133	0.013	−0.163***	−0.113	0.048
	(0.785)	(0.000)	(0.036)	(0.078)	(0.814)	(0.000)	(0.205)	(0.164)
π_{t+k}	−0.071	0.285***	−0.159**	0.072**	−0.068	0.109***	−0.105	−0.047***
	(0.273)	(0.000)	(0.035)	(0.035)	(0.239)	(0.000)	(0.132)	(0.008)
$\tilde{\pi}_{t+k}$	0.035	−0.265***	0.268***	−0.005	0.064	−0.091***	0.170	0.059**
	(0.707)	(0.000)	(0.007)	(0.881)	(0.372)	(0.000)	(0.140)	(0.020)
$\overline{y}_{t+p}$	0.029***	0.003	0.016***	−0.000	0.018*	0.012***	0.001	0.003
	(0.000)	(0.486)	(0.000)	(0.908)	(0.078)	(0.000)	(0.963)	(0.514)
i_{t-1}	1.047***	0.989***	1.015***	0.981***	1.048***	0.987***	1.034***	1.011***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
J-statistics	5.691	13.936	7.338	9.626	4.604	13.300	4.943	12.983
	(0.749)	(0.948)	(0.290)	(0.996)	(0.466)	(0.961)	(0.551)	(0.952)
Best set of addit. instrum.	d_t and $d_t^* - d_t$	d_t and $d_t^* - d_t$	d_t and q_t	d_t and $d_t^* - d_t$	d_t	d_t and $\tilde{q}_t$	d_t and q_t	q_t
SSR-value	5.691	5.628	7.374	5.123	6.172	4.310	5.776	5.132

Notes: For the notations and explanations see Tables 4a and 3a.

Table 4c
Results from the estimation of the forward looking opportunistic Taylor rule for the big countries outside the EMU.

Variables/Country	Jap		UK		US	
Horizon (k,p in months)	3	12	3	12	3	12
Traditional forward looking TR without additional instruments from the stock and currency markets						
Constant	−0.021 (0.274)	−0.009 (0.200)	−0.050 (0.488)	0.063 (0.467)	0.083 (0.733)	−0.278*** (0.001)
π_{t+k}	−0.010 (0.604)	0.030*** (0.000)	0.027 (0.427)	−0.021 (0.482)	−0.128 (0.481)	0.129*** (0.001)
$\tilde{\pi}_{t+k}$	0.013 (0.633)	0.001 (0.863)	−0.038 (0.429)	0.024 (0.577)	−0.008 (0.953)	−0.032 (0.359)
$\overline{y}_{t+p}$	0.002 (0.390)	0.002 (0.200)	0.047*** (0.000)	−0.018 (0.147)	0.044** (0.010)	0.016** (0.028)
i_{t-1}	1.085*** (0.000)	1.022*** (0.000)	0.987*** (0.000)	0.993*** (0.000)	1.092*** (0.000)	0.982*** (0.000)
J-statistics	4.593 (0.332)	10.004 (0.986)	2.106 (0.716)	10.120 (0.985)	4.409 (0.353)	12.002 (0.957)
SSR-value	0.434	0.419	7.213	8.885	17.492	9.806
Forward looking TR with additional instruments from the stock and currency markets						
Constant	−0.001 (0.926)	−0.008* (0.085)	−0.048 (0.443)	0.008 (0.925)	−0.070 (0.326)	−0.254*** (0.001)
π_{t+k}	0.006 (0.376)	0.017*** (0.002)	0.022 (0.441)	−0.002 (0.950)	−0.007 (0.858)	0.119*** (0.001)
$\tilde{\pi}_{t+k}$	−0.010 (0.427)	−0.009* (0.080)	−0.034 (0.407)	0.007 (0.838)	−0.071 (0.143)	−0.033 (0.267)
$\overline{y}_{t+p}$	0.003** (0.012)	0.003*** (0.000)	0.049*** (0.000)	0.009 (0.441)	0.035*** (0.001)	0.016** (0.012)
i_{t-1}	1.006*** (0.000)	1.015*** (0.000)	0.990*** (0.000)	0.996*** (0.000)	1.029*** (0.000)	0.979*** (0.000)
J-statistics	5.872 (0.438)	12.099 (0.979)	2.269 (0.893)	10.460 (0.992)	5.208 (0.518)	12.469 (0.963)
Best set of addit. instrum.	d_t and $\tilde{q}_t$	d_t and q_t	d_t and q_t	d_t and $d_t^* - d_t$	d_t and q_t	q_t
SSR-value	0.311	0.316	7.292	8.399	11.574	9.222

Notes: For the notations and explanations see Tables 4a and 3a.

also at the shorter horizon. Also for Sweden there is strong evidence in support of the opportunistic rule at longer horizon. In the case of this country set, the adding of financial market variables does not in fact seem to improve the validity of the instrument set as much as in the case of forward-looking rules without the inflation deviation term, as the p-values associated with the Hansen J-test statistic decrease in 4 out 8 cases, whereas for the forward-looking rules without inflation deviation the p-values increased in all cases.

Table 4d
Results from the estimation of the forward looking opportunistic Taylor rule for the small countries outside the EMU.

Variables/Country	Can		Den		Nor		Swe	
Horizon (k, p in months)	3	12	3	12	3	12	3	12
Traditional forward looking TR without additional instruments from the stock and currency markets								
Constant	0.864	0.023	−0.061	−0.144	0.349	−0.272***	0.110	−0.117**
	(0.285)	(0.900)	(0.696)	(0.121)	(0.445)	(0.000)	(0.194)	(0.022)
π_{t+k}	−0.546	−0.008	0.221	0.074	−0.518**	0.136***	0.293	0.140***
	(0.196)	(0.925)	(0.322)	(0.186)	(0.036)	(0.000)	(0.296)	(0.002)
$\tilde{\pi}_{t+k}$	0.433	0.014	−0.155	−0.114*	0.271	−0.063**	−0.166	−0.078
	(0.305)	(0.837)	(0.369)	(0.092)	(0.155)	(0.025)	(0.432)	(0.117)
$\overline{y}_{t+p}$	0.038*	0.033***	0.039**	0.041***	−0.016	−0.001	0.042	0.023***
	(0.051)	(0.002)	(0.036)	(0.000)	(0.734)	(0.764)	(0.115)	(0.009)
i_{t-1}	1.080***	0.983***	0.841***	0.992***	1.192***	0.996***	0.788***	0.966***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
J-statistics	1.250	15.925	3.165	13.180	3.155	16.372	3.137	8.617
	(0.870)	(0.820)	(0.531)	(0.928)	(0.532)	(0.990)	(0.535)	(0.995)
SSR-value	13.972	7.620	13.508	9.275	54.392	13.200	13.940	7.441
Forward looking TR with additional instruments from the stock and currency markets								
Constant	0.428*	−0.044	0.167**	−0.153**	0.573**	−0.493***	0.105***	−0.123***
	(0.087)	(0.628)	(0.012)	(0.032)	(0.018)	(0.000)	(0.001)	(0.000)
π_{t+k}	−0.264*	0.025	−0.154**	0.081**	−0.379***	0.199***	0.016	0.146***
	(0.059)	(0.559)	(0.024)	(0.035)	(0.005)	(0.000)	(0.709)	(0.000)
$\tilde{\pi}_{t+k}$	0.181	−0.010	0.199***	−0.117*	0.300***	−0.138***	0.070	−0.130***
	(0.167)	(0.838)	(0.004)	(0.074)	(0.009)	(0.002)	(0.175)	(0.000)
$\overline{y}_{t+p}$	0.032***	0.018**	0.012***	0.042***	−0.033**	0.022**	0.031***	0.026***
	(0.002)	(0.015)	(0.005)	(0.000)	(0.043)	(0.013)	(0.005)	(0.000)
i_{t-1}	1.028***	0.985***	1.042***	0.992***	1.054***	1.024***	0.937***	0.965***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
J-statistics	5.449	15.415	6.694	13.573	7.733	16.058	4.337	9.492
	(0.488)	(0.908)	(0.350)	(0.939)	(0.258)	(0.885)	(0.631)	(0.996)
Best set of addit. instrum.	d_t and $d_t^* - d_t$	d_t and q_t	d_t and $\tilde{q}_t$	d_t	d_t and $d_t^* - d_t$	d_t and q_t	d_t and $d_t^* - d_t$	d_t and $\tilde{q}_t$
SSR-value	8.656	6.187	6.419	9.335	22.582	14.769	6.987	7.023

Notes: For the notations and explanations see Tables 4a and 3a.

5. Conclusions

Since the onset of the current global financial market and aggregate economic crisis the contents of the actual information set that the central banks use when formulating their monetary policy targets and actions has been under special attention. In this paper we have analyzed the role of fairly simple forms of stock and currency market information in this respect. In our analysis the background for the inclusion of this information especially in the form of dividend yield and real exchange rate data stems from a system of partial equilibrium conditions. According to our results the central banks of the analyzed 14 OECD countries, where one subset of them forms an essential part of the EMS and the European Central Bank (ECB) during the analyzed time period of 1999–2016 might have indeed taken into account the financial market information for example in these forms as instrumental variables when formulating their monetary policy actions. Especially in small OECD countries, irrespective of whether they are members of the ECB system or not, the role of the standard Taylor rule policy variables, i.e., inflation and real economic activity deviations is highly sensitive to the inclusion of the financial market variables as instrumental variables in the analysis of the Taylor rule. Especially the role of stock market seems to be highly relevant in this respect. In addition, the recent monetary policy actions in many OECD countries actually would seem to have been opportunistic to a degree, indicating that it is not reasonable to assume that the inflation target actually would have remained constant, at least not in the short term policy actions.

In our empirical analyses we have mainly used a forward-looking Taylor rule specification with real-time data, that is more appropriate than e.g. the standard ex post form especially when the analysis involves financial market information. We have also included the interest rate smoothing term (i.e., the lagged values of the interest rate) to the rule, and in many cases the parameter estimate value of it is one or even slightly higher than one, indicating the dominating role of past levels of interest rates in monetary policy actions. For the main part this result is naturally dictated by the most recent data, where the interest rate changes in most of the analyzed OECD countries have been almost zero for clearly over 3 years now. Also Bunzel and Enders (2010) obtained the smoothing parameter values (clearly) over one for the one period lagged interest rate for an earlier time period, but the inclusion of the second lag in their analysis retained the alleged stationarity properties of the interest rate process, because the sums of the lagged parameter values were always below one. However, our results might also indicate that first of all, especially for the most recent data periods the analysis of the augmented Taylor rule should be executed using recursive or rolling estimation techniques. Furthermore, also the role of non-linearities for example in the time series processes of the additional instrumental variables or in their effects on the traditional Taylor rule policy variables and their parameter coefficients should be taken into account. These are the subjects of our further analyses, but already based on the results obtained from these simple forward-looking (and opportunistic) linear Taylor rule examinations, the role of financial and currency market information seems to be highly important in the real-time data from some of the OECD countries.

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References

Asness, C. (2000). Stock versus bonds: Explaining the equity risk premium. *Financial Analysts Journal, 56*, 96–113.
Asness, C. (2003). Fight the FED model: The relationship between future returns and stock and bond market yields. *Journal of Portfolio Management, 30*, 11–24.
Bekaert, G., & Engstrom, E. (2010). Inflation and the stock market: Understanding the "Fed Model". *Journal of Monetary Economics, 57*, 278–294.
Belke, A., & Klose, J. (2011). Does the ECB rely on a Taylor rule during the financial crisis? Comparing ex-post and real time data with real time forecasts. *Economic Analysis and Policy, 41*(2), 147–171.
Belke, A., & Polleit, T. (2007). How the ECB and the US Fed set interest rates. *Applied Economics, 39*(17), 2197–2209.
Borio, C. E., Kennedy, N., & Prowse, S. D. (1994). *Exploring aggregate asset price fluctuations across countries: Measurement, determinants and monetary policy implications* (Vol. 40). Bank for International Settlements, Monetary and Economic Department.
Brandt, M. W., & Wang, K. Q. (2003). Time-varying risk aversion and unexpected inflation. *Journal of Monetary Economics, 50*, 1457–1498.
Branson, W. H. (1983). Macroeconomic determinants of real exchange rate risk. In R. J. Herring (Ed.), *Managing foreign exchange risk*. Cambridge: Cambridge University Press.
Bunzel, H., & Enders, W. (2010). The Taylor rule and "Opportunistic" monetary policy. *Journal of Money, Credit and Banking, 42*(5), 931–949.
Campbell, J. Y., & Shiller, R. J. (1988). The dividend-price ratio and expectations of future dividends and discount factors. *Review of Financial Studies, 1*, 195–228.
Campbell, J. Y., & Vuolteenaho, T. (2004). Inflation illusion and stock prices. *American Economic Review Papers and Proceedings, 94*, 19–23.
Castro, V. (2011). Can central banks' monetary policy be described by a linear (augmented) Taylor rule or by a nonlinear rule? *Journal of Financial Stability, 7*, 228–246.
Chadha, J. S., Sarno, L., & Valente, G. (2004). Monetary policy rules, asset prices, and exchange rates. *IMF Staff Papers, 51*(3), 529–552.
Clarida, R. H. (2001). The empirics of monetary policy rules in open economies. *International Journal of Finance and Economics, 6*(October), 315–323.
Clarida, R. H., Galí, J., & Gertler, M. (1998). Monetary policy rules in practice: Some international evidence. *European Economic Review, 42*(June), 1033–1067.
Clarida, R. H., Galí, J., & Gertler, M. (2000). Monetary policy rules and macroeconomic stability: Evidence and some theory. *Quarterly Journal of Economics, 115*(February), 147–180.
Dimson, E., Marsh, P., & Staunton, M. (2002). *Triumph of the optimists: 101 years of global investment returns*. Princeton: Princeton University Press.
Dornbusch, R., & Fisher, S. (1980). Exchange rates and the current account. *American Economic Review, 70*, 960–971.
Enders, W., Im, K. S., Lee, J., & Strazicich, M. C. (2010). IV threshold cointegration tests and the Taylor rule. *Economic Modelling, 27*(6), 1463–1472.
Engle, R. F., & Granger, C. W. (1987). Co-integration and error correction: Representation, estimation, and testing. *Econometrica, 55*(2), 251–276.
Fisher, I. (1930). *The theory of interest*. New York: A.M. Kelley Reprint in 1965.
Frankel, J. (1983). Monetary and portfolio balance models of exchange rate determination. In J. Bhandari, & B. Putnam (Eds.), *Economic interdependence and flexible exchange rates* (pp. 84–114). Cambridege, MA: MIT Press.
Fuhrer, J., & Tootell, G. (2008). Eyes on the prize: How did the Fed respond to the stock market? *Journal of Monetary Economics, 55*, 796–805.
Gordon, M. J. (1962). *The investment, financing, and valuation of the corporation*. Illinois: Irwin Homewood.
Grammatikos, T., & Vermeulen, R. (2012). Transmission of the financial and sovereign debt crises to the EMU: Stock prices, CDS spreads and exchange rates. *Journal of International Money and Finance, 31*, 517–533.
Hamilton, J. D. (2016). *Why you should never use the Hodrick-Prescott filter*. University of California, Working Paper.
Johansen, S. (1988). Statistical analysis of cointegration vectors. *Journal of Economic Dynamics and Control, 12*(2–3), 231–254.
Junttila, J., & Korhonen, M. (2011). Utilizing financial market information in forecasting real growth, inflation and real exchange rate. *International Review of Economics and Finance, 20*, 281–301.
Modigliani, F., & Cohn, R. (1979). Inflation, rational valuation, and the market. *Financial Analysts Journal, 37*, 24–44.
Molodtsova, T., Nikolsko-Rzhevskyy, A., & Papell, D. (2011). Taylor rules and the Euro. *Journal of Money, Credit and Banking, 43*(2–3), 535–552.
Orphanides, A. (2001). Monetary policy rules based on real-time data. *American Economic Review, 91*, 964–985.
Quin, T., & Enders, W. (2008). In-sample and out-of-sample properties of linear and nonlinear Taylor rules. *Journal of Macroeconomics, 20*, 428–443.
Ritter, J. (2005). Economic growth and equity returns. *Pacific-Basin Finance Journal, 13*, 489–503.
Sauer, S., & Sturm, J. E. (2007). Using Taylor rules to understand European Central Bank monetary policy. *German Economic Review, 8*(3), 375–398.
Siegel, J. J. (1998). *Stocks for the long run* (2nd ed.). McGraw-Hill.
Stock, J. H., & Watson, M. W. (2003). Forecasting output and inflation: The role of asset prices. *Journal of Economic Literature, XLI*, 788–829.
Surico, P. (2003). Asymmetric reaction functions for the euro area. *Oxford Review of Economic Policy, 19*(1), 44–57.
Taylor, J. B. (1993). Discretion versus policy rules in practice. *Carnegie-Rochester Conference Series on Public Policy, 39*, 195–214.
Taylor, J. B. (2001). The role of the exchange rate in monetary-policy rules. *American Economic Review, 91*(May), 263–267.
Wei, C. (2010). Inflation and stock prices: No illusion. *Journal of Money, Credit and Banking, 42*(2–3), 325–345.

3 FED HURTS: THE EXPOSURE TO THE US MONETARY POLICY IN INFLATION TARGETING ECONOMIES

Abstract. We examine the influence of US monetary policy on domestic monetary policy in several inflation-targeting, floating exchange rate economies (Canada, Norway, Sweden, and the UK). Our focus is on the pre-financial crisis period. First, we estimate the impact of the Federal Reserve policy rate on the above-mentioned domestic interest rates within a conventional Taylor rule framework. Second, we examine the dynamic effects of US monetary policy on domestic interest rates using the policy shock measures of Romer and Romer (2004) and Gertler and Karadi (2015). Both approaches lend support to the view that at least some of our sample countries have faced a non-negligible constraint in the form of US monetary policy. Finally, we integrate the research question into the exchange market pressure framework and explore the extent to which the central banks of interest have employed foreign exchange interventions as a tool with which to enhance their monetary autonomy with respect to the US. We do not find robust evidence for this.

Keywords: international macroeconomics, monetary policy autonomy
JEL codes: E52, E58, F41

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3.1 Introduction

To what extent are the monetary conditions of a small open economy influenced by those of the core economies, such as the US and the euro area? The celebrated Mundellian Trilemma states that to exert autonomous monetary policy, a country must either restrict financial openness or let the exchange rate float freely. The interface between monetary independence and the Trilemma has attracted renewed interest in recent years. Rey (2015) and Miranda-Agrippino and Rey (2015) find evidence for the existence of a global financial cycle (GFC), a strong co-movement of asset prices, capital flows, and credit growth across countries, which seems to be partly driven by US monetary policy. Without restrictions on capital mobility, Rey's (2015) argument goes, the existence of a GFC implies that, regardless of the exchange rate regime, open economies are not free of the influence of monetary developments in the US, because the GFC projects the monetary conditions of the US onto the domestic economy. According to Rey's interpretation, this finding puts the Trilemma in question.

However, Nelson (2017) has recently argued that the mere fact that key financial variables in an open economy are, in the short run, influenced by US monetary policy is not enough to dismiss the policy autonomy argument. Nelson's claim rests on the definition of monetary policy autonomy, based on Friedman (1953), that states that a central bank should have a decisive influence on the nominal variables in the long run and on real variables in the short run. Furthermore, under a floating exchange rate, a country is monetarily independent as long as it can control the amount of base money in the economy without foreign influence. According to this definition, the observation that a country's financial conditions are affected by the monetary developments in a foreign country is not a violation of monetary autonomy.

In this paper, we carefully re-examine monetary policy autonomy in terms of the exposure of domestic monetary policy to US monetary policy in open economies, focusing on the time period before the financial crisis of 2008 and the era of unconventional monetary policy that ensued.[1] We approach the issue from two perspectives. First, we study the systematic role of US monetary policy in small open economies by estimating monetary policy reaction functions in the spirit of Taylor (1993), augmented with a federal funds rate. Second, we study the short-run dynamic effects of US monetary policy shocks on local interest rates using the Local Projections approach introduced by Jordà (2005). To explore the robustness of the results, we also consider the proxy SVAR approach popularized by Stock and Watson (2012), Mertens and Ravn (2013), and Gertler and Karadi (2015), among others.

Although restricting one's attention to the pre-financial crisis period excludes unconventional policies from the analysis, we believe there are at least two rationales for doing so. Firstly, with policy rates facing an effective lower bound,

[1] We treat the US as the primary base country in our analyses because its role as an important driver of global financial conditions has been emphasized in the recent literature.

many central banks have introduced novel policy tools, such as quantitative easing and forward guidance, as an alternative to conventional interest rate policy. Due to the multiplicity of policy tools utilized, it is difficult to develop a single indicator that will summarize the policy stance during the era of unconventional monetary policies in all the countries we analyze.[2]

Furthermore, the extremely accommodative monetary policy stance witnessed in many advanced economies has likely been at least partially due to global factors, such as low inflation expectations, a low natural rate of interest, and a high demand for safe assets, such as government bonds. These factors are the same for more or less every advanced economy. We argue that it is interesting to focus on monetary policy interdependencies during "normal times," when the space for monetary policy is less limited and there is more cross-country variability in terms of conditions that are central to monetary policy decisions.

We focus on a set of countries that have announced inflation targeting as their monetary policy framework. An inflation-targeting central bank announces a transparent target for the inflation rate and steers towards this target using the policy tools at its disposal. In principle, the successful and credible implementation of inflation targeting requires at least some degree of exchange rate flexibility: under an exchange rate peg, the central bank would be forced to adjust the short-term nominal rate, usually considered its main monetary policy instruments, in response to changes in the base country's interest rate if it wanted to maintain the peg. Therefore, by adopting an exchange rate peg, the central bank effectively sacrifices control over its domestic targets, which could potentially hinder the credibility of the inflation target. It therefore seems that inflation targeting, a flexible exchange rate and the Trilemma hypothesis are closely interlinked.

The countries we consider in this paper are Canada, Norway, Sweden, and the UK. Our choice of countries is guided by the fact that each of these countries, apart from Norway, adopted a floating exchange rate regime and inflation targeting in the 1990's. This provides us with a relatively long time series before the start of the period of unconventional monetary policy.

Foreign reserve management as a potential tool with which to enhance policy autonomy

According to Tinbergen's principle, a policymaker with multiple independent policy targets requires as many independent policy instruments to achieve these targets. Essentially, the Trilemma hypothesis is an application of this principle: There are two independent policy instruments – the interest rate and capital controls – for three separate policy targets, these being exchange rate stability, monetary policy autonomy, and capital mobility, of which only two can be achieved simultaneously. Because this study focuses on a set of advanced countries that

2 One possible remedy would be to use the shadow rate of Wu and Xia (2016), which, in addition to the period of conventional interest rate policy, also captures the period of unconventional policies. However, unfortunately, it has not been computed for every country we analyze in this paper.

have largely abolished restrictions on capital movement, making one of the dimensions of the Trilemma obsolete, our setting essentially reduces to a question about the trade-off between monetary policy autonomy and exchange rate flexibility. Moreover, because we focus on countries that have announced inflation targeting and a *de jure* floating exchange rate arrangement, we should expect to see no feedback from the centre country monetary policy onto local monetary policy if the Trilemma hypothesis holds.

As previously mentioned, there is an emerging body of literature that questions the validity of the Trilemma hypothesis. Studies by Rey (2015, 2016), among others, suggest that the Trilemma may have morphed into a Dilemma: the continued increase in financial globalization and cross-border capital flows essentially transfers the monetary conditions of the centre country to local economies, even in presence of a flexible exchange rate arrangement, conditional on capital movements not being restricted. In our setting, this would then imply spill-overs from the US monetary to local monetary policy, given that the "Dilemma" hypothesis holds.

If the domestic interest rates are obliged to closely follow the center country rates even under a floating exchange rate regime, does this mean that monetary policy autonomy is inevitably lost, regardless of which exchange rate regime a country adopts? Not necessarily: Foreign exchange interventions can potentially be used to relax the Trilemma constraint, and Steiner (2017) provides some evidence from a large panel of countries supporting this view. Foreign exchange management has typically been viewed as a policy tool most often employed in emerging market countries.[3] However, also developed economies have regularly used foreign exchange interventions in the target zone exchange rate regime to affect the domestic economy and defend the peg. Could foreign exchange interventions provide an efficient means of enhancing monetary autonomy also in advanced economies whose monetary policy frameworks are characterized by inflation targeting and a floating exchange rate regime?

Sterilized foreign exchange interventions do not alter the monetary base and, hence, the interest rate, adding one potential independent instrument to the central bank's toolkit. Could reserves management be used to achieve exchange rate stability, while providing leeway for monetary policy to pursue domestic objectives? Finally, even if it could, why should we care? After all, does exchange rate stability not seem like a small price to pay for monetary autonomy? Perhaps, but because at least some of the countries in our sample have a large export sector, vagaries of the exchange rate may, in fact, be something that policymakers would like to avoid. Changes in the exchange rate are passed along to domestic prices and may thus threaten inflation and output stability.

The second major goal of the paper is to consider whether the central banks of interest have employed foreign exchange interventions as a tool with which to enhance their monetary autonomy with respect to the US. We study this question by examining the dynamic effects of US monetary policy shocks on foreign

[3] Recent takes on the topic include Blanchard et al. (2015), Fratzscher et al. (2019), and Chertman et al. (2020).

exchange interventions in our selected open economies.

The remainder of the paper is organized as follows. Section 3.2 reviews the previous literature and discusses the present study's relationship to it. In Section 3.3, we describe the data and lay out the empirical models used in this study. Section 3.4 presents the main results and discusses the findings, and Section 3.5 examines the robustness of the results. Section 3.6 provides a discussion of our results, and finally, Section 3.7 concludes.

3.2 Previous literature

Recently, the literature on international macroeconomics has experienced an increased interest in monetary policy autonomy and the celebrated Trilemma result put forth by Mundell and Fleming in the 1960's, long regarded as an inevitable restriction on policy in a small open economy. Some studies have verified the existence of the Trilemma: Obstfeld et al. (2005), using extensive data on several advanced and emerging countries, document that the interest rates of economies with exchange rate pegs are considerably more sensitive to the base country interest rate than of those with a floating exchange rate, implying a loss of monetary independence for a country that chooses to peg its exchange rate. Klein and Shambaugh (2015) study whether "middle-ground" policies for capital controls and exchange rate pegs could enhance a country's monetary autonomy, finding that a moderate amount of exchange rate flexibility could provide some leeway for monetary policy autonomy. Aizenman et al. (2010, 2013) develop a metric for measuring each aspect of the impossible trinity (exchange rate flexibility, capital openness, and monetary independence). They introduce "Trilemma indices" that measure the extent of the achievement of each of the policy goals (Aizenman et al. 2013). Using their newly developed index, Aizenman et al. (2013) find that a linear combination of the indices adds up to a constant, indicating that the "two out of three" hypothesis is indeed correct (a rise/fall in one trilemma variable must be offset by a drop/increase in the weighted sum of the other two).

Recently, Georgiadis and Zhu (2019) find evidence in favour of the Trilemma. Restrictions on capital account openness and exchange rate flexibility reduce the base-country spill-overs onto domestic monetary policy in general; however, they also find that, for an economy operating under a flexible exchange rate, the larger the economy's foreign-currency exposure, the stronger the sensitivity of domestic monetary policy to that of the base country.

Our paper relates to the above-mentioned studies in that, first, we test whether a set of countries with *de jure* flexible exchange rates and open financial accounts have been able to exert monetary policy free of foreign influence, thus effectively testing the validity of the Trilemma hypothesis; second, we scrutinize the possibility that our countries of interest may have employed policy measures to enhance their monetary autonomy. Recently, Steiner (2017) has argued that foreign exchange interventions provide an efficient means of relaxing the Trilemma: an active reserve policy allows central banks to pursue independent monetary and exchange rate policies even when the capital account is liberalized. The fundamental idea behind this observation is that foreign exchange interventions may substitute for capital controls, providing an additional degree of freedom to the Trilemma policy space. He shows this in the framework of a theoretical portfolio balance model and provides evidence from a large panel of countries that supports this view. Related to the question of how foreign exchange interventions could be used, Alla et al. (2017) integrate FX interventions into an open economy New Keynesian model.

Among other questions, we examine the extent to which central banks employ foreign exchange interventions to ensure their monetary independence in the inflation-targeting, flexible exchange rate regime. Foreign exchange interventions have traditionally been conducted as a lean-against-the-wind activity and interventions have correlated negatively with exchange rate pressures and positively with foreign financial conditions and capital flows. Central banks have reported several motives for their intervention policy. One target for exchange rate interventions has been to steer the exchange rate toward its fundamental value; see Daude et al. (2016) and Fratzscher et al. (2019) for recent evidence. Blanchard et al. (2015) provide empirical evidence that central banks have successfully conducted open market operations among the emerging market economics to neutralize the impacts of capital flows on domestic liquidity and inflation pressures. Ghosh et al. (2017) point out how central banks have intervened to restrain exchange rate appreciation. Moreover, Benes et al. (2015) and Cavallino (2019) shows that exchange rate management with sterilized foreign exchange interventions is welfare enhancing.

Central bank interventions may be transmitted through several channels; see Sarno and Taylor (2001) for a survey. Typically, most of the interventions are sterilized, thus leaving aside the monetary policy channel. The portfolio channel is perhaps the most referred channel for central bank interventions. It is valid when the domestic and foreign assets are imperfect substitutes and uncovered interest rate parity does not hold. The financial restrictions further enhance the effects of interventions. The signalling channel predicts a central bank's hidden information to the private sector and signals the future monetary policy stance. The bank might affect currency traders and endeavour to influence the exchange rate via the traders' order flows (a co-ordination motive and microstructure channel).

Sweden, UK, and Norway have all been accustomed to using foreign exchange intervention policy over their monetary history. Sweden and Norway tied their exchange rates to European Currency Unit (ECU), which in practise, mimicked an ERM-type (European Exchange Rate Mechanism) target zone, whereas the UK participated in the ERM. Foreign exchange interventions were important in steering the exchange rate and defending the peg against realignment expectations and capital flows in the ERM, which preceded the euro. The ERM represented the target zone exchange rate regime, an intermediate type of exchange rate regime between the flexible and fixed regimes. Fratzscher et al. (2019) provide evidence that foreign exchange interventions have also been in active use since the collapse of the ERM in a group of countries that includes Canada, Norway, Sweden, and the UK, our sample countries. This lends support to the view that central bank interventions could still be widely used as a tool to shield countries' monetary sovereignty, interest rate, and exchange rate.

Our paper is also closely linked to a recent body of literature questioning the Trilemma. As mentioned in the introduction, Rey (2015, 2016) argues that the Trilemma has morphed into a Dilemma: Even a flexible exchange rate regime is not enough to guarantee monetary autonomy as long as capital is allowed to move freely. Rey argues that this is due to a high degree of financial co-movement across countries: The monetary conditions of the centre country spread to local economies through financial linkages if capital mobility is not restricted. On a similar note, Miranda-Agrippino and Rey (2015) show that contractionary shocks to US monetary policy lead to significant financial spill-overs, even in countries with a floating exchange rate, supporting the Dilemma view. The aforementioned papers focused mostly on the transmission of US monetary policy through financial intermediaries and asset prices. Our study focuses more strictly on domestic monetary policy steering interest rate exposure to US monetary policy shocks.

Obstfeld (2015) posits that emerging market economies that exploit a flexible exchange rate are better positioned concerning their monetary policy independence but not totally insulated from foreign influence. Edwards (2015), using an error correction model, finds evidence for a high pass-through from the Fed's monetary policy to interest rates in three Latin American countries (Chile, Colombia, and Mexico) with floating currencies.

Lastly, our paper relates to the literature that attempts to estimate the macroeconomic and financial effects of US monetary policy shocks on other countries. Dedola et al. (2017) study the international spill-overs of US policy shocks in a set of countries with both emerging and advanced economies. Using a structural vector autoregression (SVAR) with sign restrictions to identify US monetary policy shocks, they find that surprise contractions in the US monetary policy generally lead to a fall in economic activity and inflation in the sample countries, while they report the response of the interest rate differential vis-à-vis the US to be rather heterogeneous across countries, although bond yields increase relative to US yields in most countries. Although our focus is on the period before the global financial crisis of 2007–2008, it is also worth mentioning that some recent studies have taken the question up in the context of the unconventional policy tools that many of the prominent central banks have been using in the aftermath of the crisis. Indeed, this period should not go neglected in the literature, because the Fed lowered the federal funds target rate to its effective lower bound of 0.00–0.25% shortly after the Lehmann Brothers bankruptcy that took place in September 2008 and did not raise it until late 2015. For example, Anaya et al. (2017) find evidence for the existence of spill-overs from US unconventional monetary policy shocks into emerging market economies. In particular, they show that international portfolio flows are an important channel for shock transmission.

3.3 Data and methodology

Our sample consists of observations in four different countries. These are Canada, Norway, Sweden, and the UK. Our choice of countries is guided by the fact that each of these countries, apart from Norway, has adopted a floating exchange rate regime and inflation targeting in the 1990s, thus providing us with relatively long time series. Table 1 below summarizes the dates at which the central banks of each of these countries adopted the inflation-targeting framework. Our sample of observations for each country begins at the date indicated in Table 1 and ends in December 2007. We thus avoid challenges involved in measuring the influence of US monetary policy on domestic monetary policy in the post-financial-crisis period and at the zero-lower bound. Monetary policy at the zero-lower bound involves several tools with increasing and potentially time-varying impacts, which are difficult to master and model with a single monetary policy variable.

3.3.1 Augmented Taylor rules

We begin our empirical analysis by estimating the following regression model separately for each country of interest:

$$i_t = \rho(L)i_{t-1} + \big(1 - \rho(1)\big)\big(\beta_0 + \beta_\pi \pi_t + \beta_y y_t + \beta_{FF} FF_t\big) + \varepsilon_t \tag{2}$$

where i_t denotes the short-term interest rate, π_t is the inflation rate (as measured by year-on-year change in the log of consumer price index), y_t is a measure of real economic activity (for which we use the year-on-year change in the log of industrial production index as a proxy), and FF_t is the federal funds rate. $\rho(L)$ is a polynomial in the lag operator, included in the model to allow for inertial behaviour in the interest rate, which is commonly considered in empirical monetary policy reaction function literature, with $\rho(1) = \sum_{k=1}^{K} \rho_k$, where K is the lag order. Finally, ε_t is an independent and identically distributed error term. The data we use are of monthly frequency; see the appendix for a more detailed description of the time series used in this study.

TABLE 1 Inflation-targeting adoption dates in sample countries

Country	Date of adoption of the inflation-target
Canada	February 1991
Norway	March 2001
Sweden	January 1995
United Kingdom	October 1992

Equation (2) is essentially a Taylor rule augmented with a center country policy rate, in this paper taken to be the federal funds rate, which, during our sample period, was the primary policy instrument of the Federal Reserve. Under perfect monetary autonomy vis-à-vis the US, one would expect the regression coefficient β_{FF} to be 0 so that only domestic factors would play a role in interest rate policy. At the other end of the spectrum, a value of β_{FF} equal to 1 would indicate complete monetary dependence, as one would expect to encounter in a strict fixed exchange rate regime vis-à-vis the US dollar. In general, the magnitude of β_{FF} can be interpreted as the extent to which a central bank follows the Fed in its monetary policy, over and above what would be called for by developments in the domestic economy.[4]

Because all the countries we are interested in have implemented more-or-less free capital mobility (see e.g. the Financial Openness Index by Chinn and Ito (2006)) and a floating exchange rate during the sample period, one would expect β_{FF} not to differ statistically significantly from zero, given that the Equation (2) indeed represents the true data-generating process for the interest rate, which is, of course, unlikely. However, estimates of β_{FF} can be treated as crude evidence regarding whether the central banks of interest have been able to conduct monetary policy autonomously.

3.3.2 Local projections

While Taylor rule regressions can provide us with some descriptive evidence of the potential dependence of various central banks' monetary policy on the Federal Reserve's stance, they do not tell us about the potential dynamic effects of changes in the US monetary policy on the countries of interest. In order to disentangle the dynamic causal effect, we utilize the Local Projections (LP) approach put forth by Jordà (2005). Essentially, the method boils down to estimating the following equation:

$$i_{t+h} = \alpha^{(h)} + \gamma^{(h)} \xi_t^{US} + x_t' \beta^{(h)} + \varepsilon_{t+h} \tag{3}$$

for each horizon $h = 0, 1, 2, ..., H$. Here, ξ_t^{US} is the US monetary policy shock, and x_t is a vector of control variables which might include, for example, the domestic factors that influence the monetary policy of the central bank, such as inflation and economic activity, as well as lagged values of the dependent variable. The estimated sequence of γ's then traces out the dynamic effect of a time-t shock on the domestic interest rate.

[4] One well-known issue involved in estimating time-series regressions, such as in Equation (2), is the potential non-stationarity of variables and the resulting spurious regression. Indeed, in our case, the augmented Dickey-Fuller, as well as the Phillips-Perron unit root test, indicate that the null of hypothesis of the presence of a unit root cannot be rejected for the Swedish inflation rate. When it comes to short-term interest rates, unit root tests unanimously suggest the presence of a unit root in Norwegian and Swedish rates, and in the Fed funds rate. However, as Clarida et al. (2000) note, the null hypothesis of a unit root test is often difficult to reject for interest rate and inflation series given their persistence and the low power of the unit root tests. Additionally, they note that economic theory often implies stationarity of inflation and interest rate. We follow their approach, simply treating all the variables in the Taylor rule regressions as stationary while also being somewhat cautious in our interpretation of the results.

The LP approach does have certain advantages over (structural) Vector Autoregression (VAR) which has been commonly used in the monetary policy literature to estimate the effects of policy shocks. First, the approach is simple because the Equation (3) can be estimated using least-squares methods. Secondly, the LP approach is arguably more robust to model misspecification because it relies on a set of regressions that are separately estimated for each horizon. This is in constrast to VAR, which relies on iterating the estimated recurrence relation when computing the estimates for impulse response functions. Thus, as the horizon of the impulse response grows, potential misspecification errors are compounded in the VAR approach. For more detailed discussion of the theory and statistical inference regarding the LP method and its relation to vector autoregressions, we refer the reader to the original paper by Jordà (2005).

Obviously, the problem with Equation (3) is that we cannot directly observe US monetary policy shocks ξ_t^{US}. To circumvent the problem, we use the Romer and Romer (2004) shock series as a proxy for the monetary policy shock. The idea of the Romer-Romer (hereafter RR) approach is to extract the exogenous variation in the US monetary policy by regressing the changes in the intended federal funds rate on the Greenbook forecasts for inflation, output growth, and unemployment rate.[5] The residuals from this regression are then treated as policy shocks and should be relatively free of endogenous variation, provided that the Greenbook forecasts effectively summarize the information that the Fed utilizes when setting the policy rate.

As a robustness check, we also estimate the LPs using the shock series of Gertler and Karadi (2015), abbreviated GK hereafter. GK use federal funds futures to identify high-frequency surprises around Federal Open Market Committee (FOMC) announcements. Fed funds futures should reflect all available information about expected monetary policy rates, and fluctuations in their price within small windows of FOMC policy announcements are likely to reflect monetary policy surprises.[6] However, as pointed out by Ramey (2016), surprises in the fed fund futures, as such, do not necessarily represent actual policy shocks because they do not control for the Fed's private information about the future state of the economy. Indeed, upon a closer examination of the GK shocks, Ramey (2016) finds that they are, in fact, predicted by the Greenbook forecasts. In addition, she finds that the mean of the shock series is statistically different from zero and that the series exhibits autocorrelation, both of which are unwanted features for supposedly unpredictable shocks. Due to these apparent flaws, we treat the Romer-Romer series as our primary proxy for US monetary policy shocks. However, the GK shocks can still serve as an aid in checking the robustness of our results.

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5 The original shock series of Romer and Romer (2004) ends in 1996; we use the updated series of Wieland and Yang (2020), which covers our entire sample period, ending in December 2007.

6 We use the monetary policy shock series obtained from the replication files of Gertler and Karadi (2015). More specifically, we use the surprises in the three-months-ahead futures rate (FF4).

3.4 Results

3.4.1 Results from Taylor rule regressions

Table 2 presents the estimates of Equation (2). Simple Taylor Rule estimates imply that, during their respective inflation-targeting regimes, only the central banks of Norway and Sweden conducted monetary policy free of US influence because, for both countries, the estimated coefficient on the federal funds rate is statistically insignificant. For Canada and the UK, on the other hand, the estimated coefficient is statistically significant at the 1% level and quantitatively around 0.5, implying an increase of 25 basis points in the domestic interest rate in response to a 50 basis point hike in the federal funds rate. Obviously, it should be kept in mind that our least-squares estimates almost certainly do not reflect the true causal effect of the federal funds rate on the domestic monetary policy rate; however, at least this descriptive evidence is clear regarding a relatively strong co-movement between the federal funds rate and money market rates of Canada and the UK.

Another thing worthy of notice in the estimates shown in Table 2 is the insignificance of the inflation coefficient for all countries except Sweden. This is a somewhat odd finding because a central bank committed to an inflation-targeting regime would be expected to actively respond to changes in inflation rate by adjusting its policy instrument. One possible explanation for this is that central banks have been forward looking in their policy actions, thus paying attention to expected inflation and real activity instead of their contemporaneous values. Motivated by this notion, we also estimate monetary policy reaction functions in which the contemporaneous values of inflation and industrial production growth are replaced by their expected values. Ideally, one would use the actual central bank forecasts for inflation and industrial production growth when estimating such rules, but because these are not available at a monthly frequency, we follow the strategy of Clarida et al. (2000) and implement the estimation by replacing the expectations with actual realized values for inflation and industrial production growth, using an expectation horizon of one year. We then proceed to estimate the resulting equation via the Generalized Method of Moments[7].

The results from the GMM estimation of forward-looking Taylor rules are reported in Table 3. For the most part, the results confirm the ordinary least squares estimates of the contemporaneous Taylor rules presented above. The coefficient on the federal funds rate remains statistically significant for Canada and the UK. Its magnitude is slightly higher for Canada, whereas for the UK, it is somewhat lower as compared to contemporaneous rules. Also, in the forward-looking specification the federal funds rate coefficient for Norway is statistically

[7] As discussed in Clarida et al. (2000), the OLS estimation of the resulting equation would yield biased estimates of β_π and β_y because the error term consists of expectational errors, which are correlated with forwarded values of inflation and industrial production growth. The problem can be mitigated by using instrumental variables (GMM).

TABLE 2 Estimates of baseline Taylor Rules

	Country			
	Canada (1)	**Norway** (2)	**Sweden** (3)	**UK** (4)
β_0	1.627 (1.019)	-14.636 (23.244)	0.288 (1.164)	3.450*** (0.476)
β_π	-0.089 (0.328)	-4.146 (7.066)	1.311*** (0.306)	-0.219 (0.275)
β_y	0.248 (0.152)	0.523 (0.961)	0.161 (0.131)	0.147* (0.078)
β_{FF}	0.521*** (0.169)	8.230 (10.977)	0.067 (0.207)	0.510*** (0.106)
$\rho(1)$	0.931*** (0.022)	0.994*** (0.008)	0.934*** (0.014)	0.839*** (0.042)
R^2	0.963	0.993	0.965	0.932
S.E.E	0.335	0.166	0.298	0.280
Observations	203	82	156	183

Notes: Estimates are obtained by running, for each country, the least-squares regression $i_t = \alpha_0 + \alpha_\pi \pi_t + \alpha_y y_t + \alpha_{FF} FF_t + \sum_{k=1}^{K} \rho_k i_{t-k} + \varepsilon_t$ with Newey-West heteroskedasticity- and autocorrelation-consistent standard errors (with the truncation lag determined by the integer part of $0.75T^{(1/3)}$, where T is the number of observations). The selection of the lag order K is made based on the Bayes-Schwartz information criterion ($K = 2$ for Canada, $K = 3$ for Norway, and $K = 1$ for Sweden and the UK). The implied long-run feedback coefficients are then recovered by computing $\hat{\beta}_j = \hat{\alpha}_j / (1 - \Sigma\hat{\rho}_k)$. The standard errors of the feedback coefficients (in parentheses) are obtained via the delta method. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. For each country, the estimation sample starts on the date indicated in Table 1 and ends in December 2007.

TABLE 3 GMM estimates of forward-looking Taylor Rules

	Country			
	Canada (1)	**Norway** (2)	**Sweden** (3)	**UK** (4)
β_0	2.332** (1.120)	-13.736* (7.758)	0.173 (3.466)	1.601 (0.794)
β_π	-0.478 (0.485)	2.837* (1.471)	4.379 (3.60)	1.069** (0.466)
β_y	0.111 (0.103)	-0.094 (0.416)	-0.408 (0.493)	-0.244 (0.198)
β_{FF}	0.583*** (0.129)	4.013** (1.904)	-0.552 (0.687)	0.391*** (0.103)
$\rho(1)$	0.916*** (0.017)	0.990*** (0.004)	0.979*** (0.014)	0.886*** (0.029)
J-test	14.679	15.110	15.799	17.997
(p-value)	(0.743)	(0.654)	(0.729)	(0.523)
S.E.E	0.347	0.165	0.314	0.297
Observations	203	82	156	183

Notes: Estimates are obtained from GMM estimation of the equation $i_t = \alpha_0 + \alpha_\pi \pi_{t+h} + \alpha_y y_{t+h} + \alpha_{FF} FF_t + \sum_{k=1}^{K} \rho_k i_{t-k} + \varepsilon_t$. We use the optimal weighting matrix, accounting for the serial correlation in the residuals (Newey-West, with the truncation lag determined by the integer part of $0.75T^{(1/3)}$, where T is the number of observations). The set of instrumental variables for each country consists of six lags of the domestic interest rate, inflation, industrial production growth, the federal funds rate, and a constant term. The implied long-run feedback coefficients are then recovered by computing $\hat{\beta}_j = \hat{\alpha}_j/(1 - \Sigma\hat{\rho}_k)$. The standard errors of the feedback coefficients (in parentheses) are obtained via the delta method. ***, **, and * denote statistical significance at the 1%, 5%, and 10% levels, respectively. For each country, the estimation sample begins from the date indicated in Table 1 and ends in December 2007.

significant at the 10% level, and the estimated value is perhaps implausibly high. Nonetheless, Norway's exposure to the Fed's monetary policy may reflect the importance of the oil sector for the Norwegian economy, the role of the oil sector in the US economy, and the dollar as the vehicle currency oil trade. According to our results, Sweden is not exposed to the Fed's monetary policy.

In the forward-looking specification, the estimated inflation coefficient is statistically different from zero only for Norway and the UK, so the baffling result of there being no relationship between interest rate and (expected) inflation remains for Canada and Sweden. This finding may indicate that, instead of the ex-post realized values of inflation and real activity growth, one should indeed use actual real-time forecasts for inflation and real activity when estimating such forward-looking rules. Also, using non-revised, real-time data on inflation and industrial production index could yield different results in contemporaneous rules.[8] Because in this paper, our primary interest is not in the feedback coefficients of inflation or real activity, we do not pursue this approach here. However, another, perhaps more extreme, interpretation of these results is that, at least in some of the sample countries, dependence on US monetary policy is strong enough to prevent domestic policy from operating on the basis of the inflation objective.

Because most of our sample countries are geographically closer to the eurozone than the US and some of the EMU countries are important export destinations for Norway, Sweden, and the UK, it is interesting to consider the monetary autonomy of these countries with respect to the European Central Bank: does the euro area interest rate provide any explanatory power regarding the local interest rate, over and above the explanatory power of the Fed funds rate? As a final exercise related to central bank reaction functions, we estimate a specification in which the euro area interest rate is included in the monetary policy rule.[9] Again, we estimate both contemporaneous and forward-looking reaction functions. The results of this exercise are reported in Tables 4 and 5, where $\hat{\beta}^{EA}$ now denotes the estimated coefficient on the euro area interest rate.

Some interesting results stand out. The inclusion of the euro area interest rate in the reaction function does not change the result that for Canada and the UK, the coefficient on the federal funds rate is statistically significant and between 0.4 and 0.5 in both contemporaneous and forward-looking reaction functions. Interestingly, for Canada, the coefficient on the euro area interest rate is also statistically significant, albeit slightly lower in magnitude than the coefficient on the Federal funds rate. For Norway, on the other hand, the inclusion of the euro area rate renders the coefficient on the Federal funds rate insignificant, while the estimate on the euro area coefficient is both significant and high in magnitude in both contemporaneous and forward-looking specifications. This could be interpreted

8 See Orphanides (2001)

9 We use the euro area overnight interbank rate time series extracted from the St. Louis Fed FRED database. This series starts in January 1994; in Canada and the UK, the inflation-targeting regime had already begun already prior to that (see Table 1). For these countries, we use the German interbank rate to impute the missing observations.

TABLE 4 OLS estimates of contemporaneous Taylor rules with the euro area interest rate as an additional regressor

	Country			
	Canada (1)	**Norway** (2)	**Sweden** (3)	**UK** (4)
β_0	0.476 (0.493)	-2.869*** (0.756)	0.157 (0.907)	3.520*** (0.524)
β_π	0.059 (0.151)	-0.127 (0.396)	1.171** (0.495)	-0.100 (0.237)
β_y	0.122 (0.079)	0.057 (0.059)	0.152 (0.149)	0.161* (0.087)
β_{FF}	0.436*** (0.109)	-0.046 (0.386)	-0.013 (0.414)	0.492*** (0.103)
β_{EA}	0.372*** (0.135)	2.558*** (0.336)	0.193 (0.745)	-0.058 (0.129)
$\rho(1)$	0.868*** (0.042)	0.937*** (0.027)	0.930*** (0.025)	0.848*** (0.04)
R^2	0.963	0.993	0.965	0.930
S.E.E	0.330	0.161	0.299	0.284
Observations	203	82	156	183

Notes: Estimates are obtained by running, for each country, the least-squares regression $i_t = \alpha_0 + \alpha_\pi \pi_t + \alpha_y y_t + \alpha_{FF} FF_t + \alpha_{EA} i_t^{EA} + \sum_{k=1}^{K} \rho_k i_{t-k} + \varepsilon_t$ with Newey-West HAC standard errors (with the truncation lag determined by the integer part of $0.75T^{(1/3)}$, where T is the number of observations). i_t^{EA} is the euro area interest rate. For additional notes, see Table 2.

as evidence that, for Norway, the euro area interest rate has been a more important driver of the local interest rate than the federal funds rate. This implies that, in the case of Norway, we should perhaps more carefully consider its monetary autonomy vis-à-vis the euro area instead of the US.

For Sweden, our analysis does not reveal any significant monetary policy exposure to the Fed or to the ECB monetary policy. This calls for other channels of dependence on the part of the Swedish economy on the euro area and, in this respect, stands in contrast with the statements of the governor of the Riksbank, Stefan Ingves.[10]

Comparing our Taylor rule estimates with those of previous studies, Georgiadis and Zhu (2019) estimate reaction functions similar to our specification in a panel setting. They group the sample countries into categories: (i) "limited exchange rate flexibility" and "limited capital controls", (ii) "limited exchange rate flexibility" and "extensive capital controls", (iii) "extensive exchange rate flexibility" and "limited capital controls", and (iv) "extensive exchange rate flexibility" and "extensive capital controls." The countries in our sample are best characterized by category (iii). The baseline estimate of the feedback coefficient on the base country policy rate that Georgiadis and Zhu obtain for the countries in category (iii) is 0.45. This estimate is quantitatively quite well in line with our estimates for the feedback coefficient for Canada and the UK. However, their estimate is more difficult to reconcile with our estimates for Sweden and Norway.

3.4.2 Results from Local Projections

Next, we turn to the estimated dynamic effects of US monetary policy shocks. The impulse responses, based on local projections with Romer-Romer monetary policy shocks, are reported in Figure 1. The impulse responses are produced by estimating the dynamic effect, i.e., $\gamma^{(h)}$ in Equation (3) for each horizon h.[11] The vector of control variables includes contemporaneous values for output growth and inflation, as well as their three lags. Hence, the LP regressions described in Equation (3) can also be interpreted as monetary policy reaction functions of a kind.

By including three lags of output growth and inflation in the regression equations, we control for the possibility that the central banks may take into account not only the contemporaneous values of inflation and output growth, but also their values in the previous quarter when deciding their monetary policy. While the previous-quarter values might not matter for the policy decisions, they might provide information about the contemporary values of inflation and output growth, which are often observed with imprecision. In addition, we also include lags of the dependent variable, i.e., the overnight interbank rate, in the set of control variables to control for autocorrelation. The number of lags included is chosen on the basis of the Bayes-Schwartz information criterion.

10 The governor of the Sveriges Riksbank in Dagens Nyheter's interview (3 October 2017, URL: https://www.dn.se/ekonomi/ingves-vi-ar-granne-med-en-elefant/).

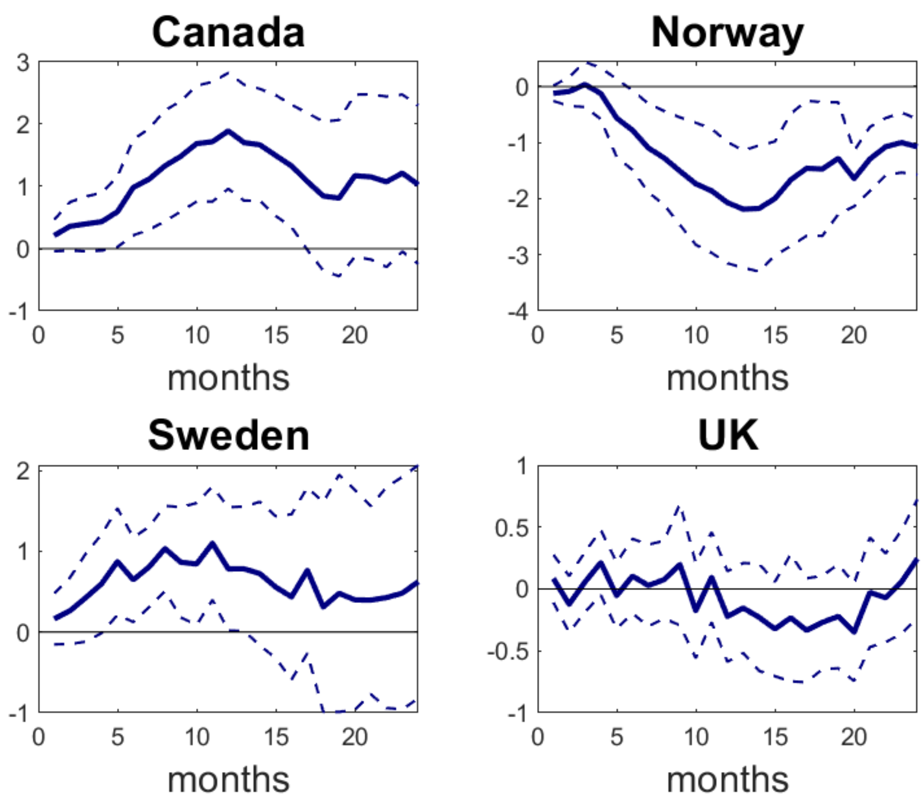
11 The estimation of local projections was carried out using the R package 'lpirfs'.

TABLE 5 GMM estimates of forward-looking Taylor rules with the euro area interest rate as an additional regressor

	Country			
	Canada (1)	**Norway** (2)	**Sweden** (3)	**UK** (4)
β_0	1.149 (0.718)	-3.330 *** (0.710)	-0.802 (2.171)	-0.994 (2.688)
β_π	0.101 (0.214)	0.216 (0.203)	2.30* (1.369)	2.203 (1.405)
β_y	0.004 (0.059)	0.021 (0.061)	-0.151 (0.294)	-0.301 (0.319)
β_{FF}	0.466*** (0.077)	-0.015 (0.217)	-0.625 (0.425)	0.400** (0.200)
β_{EA}	0.239* (0.122)	2.427*** (0.228)	0.946 (0.753)	0.061 (0.308)
$\rho(1)$	0.889*** (0.024)	0.943*** (0.012)	0.968*** (0.016)	0.938*** (0.034)
J-test	15.993	14.820	18.407	21.885
(p-value)	(0.888)	(0.901)	(0.825)	(0.586)
S.E.E	0.336	0.161	0.309	0.259
Observations	203	82	156	162

Notes: Estimates are obtained from GMM estimation of the equation $i_t = \alpha_0 + \alpha_\pi \pi_{t+h} + \alpha_y y_{t+h} + \alpha_{FF} FF_t + \alpha_{EA} i_t^{EA} + \sum_{k=1}^{K} \rho_k i_{t-k} + \varepsilon_t$. We use the optimal weighting matrix, accounting for the serial correlation in the residuals (Newey-West, with the truncation lag determined by the integer part of $0.75T^{(1/3)}$, where T is the number of observations). The set of instrumental variables for each country consists of six lags of domestic interest rate, inflation, industrial production growth, the federal funds rate, the euro area interest rate, and a constant term. For additional notes, see Table 3.

FIGURE 1 Impulse responses of the overnight interbank rate to a MP shock (Romer-Romer). Estimated impulse response (solid blue line) and 90% confidence intervals (dashed lines).



Notes: Impulse responses to a unit monetary policy shock (Romer-Romer), obtained by estimating Equation (2). The set of control variables consists of contemporaneous values of inflation and industrial production growth, as well as three of their lags. We also add lags of the interest rate on the right-hand side of the equation, the number of which is determined by the Bayes-Schwartz information criterion (maximum number of lags to consider being 6). Dashed lines represent 90% confidence intervals. For each country, the estimation sample starts on the date indicated in Table 1 and ends in December 2007.

Considering the dynamic responses to US monetary policy shock as measured by the Romer-Romer method, it is clear that, for Canada, the response of overnight money market rate is well in line with the earlier Taylor-rule-based evidence on significant co-movement in the respective monetary policies of the Fed and the Central Bank of Canada. A positive monetary policy shock induces an increase in the Canadian interest rate that is statistically significant between 5 and 15 months after the impact.

Although, for Sweden, we could not find evidence of US monetary policy's influence in the Taylor-rule estimations, the dynamic responses indicate that monetary policy shocks in the US do have a non-negligible effect on the Swedish interbank rate because the estimated responses are positive and also statistically significant between 5 and 10 months following the impact. Similar result holds for Norway: although the Taylor rule analysis did not reveal strong evidence for the influence of the federal funds rate on the Norwegian interest rate, here, we do observe a statistically significant impact following a monetary policy shock at longer horizons. What is interesting is that the effect is negative, indicating contrasting movements in the countries' respective monetary policies. Even though Taylor-rule estimates yielded some evidence for the dependence of the UK interest rate on US monetary policy, the impulse response analysis does not confirm this finding: although the response is positive at some horizons, the estimated magnitude of the response is rather small and statistically insignificant.

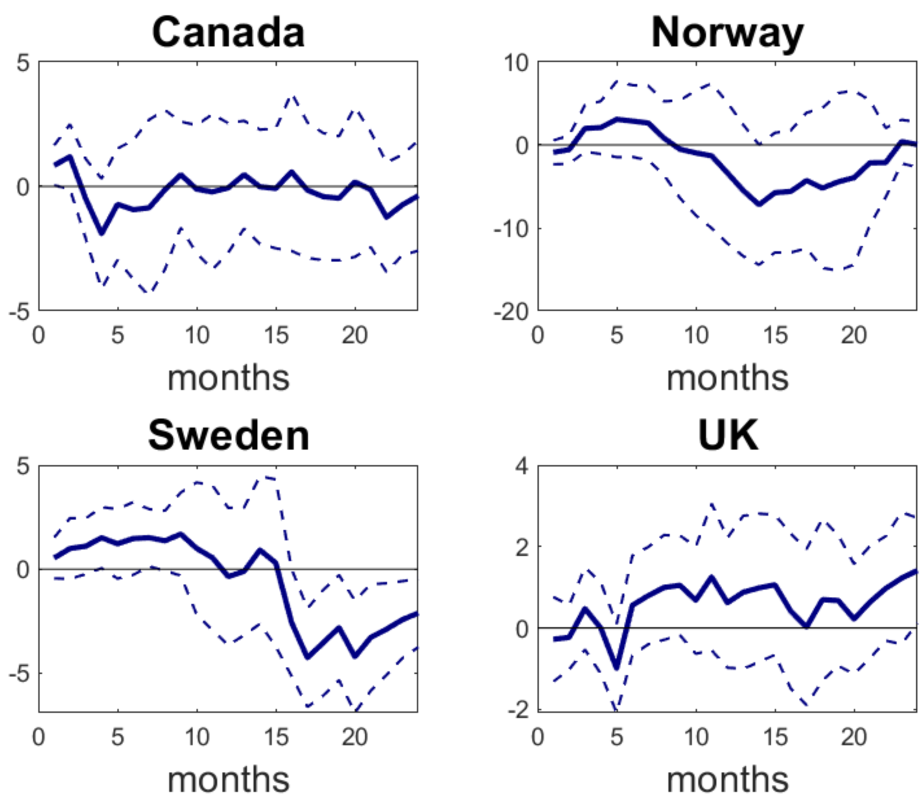
As a robustness check, we also ran the same LP exercise with the Romer-Romer monetary policy shocks replaced by the shock proxy proposed by Gertler and Karadi (2015). The results of this exercise are depicted in Figure 2. When using the GK shock, the evidence for significant effects on the part of US monetary policy is less clear-cut. In fact, GK shock does have a positive impact on Canadian interest rate, but the response is not statistically significant for subsequent horizons following the shock. For Norway, we verify the negative dynamic effect of the shock at longer horizons; however, the estimated impulse response is not statistically significant. Nor is it significant for Sweden, although the response of the interest rate is positive, as was the case with the RR shock. For the UK, the response is positive at longer horizons but, again, not statistically significant. Therefore, we conclude that the evidence for the dynamic effects of US monetary policy shock on the domestic interest rate is not undisputed, although both shock proxies yield results that are quite similar qualitatively.

3.4.3 Foreign exchange interventions and monetary policy autonomy

The results presented above lend some tentative support to the view that the central banks of interest have indeed faced a non-negligible constraint in the form of US monetary policy during the sample period. In this section we examine whether domestic central banks have attempted to use additional policy tools in order to enhance their monetary independence *vis-à-vis* the US. More specifically, we consider the possibility that the central banks have used foreign reserve interventions in response to monetary policy developments in the US. Reserve management can be seen as an independent policy instrument that could provide a means of managing the exchange rate while simultaneously providing an additional degree of freedom for the central bank to set the interest rate as a function of domestic objectives. Our analysis complements a recent study of Steiner (2017), which shows that, in a simple portfolio balance model framework, reserve interventions can in fact be used as a substitute for capital controls, thus relaxing the trade-off between monetary policy autonomy and exchange rate stability under freely moving capital.

The model presented in Steiner (2017) closely follows Blanchard et al. (2005) and the portfolio balance tradition. It is a non-micro-founded partial equilibrium model consisting of two countries, the US and a foreign country representing the rest of the world. The model extends Blanchard et al. by assuming that there is a foreign central bank that can affect exchange rate determination via foreign

FIGURE 2 Impulse responses of the overnight interbank rate to a US monetary policy shock (Gertler-Karadi). Estimated impulse response (solid blue line) and 90% confidence intervals (dashed lines).



Notes: Impulse responses to a unit monetary policy shock (Gertler-Karadi), obtained by estimating Equation (3). See Figure 1 for additional notes.

exchange interventions. This property of the model stems from the assumption that US and foreign bonds are imperfect substitutes, which breaks the interest parity condition. By engaging in FX interventions, the central bank can affect the relative supply of and demand for assets and, hence, the exchange rate for a given interest rate policy.

Another recent, model-based exposition of FX interventions as an additional policy tool is the paper by Alla et al. (2017), who propose a New Keynesian small open economy model with a friction in international capital markets. Shocks to foreign investors' risk perception towards domestic bonds drive a wedge between the real exchange rate and consumption plans between the home country and foreign country (i.e., a wedge in the Backus-Smith condition), which induces volatility and reduces welfare. The central bank can mitigate this wedge via foreign exchange interventions. This is due to an endogenous premium that foreign investors demand for holding home-country bonds. This premium depends on the level of international reserves – the larger the stock of local assets held by foreign investors, the higher the yield they demand on these assets (this is also portfolio balancing channel).

The studies mentioned above provide some motivation for our empirical investigation. One obvious problem with the analysis of central bank FX interventions is that the official intervention data are rarely public (see, e.g., Fratzscher et al. (2019), who analyze 33 central banks, 23 of which do not make their intervention data public). Following Steiner (2017), we compute a proxy for FX interventions (denoted by FXI_t) as follows[12]:

$$FXI_t = -\frac{\Delta R_t}{M_{t-1}} \frac{1}{EMP_t},$$

where R_t is the total foreign reserves at the central bank, M_{t-1} is the monetary base inherited from the previous period[13], Δ is the first-difference operator, and EMP_t denotes the exchange market pressure index (EMP). EMP, a concept first introduced by Girton and Roper (1977), measures the excess demand for the domestic currency that can be relieved through changes in reserves or the exchange rate:

$$EMP_t = \%\Delta S_t - \frac{\Delta R_t}{M_{t-1}},$$

where $\%\Delta S_t$ denotes the percentage change in the nominal exchange rate. In other words, EMP is the sum of exchange rate depreciation and the change in foreign reserves scaled by the inherited monetary base. It should be noted that the definition of EMP provided here closely follows the original definition of Girton and Roper. However, as Weymark (1995) points out, EMP always depends on the underlying model. Because our approach is purely empirical, we use the original definition of Girton and Roper when computing EMP.[14]

Essentially, the intervention index tells us the degree of exchange market pressure that is relieved through exchange market intervention. This method of computing a proxy for FX interventions is based on Weymark (1995). Theoretically, the intervention index can take values between $-\infty$ and ∞. If the index is equal to zero, this means that exchange market pressure is relieved entirely through changes in the value of currency and, hence, that the central bank allows the exchange rate to float freely. When the value of the index equals unity, the interpretation is that the central bank uses foreign exchange intervention to hold the exchange rate completely fixed. Negative values of the index mean that the central bank actively magnifies the exchange rate change induced by the exchange market pressure; conversely, values greater than one indicate that the cen-

12 Foreign exchange reserves are widely used as a proxy for FX interventions. Neely (2000) and Suardi and Chang (2012) provide evidence for the co-movement of reserves with FX interventions. Among others, Blanchard et al. (2015) provide robust results regarding the effects of interventions using the data on FX reserves.

13 Norwegian data on the monetary base (M0) were not available for the sample period, and because of this, we used a broader monetary aggregate (M1) when constructing the intervention index for Norway.

14 Note that some authors include an interest rate differential *vis-à-vis* the base country in their definition of EMP. We do not include the interest rate differential, because we maintain the assumption that the central bank does not aim to mitigate the EMP via the adjustment of the short-term nominal rate

tral bank interventions more than offset the exchange market pressures. The computed FX intervention indices for our sample countries are shown in Figure 9 in the appendix.

The dynamic effect of US monetary policy shocks on reserves interventions is estimated again via local projections, as in Equation (3), but this time, we replace the interest rate on the left-hand side of the equation with the intervention measure:

$$FXI_{t+h} = \alpha^{(h)} + \gamma^{(h)}\xi_t^{US} + x_t'\beta^{(h)} + \varepsilon_{t+h} \tag{4}$$

for each horizon $h = 0, 1, 2, ..., H$. Analogous to the model with interest rate as a dependent variable, the estimated sequence of γ's provides the dynamic effect of US monetary policy shock on the central bank's foreign exchange interventions. The vector of the control variables again includes the contemporaneous values of inflation and industrial production growth, their three lags, and up to six lags of the intervention proxy, with the number of lags again being selected according to the Bayes-Schwartz information criterion.

What kind of response on the part of foreign exchange interventions should one expect given a surprise contraction in the federal funds rate, taking it as a given that the domestic central bank indeed pursues an active foreign reserve management policy to provide additional leeway for interest rate policy, and that capital is perfectly mobile? To answer the question, consider the following simplified argument. The starting point is a generalized uncovered interest rate parity condition linking the expected exchange rate change and the interest rate differential:

$$s_{t+1}^e - s_t = i_t - i_t^f + u_t, \tag{5}$$

where s_t is the (log) nominal exchange rate (measured as the domestic currency price of one dollar), s_{t+1}^e is the expected (log) nominal exchange rate next period, i_t is the domestic interest rate, and i_t^f is the foreign (the US) interest rate. The additional term u_t represents the deviation from the parity condition in exchange-rate-equivalent units. When the uncovered interest rate parity holds, $u_t = 0$. In this case, the domestic central bank could perfectly stabilize the exchange rate by giving up its monetary independence and setting $i_t = i_t^f$.

If the central bank tolerated some exchange rate instability but still wanted to partly mitigate exchange rate volatility, it would adjust the domestic interest rate to less than one-to-one with respect to the foreign rate. However, this could hinder the credibility of inflation targeting policy, especially if the interest rate adjustment in response to exchange rate pressure conflicted with the direction of the adjustment in response to a change in the inflation outlook due to purely domestic factors.

Now, consider a situation in which $u_t \neq 0$. In this case, the central bank has at least some control over u_t via an alternative monetary policy instrument that is independent of its main policy tool, the short-term rate. One such instrument could be (sterilized) foreign exchange intervention – this could be motivated by invoking the assumption of the imperfect substitutability of domestic and foreign assets. Given that FX interventions can influence exchange rate determination through the generalized uncovered interest rate parity condition of Equation (5), pressure on the exchange rate resulting from a surprise change in the foreign interest rate could be relieved through foreign reserve management. Consider a simple argument evolving around Equation (5). Assume that the central bank influences the deviation term u_t by manipulating its foreign reserve holdings. Suppose there is a surprise contraction in US monetary policy, i.e., i_t^f increases, leading to a decrease in the interest rate differential in Equation (5). In the absence of any policy intervention, this should lead to expected appreciation of the domestic currency. Fixing the expectations of the level of the future exchange rate, this implies that the current exchange rate should depreciate. However, if the central bank engaged in a sterilized foreign exchange intervention, leaving the domestic interest rate unchanged, the depreciation of the domestic currency needed to make Equation (5) hold need not be as great as in the absence of a policy intervention. The central bank can buy domestic currency denominated assets in exchange for foreign currency denominated assets, thus depleting its foreign reserves, and, in this way, offsetting some of the depreciation pressure directed towards the domestic currency.

Reflecting on the previous logic, in addition to the responses of FX interventions, we also consider the dynamic response of the nominal exchange rate to a US monetary policy shock. To this end, we estimate the equation

$$s_{t+h} = \alpha^{(h)} + \gamma^{(h)}\xi_t^{US} + x_t'\beta^{(h)} + \varepsilon_{t+h} \tag{6}$$

where s_{t+h} is the log of the nominal exchange rate (multiplied by 100). Again, analogous to Equations (3) and (4), the estimated sequence of γ's provides the dynamic response on the part of the dependent variable. As in previous models, the vector of control variables includes the contemporaneous values of inflation and industrial production growth, their three lags, and up to six lags of the nominal exchange rate. The number of lags is again selected on the basis of the Bayes-Schwartz information criterion.

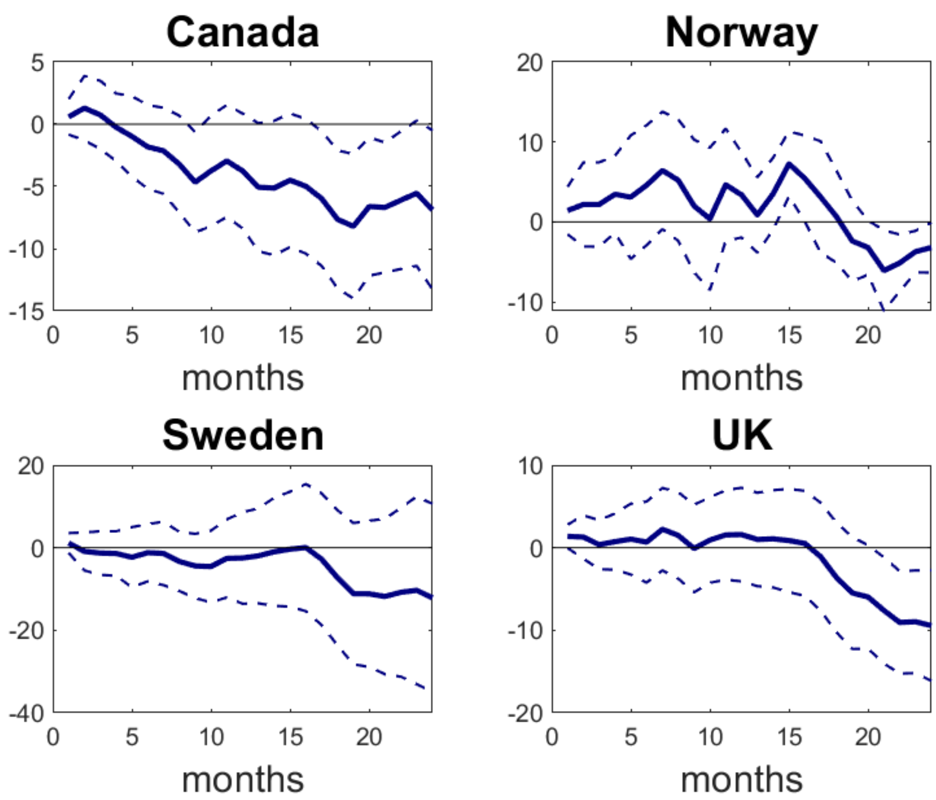
The responses of the nominal exchange rate to a Romer-Romer shock are shown in Figure 3. The estimated impulse responses do not show a statistically significant reaction on the part of the exchange rate in any of the countries at short horizons. However, the exchange rate appreciates to a statistically significant degree at longer horizons in Canada, Norway, and the UK. One potential interpretation invokes the uncovered interest rate parity: A decrease in the interest rate differential resulting from a monetary contraction in the US induces an expected appreciation in the exchange rate, which is realized over longer horizons. On the other hand, the fact that exchange rates do not react statistically significantly to a US monetary policy shock could result from the interventionist policies of central banks. The impulse response plots of domestic interest rates to the RR shock, presented in Figure 1 earlier, showed a clear positive response on the part of Canadian and Swedish interest rates to a US policy shock, potentially indicating that the response of domestic interest rates to the direction of the shock stabilizes the exchange rate movements. As a robustness check, the responses of exchange rates to a Gertler-Karadi shock are shown in Figure 10 in the appendix. Qualitatively, the responses are quite similar to those obtained using Romer-Romer shocks. However, the magnitudes of responses are far greater. It should be noted that the responses for Canada and UK are statistically significant at medium-run horizons as well.

In the light of the logic evolving around the generalized uncovered interest rate parity condition in Equation (5), an insignificant response on the part of both the exchange rate and the domestic interest rate to a surprise US monetary contraction could suggest that the central banks of our countries of interest have pursued FX reserve management in some form. Let us now turn to the dynamic responses of the foreign exchange intervention. Figure 4 shows the responses of the intervention index to a US monetary policy shock (as measured by the Romer-Romer series). The estimated impulse responses are quite erratic and do not display a clear pattern of increase or decline in the intervention measure following a surprise contraction in the Fed's monetary policy for any country, except perhaps Norway. For Norway, the response of intervention activity is predominantly negative and statistically significant at the 90-% level at around 7 to 12 months following the shock. Again, as a robustness check, we conduct the same exercise using Gertler-Karadi high-frequency surprises in the Fed funds futures instead of Romer-Romer shocks. The results are reported in Figure 11 in the appendix. These responses corroborate the narrative that was obtained using RR shocks. For none of the countries do we obtain impulse responses displaying a clear statistically significant pattern with regard to a US monetary policy shock.

As a robustness exercise, we estimate the previous model, this time simply using the log of total international reserves as a proxy for foreign exchange intervention activity. That is, we replace FXI_t on the left-hand side of Equation (4) with the log of international reserves (multiplied by 100). Figure 5 shows the estimated impulse responses obtained using RR shocks. None of the estimated impulse responses appear to be significant at short horizons. Looking at the directions of the responses, the hypothesis about the central banks depleting their foreign reserves to counter the depreciation pressure induced by a decrease in the interest rate differential does not seem to be supported, except in the case of Canada at longer horizons. Again, we report the responses of the log of total international reserves to a GK shock in Figure 12 in the appendix.

In summary, our results do not provide clear and obvious evidence for the hypothesis that the central banks of our sample countries have used foreign exchange interventions to enhance their monetary autonomy with respect to the US, although we found some support for the non-negligible influence of US monetary policy shocks on local monetary policy decisions. Because the exchange rate does not respond significantly, at least directly following the shock, one would be inclined to conclude that the domestic central bank uses policy measures of some form to curb the depreciation pressures induced by US monetary policy shocks. However, based on our analysis, foreign exchange interventions do not seem to be among such measures in the countries we consider. Some previous studies, including Fratzscher at al. (2019), which used daily data, have found that FX interventions have proven successful in steering the exchange rate and smoothing

FIGURE 3 Responses of the log nominal exchange rate to a unit Romer-Romer US monetary policy shock. Estimated impulse response (solid blue line) and 90% confidence intervals (dashed lines).



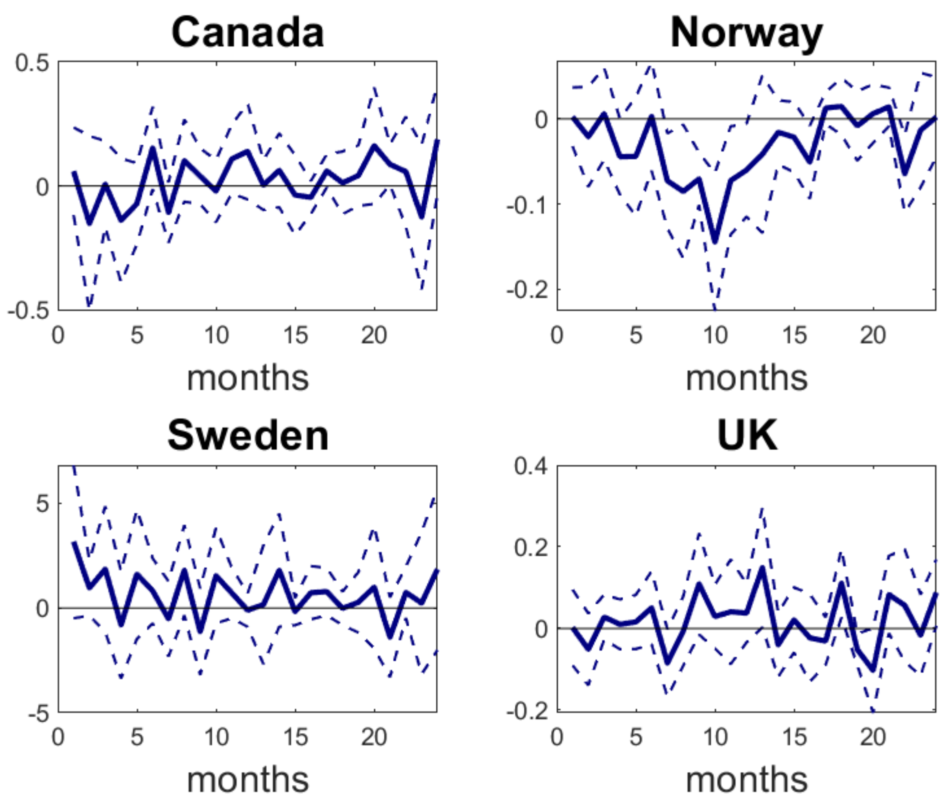
Notes: Impulse responses to a unit monetary policy shock (Romer-Romer), obtained by estimating Equation (6). The set of control variables consists of contemporaneous values of inflation and industrial production growth, as well as three of their lags. We also add lags of the nominal exchange rate on the right-hand side of the equation, the number of which is determined by the Bayes-Schwartz information criterion (with the maximum number of lags to consider being six). Dashed lines represent 90% confidence intervals. For each country, the estimation sample starts on the date indicated in Table 1 and ends in December 2007.

the impact of capital flows. Thus, our weak results regarding the efficacy of FX interventions may be related to the monthly data used in this study.

3.5 Robustness analysis: A proxy SVAR

How robust are our results to various methodologies? This section explores an alternative way of uncovering the dynamic effects of US monetary shocks on small open economies' policies. More precisely, we exploit another methodology that makes use of externally constructed measures of structural shocks in estimating the dynamic causal effect: the proxy SVAR, introduced by Stock and Watson (2012), Mertens and Ravn (2013), and Gertler and Karadi (2015), among others.

FIGURE 4 Responses of FX intervention index to a unit Romer-Romer US monetary policy shock. Estimated impulse response (solid blue line) and 90% confidence intervals (dashed lines).



Notes: Impulse responses to a unit monetary policy shock (Romer-Romer), obtained by estimating Equation (4). The set of control variables consists of contemporaneous values of inflation and industrial production growth, as well as three of their lags. We also add lags of the interest rate on the right-hand side of the equation, the number of which is determined by the Bayes-Schwartz information criterion (with the maximum number of lags to consider being six). Dashed lines represent 90% confidence intervals. For each country, the estimation sample starts from the date indicated in Table 1 and ends in December 2007.

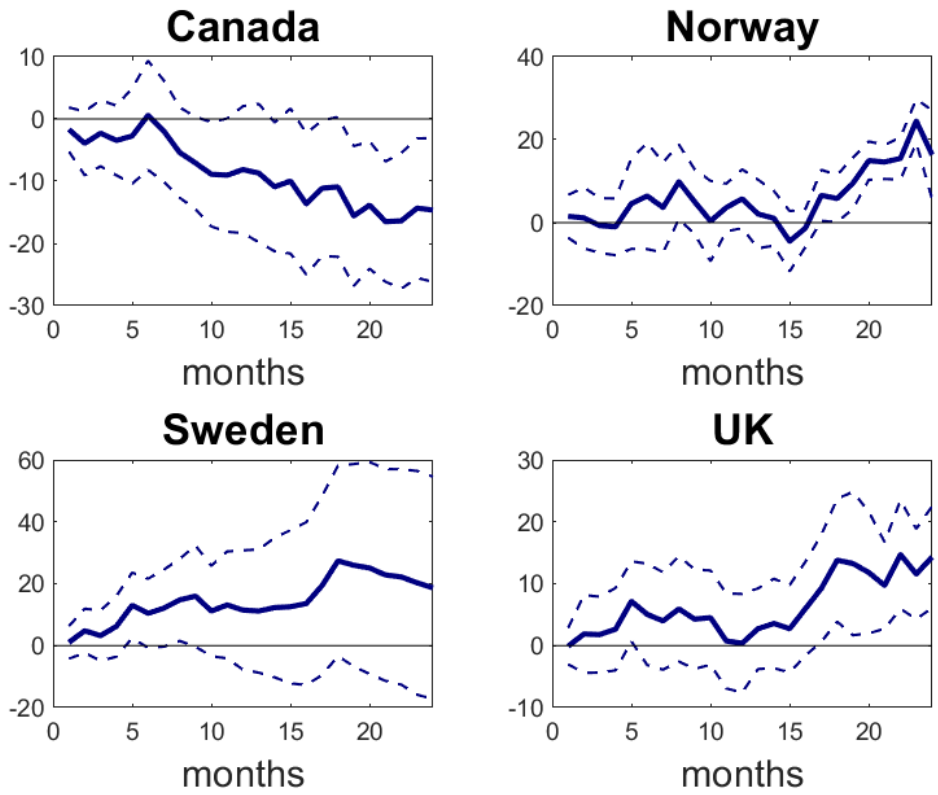
For the sake of space, the method is described rather briefly here: more detailed expositions can be found in the abovementioned papers.

Suppose that our starting point is the following structural VAR model:

$$\mathbf{A}\mathbf{y}_t = \sum_{j=1}^{p} \mathbf{C}_j \mathbf{y}_{t-j} + \varepsilon_t, \tag{7}$$

where $\mathbf{y}_t$ is an N-dimensional vector containing the observable variables of interest, $\mathbf{C}_j$ are slope coefficient matrices, ε_t is the vector of structural shocks with $E[\varepsilon_t \varepsilon_t'] = \mathbf{I}_N$, where $\mathbf{I}_N$ is an $N \times N$ identity matrix, and the matrix $\mathbf{A}$ describes contemporaneous relationships between the model variables. Assuming that $\mathbf{A}$

FIGURE 5 Responses of log total international reserves (multiplied by 100) to a unit Romer-Romer US monetary policy shock. Estimated impulse response (solid blue line) and 90% confidence intervals (dashed lines).



Notes: See Figure 4.

is invertible, the model has a reduced-form representation,

$$\mathbf{y}_t = \sum_{j=1}^{p} \mathbf{B}_j \mathbf{y}_{t-j} + \mathbf{u}_t, \tag{8}$$

where $\mathbf{B}_j = \mathbf{A}^{-1}\mathbf{C}_j$, and $\mathbf{u}_t = \mathbf{A}^{-1}\varepsilon_t = \mathbf{H}\varepsilon_t$ is the vector of reduced-form errors. The identification problem amounts to going from (estimable) reduced-form errors to structural shocks, i.e. finding the short-run impact matrix $\mathbf{H}$. To do this, restrictions must be placed on the elements of $\mathbf{H}$. Because the covariance matrix of reduced-form errors, $\mathbf{\Sigma}_u$, contains $\frac{N(N+1)}{2}$ independent elements, a total of $\frac{N(N-1)}{2}$ must be placed on the elements of $\mathbf{H}$. One common method in the VAR literature is to assume a recursive causal chain among the model variables, i.e., to assume that $\mathbf{H}$ is lower triangular. Finding $\mathbf{H}$ then amounts to solving for the Cholesky factor of $\mathbf{\Sigma}_u$. Alternatively, one can place exclusion restrictions on $\mathbf{H}$ based on, for example, institutional features that give rise to a certain timing between variables.

In our case, imposing exclusion restrictions on the short-run impact matrix $\mathbf{H}$ is arguably not meaningful because our system includes several fast-moving variables, such as interest rates, foreign reserves interventions, and the exchange rate. Thus, developing plausible short-run exclusion restrictions becomes a challenge. In addition, we are only interested in the effects of a single shock, so we need not find the elements of the entire matrix but, rather, only the column corresponding to the impact effects of the shock of interest.We exploit the methodology developed by Stock and Watson (2012) and Mertens and Ravn (2013), among others, which makes use of externally constructed proxies for structural shocks. Thus, the method also blends well with the local projections exercise conducted earlier.

Suppose there is a variable z_t that can serve as a proxy for the true underlying structural shock whose effects we want to study, in this case US monetary policy shock. Without a loss of generality, assume that the order of variables is such that the federal funds rate FF_t is ordered first in the vector y_t. Therefore, $\varepsilon_{1,t}$ is the structural shock associated with the federal funds rate. Also suppose that

$$E_t[z_t \varepsilon_{1,t}] = \phi, \tag{9}$$
$$E_t[z_t \varepsilon_{j,t}] = 0, \qquad j = 2, ..., N, \tag{10}$$

or, in other words, that z_t satisfies the relevance and exogeneity conditions, which are familiar from the instrumental variables estimation literature. These conditions, combined with the linear relationship between the reduced-form errors and structural shocks, then provide us with the following moment restriction:

$$\phi \mathbf{h}^{(1)} = E[z_t \mathbf{u}_t], \tag{11}$$

where $\mathbf{h}^{(1)}$ denotes the first column of the matrix $\mathbf{H}$, implying that the impact effect of the structural US monetary shock is identified up to scale ϕ. Assuming that the impact effect of the structural shock on the reduced-form prediction error associated with the federal funds rate equation is one, i.e. $\mathbf{H}_{11} = h_1^{(1)} = 1$, we then have

$$\phi = E[z_t u_{1,t}], \tag{12}$$

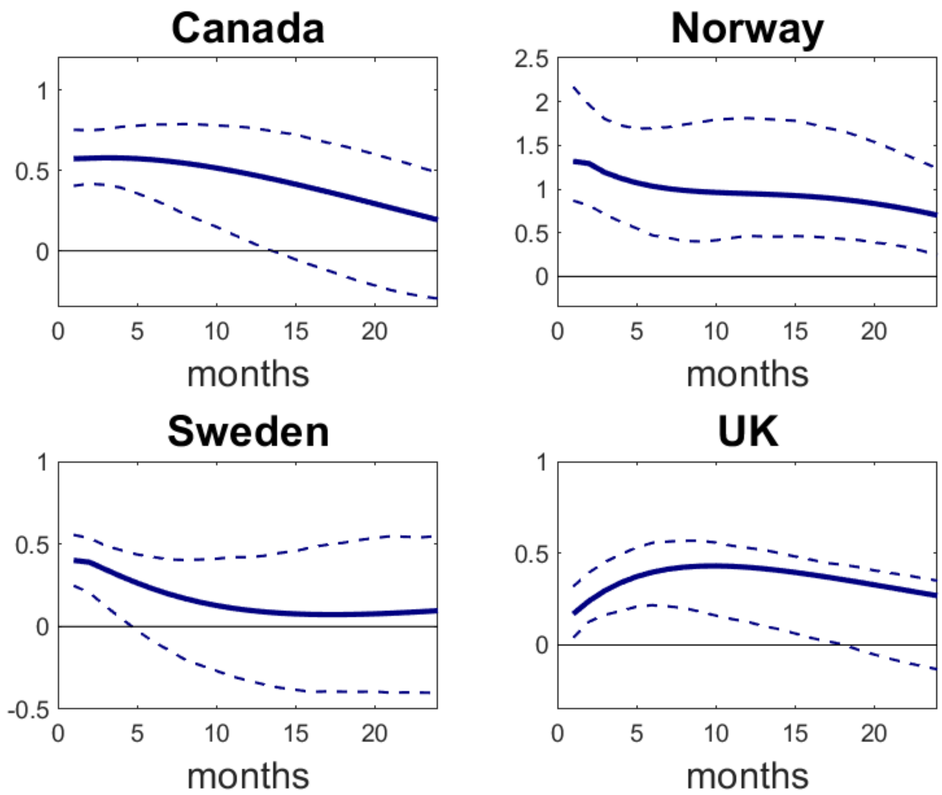
which gives us the appropriate scale ϕ. As our primary external instrument z_t, we use the Romer-Romer shock proxy that was included directly in the set of local projection regression equations estimated above. In addition, we conduct a robustness check by replacing the Romer-Romer series with the Gertler-Karadi shock proxy.

The results obtained from the proxy SVAR approach are described below. We estimate a model in which the vector of endogenous variables consists of the federal funds rate, output growth, inflation, the domestic interest rate, the log of nominal exchange rate (multiplied by 100), and an FX interventions proxy. As in the case of Taylor rules and local projections, the model is estimated separately for each country. The lag order for each country-specific model is selected according to the Bayes-Schwartz information criterion. For all countries, the optimal lag structure according to the information criterion turned out be one lag.

Figure 6 depicts the impulse responses of domestic interest rates to a US monetary policy shock obtained from the estimated SVAR, identified by using the

Romer-Romer shock series as an external instrument. In the interest of brevity, we do not report the responses of the other variables, because they are not our primary interest. Examining Figure 6, we conclude that SVAR impulse responses

FIGURE 6 Dynamic responses of the domestic interest rate to a US monetary policy shock from a SVAR identified using an external instrument (Romer-Romer).



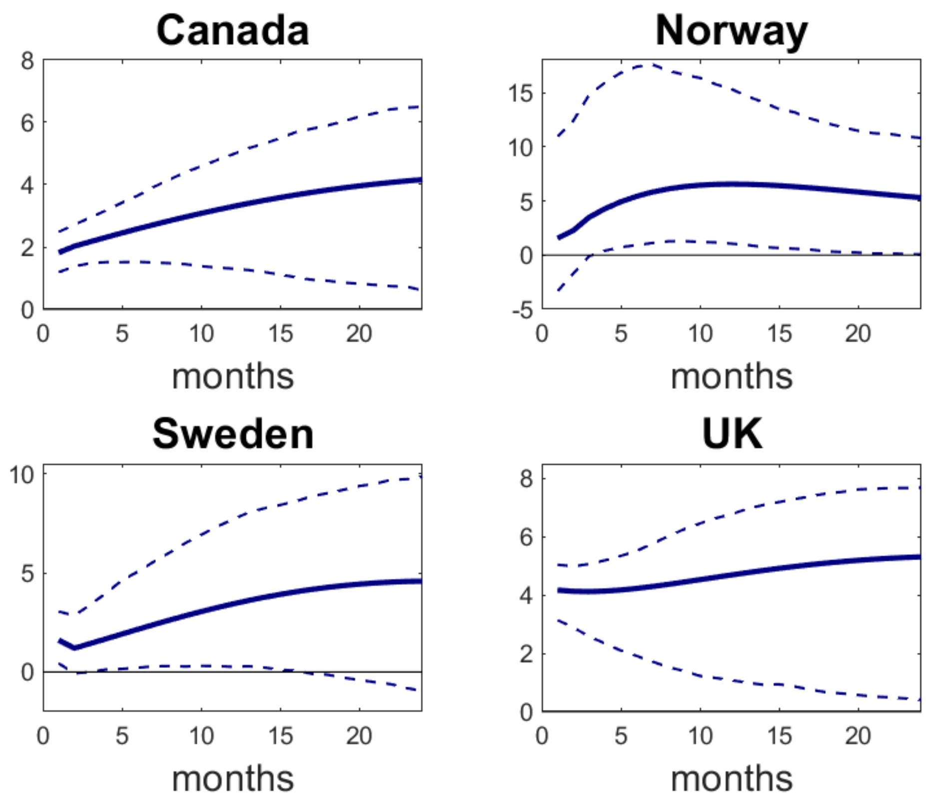
Notes: Dashed lines represent 90% bootstrapped confidence intervals. For each country, the estimation sample starts on the date indicated in Table 1 and ends in December 2007.

indicate a stronger reaction on the part of domestic interest rates than the impulse responses obtained from the LP approach. Following a contraction in US monetary policy, overnight rates increase in all the sample countries. As with the LP exercise, we also report the dynamic responses of the nominal exchange rate and the FX intervention proxy in Figure 7 and Figure 8, respectively. The exchange rate depreciates in all countries following a US monetary contraction.

On impact, the responses of the FX intervention indices are positive and statistically significant in Canada and Sweden. At face value, the statistically significant depreciation of the exchange rate would indicate that the central banks of interest do not take action in attempting to stabilize the exchange rate in the face of a surprise monetary contraction in the US, or, even if they do, that the stabilization policy is not very successful. Significant responses on the part of the FX intervention index in Canada and Sweden could be interpreted to mean that the central banks of these countries have attempted to stabilize exchange rate movements via reserve management. However, because both the domestic interest rate and the exchange rate move statistically significantly in response to a US policy shock, the effect of these potential interventions may be deemed as imperfect.

Of course, one general caveat in our analysis is that we cannot observe the counterfactual, that is, how the exchange rate and the domestic interest rate would move in response to a US monetary policy shock in the absence of any possible FX interventions. Thus, we cannot be decisive regarding the ultimate effectiveness of FX interventions: even if the exchange rate and the domestic interest rate move significantly in response to a shock, they could have been even more volatile in the absence of any interventionist policies by the central bank. Therefore, our results should be viewed as suggestive evidence at best.[15]

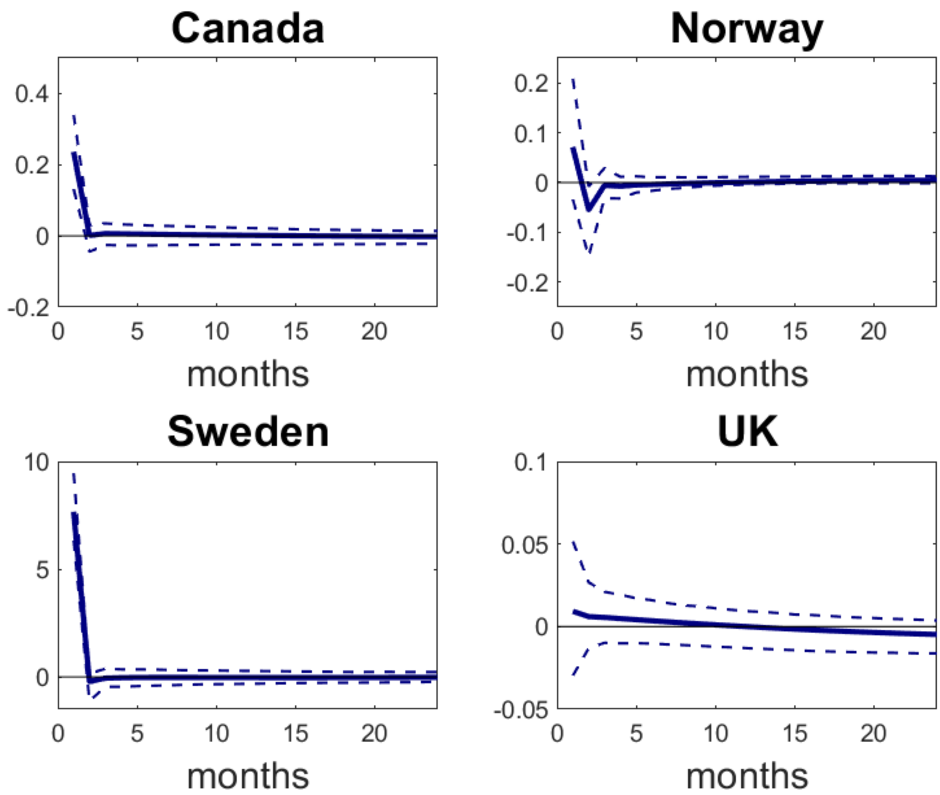
FIGURE 7 Dynamic responses of the log of exchange rate (multiplied by 100) to a US monetary policy shock from a SVAR identified using an external instrument (Romer-Romer).



Notes: A positive response indicates the depreciation of the currency. Dashed lines represent 90% bootstrapped confidence intervals. For each country, the estimation sample starts on the date indicated in Table 1 and ends in December 2007.

15 Finally, one should also point out that due to inherent differences in the two methods of obtaining impulse responses (LP being a "direct forecast"-based method vs. VAR being an iterative method), the resulting estimated responses are quite different in shape and magnitude.

FIGURE 8 Dynamic responses of the FX intervention index to a US monetary policy shock from a SVAR identified using an external instrument (Romer-Romer).



Dashed lines represent 90% bootstrapped confidence intervals. For each country, the estimation sample starts on the date indicated in Table 1 and ends in December 2007.

3.6 Discussion and avenues for future research

Our research question can be linked to both the literature on the effects of US monetary policy spillovers, as well as the literature on the monetary policy autonomy in a small open economy. While the analysis in our paper resembles, from the methodological point of view at least, that of Miranda-Agrippino and Rey (2015) in the sense that they consider dynamic effects of US monetary policy shocks like we do, our paper does not provide as detailed an analysis of the transmission mechanism for those shocks. However, our paper presents a country-specific analysis regarding the effects of US policy shocks, thus providing some additional insights into potential heterogeneities in different countries' exposure to US monetary policy.

Because all of our sample countries have implemented inflation targeting during the observation period, our study also provides an evaluation of the success of that particular policy regime in buttressing the domestic economy against the influence of foreign policy developments. Reflecting on our results, it seems that inflation targeting framework may not secure monetary autonomy. Therefore, our conclusions resemble those of Rey (2015): Monetary conditions in the US seem to be at least partly transferred to small open economies, regardless of the exchange rate regime. This point is also taken up by Edwards (2015), who examines the extent to which the US monetary policy stance is imported to a handful of Latin American emerging market economies with a floating currency and an inflation target, namely Chile, Colombia, and Mexico. By estimating error correction models, he finds that there is a high pass-through from US monetary policy to the interest rates of said countries. Our results partly extend his findings for a group of advanced economies as well.

In addition to the question of monetary policy autonomy, another central research question in our paper has been whether the central banks we have scrutinized have implemented foreign exchange intervention policies to enhance their monetary autonomy. This question is close to what Steiner (2017) considers. Where we differ from Steiner, however, is that instead of analyzing the tightness of the Trilemma constraint and the potential leeway that FX interventions could offer in a static panel regression context, we focus on the dynamic effects of US monetary policy shocks on FX interventions in our sample countries separately. Steiner finds that FX interventions have been effective in relaxing the Trilemma constraint in industrialized countries (although somewhat less so than in emerging market economies). In contrast, our results do not provide undisputed evidence in favor of the central banks in our sample using FX interventions in response to US monetary policy shocks to provide leeway for conventional interest rate policy. One reason for the rather weak evidence of central bank intervention policy for monetary autonomy may stem from the data being at a monthly frequency. Fratzscher et al. (2019), using daily data, find that interventions are a widely used and effective policy tool in smoothing the path of the exchange rate. Based on this finding, there is a case for an active use of FX interventions in monetary policy, but such intervention activities seem negligible in our monthly data.

Another novel aspect in our analysis is the sample period and the set of countries we focus on. Our sample is rather homogenous in the sense that all countries therein are advanced economies with an inflation-targeting monetary policy framework. Among others, Rey (2016) examines the impacts of US monetary policy shocks on the Swedish economy in a sample that includes the era of ERM target zone membership and after the financial crisis of 2007–2008. In many advanced economies, monetary policy has become increasingly synchronized in the decade following the great financial crisis. The bulk of recent studies on monetary policy independence or spillovers from US monetary policy account also for the period of unconventional monetary policy that began in 2008. This, admittedly, is a virtue that our study lacks. However, our study provides a historical account of the issue, and the results indicate that monetary policy of the US may be an important factor for the central bankers in small open economies during "normal times" as well.

Also, the contemporaneous literature on monetary policy spillovers and monetary policy independence has focused on the "mean" effects by utilizing panel data, for example. Miranda-Agrippino and Rey (2015) consider the effect of US monetary policy shocks on global financial variables but do not report a country-specific analysis. The transmission mechanism for shocks that we allow for in our paper is narrower because our empirical models do not account for variables – beyond those traditionally included in the Taylor rule – that could potentially be important for the transmission.

As a final remark, some words of caution regarding the interpretation of the results are in order. Even though our results indicate that US monetary policy seems to influence monetary policy in a small open economy with an inflation target and flexible exchange rate, this, in itself, may not be enough to determine whether monetary policy autonomy is, in fact, in question. Recent decades have witnessed a considerable increase in globalization and, as a result, a growing synchronization of the business cycle across countries. Even if one observes that monetary policy movements in a small open economy closely follow those in the United States, this is obviously not a conclusive proof that the small open economy in question has lost its monetary autonomy – monetary authorities may simply find it optimal to conduct monetary policy in a manner that mimics the US policy stance.

Although, in our empirical analyses, we have attempted to control for domestic economic conditions by including inflation and real economic activity in the estimated models, fully separating the components of domestic economic conditions that are driven by developments elsewhere is difficult. The need to better address this issue should provide a fruitful avenue for future work.

3.7 Conclusion

This paper has studied the influence of US monetary policy on several inflation-targeting economies before the financial crisis of 2007–2008. We have approached the issue of monetary independence, in terms of domestic interest rate exposure to US monetary policy, from two methodological perspectives; firstly, we estimated Taylor-type central bank reaction functions and found that the federal funds rate was a significant predictor of the domestic interest rate after controlling for inflation and economic activity, especially for Canada and the UK. This was the case in both contemporaneous and forward-looking monetary policy rules.

Secondly, we attempted to uncover the dynamic effects of US monetary policy shocks on domestic interest rates using Local Projections and extraneous monetary policy shocks. The estimations performed using the monetary policy shock proxy of Romer and Romer (2004) did yield some evidence in favour of the unanticipated contractions in the Federal Reserve's policy influencing local monetary policy after controlling for domestic objectives (inflation and real activity growth) in Canada and Sweden. However, these effects could not be replicated when using shocks identified by high-frequency movements in federal funds futures around FOMC announcements, in the spirit of Gertler and Karadi (2015). In addition to local projections, as a robustness check, we also estimated the dynamic effects of US policy shocks using a proxy SVAR. The results of this exercise largely confirm the results obtained via the LP method. In fact, the SVAR impulse responses indicate a significant effect on the part of US policy shocks (identified by using Romer-Romer series as a proxy) on all our sample countries' overnight interbank rate.

Lastly, we examined whether the central banks of our sample countries have implemented foreign reserve management in order to buffer the depreciation pressures of the local currency brought about by an unanticipated monetary tightening in the US, thus providing some additional room for interest rate policy to operate on the basis of domestic objectives (the inflation target most importantly). We could not find robust evidence supporting this view, using either the LP or structural VAR methodology.

To summarize, our results lend some support to the view that monetary policy in a small open economy with a flexible exchange rate regime and an inflation target is not completely free of the foreign influence. In this paper, we have treated the US as the core country, but it is worth mentioning that the role of the European Central Bank's monetary policy for our sample countries should also be examined more carefully. We briefly touched on this issue in our reaction function estimations, but a more detailed analysis will be left for the future. Moreover, the question regarding the sovereignty of the monetary base in a flexible exchange rate regime remains untouched. Irrespective of limited interest rate autonomy, a country should still have degrees of freedom to steer the nominal variables in the long run and the real variables in the short run.

Appendix 3.A Additional tables and figures

FIGURE 9 FX intervention proxies for the sample countries

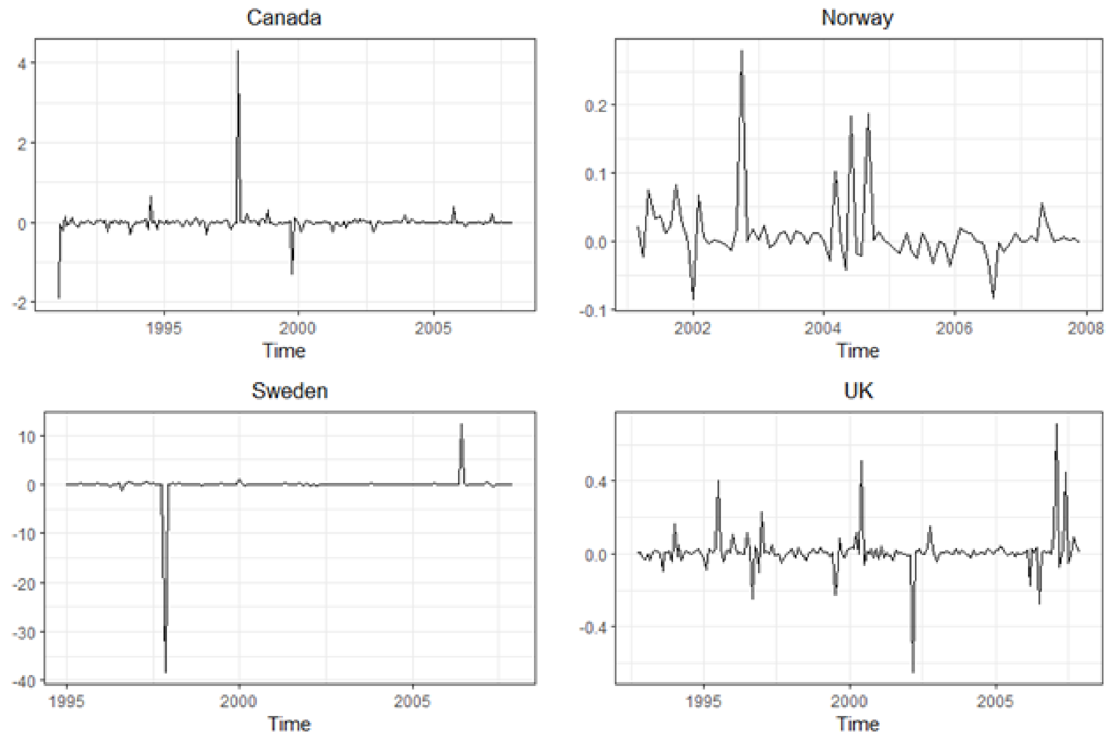


FIGURE 10 Responses of log nominal exchange rate (multiplied by 100) to a unit Gertler-Karadi US monetary policy shock. Estimated impulse response (solid blue line) and 90% confidence intervals (dashed lines).

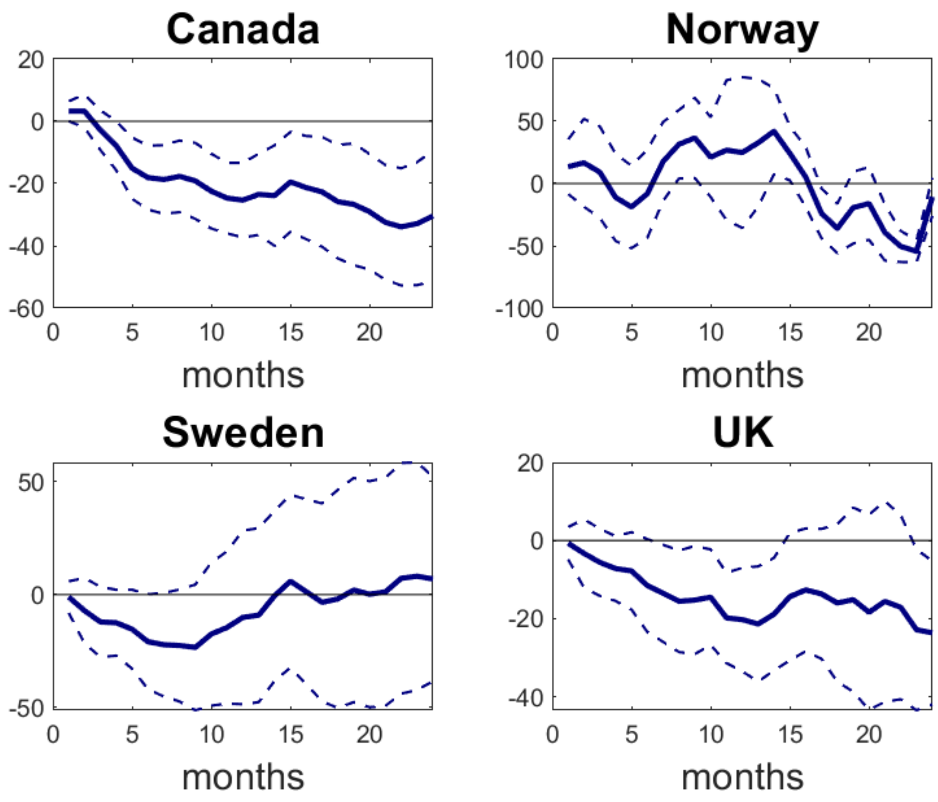


TABLE 6 List of data series used in empirical analyses

Series	Explanation	Source
Interbank rate	Immediate Rates: Less than 24 Hours: Call Money/Interbank Rate	FRED Database
Consumer price index	Consumer Price Index of All Items, Index 2015=100, Monthly, Not Seasonally Adjusted	FRED Database
Industrial production index	Production of Total Industry, Index 2015=100, Monthly, Seasonally Adjusted	FRED Database
Exchange rate	Domestic Currency to US Dollar, Monthly, Not Seasonally Adjusted	FRED Database
Reserves	Official international reserves, Standardized (billions USD)	Thomson Reuters Eikon
Monetary base (M0)	Standardized (billions USD)	Thomson Reuters Eikon
M1 (Norway)	National currency, seasonally adjusted (converted to USD in the empirical analysis using the nominal exchange rate)	FRED Database
Euro area interest rate	Combination of German interbank rate (Immediate Rates: Less than 24 Hours: Call Money/Interbank Rate for Germany prior to 1994) and Euro area interbank rate (Immediate Rates: Less than 24 Hours: Call Money/Interbank Rate for the Euro Area, from 1994 onward).	FRED Database
Romer-Romer monetary shock	Updated Romer and Romer (2004) shock series by Wieland and Yang (2019)	Johannes Wieland's webpage (https://sites.google.com/site/johannesfwieland/)
Gertler-Karadi monetary shock	Gertler and Karadi (2015)	Gertler and Karadi (2015) replication files (https://doi.org/10.1257/mac.20130329)

FIGURE 11 Responses of the FX intervention index to a unit Gertler-Karadi US monetary policy shock. Estimated impulse response (solid blue line) and 90% confidence intervals (dashed lines).

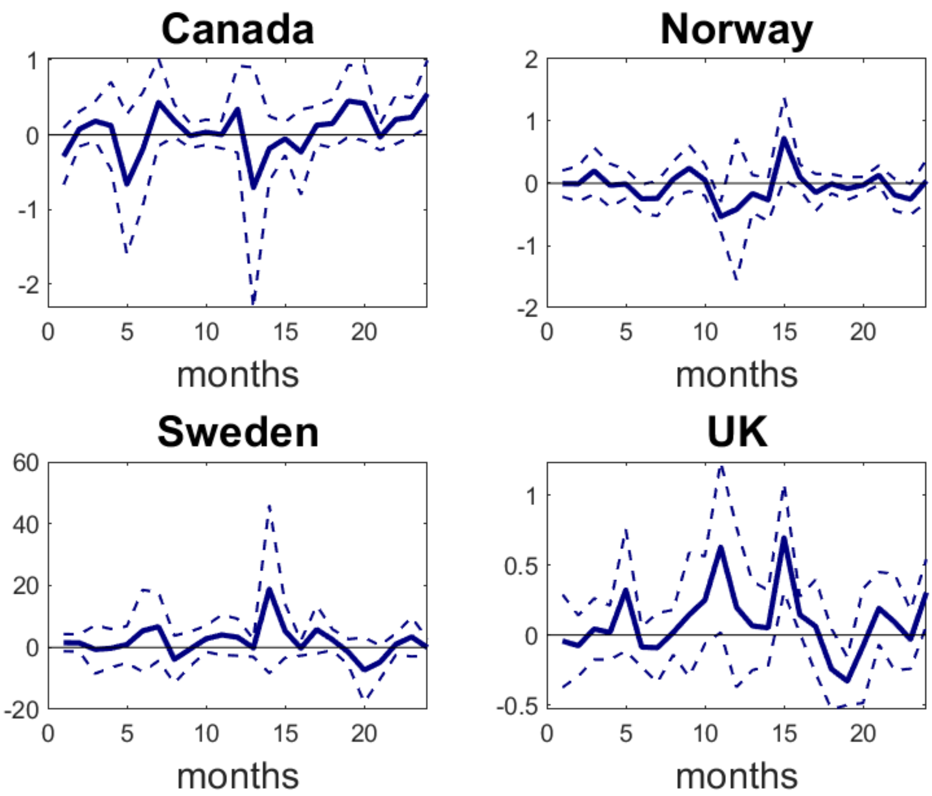
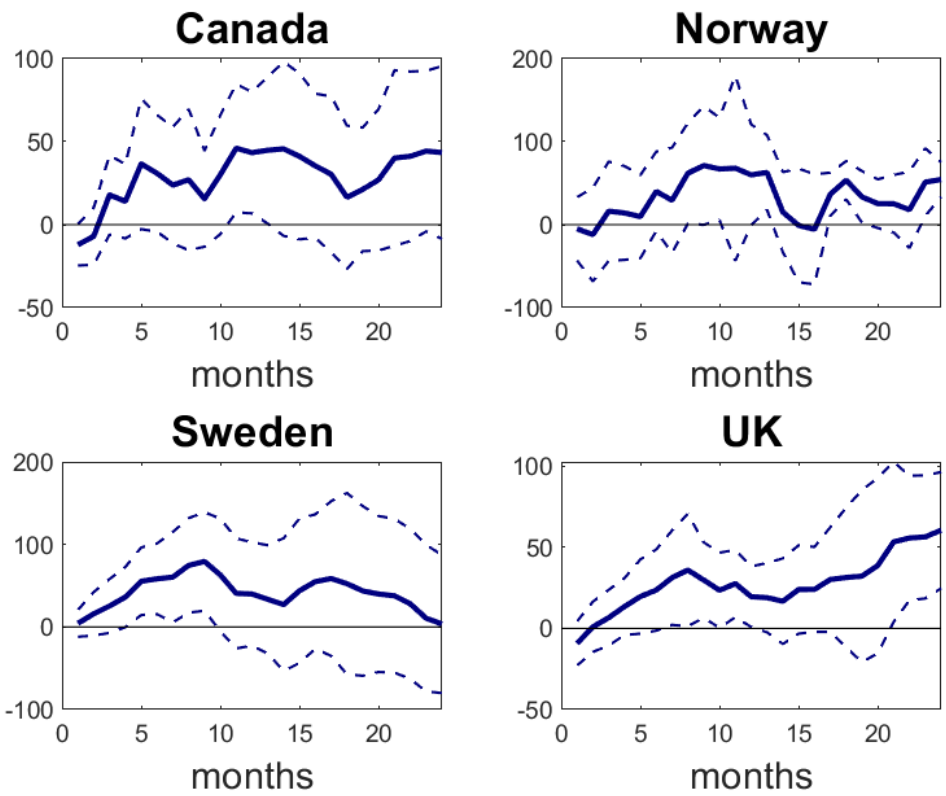


FIGURE 12 Responses of log total reserves (multiplied by 100) to a unit Gertler-Karadi US monetary policy shock. Estimated impulse response (solid blue line) and 90% confidence intervals (dashed lines).



REFERENCES

Aizenman, J., Chinn, M. D., and Ito, H. (2010). The emerging global financial architecture: Tracing and evaluating new patterns of the Trilemma configuration. *Journal of International Money and Finance*, 29(4):615–641.

Aizenman, J., Chinn, M. D., and Ito, H. (2013). The "Impossible Trinity" hypothesis in an era of global imbalances: Measurement and testing. *Review of International Economics*, 21(3):447–458.

Alla, Z., Espinoza, R. A., and Ghosh, A. R. (2017). FX intervention in the New Keynesian model. *Journal of Money, Credit and Banking*.

Anaya, P., Hachula, M., and Offermanns, C. J. (2017). Spillovers of US unconventional monetary policy to emerging markets: The role of capital flows. *Journal of International Money and Finance*, 73:275–295.

Benes, J., Berg, A., Portillo, R. A., and Vavra, D. (2015). Modeling sterilized interventions and balance sheet effects of monetary policy in a New-Keynesian framework. *Open Economies Review*, 26(1):81–108.

Blanchard, O., Adler, G., and Filho, I. d. C. (2015). Can foreign exchange intervention stem exchange rate pressures from global capital flow shocks? Working Paper 21427, National Bureau of Economic Research.

Blanchard, O., Giavazzi, F., and Sa, F. (2005). International investors, the US current account, and the dollar. *Brookings Papers on Economic Activity*, 1:1–65.

Cavallino, P. (2019). Capital flows and foreign exchange intervention. *American Economic Journal: Macroeconomics*, 11(2):127–70.

Chertman, F., Hutchison, M., and Zink, D. (2020). Facing the Quadrilemma: Taylor rules, intervention policy and capital controls in large emerging markets. *Journal of International Money and Finance*, 102:102–122.

Chinn, M. D. and Ito, H. (2006). What matters for financial development? Capital controls, institutions, and interactions. *Journal of Development Economics*, 81(1):163–192.

Clarida, R., Gali, J., and Gertler, M. (2000). Monetary policy rules and macroeconomic stability: Evidence and some theory. *The Quarterly Journal of Economics*, 115(1):147–180.

Daude, C., Yeyati, E. L., and Nagengast, A. J. (2016). On the effectiveness of exchange rate interventions in emerging markets. *Journal of International Money and Finance*, 64:239–261.

Dedola, L., Rivolta, G., and Stracca, L. (2017). If the Fed sneezes, who catches a cold? *Journal of International Economics*, 108:S23–S41.

Edwards, S. (2015). Monetary policy independence under flexible exchange rates: An illusion? *The World Economy*, 38(5):773–787.

Fratzscher, M., Gloede, O., Menkhoff, L., Sarno, L., and Stöhr, T. (2019). When is foreign exchange intervention effective? Evidence from 33 countries. *American Economic Journal: Macroeconomics*, 11(1):132–56.

Friedman, M. (1953). The case for flexible exchange rates. In Friedman, M., editor, *Essays in Positive Economics*, pages 157–203. University of Chicago Press.

Georgiadis, G. and Zhu, F. (2019). Monetary policy spillovers, capital controls and exchange rate flexibility, and the financial channel of exchange rates.

Gertler, M. and Karadi, P. (2015). Monetary policy surprises, credit costs, and economic activity. *American Economic Journal: Macroeconomics*, 7(1):44–76.

Ghosh, A. R., Ostry, J. D., and Qureshi, M. S. (2017). Managing the tide: How do emerging markets respond to capital flows?

Girton, L. and Roper, D. (1977). A monetary model of exchange market pressure applied to the postwar Canadian experience. *The American Economic Review*, 67(4):537–548.

Jordà, Ò. (2005). Estimation and inference of impulse responses by local projections. *American Economic Review*, 95(1):161–182.

Klein, M. W. and Shambaugh, J. C. (2015). Rounding the corners of the policy trilemma: Sources of monetary policy autonomy. *American Economic Journal: Macroeconomics*, 7(4):33–66.

Mertens, K. and Ravn, M. O. (2013). The dynamic effects of personal and corporate income tax changes in the United States. *American Economic Review*, 103(4):1212–47.

Miranda-Agrippino, S. and Rey, H. (2015). US monetary policy and the global financial cycle. Working Paper 21722, National Bureau of Economic Research.

Neely, C. J. (2000). Are changes in foreign exchange reserves well correlated with official intervention? *Review: Federal Reserve Bank of Saint Louis*, 82(5):17–32.

Nelson, E. (2017). The continuing validity of monetary policy autonomy under floating exchange rates. Finance and Economics Discussion Series 2017-112. Washington: Board of Governors of the Federal Reserve System.

Obstfeld, M. (2015). Trilemmas and trade-offs: Living with financial globalisation.

Obstfeld, M., Shambaugh, J. C., and Taylor, A. M. (2005). The Trilemma in history: Tradeoffs among exchange rates, monetary policies, and capital mobility. *Review of Economics and Statistics*, 87(3):423–438.

Orphanides, A. (2001). Monetary policy rules based on real-time data. *American Economic Review*, 91(4):964–985.

Ramey, V. A. (2016). Macroeconomic shocks and their propagation. In *Handbook of Macroeconomics*, volume 2, pages 71–162. Elsevier.

Rey, H. (2015). Dilemma not Trilemma: The global financial cycle and monetary policy independence. Working Paper 21162, National Bureau of Economic Research.

Rey, H. (2016). International channels of transmission of monetary policy and the Mundellian trilemma. *IMF Economic Review*, 64(1):6–35.

Romer, C. D. and Romer, D. H. (2004). A new measure of monetary shocks: Derivation and implications. *American Economic Review*, 94(4):1055–1084.

Sarno, L. and Taylor, M. P. (2001). Official intervention in the foreign exchange market: Is it effective and, if so, how does it work? *Journal of Economic Literature*, 39(3):839–868.

Steiner, A. (2017). Central banks and macroeconomic policy choices: Relaxing the Trilemma. *Journal of Banking & Finance*, 77:283–299.

Stock, J. H. and Watson, M. W. (2012). Disentangling the Channels of the 2007-2009 Recession. Working Paper 18094, National Bureau of Economic Research.

Suardi, S. and Chang, Y. (2012). Are changes in foreign exchange reserves a good proxy for official intervention? *Journal of International Financial Markets, Institutions and Money*, 22(4):678–695.

Taylor, J. B. (1993). Discretion versus policy rules in practice. In *Carnegie-Rochester Conference Series on Public Policy*, volume 39, pages 195–214. Elsevier.

Weymark, D. N. (1995). Estimating exchange market pressure and the degree of exchange market intervention for Canada. *Journal of International Economics*, 39(3-4):273–295.

Wieland, J. F. and Yang, M.-J. (2020). Financial dampening. *Journal of Money, Credit and Banking*, 52(1):79–113.

Wu, J. C. and Xia, F. D. (2016). Measuring the macroeconomic impact of monetary policy at the zero lower bound. *Journal of Money, Credit and Banking*, 48(2-3):253–291.

4 THE FISCAL CHANNEL OF QUANTITATIVE EASING: INSIGHTS FROM A TWO-AGENT NEW KEYNESIAN MODEL

Abstract.
This paper studies the implications of different fiscal policy configurations for the macroeconomic effects of quantitative easing in a simple two-agent New Keynesian (TANK) model, where a fraction of households do not participate in the asset market and behave in a hand-to-mouth fashion. Three alternative fiscal policy scenarios are considered: i) "tax-financing", where the government adjusts lump-sum taxes to ensure that its budget constraint holds while keeping the issuance of debt constant, ii) "short-term debt financing", where the government follows a tax rule and closes the budget constraint by adjusting short-term debt issuance, and iii) "long-term debt financing", which is otherwise similar to the previous scenario except that the government budget constraint is closed by adjusting long-term debt. The dynamics of the model suggest that the macroeconomic impacts of quantitative easing are the largest under tax financing. However, positive responses of certain model variables are more prolonged under long-term debt financing compared to the other two fiscal policy scenarios. As a separate issue, the determinacy and stability properties of the model are considered using numerical simulations.

Keywords: Unconventional monetary policy, quantitative easing, fiscal policy, heterogeneous agents
JEL codes: E52, E58, E63

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4.1 Introduction

In the macroeconomic literature, it has long been recognised that monetary policy has fiscal consequences and that monetary policy and fiscal policy should be analysed jointly. For example, when the central bank raises interest rates, the expenditures on outstanding government debt increase, leading to fiscal policy considerations: should the increased interest rate expenditure be financed through an increase in taxes or the issuance of new government debt? The literature on the interaction of monetary and fiscal policies dates back at least to the seminal paper of Sargent and Wallace (1981), who showed that the central bank's ability to control inflation crucially depends on the coordination between fiscal and monetary policies. Leeper (1991), Sims (1994), and Woodford (1995), among others, extended the analysis to what became known as the fiscal theory of the price level.[1]

In the United States and elsewhere, the decade following the financial crisis of 2007–2008 was characterised by a near-zero short-term nominal interest rate. With policy interest rates at their effective lower bound, central banks attempted to stimulate the economy by employing policies such as quantitative easing (QE) and forward guidance to flatten the long end of the yield curve. At the time of writing, these policy tools are again being employed at an unprecedented scope[2], as policy makers are attempting to mitigate the economic downturn caused by the global COVID-19 pandemic.

Following the large-scale asset purchase programmes conducted by various prominent central banks, several experts have voiced concerns about monetary policy effectively treading on fiscal authorities' territory. By purchasing large amounts of government debt, the central bank affects the interest rate and hence the debt expenditures of the central government. This naturally leads to questions about the fiscal consequences of large-scale asset purchase measures.

Some questions regarding unconventional central bank policies are how they interact with taxation that the fiscal authority (the treasury) imposes on

[1] According to the fiscal theory of the price level, the determination of the price level in dynamic general equilibrium models depends on the joint configuration of monetary and fiscal policies. In a situation where the monetary authority follows an "active" policy in the sense of adjusting the nominal interest rate sufficiently strongly in response to changes in inflation, while the fiscal authority is "passive" in the sense that it adjusts the primary surplus to ensure that its intertemporal budget constraint holds at the given price level and interest rate paths implied by monetary policy, a unique equilibrium in achieved. In this situation, it is monetary policy that determines the price level while fiscal policy merely accommodates. However, the price level is also uniquely determined in a situation where the roles are reversed: fiscal policy is active while monetary policy accommodates.

[2] On March 15, 2020, the Federal Reserve initially announced that in order to promote its employment and price stability goals, it would increase its holdings of Treasury securities by at least \$500 billion and its holdings of agency mortgage-backed securities by at least \$200 billion over the coming months. The asset purchases have continued, and by the end of September 2021, the total assets held by the Federal Reserve had increased from their pre-pandemic level of ca. \$4.2 trillion to around \$8.4 trillion.

households or with the issuance of new government debt. For example, by holding massive amounts of risky assets in its balance sheet, the central bank may experience extensive income losses if the market values of those assets fall. This may have consequences for the fiscal authority's budget as well, as it is a common arrangement that the central bank transfers the net profits it receives to the fiscal authority. In an arrangement like this, in case of central bank losses the fiscal authority then commits to support the central bank. Effectively, losses of the central bank become liabilities of the fiscal authority, and the latter has to raise sufficient funds to cover these losses. Clearly, this has implications for taxation and government debt issuance.[3]

Furthermore, some researches have expressed worries over the possibility that government debt management policies could potentially offset some of the effects of QE. For example, if the central bank is committed to keep the long-term interest rates low by purchasing long-term securities from the private sector, the treasury may be tempted to lengthen the maturity of its outstanding debt because of low financing costs, thus partly offsetting the attempted reduction of the long-maturity debt held in the hands of the private sector by the central bank (Borio and Disyatat, 2010).

This research paper examines the implications of QE for fiscal policy and how different fiscal policy configurations may affect the transmission of QE. Specifically, this paper asks the following questions: Does it make a difference whether the changes in the government resources induced by QE are accommodated by taxes or debt? If it is the latter fiscal policy instrument that accommodates, does it matter whether the treasury issues short- or long-term debt?

In the standard representative agent DSGE framework with complete asset markets, the Ricardian equivalence implies that it is irrelevant whether the government finances its expenses by taxes or debt. One therefore has to step outside of the conventional framework to make the analysis of the above-mentioned questions meaningful and interesting. Indeed, one of the focal points of the present article is to study the implications of QE in an economy where the assumption about single representative agent is abandoned.

Recently, a growing body of literature has emerged that studies the effects of monetary and fiscal policies in the "HANK" (*Heterogeneous agent New Keynesian models*) framework, prominent examples being McKay et al. (2016), McKay and Reis (2016), and Kaplan et al. (2018), among others. Typically, the models of this kind assume a continuum of households with uninsurable idiosyncratic income risk, in the style of Imrohoroğlu (1989), Aiyagari (1994), Huggett (1993), and Krusell and Smith (1998). For the sake of tractability, I take a simpler route and assume, following the example of "first-generation" papers incorpo-

3 A related question, which I do not explore here, is how unconventional monetary policy operations potentially affect the solvency of the central bank. Common wisdom states that a central bank can never be insolvent, as it can always print currency to cover its losses. However, as pointed out by Hall and Reis (2015), a central bank can become financially unstable. They argue that this can happen in a situation where the dividend payout rule of the central bank is such that adherence to the rule implies an explosive path for central bank reserves.

rating household heterogeneity into the New Keynesian framework, that there are two types of households populating the economy: those that can access the asset markets and those that behave in a "hand-to-mouth" fashion, consuming their entire current-period income. Seminal papers by Galí et al. (2007) and Bilbiie (2008) show that such stylised forms of household heterogeneity can have important consequences for the conduct of monetary and fiscal policy because hand-to-mouth households react strongly to transitory income shocks.[4] The empirical relevance of this assumption is supported, for example, by Kaplan et al. (2014) that document that in the US, as many as 30% of households are hand to mouth in the sense that their marginal propensity to consume out of current income is high.

The introduction of hand-to-mouth households breaks the Ricardian equivalence and makes the fiscal channel of QE nontrivial. As Kaplan et al. (2018) show, the fiscal response to a monetary policy shock can have important consequences for the overall macroeconomic responses. Monetary policy changes the path of interest rates, which has an effect on the intertemporal government budget constraint and thus generates a fiscal response that affects the disposable income of households. In representative agent models where the Ricardian equivalence holds, this would have little effect on the overall economic impact. In an economy where the Ricardian equivalence does not hold, however, the fiscal response may play a key role.

In this paper, I build a simple New Keynesian business cycle model with a role for QE. The effectiveness of QE stems from the so-called "preferred habitat" assumption: households regard short and long government bonds as imperfect substitutes, which makes the relative returns of bonds of different maturities dependent on their relative supplies. A QE operation by the central bank reduces the relative amount of long-term bonds held by the public, which through the imperfect substitutability assumption reduces the difference in the returns on long- and short-term government bonds, stimulating consumption.

Another channel through which QE works is the fiscal channel: some households in the model cannot smooth consumption intertemporally and behave in a "hand-to-mouth" fashion, consuming their entire periodic income, which depends on taxes collected by the government. To the extent that QE affects the government budget constraint and taxation, it will have an impact on the consumption possibilities of hand-to-mouth households as well. This channel is of particular interest in the present paper. Indeed, the novel contribution is to study a standard New Keynesian model with a tractable and stylised form of household heterogeneity, with an emphasis on the fiscal channel and its role in the overall transmission of QE. The macroeconomic effects of QE under different fiscal policy configurations are considered. As a by-product of the analysis, it is established that, in a model where the imperfect substitutability is modelled by imposing a portfolio adjustment cost on households, positive steady-state quantitative easing in fact leads to an inverted yield curve in the steady state: the effective hold-

[4] More recent papers on TANK models include Debortoli and Galí (2018), Bilbiie (2019), and Maliar and Naubert (2020).

ing return on the long-term government bond is strictly lower than the return on the short-term bond.

The two-agent framework also lends itself to the analysis of potential inequal effects of QE on different households. One of the most apparent societal concerns regarding unconventional monetary policy is its impact on economic inequality. It is often argued that QE has led to growing disparities in income and wealth, for example, through its inflationary effects on the prices of assets whose ownership is mostly concentrated in the hands of the rich. However, QE might also have mitigating effects on inequality through its impact on employment, wages, and other income channels that benefit non-savers, as Lenza and Slacalek (2018) argue. The model laid out in this paper can shed some light on the the role of the fiscal channel in contributing to the potential dissimilar effects of QE across different households.

Some earlier papers that study the effects of central bank asset purchases, such as Chen et al. (2012) and Carlstrom et al. (2017), model QE as an exogenous shock to the outstanding government debt or its composition. While QE does alter the amount of government bonds available to the private sector, modelling QE in this way makes it essentially indistinguishable from a fiscal shock. This paper takes a slightly more realistic view by assuming that the central bank finances its asset purchases by issuing interest-bearing central-bank reserves. In the model, reserves have nothing special to them in the sense that households regard them as perfect substitutes with short-term government bonds. However, modelling reserves gives rise to the realistic property that QE shifts the portfolio of households from long-term to short-term assets, leading to changes in portfolio costs.

To briefly preview the results, the impulse responses to an exogenous QE shock suggest that, on impact, the effects of QE on aggregate demand are the largest under tax financing, that is, when the government adjusts lump-sum taxes to ensure that its budget constraint holds while keeping debt issuance constant. However, positive responses to a QE shock are more prolonged under debt financing, where the government follows a "passive" tax rule and closes the budget constraint by adjusting its debt issuance. Particularly this is the case when long-term government debt is adjusted to close the budget constraint. As a separate issue, I also consider the determinacy and stability properties of the model using numerical simulations. Although it is shown that, as is common in TANK models, the interplay between the degree of price stickiness and the share of hand-to-mouth households plays an important role in the stability and uniqueness of the rational expectations equilibrium, the stance of fiscal policy does not have a significant effect on the model's determinacy region, unless we consider rather low levels of price rigidity.

The paper is structured as follows. Section 4.2 reviews some of the earlier studies on QE and in particular how QE is modelled in the earlier literature. Section 4.3 outlines the baseline model of this paper. Section 4.4 discusses the different fiscal and monetary policies to be analysed. Section 4.5 presents the quantitative results and some analysis of the qualitative properties of the model, and Section 4.6 further discusses its determinacy properties. Finally, Section 4.7

concludes the paper.

4.2 The theoretical mechanisms of QE

From a theoretical perspective, the macroeconomic literature has not yet clarified why quantitative easing works in the first place. The former Federal reserve chairman Ben Bernanke once stated that "the problem with quantitative easing is that it works in practice but it doesn't work in theory".[5]

A QE operation carried out by a central bank changes the composition of the private sector portfolio because the central bank buys assets from the private sector in exchange for central bank reserves. Eggertsson and Woodford (2003) show that in a monetary New Keynesian model with representative household and price rigidities in the intermediate goods sector, the portfolio composition of the representative household does not affect the equilibrium allocations and prices, thus rendering QE ineffective. In the standard New Keynesian model that they analyse, QE can influence the real economy and prices only to the extent that it changes the expectations of the private sector about the way that the central bank will set the short-term nominal rate in the future.[6]

Recent studies have proposed modifications to the standard framework in order to break the neutrality of QE operations. Generally speaking, they usually do so by assuming some kind of imperfection in the financial markets.

For example, Chen et al. (2012) assume segmented markets for government bonds of different maturities. This limits the arbitrage opportunities across different government securities, essentially making short-term and long-term bonds imperfect substitutes. In the model of Chen et al. (2012), a fraction of households are allowed to trade only in long-term government bonds, while the remaining fraction of households are unrestricted so that they can trade in both long-term and short-term bonds. However, unrestricted households pay a transaction cost when trading in long-term bonds. The transaction cost is a function of the ratio of the market values of long-term bonds and short-term bonds held by the private sector. Therefore, a shock to the composition of government debt (i.e. an asset purchase shock in their model) alters the level of the transaction cost.

Unconstrained households can, up to this transaction cost, arbitrage away the differences in the risk-adjusted expected return on long-term and short-term bonds. With no segmentation in the bonds market, following an asset purchase shock that alters the risk premium, households would simply adjust their portfolios until the effective returns (i.e. returns inclusive of the transaction cost) of the

5 See Bernanke (2014).

6 Eggertsson and Woodford (2003) were not the first to propose the neutrality of the central bank's open market operations. In fact, Wallace (1981) showed that the path of the government's portfolio composition, determined by the central bank via open-market operations, is irrelevant for equilibrium consumption and price level in an overlapping-generations environment. However, it should be noted that Wallace considered only the case where fiscal policy, that is, the path of government deficits, is held constant.

two bonds were equated, implying no adjustment in the stochastic discount factor of households and hence no real effects from the asset purchases. However, since a fraction of households are constrained to trade only in long-term bonds and face no transaction costs, an asset purchase shock will change the return on long-term bonds from their perspective exactly because they face no transaction cost. Hence, their stochastic discount factor has to be adjusted, which alters their intertemporal consumption profile and implying that asset purchases affect real variables in equilibrium.

Andres et al. (2004) and Harrison (2012, 2017) assume imperfect substitutability between short-term and long-term securities, stemming from the presence of a preferred maturity composition for government liabilities that households hold in their portfolios. Households prefer to smooth consumption intertemporally by certain combination of long-term bonds and money, as in Andres et al. (2004), or short-term bonds, and long-term bonds as in Harrison (2012, 2017). The presence of a term in a household's utility function or budget constraint, reflecting the cost of deviating from this preferred maturity composition, can be interpreted to capture the preference for liquidity: households regard short-term bonds/money as more liquid than long-term bonds, and thus, to compensate for a loss of liquidity, want to hold more of the former as their holdings of long-term bonds grow.

A similar "preferred habitat" logic is also in play in Ellison and Tischbirek (2014). However, instead of assuming that households directly hold assets of different maturities, they introduce a representative bank that offers a composite savings device to households, comprising government bonds of different maturities. The imperfect substitutability between bonds of different maturities is reflected in the assumption that the representative bank perceives households as heterogeneous with regard to their investment horizon. The bank's optimization problem implies a set of demand schedules for each maturity that depends on the relative prices of assets. By purchasing government bonds of different maturities, the central bank can reduce the supply of those assets available to the bank, which increases their equilibrium prices. This pushes up the price of composite savings device as well, inducing households to cut back their savings and increase their current consumption.

In Andres et al. (2004), there are two components that affect the term premium between short-term and long-term bonds. First, the authors assume that trading in long-term bonds is subject to an exogenously evolving transaction cost. Second, households have a self-imposed "reserve requirement" discussed earlier: They want to hold more money balances as their stock of long-term government bonds grows. These two components induce a term premium between short-term and long-term bonds that has an endogenous and an exogenous component.

In the baseline version of the model by Andres et al. (2004), variations in the relative supply of long-term bonds are not sufficient to have implications for the determination of aggregate demand since households can still enforce their consumption plans by trading in short-term bonds.[7] Thus, QE would be

[7] Andres et al. (2004) also consider a version of the model where a fraction agents are re-

ineffective in this baseline model because its effect on the supply of long-term bonds and hence their returns would not matter for aggregate demand. Harrison (2012, 2017) builds on a similar idea as that of Andres et al. (2004), but instead he assumes that the endogenous component[8] of the term premium depends on the households' relative holdings of (the market value of) long-term and short-term government bonds. Hence, both short-term and long-term rates enter the IS equation and thus matter for aggregate demand. The central bank can then influence aggregate demand by varying the amount of long-term bonds available for households. In the present paper, I follow this approach also.

Other papers, such as Gertler and Karadi (2011) and Carlstrom et al. (2017), take a slightly different approach in modelling the transmission mechanism of QE. In the theoretical model of Gertler and Karadi (GK), the effectiveness of QE stems from its impact on the private credit markets. Departing from the conventional setup with frictionless financial markets, GK assume that financial intermediaries face a balance sheet constraint that limits their ability to obtain funds, i.e. the ability to supply credit to non-financial firms, which need credit in order to finance their capital purchases (capital is used in production). This constraint is tied to the intermediaries' equity capital. A tightening of the balance sheet constraint disrupts private credit intermediation. The central bank can mitigate the situation by lending to intermediaries. This loosens their balance sheet constraint and helps the flow of credit in the economy.

Carlstrom et al. (2017) in turn assume segmented financial markets. In their model, households must finance new capital investment by issuing long-term investment bonds. They cannot directly save in long-term government securities, but they can indirectly do so through deposits within financial intermediaries. Intermediaries in turn can purchase long-term debt (both government debt and investment bonds): their holdings of long-term securities are financed by deposits and net worth. A leverage constraint prevents the intermediaries from fully arbitraging away the term premium, that is, the difference between the returns on long-term bonds and deposits. This will have an effect on the real economy due to the fact that households' capital investment must be financed through long investment bonds. A QE operation, modelled as an exogenous reduction in the outstanding long-term government debt, reduces the amount of long-term government securities held by the financial intermediaries, thus loosening the balance sheet constraint. This triggers lending towards households. Intermediaries purchase more investment bonds, driving up their prices and reducing their yields. This brings the term premium down, increasing investment and output.

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stricted in the sense that they can only trade in long-term bonds. Unrestricted agents face exogenous transaction costs and are subject to "reserve requirements". This has a consequence that the investment-savings (IS) equation depends on both short-term and long-term real rates. In the standard New Keynesian model with a representative agent and perfect asset substitutability (or only a short-term asset, for that matter), the IS equation links output to the expected path of the short-term real interest rate only.

8 Harrison (2012, 2017) does not assume transaction costs when trading in long-term bonds, and hence the term premium is in fact fully endogenous in his model.

4.3 The baseline model

This section outlines the model that is studied in this paper. Before elaborating on the details of agents' optimisation problems, I describe the asset markets in the economy. The central bank issues reserves, denoted by X_t, that earn a risk-free nominal interest rate of R_t^X in the beginning of period $t+1$. It is assumed that the central bank can issue reserves without a cost and set the nominal return on them. The fiscal authority issues two kinds of bonds: long-term bonds, which are described in detail below, and short-term bonds. Short-term bonds, denoted by B_t, are nominal one-period bonds that cost one unit of account at time t and pay a nominal amount of $R_t B_t$ in the beginning of period $t+1$, where R_t is the nominal gross interest rate. Since from the households' perspective central bank reserves and short-term government debt are perfect substitutes, then by arbitrage $R_t^X = R_t$. Therefore, by setting R_t^X the central bank also sets the nominal gross interest rate on short-term government bonds.

Long-term bonds are modelled as in Woodford (2001), Chen et al. (2012), and Harrison (2012), among others. It is assumed that long-term bonds are perpetuities with coupon payments that decay geometrically at rate $\kappa \in [0,1]$. Let V_t denote a new perpetuity issued a time-t. Then, a coupon payment from V_t in period $t+j$ is equal to $\kappa^{j-1} V_t$. One advantage of modelling long-term bonds this way is that, at time t, it is possible to express the entire stock of outstanding perpetuities in terms of the price of a perpetuity issued at time t, which will be here denoted by Q_t. This follows from the fact that the time-t price of a perpetuity issued j periods ago, denoted by $Q_{t,j}$, is a function of the price of a newly issued perpetuity, i.e. a function Q_t (see, for example, the online appendix of Chen et al. (2012)):

$$Q_{t,j} = \kappa^j Q_t.$$

It then follows that one needs to keep track of only the price of newly issued debt, which reduces the dimension of the state space.

The gross yield-to-maturity of a perpetuity issued at time t is obtained as the solution to the following equation:

$$Q_t = \sum_{j=1}^{\infty} \frac{\kappa^{j-1}}{YTM_t^j} = \frac{1}{YTM_t - \kappa} \tag{13}$$

where the second equality follows from properties of a geometric series, assuming that $YTM_t > 1$. The duration of a perpetuity is related to its yield-to-maturity and given by[9] $\frac{YTM_t}{YTM_t - \kappa}$. When calibrating the model, the value for the coupon payment rate κ can be chosen so as to match the steady-state duration of a perpetuity with average duration calculated from the data. For example, Chen et al. (2012) choose κ to match the average duration of 10-year Treasury Bills.

Later on, it will become clear that it is convenient to rephrase the household's optimization problem in terms of the outstanding stock of long-term bonds

[9] See again Chen et al. (2012).

instead of the current period's purchases of long-term bonds. The payment position of the existing portfolio of long-term bonds at the beginning of period $t+1$ can be written as

$$B_t^L \equiv V_t + \kappa V_{t-1} + \kappa^2 V_{t-2} + ...$$

Rolling back one period,

$$B_{t-1}^L \equiv V_{t-1} + \kappa V_{t-2} + \kappa^2 V_{t-3} + ...$$

Thus, we can conveniently express the evolution of the long-term bond payment position recursively as

$$B_t^L = V_t + \kappa B_{t-1}^L.$$

It will also be convenient to define the market value of the stock of existing long-term bonds. To this end, denote the time-t price of a perpetuity issued j periods ago by $Q_{t,j}$, and note that the market value of the existing portfolio of perpetuities in the beginning of period $t+1$, before shocks are realised and agents make their decisions, is given by

$$\begin{aligned} MV_{L,t} &\equiv Q_t V_t + Q_{t,1} V_{t-1} + Q_{t,2} V_{t-2} + ... \\ &= Q_t V_t + Q_t \kappa V_{t-1} + Q_t \kappa^2 V_{t-2} + ... \\ &= Q_t \left(V_t + \kappa V_{t-1} + \kappa^2 V_{t-2} + ... \right) \\ &= Q_t B_t^L. \end{aligned}$$

Furthermore, the model takes the "cashless economy" approach, as in Woodford (1998). Money, defined as a government paper that pays no interest, serves purely as a unit of account. It provides no transaction services, or utility, or anything that would justify holding it in equilibrium when there exists another risk-free asset that yields a higher rate of return, that is, central bank reserves.

4.3.1 Savers

Let us now turn to the optimisation problem of the households. A fraction $1-\lambda$ of households populating the economy can participate in the asset market. These households will be referred to as savers. Each period, the representative saver household's flow budget constraint in nominal terms is

$$\begin{aligned} P_t c_{s,t} + X_{s,t} + B_{s,t} + Q_t V_{s,t} \leq R_{t-1} B_{s,t-1} + R_{t-1}^X X_{s,t-1} + B_{s,t-1}^L \\ + W_t n_{s,t} + \mathcal{P}_{s,t} - P_t \tau_{s,t} - P_t \frac{d}{2} \left[\delta \frac{(X_{s,t} + B_{s,t})}{Q_t B_{s,t}^L} - 1 \right]^2, \end{aligned}$$

where $c_{s,t}$ is the quantity of the aggregate consumption good consumed by the saver household, P_t is the aggregate price index, W_t is the nominal wage rate, $\tau_{s,t}$ are the lump-sum taxes paid to the government in real terms, and $\mathcal{P}_{s,t}$ denotes the profits from the firms owned by saver households, distributed in a lump-sum fashion. It should be noted that while it is unrealistic that households directly hold central bank reserves $X_{s,t}$, I emphasise that, in this article, I also abstract away from financial intermediaries. One could, for example, formulate the problem to contain household-owned intermediaries with central bank reserves on the asset side and deposits from the households on the liability side, making households indirect holders of central bank reserves. In the absence of any frictions in the financial intermediation, this would very likely have negligible effects on the behaviour of the model.

The last term on the right-hand side of the representative saver household's budget constraint reflects the cost that the household incurs from deviating from the steady-state ratio of market value of long-term securities to that of short-term securities held in its portfolio, denoted by δ. This cost gives rise to imperfect substitutability between short-term and long-term securities. One interpretation of this cost term is the preference for liquidity: saver households perceive long-term government bonds as less liquid and thus want to hold additional short-term assets as the market value of their long-term bond stock increases. Parameter d reflects the degree of liquidity costs: the higher d, the less the saver household will make adjustments to its portfolio, leading to a larger term premium. In the extreme case of $d = 0$, short-term and long-term assets are perfect substitutes.

Using the earlier auxiliary results discussed in Section 4.3, it is possible to eliminate the purchases of time-t-issued long-term bonds from the budget constraint and write it instead in terms of the outstanding stock of bonds:

$$\begin{aligned} P_t c_{s,t} + X_{s,t} + B_{s,t} + Q_t B^L_{s,t} = {} & R_{t-1}(X_{s,t-1} + B_{s,t-1}) + R^L_t Q_{t-1} B^L_{s,t-1} \\ & + W_t n_{s,t} + \mathcal{P}_{s,t} - P_t \tau_{s,t} - P_t \frac{d}{2}\left[\delta \frac{(X_{s,t} + B_{s,t})}{Q_t B^L_{s,t}} - 1\right]^2 \end{aligned} \tag{14}$$

where I have defined

$$R^L_t \equiv \frac{1 + \kappa Q_t}{Q_{t-1}}$$

as the one-period return from holding long-term government debt. Furthermore, in the above formulation I have also used the fact that, by arbitrage, one-period government bonds and central bank reserves pay the same return, R_{t-1}.

The representative saver household chooses its consumption, hours worked, savings in short-term bonds, central bank reserves, and long-term bonds in order to maximise the following discounted lifetime utility:

$$\mathbb{E}_t \sum_{j=0}^{\infty} \beta^{t+j} \left\{ \frac{c^{1-\sigma}_{s,t+j}}{1-\sigma} - \frac{n^{1+\psi}_{s,t+j}}{1+\psi} \right\} \tag{15}$$

subject to the flow budget constraint and non-negativity constraints $c_{s,t} \geq 0$, $n_{s,t} \geq 0$, $X_{s,t} \geq 0$, $B_{s,t} \geq 0$, $B^L_{s,t} \geq 0$. In other words, it is assumed that the savers do not borrow from the central bank and the fiscal authority in equilibrium.

The optimal plan of the representative saver household is characterised by the following first-order conditions:

$$\begin{aligned}
P_t \lambda_{s,t} &= c_{s,t}^{-\sigma} \\
\lambda_{s,t} W_t &= (n_{s,t})^{\psi} \\
\lambda_{s,t} - P_t \lambda_{s,t} d \left[\delta \frac{(X_{s,t} + B_{s,t})}{Q_t B_{s,t}^L} - 1 \right] \frac{\delta (X_{s,t} + B_{s,t})}{(Q_t B_{s,t}^L)^2} &= \beta \, \mathbb{E}_t \, \lambda_{s,t+1} R_{t+1}^L \\
\lambda_{s,t} + P_t \lambda_{s,t} d \left[\delta \frac{(X_{s,t} + B_{s,t})}{Q_t B_{s,t}^L} - 1 \right] \frac{\delta}{Q_t B_{s,t}^L} &= \beta R_t \, \mathbb{E}_t \, \lambda_{s,t+1},
\end{aligned}$$

where $\lambda_{s,t}$ is the marginal utility of nominal wealth, that is, the Lagrange multiplier associated with the saver household's nominal budget constraint. In addition, it is required that the following transversality condition holds:

$$\lim_{T \to \infty} \mathbb{E}_t \left\{ \mathcal{Q}_{t,T} \left[X_{s,T} + B_{s,T} + B_{s,T}^L \right] \right\} = 0, \tag{16}$$

where $\mathcal{Q}_{t,T} = \beta^{T-t} \lambda_{s,T} / \lambda_{s,t}$ is the stochastic discount factor with which to evaluate nominal wealth at time T with respect to time t.

The first-order conditions of the saver household can also be rewritten in terms of real variables:

$$\Lambda_{s,t} = c_{s,t}^{-\sigma} \tag{17}$$

$$\Lambda_{s,t} w_t = (n_{s,t})^{\psi} \tag{18}$$

$$\Lambda_{s,t} - \Lambda_{s,t} d \left[\delta \frac{(x_{s,t} + b_{s,t})}{Q_t b_{s,t}^L} - 1 \right] \frac{\delta (x_{s,t} + b_{s,t})}{(Q_t b_{s,t}^L)^2} = \beta \, \mathbb{E}_t \, \Lambda_{s,t} \frac{R_{t+1}^L}{\Pi_{t+1}} \tag{19}$$

$$\Lambda_{s,t} + \Lambda_{s,t} d \left[\delta \frac{(x_{s,t} + b_{s,t})}{Q_t b_{s,t}^L} - 1 \right] \frac{\delta}{Q_t b_{s,t}^L} = \beta R_t \, \mathbb{E}_t \, \frac{\Lambda_{s,t+1}}{\Pi_{t+1}}, \tag{20}$$

where $\Lambda_{s,t} = P_t \lambda_{s,t}$ and $\Pi_{t+1} = P_{t+1} / P_t$ is the gross inflation rate. $w_t = W_t / P_t$ is the real wage, and $b_{s,t} = B_{s,t} / P_t$, $b_{s,t}^L = B_{s,t}^L / P_t$ and $x_{s,t} = X_{s,t} / P_t$ denote the saver household's real holdings of short-term government bonds, long-term government bonds, and central bank reserves, respectively.

4.3.2 Hand-to-mouth households

The remaining fraction λ of households behave in a "hand-to-mouth" fashion, consuming their entire disposable income each period. These hand-to-mouth households are constrained in the sense that they do not participate in the asset market. The exact microfoundations for why they behave in this way are not modelled in this study. One could, however, attribute this behaviour to myopia or continuously binding borrowing constraints.

Hand-to-mouth households' nominal income consists of labour income $W_t n_{r,t}$, net of lump-sum taxes $P_t \tau_{r,t}$. The variables relating to these households are indexed with the letter r. The flow budget constraint of a representative hand-to-mouth household is

$$P_t c_{r,t} \leq W_t n_{r,t} - P_t \tau_{r,t} \tag{21}$$

I assume that the utility function of hand-to-mouth households is identical to that of saver households. Since the hand-to-mouth households do not have a possibility to smooth consumption intertemporally, the only condition arising from their optimisation problem, along with the budget constraint binding in equilibrium, is

$$\frac{n_{r,t}^{\psi}}{c_{r,t}^{-\sigma}} = w_t, \tag{22}$$

where w_t is the real wage, as defined above. This condition gives the labour supply schedule of the representative hand-to-mouth household.

As the hand-to-mouth households are confined to consume their entire income, Equation (21) reveals that QE can affect their consumption via two channels: first, through its effects of labour income of the hand-to-mouth household, and second, through its effects on taxes.

4.3.3 Fiscal authority

The Treasury acts as a fiscal authority, that is, it conducts fiscal policy by collecting taxes from the households and issuing government bonds. The fiscal authority's budget constraint is given by

$$B_{F,t} + Q_t V_t + P_t \tau_t + P_t \tau_{M,t} = B_{L,t-1} + R_{t-1} B_{F,t-1}. \tag{23}$$

The left-hand side represents the sources of nominal revenue for the Treasury: new short-term debt issuances (B_t^F), new long-term debt issuances ($Q_t V_t$), taxes collected from households ($P_t \tau_t$), and remittances from the central bank ($P_t \tau_{M,t}$). The right-hand side summarises the fiscal authority's nominal obligations, which consist of interest payments on short-term debt ($R_{t-1} B_{F,t-1}$) and coupon payments on long-term debt (B_{t-1}^L). Using the recursive formula for the long-term debt payment position introduced earlier in Section 4.3, one can rewrite the constraint as

$$B_{F,t} + Q_t B_{F,t}^L + P_t \tau_t + P_t \tau_{M,t} = R_{t-1} B_{F,t-1} + (1 + \kappa Q_t) B_{F,t-1}^L. \tag{24}$$

It is assumed that the government debt is risk-free and there is no possibility of government default. For simplicity, I abstract from government spending altogether. Equation (24) can be further written in terms of real variables by dividing both sides by the price level P_t and doing some algebraic manipulation:

$$b_{F,t} + Q_t b_{F,t}^L + \tau_t + \tau_{M,t} = \frac{R_{t-1} b_{F,t-1}}{\Pi_t} + \frac{R_t^L Q_{t-1} b_{F,t-1}^L}{\Pi_t} \tag{25}$$

Monetary policy has fiscal implications via three distinct channels. First, it affects the interest expenses of the government: Tighter monetary policy, in the form of higher interest rates, means higher expenditures on existing debt. Second, monetary policy has an effect on the income that the central bank generates and, therefore, on its budget constraint, as we will see below. This, in turn, affects the remittances to the Treasury, $P_t\tau_{M,t}$. Third, monetary policy indirectly affects the fiscal authority's budget constraint via its effect on inflation Π_t.

4.3.4 Central bank

Essentially, there are three different dimensions to central bank policy. First, the central bank sets the interest rate paid on reserves, R_t^X, which in equilibrium equals the interest rate on short-term government bonds. Thus, the central bank effectively also sets the interest rate on short-term government debt.

The second dimension of monetary policy comes from varying the size and composition of the central bank's balance sheet. For simplicity, I assume that the only kind of government debt that the central bank buys is long-term debt. This assumption is unrealistic, as conventional central bank open-market operations, for example, usually involve buying government debt that is short-term. However, the focus of this study is on unconventional monetary policy operations, such as QE2 by the Fed and the gilt purchase programme by the Bank of England, which have concentrated mostly on long-term government securities. To facilitate the analysis, I abstract from the purchases of short-term government debt by the central bank. On the liability side, I also abstract from non-interest bearing central bank liabilities, that is, money.[10] Finally, it should be noted that, sometimes, a distinction is made between QE and credit easing. In the literature, the former is usually taken to mean a central bank policy that aims to expand central bank liabilities without a specific focus on the composition of assets on the other side of the balance sheet, whereas the latter involves central bank purchases concentrated on some specific type of asset(s).[11] Here, the central bank only trades in long-term government bonds, and therefore QE and credit easing are treated interchangeably.

The third dimension of central bank policy concerns the dividend payments that the central bank makes to the fiscal authority, that is, remittances. At this point, it is useful to state the central bank's resource constraint:

$$X_t - X_{t-1} = \left[Q_t B_{M,t}^L - Q_{t-1} B_{M,t-1}^L - B_{M,t-1}^L\right] + \left(R_{t-1}^X - 1\right) X_{t-1} + P_t \tau_{M,t}$$

In other words, the change in the issuance of central bank reserves $(X_t - X_{t-1})$ equals the sum of the change in the market value of the central bank's assets, net of the coupon payments on them $(Q_t B_{M,t}^L - Q_{t-1} B_{M,t-1}^L - B_{M,t-1}^L)$, the interest payments on the reserves issued in previous period[12] $(\left[R_{t-1}^X - 1\right] X_{t-1})$, and the

10 Recently, Benigno and Nisticò (2020) among others have studied the consequences of the central bank balance policies in a more general setting, where the central bank can issue non-interest bearing reserves as well

11 See e.g. Bernanke (2009).

12 Note that throughout the paper, the gross interest rate on central bank reserves is denoted by R_t^X. Therefore, $(R_t^X - 1)$ is the net interest they earn.

remittances to the fiscal authority ($P_t \tau_{M,t}$). Using the fact that $Q_{t-1} = \kappa Q_t$, the definition of one-period return on long-term bonds R_t^L, and rearranging terms, the constraint can be re-expressed as

$$Q_t B_{M,t}^L - X_t = R_t^L Q_{t-1} B_{M,t-1}^L - R_{t-1}^X X_{t-1} - P_t \tau_{M,t} \tag{26}$$

This equation states that the central bank net worth, that is, the difference between the market value of central bank's assets and liabilities, equals the periodic net interest income of the central bank ($R_t^L Q_{t-1} B_{M,t-1}^L - R_{t-1}^X X_{t-1}$) minus the remittances it makes to the fiscal authority. In fact, the dimension of central bank policy concerning remittances is often neglected in the literature because the central bank and the fiscal authority are usually treated as a single entity: the resource constraints of the two are consolidated through central bank remittances, which makes the study of different remittance rules' implications for central bank solvency uninteresting. However, as Hall and Reis (2015) point out, in most (advanced) economies central banks are separate organisations with the freedom to pursue their mandate independently of the rest of the government. Hall and Reis also analyse the implications of different dividend payment rules for the financial stability of the central bank and its independence from the fiscal authority. I reserve the discussion of alternative remittance rules to later sections.

4.3.5 Firms

The supply side of the model is as in the standard textbook New Keynesian model. A competitive final good firm bundles intermediate goods into a final good using the following aggregation technology:

$$y_t = \left[\int_0^1 y_t(j)^{\frac{\varepsilon-1}{\varepsilon}} dj \right]^{\frac{\varepsilon}{\varepsilon-1}}, \tag{27}$$

where $\varepsilon > 1$ is the elasticity of substitution between goods. There is a continuum of monopolistically competitive intermediate goods firms owned by the saver households. Each firm $j \in (0,1)$ produces a differentiated intermediate good using labour as input and constant returns to scale technology:

$$y_t(j) = A_t n_t(j). \tag{28}$$

A_t is an exogenous productivity parameter that is common to all firms. Each intermediate firm j faces a demand curve of the form

$$y_t(j) = \left(\frac{P_t(j)}{P_t} \right)^{-\varepsilon} y_t, \tag{29}$$

where $P_t \equiv \int_0^1 P_t(j)^{1-\varepsilon} dj$ is an aggregate price index. Intermediate firms price setting is subject to a Calvo-type rigidity. Each period a firm gets to adjust its price with probability $1 - \theta$. Whether a firm is allowed to adjust its price or not is independent of the history of adjustment and the adjustment prospects of other firms. If the firm is not allowed to adjust its price in a given period, it will set the price equal to the previous period's price. When allowed to adjust, the firm chooses its price $P(j)_t^*$ to maximise the discounted stream of future profits, given that the price it chooses will be relevant forever. A firm that is allowed to adjust its price in period t thus faces the following problem of picking the optimal price, $P_t^*(j)$, conditional on it staying in place forever to maximise the expected stream of discounted future profits:

$$\max_{P_t^*(j)} \mathbb{E}_t \sum_{h=0}^{\infty} \theta^h \mathcal{Q}_{t,t+h} \left[\frac{P_t^*(j)}{P_{t+h}} y_{t+h}(j) - \mathcal{MC}_{t+h} y_{t+h}(j) \right],$$

where $\mathcal{Q}_{t,t+h} \equiv \beta \left(\frac{C_{s,t+h}}{C_{s,t}} \right)^{-\sigma}$ is the discount factor used to discount expected future profits. Since intermediate firms are owned by saver households, the discounting of future profits is done using the stochastic discount factor of the representative saver household. $\mathcal{MC}_{t+h} = \frac{W_t/P_t}{A_t}$ is the real marginal cost. It is the same to all firms due to constant returns to scale technology as in Equation (28), and therefore the firm-specific subscript is dropped from the notation. Because all firms that are allowed to adjust their prices in period t face the same information, the same demand curves, and produce using identical technology, their maximisation problems are identical. Therefore, $P_t^*(j) = P_t^*$ for all j. Plugging the demand curve of Equation (29) into the objective function and differentiating with respect to P_t^* yields the following first-order condition:

$$P_t^* = \left(\frac{\varepsilon}{\varepsilon - 1} \right) \frac{\mathbb{E}_t \sum_{h=0}^{\infty} (\theta\beta)^h \Lambda_{s,t+h} \mathcal{MC}_{t+h} Y_{t+h} P_{t+h}^{\varepsilon}}{\mathbb{E}_t \sum_{h=0}^{\infty} (\theta\beta)^h \Lambda_{s,t+h} Y_{t+h} P_{t+h}^{\varepsilon-1}}.$$

Under flexible prices ($\theta = 0$), the above condition reduces to the standard profit maximisation condition of a monopolistically competitive firm, which states that the optimal price is equal to a constant markup over the nominal marginal cost:

$$P_t^* = \left(\frac{\varepsilon}{\varepsilon - 1} \right) P_t \mathcal{MC}_t.$$

Furthermore, the price level can be eliminated from the pricing condition by rewriting the latter in terms of inflation rates:

$$\Pi_t^* = \left(\frac{\varepsilon}{\varepsilon - 1} \right) \frac{\mathbb{E}_t \sum_{h=0}^{\infty} (\theta\beta)^h \Lambda_{s,t+h} \mathcal{MC}_{t+h} Y_{t+h} \prod_{k=1}^{h} \Pi_{t+k}^{\varepsilon}}{\mathbb{E}_t \sum_{h=0}^{\infty} (\theta\beta)^h \Lambda_{s,t+h} Y_{t+h} \prod_{k=1}^{h} \Pi_{t+k}^{\varepsilon-1}}, \tag{30}$$

where $\Pi_t^* = P_t^*/P_t$. As for the evolution of aggregate price level, a random fraction $1 - \theta$ of firms will set their price equal to P_t^*, while the remaining fraction θ will keep the price unchanged from the previous period. By the law of large numbers, the aggregate price index thus satisfies

$$P_t^{1-\varepsilon} = (1 - \theta)(P_t^*)^{1-\varepsilon} + \theta P_{t-1}^{1-\varepsilon},$$

or, when written in terms of the inflation rate,

$$1 = \theta \Pi_t^{\varepsilon-1} + (1 - \theta)(\Pi_t^*)^{1-\varepsilon}. \tag{31}$$

4.3.6 Market clearing and aggregation

In what follows, in the case of nominal variables (government bonds, central bank reserves, nominal wage), the lower-case letters will denote their real values, i.e., variables divided by the aggregate price index P_t.

By the aggregate resource constraint, the aggregate output produced in the economy must be allocated between aggregate consumption and portfolio adjustment costs:

$$y_t = c_t + (1-\lambda)\frac{d}{2}\left[\delta\frac{b_{s,t}}{Qb^L_{s,t}} - 1\right]^2. \tag{32}$$

Aggregate output is given by

$$y_t = \frac{An_t}{\mathcal{D}_t}, \tag{33}$$

where $\mathcal{D}_t = \int_0^1 \left(\frac{P_t(i)}{P_t}\right)^{-\varepsilon} di$ is the price dispersion in the economy, evolving according to

$$\mathcal{D}_t = (1-\theta)\Pi_t^{*-\varepsilon}\Pi_t^{\varepsilon} + \Pi_t^{\varepsilon}\theta\mathcal{D}_{t-1} \tag{34}$$

As usual in the class of New Keynesian models, infrequent price adjustment leads to a dispersion of relative prices across intermediate producers. This leads to inefficiency because it implies that the prices of different goods do not fully reflect the underlying marginal costs of producing these goods. However, the price dispersion term will be of second order, and when the model is solved using a first-order approximation as is done here, the term will not affect the solution.

Another inefficiency originates from monopolistic competition in the goods market. The aggregate resource constraint in Equation (32) reflects the third source of inefficiency in the model: in the presence of portfolio adjustment costs, part of the output will be allocated to these costs instead of consumption, which reduces the welfare of saver households.

In equilibrium, the following market-clearing conditions for short-term bonds, long-term bonds, central bank reserves, and labour clear:

$$(1-\lambda)b_{s,t} = b_{F,t} \tag{35}$$

$$(1-\lambda)b^L_{s,t} = b^L_{F,t} - b^L_{M,t} \tag{36}$$

$$(1-\lambda)x_{s,t} = x_t \tag{37}$$

$$n_t = (1-\lambda)n_{s,t} + \lambda n_{r,t}. \tag{38}$$

Equation (35) states that the short-term bond holdings aggregated over all saver households must equal the short-term debt issued by the government. In this model, it is assumed that $B_t > 0$, that is, the government is a net debtor. Similarly, Equation (36) says that long-term bond holdings, in terms of their market value, aggregated over saver households must equal the market value of long-term debt issued by the governmentminus the market value of long-term debt held by the central bank. Equation (37) states that the holdings of central bank reserves, aggregated over saver households, must equal the reserves issued by the central bank. Finally, the labour market clearing condition in Equation (38) requires that the aggregate demand for labour by firms equals the aggregate labour supplied by the households.

Aggregate consumption is defined as the weighted average of consumption over the two household types:

$$c_t \equiv (1-\lambda)c_{s,t} + \lambda c_{r,t} \tag{39}$$

Total lump-sum taxes collected by the government are equal to the weighted average of the taxes paid by households:

$$\tau_t = (1-\lambda)\tau_{s,t} + \lambda \tau_{r,t} \tag{40}$$

Finally, profits from intermediate firms rebated to saver households are

$$\mathcal{P}_{s,t}^{real} = \frac{1}{1-\lambda}\mathcal{P}_t^{real}, \tag{41}$$

where aggregate real profits $\mathcal{P}_t^{real} \equiv \frac{\mathcal{P}}{P_t}$ are given by

$$\begin{aligned}
\mathcal{P}_t^{real} &= \int_0^1 \Big(\frac{P_t(i)}{P_t} y_t(i) - w_t n_t(i)\Big) di \qquad (42)\\
&= \int_0^1 \frac{P_t(i)}{P_t} y_t(i) - w_t n_t \\
&= P_t^{\varepsilon-1} y_t \int_0^1 P_t^{1-\varepsilon}(i) di - w_t n_t \\
&= y_t - w_t n_t,
\end{aligned}$$

where the third and fourth equalities have made use of the demand function of an individual firm and the definition of the aggregate price index, respectively.

4.4 Monetary and fiscal policies

4.4.1 Conventional monetary policy

Let us now discuss the different aspects of monetary and fiscal policies. For the rest of the paper, "conventional" monetary policy amounts to choosing an interest rate for central bank reserves, which, by arbitrage, also means choosing the interest rate on short-term government bonds. Conventional monetary policy is described by the following Taylor-type rule:

$$\frac{R_t}{R} = \left(\frac{\Pi_t}{\Pi^T}\right)^{\phi_\pi} \exp(\varepsilon_t^R). \tag{43}$$

The rule is a standard one, as it assumes that the central bank responds to deviations of inflation from a time-invariant target, Π^T, by adjusting the nominal interest rate. The magnitude of the response is determined by the feedback coefficient ϕ_π.

4.4.2 Unconventional monetary policy

The "unconventional" dimension of monetary policy is summarised by the balance sheet of the central bank. The change in the value of assets that it holds must be equal to the change in the value of its liabilities, that is, reserves and equity. The central bank conducts unconventional monetary policy, or QE, by purchasing long-term government bonds from the private sector. To this end, one needs to specify an equation that determines how central bank asset purchases evolve over time. The following simple exogenous process for central bank asset purchases is assumed:

$$mv^L_{M,t} = (1-\rho_{QE})mv^L_M + \rho_{QE}mv^L_{M,t-1} + \varepsilon^{QE}_t, \tag{44}$$

where $mv^L_{M,t} \equiv Q_t b^L_{M,t}$ is the real market value of central bank asset holdings, and ε^{QE}_t is interpreted as an unconventional monetary policy shock. In other words, QE follows a first-order autoregressive process, with ρ_{QE} measuring the persistence of an asset purchase programme.

4.4.3 Central bank remittance policies

Full fiscal support

As was briefly discussed earlier, in addition to choosing the interest rate paid on reserves and the size of its balance sheet, the central bank also chooses its transfer policy. This amounts to choosing the remittances $\tau_{M,t}$ that it transfers to the fiscal authority. The implications of different transfer regimes for the solvency of the central bank are carefully analysed, for example, in Hall and Reis (2015) and Benigno and Nisticò (2020). My objective is not to conduct a rigorous theoretical analysis on the implications of different regimes for equilibrium determination, like, for instance, Benigno and Nisticò do. Instead, quantitative implications in a workhorse dynamic general equilibrium model are the main focus of this article.

The baseline remittance regime in this study is one in which the central bank rebates all of its capital gains to the fiscal authority. This is what Hall and Reis (2015) call a "mark-to-market dividend rule". Under this remittance rule,

$$P_t\tau_{M,t} = (1+\kappa Q_t - Q_{t-1})B^L_{M,t-1} - (R^X_{t-1}-1)X_{t-1} \equiv \Phi_{M,t}, \tag{45}$$

where $\Phi_{M,t}$ denotes the periodic capital gain (i.e. profits) of the central bank. One should note that the capital may well be negative, in which case the central bank experiences losses. In the case of negative capital gain, the fiscal authority will have to cover the central bank losses through its budget constraint. Reflecting on this, Benigno and Nisticò (2020) refer to such a transfer regime as "full Treasury's support". This particular transfer regime implies that the central bank's net worth is constant over time: this can be seen by inserting $P_t\tau_{M,t} = \Phi_{M,t}$ into the central bank's resource constraint and noting that

$$Q_t B^L_{M,t} - X_t = Q_{t-1}B^L_{M,t-1} - X_{t-1},$$

which implies a constant net worth, as the difference between the market value of central bank assets and liabilities is time-invariant. This leads us to the conclusion that

$$Q_t B_{M,t}^L - X_t = Q_0 B_{M,0}^L - X_0 \equiv \mathcal{N}_0, \tag{46}$$

where $\mathcal{N}_0$ denotes the initial net worth of the central bank, that is, the difference between the market value of its assets and liabilities in period 0. Full fiscal support implies the following path for real central bank reserves:

$$x_t = Q_t b_{M,t}^L - \frac{1}{\prod_{j=0}^{t-1} \Pi_{t-j}} \mathcal{N}_0^{real}, \tag{47}$$

where $\mathcal{N}_0^{real}$ denotes the initial real net worth of the central bank — this result is also derived in Hall and Reis (2015). Real central bank reserves are thus a function of a fully state-dependent component $Q_t b_{M,t}^L$ and a negative component that depends on the arbitrary initial real net worth $\mathcal{N}_0^{real}$. As long as deflationary equilibrium paths for the price level can be ruled out, real reserves will be bounded. With the assumption that $\mathcal{N}_0^{real} = 0$, real central bank reserves always equal the real market value of its assets.

Under this kind of full fiscal support, the potential losses of the central bank become a liability of the fiscal authority. Hall and Reis (2015) have shown that under such a remittance policy, the central bank can never become insolvent.

Passive remittance policy

Benigno and Nisticò (2020) define a *passive policy of central bank remittances* to be such that the stochastic path of remittances $\tau_{M,t}$ is chosen to ensure that the discounted real net worth of the central bank eventually converges to zero for *any* equilibrium price level path. Although above it was shown that for non-deflationary price level paths the real net worth converges to zero, could one design a remittance policy that would ensure the convergence for all possible price level paths? Benigno and Nisticò consider a rule of the form

$$\tau_{M,t} = \tau_M + \gamma_C \frac{\Phi_{M,t}}{P_t} + \phi_C \frac{\mathcal{N}_{t-1}}{P_t},$$

and show that it belongs to the class of passive remittance rules if and only if $0 < \gamma_C < 2$ and $0 < \phi_C < 2$. I consider a similar rule, modified slightly so that the central bank remittances are a function of (and written in terms of) deviations from the steady state (I also write the rule in terms of real variables and inflation rate, so the price level is eliminated):

$$\tau_{M,t} - \tau_M = \gamma_C \left(\Phi_{M,t}^{real} - \Phi_M^{real} \right) + \phi_C \left[\frac{\mathcal{N}_{t-1}^{real}}{\Pi_t} - \frac{\mathcal{N}^{real}}{\Pi} \right], \tag{48}$$

where $\Phi_{M,t}^{real}$ and $\mathcal{N}_t^{real}$ denote the real central bank capital gains and real central bank net worth, respectively.

4.4.4 Fiscal policies

The policy choice of the fiscal authority consists of three dimensions. First, it chooses the amount and the maturity structure of debt that it issues. Second, and closely related to the previous point through the government's resource constraint, it chooses the amount of taxes to collect from households. Third, the government chooses how it distributes the tax burden across different household types.

Government debt issuance in the steady state

Regarding the first point, the baseline assumption is that, in the steady state, the fiscal authority keeps the relative supply of long- and short-term bond such that it is line with the saver households' maturity preferences. This ensures that, in the absence of QE, the steady state is efficient when it comes to the portfolio friction. The steady-state bond issuance policy is implicitly given by the steady-state maturity preference of saver households:

$$\frac{Qb_F^L}{b_F} = \delta = \frac{Q\bar{b}_s^L}{\bar{b}_s}, \tag{49}$$

where $\bar{b}_s^L$ and $\bar{b}_s$ denote the preferred steady-state long- and short-term bond holdings of the saver household, respectively. Their ratio, δ, is an exogenous parameter with a given value. When there is no QE in the steady state, so that $Qb_M^L = 0$, all the government debt is acquired by the saver households, and their preferred portfolio composition is achieved. Therefore, portfolio adjustment costs vanish in the zero-QE steady state.

Collection of taxes

The second aspect of fiscal policy concerns the way in which the fiscal authority sets the taxes that it levies on households. This amounts to choosing τ_t. In the baseline case, the issuance of government debt is always constant and given exogenously as described in Equation (49). Thus, taxes will be adjust in a way that supports the debt issuance policy, or in other words, so that the government budget constraint holds at all times. Here, I call such a regime *tax financing*. The second case considered is the one in which tax collection is determined by a rule. Quite commonly, the existing literature specifies a rule whereby the government adjusts the lump-sump taxes as a function of the outstanding real government debt (see e.g. the seminal papers of Leeper (1991) and Sims (1994)). I make the same assumption and consider the fiscal rule of the following form:

$$\tau_t - \tau = -\gamma_F(\tau_{M,t} - \tau_M) + \phi_F\left(\frac{R_{t-1}b_{F,t-1}}{\Pi_t} - \frac{Rb_F}{\Pi}\right) + \phi_F\left(\frac{R_t^L Q_{t-1}b_{F,t-1}^L}{\Pi_t} - \frac{R^L Qb_F^L}{\Pi}\right). \tag{50}$$

Again, such a rule is analysed by Benigno and Nisticò (2020).[13] They show that with parameter values $\gamma_F = 1$ and $0 < \phi < 2$, the rule belongs to the class of *passive fiscal policies*. This kind of fiscal rule ensures that the expected present discounted real value of government liabilities converges to zero for *any* equilibrium path of prices, given *any* conventional monetary policy.

Note that when the lump-sum taxes are determined by a fiscal rule such as (50), either $b^L_{F,t}$ or $b_{F,t}$ has to adjust endogenously to ensure that the periodic government budget constraint holds. In the case where the short-term bonds adjust, the dynamics of $b_{F,t}$ are given by the government budget constraint, once the fiscal rule (50) is substituted for τ_t in the government budget constraint in Equation (25), and it is assumed that $b^L_{F,t} = b^L_F$ for all t. The dynamics of short-term government debt are then pinned down by:

$$\begin{aligned} &b_{F,t} + Q_t b^L_F + \tau + (1-\gamma_F)\tau_{M,t} + \gamma_F \tau_M \\ &\quad = (1-\phi_F)\frac{R_{t-1} b_{F,t-1}}{\Pi_t} + (1-\phi_F)\frac{R^L_t Q_{t-1}}{\Pi_t} b^L_F + \phi_F \frac{R}{\Pi} b_F + \phi_F \frac{R^L Q}{\Pi} b^L_F \end{aligned} \tag{51}$$

Conversely, when the long-term debt adjusts, the dynamics of $b^L_{F,t}$ are given by the government budget constraint while $b_{F,t} = b_F$ for all t. In this scenario, the dynamics of long-term government debt are pinned down by:

$$\begin{aligned} &b_F + Q_t b^L_{F,t} + \tau + (1-\gamma_F)\tau_{M,t} + \gamma_F \tau_M \\ &\quad = (1-\phi_F)\frac{R_{t-1} b_F}{\Pi_t} + (1-\phi_F)\frac{R^L_t Q_{t-1}}{\Pi_t} b^L_{F,t-1} + \phi_F \frac{R}{\Pi} b_F + \phi_F \frac{R^L Q}{\Pi} b^L_F \end{aligned} \tag{52}$$

In what follows, both of these scenarios will be considered separately.

Fiscal redistribution

The last aspect of fiscal policy that needs to be specified is the distribution of the tax burden across different household types. Recalling that aggregating over households yields

$$(1-\lambda)\tau_{s,t} + \lambda \tau_{r,t} = \tau_t, \tag{53}$$

this amounts to choosing $\tau_{r,t}$ and $\tau_{s,t}$ so that the above equation holds. To this end, I follow Bilbiie (2019) and consider *exogenous redistribution*, which assumes that constrained hand-to-mouth households pay an (exogenous) arbitrary share of total taxes $\lambda\tau_{r,t} = \alpha\tau_t$, while savers pay $(1-\lambda)\tau_{s,t} = (1-\alpha)\tau_{s,t}$. To put it more precisely, the distribution of taxes is assumed to be "uniform" in the sense that each household type pays a share of total taxes corresponding to their population share such that $\alpha = \lambda$.

[13] To be precise, as in the case of central banks remittance rules, my specification differs somewhat from that of Benigno and Nisticò as I define the rule in terms of deviations from the steady state. This is however of little relevance as Benigno and Nisticò also include an arbitrary constant term in the rule.

4.5 Quantitative analysis

In this section, the results from the quantitative simulations are presented. The effects of an exogenous QE shock are considered. First, some baseline dynamics are presented to shed light on the monetary policy transmission mechanism. Next, I consider the macroeconomic effects of QE under various fiscal policy configurations. The implications of different central bank remittance regimes (full fiscal support vs. passive remittance rule) for the effectiveness of QE are also considered. Finally, I briefly examine some steady state properties of the model as well as the determinacy of the rational expectations equilibrium in the model.

4.5.1 Calibration

This subsection describes the calibration used in subsequent policy simulations. Regarding the more conventional parameters, I set $\beta = 0.995$, $\sigma = 1.5$, $\psi = 1.5$, $\epsilon = 5$, $\theta = 0.75$, and $\phi_\pi = 1.5$, which are in the range of standard values used in the New Keynesian DSGE literature.

As steady-state output is normalised to one, steady-state values Qb_F^L and b_F can be interpreted as fractions of government debt to GDP. I set Qb_F^L and b_F so that they match the US data. To choose these values, I utilize the Monthly Statements of the Public Debt of the US Treasury, which summarise the outstanding public debt of the US government. In particular, I set the steady-state values Qb_L^F and b^F according to the December 2007 public debt report, as this reflects the situation shortly before the escalation of the financial crisis and the beginning of the era of unconventional monetary policy in the US. The Monthly Statement of Public Debt includes a decomposition of outstanding debt into Treasury securities of different maturities. To assign the value for b^F, I first calculate the market value of total outstanding Treasury bills (i.e. Treasury securities with a maturity of one year or less) divided by the 2007 nominal GDP (obtained from St. Louis Fed's FRED database). The former number is 1,003.875 billion USD, whereas the latter is 14,451.860. Their ratio is 0.0695, and thus $\frac{b_F}{4y} = 0.0695$ in the model, which implies $b_F = 0.2779$, based on the fact that the steady-state output y is normalised to one.

For long-term debt b_F^L, I use the outstanding market value of Treasury bonds (Treasury securities with a maturity of 10 years or more). In December 2007, according to the Monthly Statement of Public Debt, the market value of total outstanding Treasury bonds was 558.538 billion USD, therefore implying a ratio of 0.0386 to annual GDP. Thus, we have $\frac{Qb_F^L}{4y} = 0.0386$ in the model, implying that $Qb_F^L = 0.1544$. The value of κ is chosen to be 0.975, implying a steady-state duration of outstanding government long-term bonds between 7 and 8 years, as in Harrison (2017). Furthermore, as the steady state long-term bond price $Q = \left(\Pi/\beta - \kappa\right)^{-1} = \left(1/0.995 - 0.975\right)^{-1} = 33.3054$, we have $b_F^L = \frac{0.1544}{33.3054} = 0.0046$. This calibration exercise implies a value for the saver households' portfolio maturity preference parameter, $\delta = \frac{Qb_F^L}{b_F} = \frac{0.1544}{0.2779} = 0.5542$.

There exists some empirical guidance on how to set the value of λ, which reflects the share of hand-to-mouth households in the economy. For example, Campbell and Mankiw (1989) find that around half of the households in G7 countries behave in a rule-of-thumb fashion, consuming their entire current income. More recently, Kaplan et al. (2014) find that between 25 and 40 % of the US households are "hand-to-mouth", of which about one-third hold no liquid wealth; this would imply that roughly 8 to 10 % of the US households are "poor hand-to-mouth". Since the model studied in this paper does not make a distinction between wealthy and poor hand-to-mouth households, I set the value of λ in the baseline parameterisation equal to 0.33, a midpoint in the range estimated by Kaplan et al. (2014).

As the model is solved using a linear first-order approximation, the calibration of the size of the QE shock ε_t^{QE} is rather irrelevant, as the only thing affected by it is the scale of the impulse responses. In the following simulations, the standard deviation of the shock is set equal to 0.01. This can be interpreted as the central bank buying government bonds in the scale of 1% of steady state GDP (the steady state output is normalized to one). Finally, the value for the parameter d is chosen. The parameter plays an important role, as it affects the impact of an asset purchase programme on the spread between short- and long-term government bonds and hence the strength of the saver household's consumption response. Given the size of the QE shock, I treat d as a free parameter and choose it to make the responses to QE empirically plausible in the baseline model. Weale and Wieladek (2016), using a sing-restricted structural vector autoregression, estimate that an asset purchase announcement of 1% of GDP leads to an increase of 0.58% and 0.62% in real GDP and CPI in the US. The value for d is chosen to match the response of output as closely as possible in the baseline version of the model. Based on this, a value of 0.0285 is chosen. Table 7 summarises the baseline parameterisation.

4.5.2 Baseline dynamics

To begin with, the impulse responses from a simple representative agent New Keynesian (RANK) model (with $\lambda = 0$) are presented and compared with those from the baseline TANK. In the baseline TANK model, government debt issuance is constant at its steady-state level, and lump-sum taxes are adjusted each period in order to satisfy the periodic government budget constraint. Steady-state central bank asset purchases are assumed to be zero. The central bank enjoys full fiscal support. The impulse responses are presented in Figure 13.

In both versions of the model, a positive shock to the central bank's asset holdings leads to a positive response of aggregate output. A central bank asset purchase operation reduces the amount of long-term bonds held by the saver households while increasing their holdings of central bank reserves, which, through imperfect substitution between long- and short-maturity securities, induces a decrease in the expected return on long-term bonds relative to the return

TABLE 7 Baseline parameterisation

Parameter	**Value/Target**	**Description**
β	0.995	Discount factor
δ	0.5542	Desired portfolio maturity structure
θ	0.75	Calvo parameter
σ	1.5	Inverse of elasticity of intertemp. substitution
ε	5	Elasticity of substitution intermediate goods
d	0.0285	Portfolio adjustment cost parameter
λ	0.33	Share of hand-to-mouth households
ψ	1.5	Inverse of Frisch elasticity of labour supply
ϕ_π	1.5	Inflation coefficient in the Taylor rule
κ	0.975	Long-term government bond duration
b_M^L	0	Steady-state central bank asset holdings
b_F^L	$\frac{Qb_F^L}{4y} = 0.1544$	Steady-state long-term government debt
b_F	$\frac{b_F}{4y} = 0.2779$	Steady-state short-term government debt

on short-term bonds. The term premium (i.e. the difference between the one-period holding return on long-term bonds and the return on short-term bonds) thus decreases. The price of long-term government bonds rises in order to bring this about.

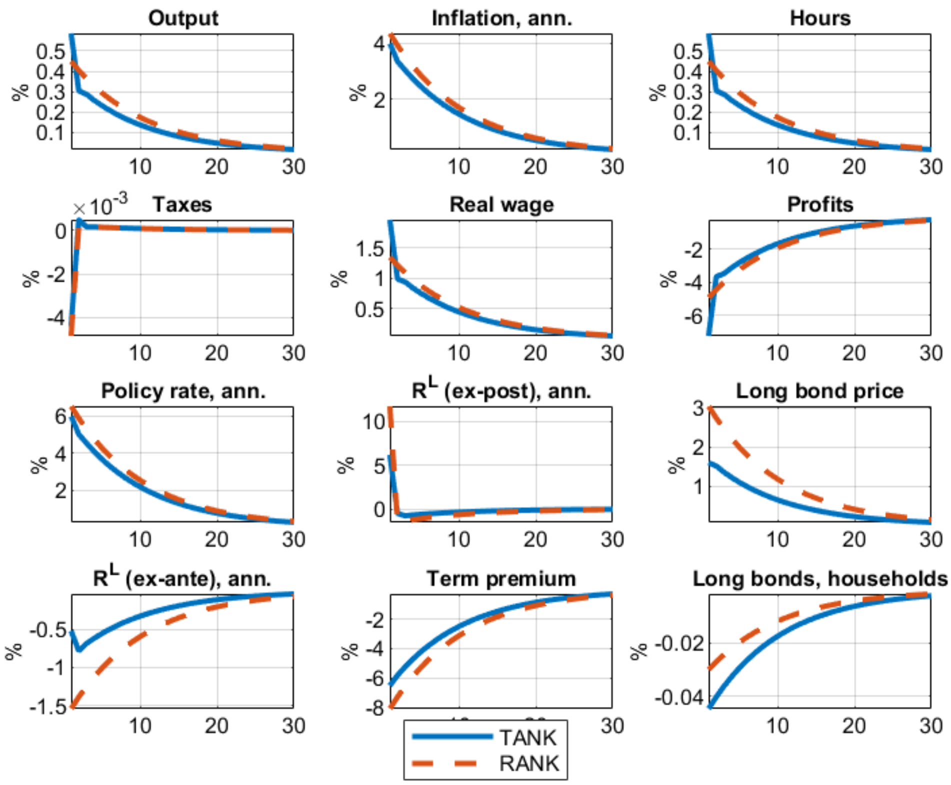
Perhaps the most striking difference in the dynamics of the two models is related to the behaviour of long-term bond prices. In the representative agent version, the response of the long-term bond price is stronger than in the two-agent model. Consequently, the responses of expected and ex-post one-period holding returns on long-term bonds are greater in magnitude in the RANK model. This seems logical because in the RANK version of the model, all households trade in government bonds, and therefore one would expect QE to have larger effects on bond prices compared to the TANK model.

For the sake of comparison, the dynamic responses to a conventional Taylor rule shock of 25 basis points in the baseline TANK model are also presented.[14] The size of the QE shock is again 1% (relative to steady state output). To facilitate intuition, I consider responses to **i)** completely transitory shocks, that is, the autoregressive parameters in the shock processes are set equal to zero (in Figure 14), and **ii)** persistent shocks, where autoregressive parameters are set equal to 0.9 for both conventional and unconventional policy shock processes (in Figure 15).

Let us first consider the responses to purely transitory shocks. Qualitatively, the responses of real variables to conventional and unconventional monetary policy shocks are quite similar. However, the magnitudes of the responses differ. A negative shock to the Taylor rule initially leads to a decrease in the short-term interest rate, which increases the expected relative one-period return on long-term government bonds. The representative saver would like to shift her portfolio towards higher-yielding long-term assets, but as the supply of government debt is

[14] Note that the shock is accommodative, that, a negative shock to the Taylor rule occurs.

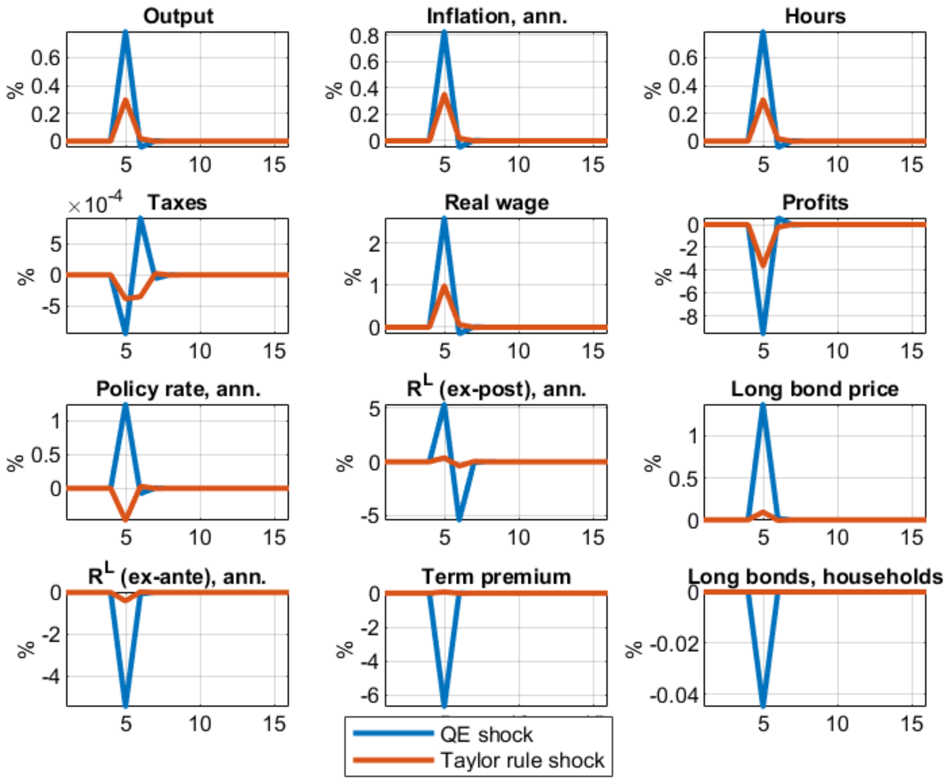
FIGURE 13 Dynamic responses to a QE shock: RANK versus TANK. All variables are in percentage deviations from the steady state, except taxes, which is in percentage deviation from the steady state relative to steady-state output. Red dashed line: responses from the RANK model. Blue solid line: responses from the TANK model.



held fixed, the expected one-period return on the long-term bond has to decrease in order to support the equilibrium. The long-term bond price therefore has to increase. As the returns on financial assets decrease across the board, the representative saver household finds it more lucrative to increase current consumption. As prices are sticky, firms partly accommodate the increase in aggregate demand by producing more. The demand for labour increases, and the real wage increases to bring equilibrium to the labour market; aggregate hours increase. The initial decrease in the policy interest rate is partly offset by the equilibrium response to the increase in inflation via the Taylor rule. The mechanism behind a QE shock is otherwise similar, but the macroeconomic effects are larger than those of a standard 25bp interest rate cut.

The dynamics of certain variables change somewhat when a persistent shock is considered. Especially the dynamics of interest rates are affected: The equilibrium response of the short-term interest rate is actually positive despite a negative initial shock. The central bank responds to the increase in inflation caused by the initial monetary shock by raising the policy rate via the Taylor rule. Therefore, both the policy rate and inflation increase in equilibrium.

FIGURE 14 Dynamic responses to purely transitory shocks: Taylor rule shock versus QE shock.



4.5.3 The effects of a QE shock in the TANK model under different fiscal policies

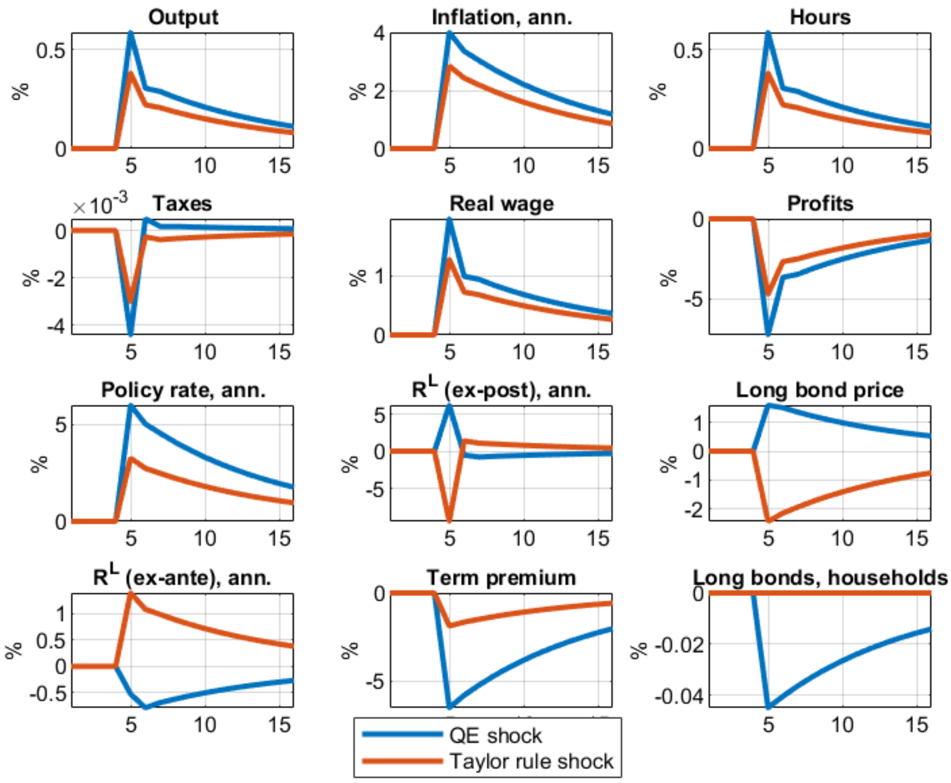
4.5.3.1 Full Treasury's support

In this section, the effects of QE when the central bank enjoys full fiscal support from the fiscal authority are studied. That is, it is assumed that the fiscal authority commits to recapitalise the central bank in case of income losses (conversely, the central bank remits all potential profits to the fiscal authority). In the present context, this means that the fiscal authority makes a financial transfer to the central bank, which it has to fund by an increase in taxes or government bonds. Mathematically, this amounts to stating that $\Phi_{M,t} = P_t \tau_{M,t}$ for all t.

Two different fiscal policy schemes are considered: one in which government debt policy is held constant and lump-sum taxes are adjusted so that the periodic government budget constraint holds, and one in which taxes are adjusted according to the fiscal rule described in Section 4.4.4. In this latter scenario, it is government debt that is adjusted to ensure that the government budget constraint holds. The question that then arises is, should it be short-term or long-term debt that is adjusted? In what follows, both scenarios are considered.

Figure 16 plots the impulse responses of selected real variables to a QE shock under different fiscal policy configurations. Under scenarios for which the fiscal

FIGURE 15 Dynamic responses to persistent shocks: Taylor rule shock versus QE shock.

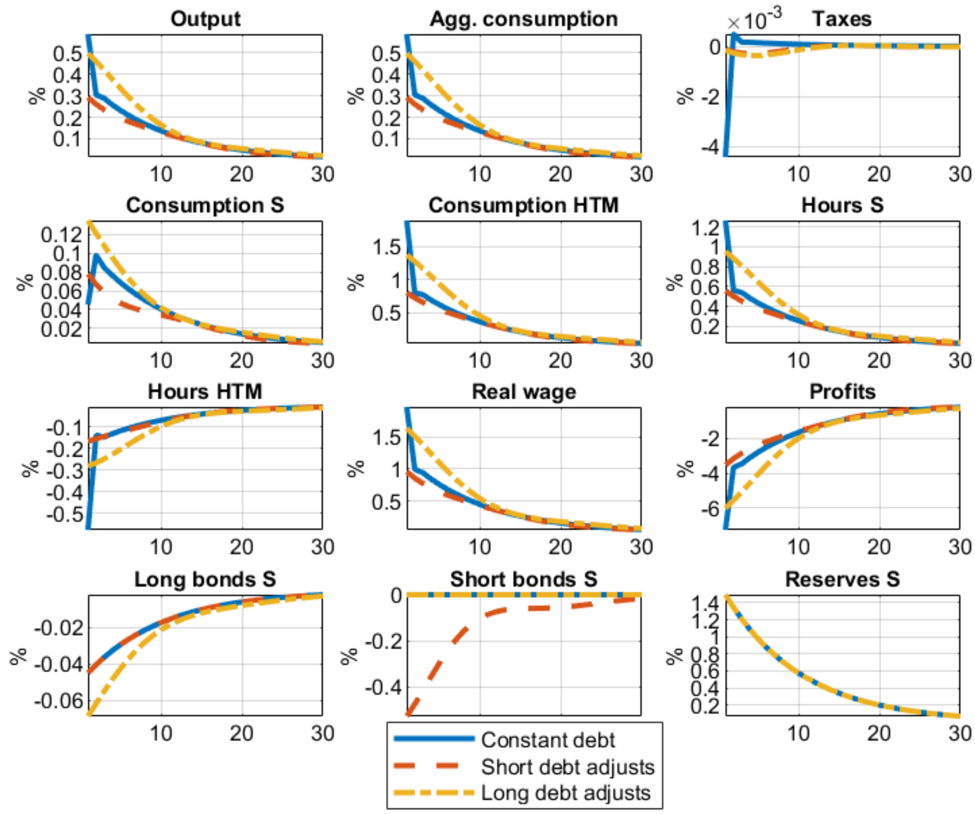


rule of Equation (50) is in place, I set $\gamma_F = 1$ and $\phi_F = 0.33$. With γ_F equal to one, the fiscal authority effectively rebates the central bank remittances to the private sector (or, in case of central bank capital losses, covers those losses by imposing additional taxes on the private sector). The parameter ϕ_F is set according to Galí et al. (2007), who choose the value on the basis of their empirical findings. The solid blue line depicts the responses of variables under tax financing (i.e. when lump-sum taxes adjusts to ensure that the government budget constraint holds). The dashed red line and the dash-dotted yellow line depict the responses in a scenario where government follows a fiscal rule and either the short-term debt (red line) or the long-term debt (yellow line) is adjusted.

First, let us focus on the responses in the tax-financing scenario, pictured by the blue line in Figure 16. A QE shock leads to an increase in the long-term bond price through mechanisms described in the earlier sections. Given constant long-term bond supply by the fiscal authority, government revenue from newly issued long-term debt increases, more so than the interest expenditure on the existing debt. As a consequence, the government budget constraint is relaxed, and the amount of taxes required to finance the budget decreases. This implies that households' net tax burden decreases as well. This in turn has a direct effect on the representative hand-to-mouth household's consumption: It increases, which amplifies the initial positive effect of a QE shock. Figure 17 shows the responses of selected nominal variables of the model.

The yellow dash-dotted lines depict the dynamic responses under the as-

FIGURE 16 Dynamic responses of selected real variables under different fiscal policies (assuming full fiscal support).

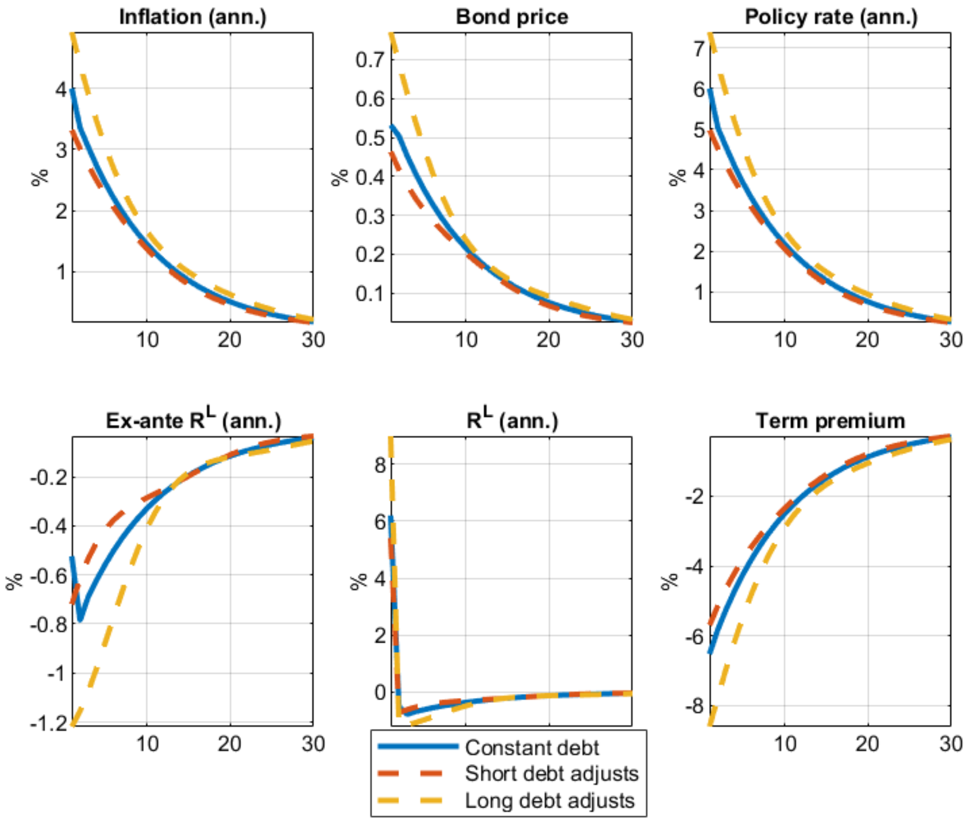


sumption that the government follows the fiscal rule of Equation (50) and closes its budget constraint by adjusting long-term debt. Also in this case government taxes react negatively, but much less so than in the previous scenario where taxes were assumed to close the government budget constraint. The initial effect of a QE operation is to increase the price of the long-term bond, which then also increases the realised one-period holding return on the long-term bond. All else being equal, the government should increase taxes relative to the steady state in response to this through the fiscal rule (50). However, one can observe that the equilibrium response of taxes is negative. This is because the increase in inflation is relatively stronger, which erodes the real interest expenses on long-term debt relative to their steady-state value and, through the fiscal rule (50), makes the taxes respond negatively. In fact, this seems to be an important channel of transmission. For example, when the price stickiness parameter θ is set equal to 0.95, an implausibly high value in light of the existing empirical evidence, the effect of a QE shock on government lump-sum taxes reverses: following the shock, taxes increase with the real interest expenditures on long-term debt.[15]

Moreover, the impact responses of real variables when the long-term debt is adjusted are stronger than when the short-term debt is adjusted. My intuition on

15 The dynamic responses under that scenario are not presented here, but they are available from the author upon request.

FIGURE 17 Dynamic responses of selected nominal variables under different fiscal policies (assuming full fiscal support).



why this happens is as follows. Looking at the response of long-term debt held by the representative saver household in the long-term-debt-adjusts scenario, one can see that it decreases relatively more than in the two other scenarios. As the government budget constraint is loosened as a consequence of a QE shock, the fiscal authority decreases its outstanding long-term debt. Given the assets acquired by the central bank via QE, this implies that the relative long-term government bond holdings of a representative saver household have to decrease in equilibrium. At the same time, her holdings of short-term government liabilities increase as she absorbs the newly created central bank reserves that are used to finance asset purchases; however, the equilibrium supply of short-term debt available to the saver is unaltered.

Compare this to the situation in which the fiscal authority adjusts by decreasing short-term debt to close the government budget constraint. There, the saver household's equilibrium holdings of short-term government liabilities increase *relatively less* than in the long-term-debt-adjusts scenario because the short-term debt available to the household decreases, while her holdings of reserves increase. Concurrently, her holdings of long-term government bonds decrease, but again relatively less than in the long-term-debt-adjusts case, as the supply of long-term bonds from the government is held constant. Therefore, the relative portfolio position of short-term to long-term bonds changes less, and, through the saver household's Euler equations, the impact on the term premium is smaller than in the long-term-debt-adjusts case. The conclusion is therefore that when the government adjusts long-term debt to close the budget constraint, QE operations have a greater decreasing effect on the term premium and hence a greater effect on saver household's current consumption. This then leads to a greater overall macroeconomic impact of QE compared to the scenario where the short-term debt is adjusted. Essentially, the result is driven by the fact that saver households perceive short-term government bonds and central bank reserves as perfect substitutes. This leads to greater changes in the relative positions of short- and long-term assets in a representative saver's portfolio when the fiscal authority adjusts long-term debt.

To summarise, the impulse responses indicate that tax-financing yields the greatest macroeconomic response on impact. However, when the fiscal authority follows a fiscal rule and closes the government budget constraint by adjusting long-term debt, the positive effects of QE are more long-lasting than under the two other scenarios. Considering the individual consumption responses of each household type, the consumption of a representative hand-to-mouth household increases relatively more (in terms of percentage deviations from the steady state) than that of a representative saver. In equilibrium, hand-to-mouth households also decrease their labour supply relative to the steady state, whereas savers work more. These results might seem surprising given the widely expressed concerns about QE having an adverse effect on inequality. Clearly, some of the discrepancy in the consumption responses of different household types stems from the fact that savers smooth consumption intertemporally, while hand-to-mouth households cannot do so. It should also be kept in mind that the model presented in this paper is really not adequate to analyse the effects of QE on the distribution of wealth, which as a concept is different from income distribution.

4.5.3.2 Passive central bank remittance rule

In this section, the assumption that the central bank enjoys full fiscal support is relaxed. Instead of transferring its capital gains (or losses) to the fiscal authority each period, the central bank is assumed to follow a remittance rule as in Equation (48). When the model is solved via linear approximation, the central bank remittances do not matter when there is no QE in the steady state. One can see this by using the maintained assumption about zero initial central bank net worth in the definition of central bank capital gains, which implies $Q_{t-1}B^L_{M,t-1} = X_{t-1}$, and so that

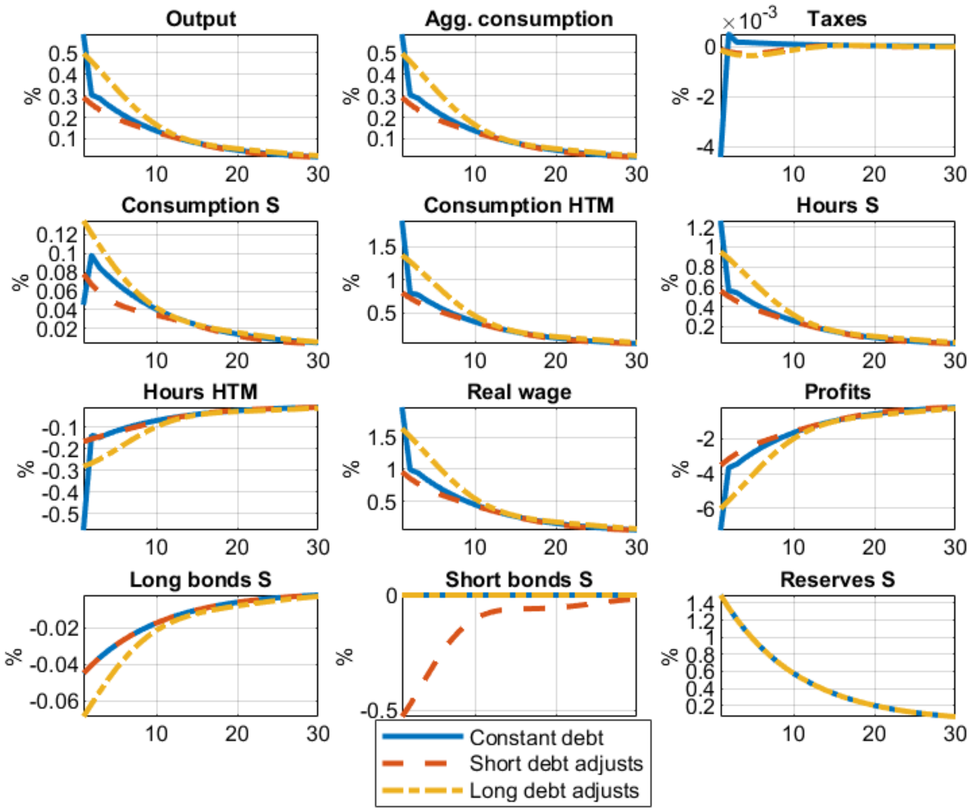
$$\Phi^M_t = \left[R^L_t - R_{t-1}\right] Q_{t-1} B^L_{M,t-1}, \tag{54}$$

where the definition of R^L_t has been invoked, and the fact that the equilibrium returns on reserves and short-term government bonds are equal by arbitrage is used. A straightforward application of a first-order Taylor approximation on the above equation yields

$$
\begin{aligned}
(\Phi_t^M - \Phi^M) \approx\ & [R^L - R]\, Q (B_{M,t-1}^L - B_M^L) \\
& + [R^L - R]\, B_M^L (Q_{t-1} - Q) \\
& + Q B_M^L (R_t^L - R^L) - Q B_M^L (R_{t-1} - R).
\end{aligned}
$$

Under zero-steady state QE, $B_M^L = 0$, and hence all but the first term on the right-hand side of the above approximation will cancel. But under zero-steady state QE, the steady-state term premium will also be zero, so $R^L - R = 0$.[16] Hence, in the first-order solution central bank remittances will be negligible, and it is thus not surprising that the dynamics of the model are very similar to the full fiscal support scenario, as one can infer from Figures 18 and 19, in which the responses of selected real and nominal variables of the model are plotted. In these simulations, parameter values $\gamma_C = 1.5$ and $\phi_C = 1.5$ in the central bank's remittance rule (48) are considered.

FIGURE 18 Dynamic responses of selected real variables under different fiscal policies (assuming the central bank obeys a passive remittance rule).

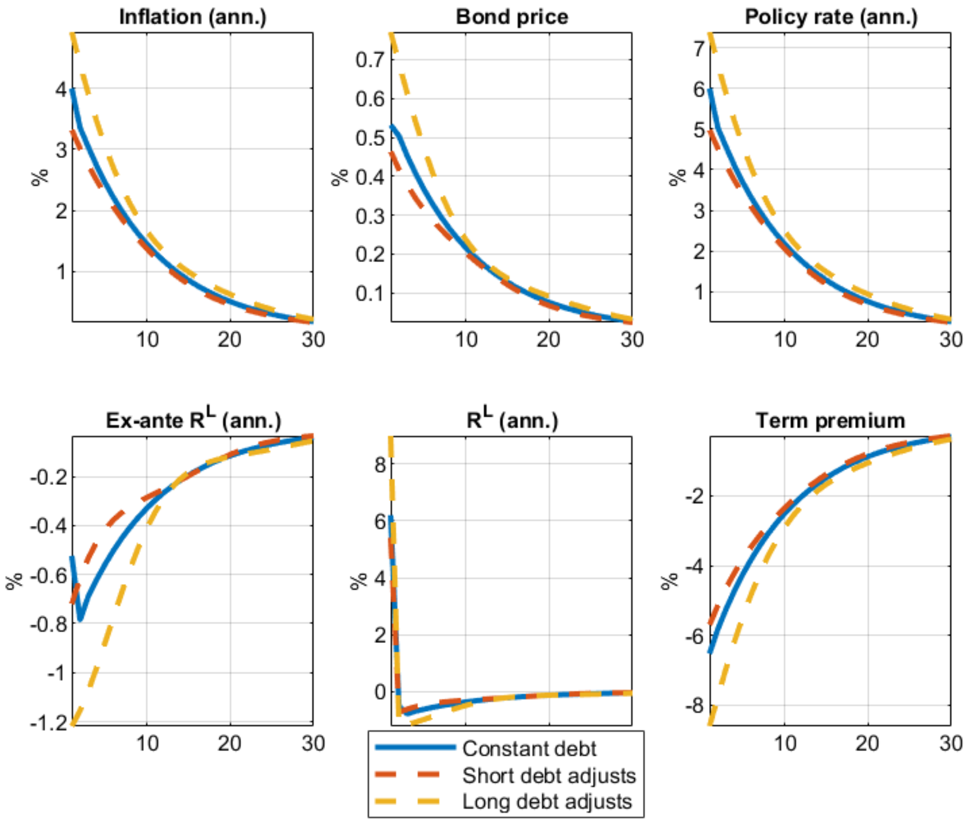


4.5.4 Non-zero QE in the steady state

Thus far, I have assumed that the steady state is efficient when it comes to the portfolio friction: All of the outstanding government debt is held by the house-

16 This result is discussed in the next subsection.

FIGURE 19 Dynamic responses of selected nominal variables under different fiscal policies (assuming the central bank obeys a passive remittance rule).



hold sector, and the maturity structure of debt is such that the saver households' optimal portfolio mix is satisfied. This makes the portfolio adjustment cost vanish in the steady state. An implication of this is that, in the zero-QE steady state, the effective returns on short- and long-term government bonds are equalised. However, things change once the assumption about non-zero steady-state asset holdings of the central bank is abandoned. Now, there is an inefficiency stemming from the fact that not all government debt is held by the saver households, and their optimal maturity composition is not achieved. This implies a non-zero return differential for the two government bonds in the steady state. This is established in the following proposition:

Proposition 1 *Under the assumptions that the steady-state government debt structure is in line with the representative saver household's maturity preference and that the initial central bank real net worth* $\mathcal{N}_0^{real}$ *is zero, strictly positive central bank asset holdings imply an* ***inverted yield curve*** *in the sense that the effective return on the long-term bond is strictly lower than the return on short-term government debt in the steady state.*

Proof. In the Appendix. ■

The implications of this auxiliary result are not discussed further here, but it should be noted that this result could be worth examining more in future research. Reflecting on the result presented in the previous subsection, non-zero

QE in the steady state could potentially have an effect on the dynamics when the central bank follows a passive remittance rule. To analyse the dynamics under the assumption about non-zero steady-state QE, one would need to consider a higher-order approximation of the model. This could be considered in future work.

4.6 Determinacy and stability properties of rational expectations equilibrium

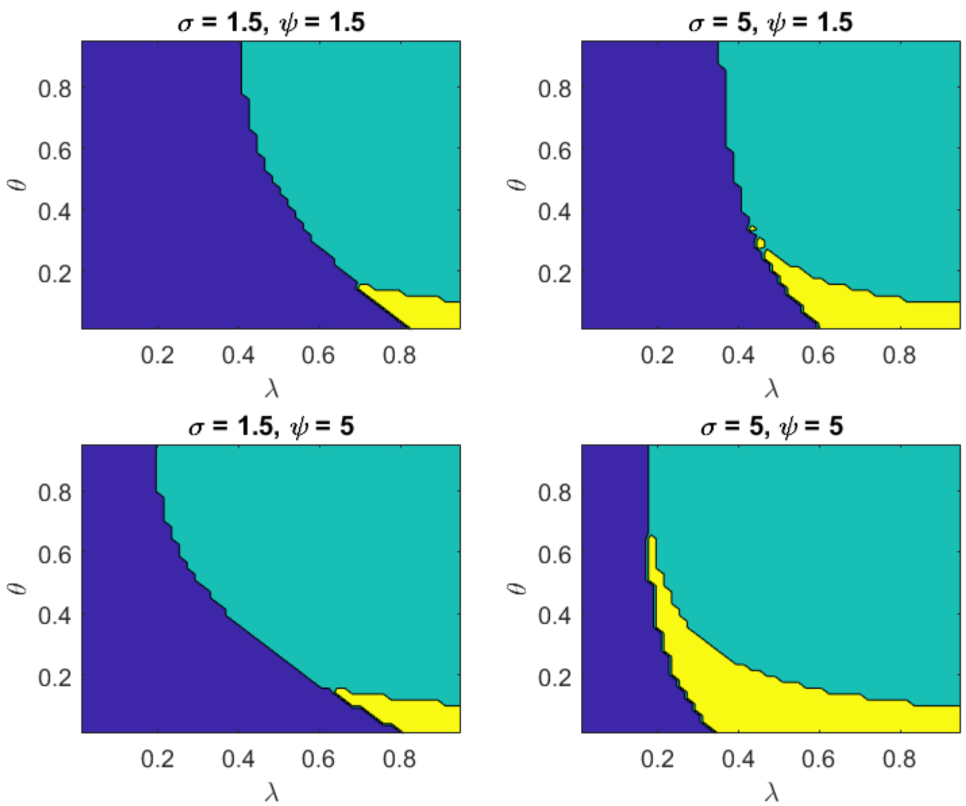
Several earlier studies, such as Galí et al. (2004, 2007) and Colciago (2011), have shown that the New Keynesian model with non-Ricardian households suffers from the (local) indeterminacy of equilibrium in some regions of the parameter space. Galí et al. (2004) study the determinacy properties of a standard New Keynesian model with capital accumulation and rule-of-thumb consumers[17] and without a fiscal block. They find that the presence of rule-of-thumb consumers drastically alters the determinacy region compared to the representative agent model. In particular, in the heterogeneous-agent model, the fulfillment of the so-called Taylor principle[18] might not be enough to guarantee the uniqueness of the rational expectations equilibrium if the degree of price stickiness and/or the share of hand-to-mouth consumers is high. Moreover, they find that the parameters governing the intertemporal elasticity of substitution and the Frisch elasticity of labour supply affect the size of the region of the parameter space where the uniqueness of equilibrium is guaranteed. When both the elasticity of the labour supply and the elasticity of intertemporal substitution are low, the determinacy region is reduced substantially. Increasing the inflation coefficient in the Taylor rule, that is, assuming that monetary policy responds more aggressively to changes in inflation, is shown to restore equilibrium determinacy. However, as the share of hand-mouth households grows, a very high value of inflation feedback coefficient is required to guarantee determinacy.

Galí et al. (2007) analyse an otherwise similar model, but augmented with a fiscal block. The finding of Galí et al. (2004) largely carries over to that version of the model: When both the degree of price stickiness and the share of hand-to-mouth households are high, indeterminacy of rational expectations equilibrium is obtained. Colciago (2011) analyses the New Keynesian model with hand-to-mouth households and sticky nominal wages. He shows numerically that when wage stickiness is taken into account, the Taylor principle again becomes a necessary and sufficient condition for equilibrium determinacy, given that the value

[17] They call households that behave in a hand-to-mouth fashion rule-of-thumb consumer.

[18] The Taylor principle posits that the central bank should eventually raise the nominal rate more than one-to-one in response to an increase in inflation, or in other words, that $\phi_\pi > 1$ in the context of the New Keynesian model with a monetary policy described by a Taylor rule, such as in Equation (43). Bullard and Mitra (2002) show that, in the standard model, adherence to the Taylor principle strictly induces a unique rational expectations equilibrium when the feedback coefficient on the output gap is zero.

FIGURE 20 Determinacy region in the baseline TANK model. Blue region: determinacy. Light green region: indeterminacy. Yellow region: No unique stable equilibrium.



of the parameter determining the share of hand-to-mouth households lies in an empirically plausible range. Furthermore, an analytical proof of the result is provided in Ascari et al. (2016).

In this section, I conduct a numerical determinacy analysis of the model outlined in this paper. I consider the issue from a perspective that is interesting given the research question of this paper: As a novel contribution compared to earlier studies, I study whether the fiscal policy configuration matters for equilibrium determinacy.

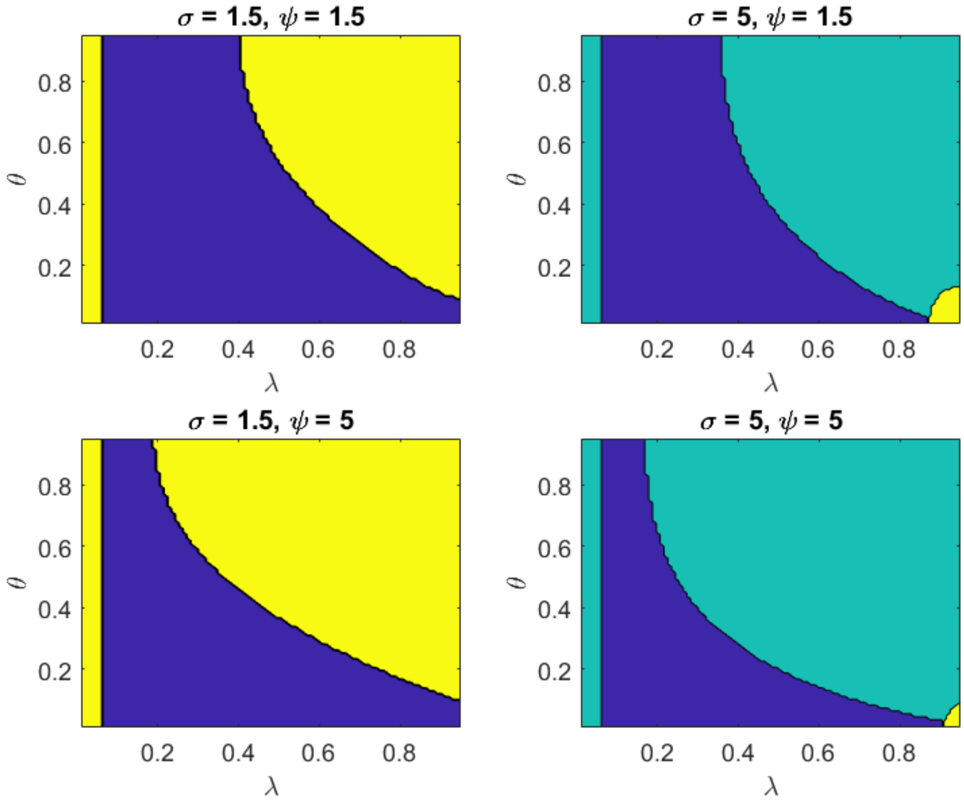
Figure 20 plots the determinacy regions in the baseline TANK model for different parameter values in the spirit of Galí et al. (2004). Again, recall that the baseline assumption is that all the adjustment required in the government budget comes through changes in taxes, while real debt issuance is held constant. In particular, the interaction of price stickiness (parameter θ) and the share of hand-to-mouth households (parameter λ) is under scrutiny. Like Galí et al. (2004), I consider different values of σ and ψ and their implications for equilibrium determinacy. A very similar result seems to hold here as in Galí et al. (2004): For low values of σ and ψ (top left panel in Figure 20) the rational expectations equilibrium is unique for a relatively large range of values for θ and λ. Given the value for price stickiness considered in the quantitative simulations of the previous sections, $\theta = 0.75$, the threshold value for λ that still yields determinacy is around 0.41. For comparison, in the model of Galí et al. (2004), the corresponding threshold for λ is around 0.6; however, it should be pointed out that their parameterisation differs somewhat from that of the model of this paper (e.g. in their baseline configuration both σ and ψ are equal to one and the central bank is assumed to respond also to changes in output gap instead of strict inflation targeting like here). When the values of σ and ψ are both increased to 5 (the bottom right panel in Figure 20), the uniqueness of rational expectations equilibrium is guaranteed for a significantly narrower region. In addition, the region in the parameter space for which there is no unique stable equilibrium is considerably augmented.

How is the situation altered when part of the accommodation in the government budget constraint comes from adjusting debt, that is, the fiscal authority follows the fiscal rule described in Equation (50)? Figures 21 and 22 plot the determinacy regions when the fiscal rule is in place and short-term debt and long-term government debt, respectively, are adjusted to close the government budget constraint. The main conclusion is still the same: When the elasticity of substitution and the Frisch elasticity of labour supply are both low (i.e. their inverses σ and ψ are high), the equilibrium is determinate for a considerably narrower region in the (θ, λ) space.

Curiously, under a fiscal rule the value of σ seems to be the deciding factor in whether the equilibrium is indeterminate or unstable. Holding the inverse of the Frisch elasticity of labour supply ϕ constant, increasing σ makes unstable regions in the (θ, λ) space indeterminate. This observation is true when the government budget constraint is closed by adjusting short-term debt as well as when it is closed via long-term debt. It is interesting that when short-term government debt is adjusted to ensure that the government budget constraint is satisfied, there is no stable equilibrium or the equilibrium becomes indeterminate (depending on the value of σ) when the economy approaches the representative agent economy (i.e. λ goes to zero), regardless of the degree of price stickiness. This does not happen either under tax financing or under a fiscal rule coupled with adjustments in long-term debt. Another noteworthy finding is that when the fiscal authority follows the tax rule of the Equation (50), there seems to be a stable unique equilibrium when prices are near-flexible (θ approaches 0), even for a very high share of hand-to-mouth households.

To summarise, the numerical results echo the findings of Galí et al. (2004, 2007): When considering the design of monetary policies, the share of constrained agents plays an important role. In a two-agent New Keynesian model with short- and long-term government debt and imperfect substitutability between the two, conventional monetary policy as summarised by a Taylor rule might not be sufficient to guarantee the existence of a unique rational expectations equilibrium, even when the Taylor principle is satisfied. This result holds regardless of the stance of the fiscal policy.

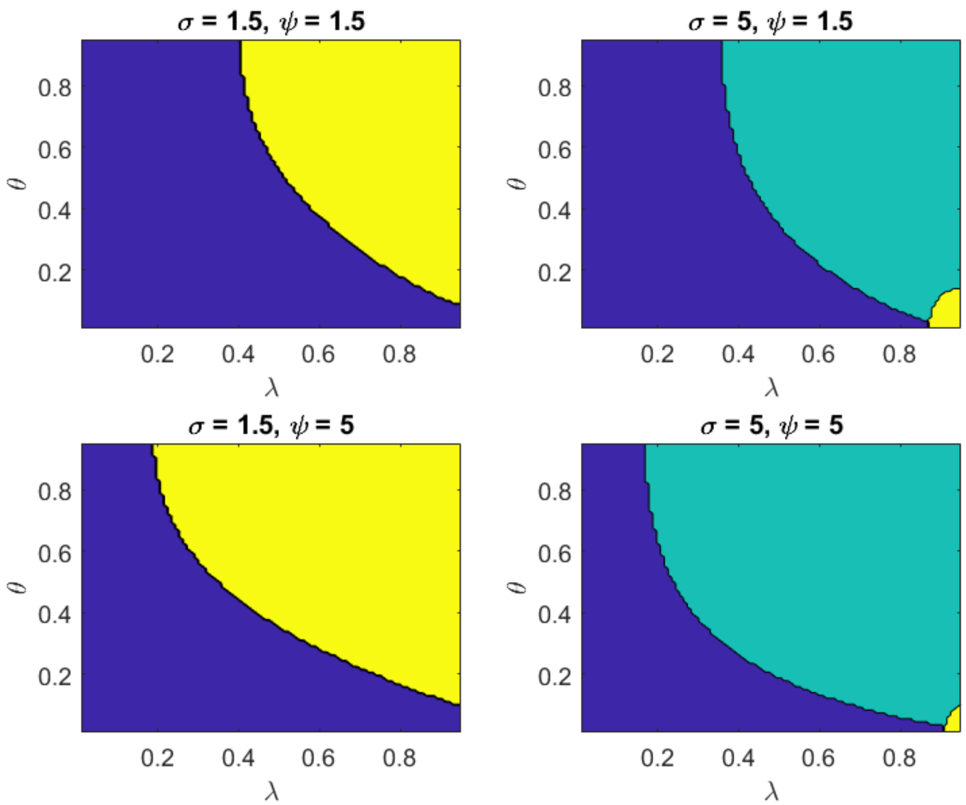
FIGURE 21 Determinacy region in the TANK model under a fiscal rule when short-term government debt is adjusted to close the government budget constraint. Blue region: determinacy. Light green region: indeterminacy. Yellow region: No unique stable equilibrium.



4.7 Conclusion

Large-scale asset purchases, also known as QE, have been one of the most important tools of monetary policy since the onset of the great financial crisis of 2007–2008. Central banks across the globe have embarked on these unconventional monetary policies on an enormous scale. One of the several disputes surrounding QE pertains to the environment it creates for fiscal policy and whether the overall macroeconomic effects of QE may be dependent on the fiscal policy that the government pursues. This paper has attempted to answer the latter question by building a simple business cycle model of the New Keynesian tradition, augmented with a stylised form of household heterogeneity. Simulations show that fiscal policy matters for the transmission of QE. In particular, when the fiscal authority follows a "tax-financing" regime, closing its budget constraint each period by adjusting lump-sum taxes while holding the issuance of government debt constant, the responses of the real economy are highest on impact. However, a "passive" tax policy regime, where the central bank follows a certain rule whereby it sets the lump-sum taxes in response to outstanding government debt and issues new debt to close the budget constraint, leads to macroeconomic ef-

FIGURE 22 Determinacy region in the TANK model under a fiscal rule when long-term government debt is adjusted to close the government budget constraint. Blue region: determinacy. Light green region: indeterminacy. Yellow region: No unique stable equilibrium.



fects that are more persistent. Especially, this is the case when the government budget is closed by adjusting long-term debt.

This observation is interesting given that some researchers have expressed worries that certain debt management policies might offset the effects of QE, for example, if the fiscal authority pursues a debt policy that increases the availability of long-term debt to the private sector when the central bank is simultaneously attempting to reduce it. Here, under long-term debt financing, the effects of QE are amplified relative to short-term debt financing. The reason for this is that, in the model, QE operations by the central bank loosen the budget constraint of the fiscal authority. As a result, the fiscal authority lowers its debt issuance. Because the central bank purchases a fixed amount of outstanding government debt, long-term debt accommodation means that, in equilibrium, there is less long-term debt available to savers, compared to the case where the government budget is closed by adjusting short-term debt. This, in turn, triggers a relatively greater response in the term premium, leading to a higher overall macroeconomic response. This result emphasises the importance of considering how QE operations will affect the government budget constraint.

The model outlined in this study assumes that QE is effective because households participating in the asset market are so-called preferred habitat investors, that is, they have a preference for a certain maturity composition for assets they hold in their portfolios. As a byproduct of the analysis, it is shown that this assumption implies that when the steady-state asset purchases of the central bank are positive, the steady state of the model features an "inverted yield curve" in the sense that the holding return on a long-term government bond is lower than the interest rate on a one-period government bond. One interpretation of this result could be that when the central bank conducts QE for a very long time, the yield curve becomes inverted.

The goal of the present paper has been merely to highlight the role that fiscal policy could potentially have for the effectiveness of QE and to show that the design of fiscal policy might be something to think about when central bankers are implementing QE programmes. Some important questions, such as the optimal debt management policy in response to a QE shock, are left out of the present analysis. Moreover, welfare implications of different policies are not considered here. Both of these issues could prove to be interesting topics for future research. Further, in this paper the fiscal sector is assumed to be quite simplistic; for example, taxes are assumed to be only lump-sum. A model with a more realistic structure for public finances, for example in the form of distorting taxation, could also be worth examining more carefully in future work.

Appendix 4.A Proofs

Proof of proposition 1

Proof. The result can be derived by evaluating the representative saver's Euler equations (19) and (20) in the steady state, and using the asset market clearing conditions (35), (36) and (37):

$$R^L = \frac{\Pi}{\beta}\left[1 - d\left(\frac{\delta(x+b_F)}{Q(b_F^L - b_M^L)} - 1\right)\frac{\delta(1-\lambda)(x+b_F)}{(Qb_F^L - Qb_M^L)^2}\right]$$

and

$$R = \frac{\Pi}{\beta}\left[1 + d\left(\frac{\delta(x+b_F)}{Q(b_F^L - b_M^L)} - 1\right)\frac{\delta(1-\lambda)}{Q(b_F^L - b_M^L)}\right].$$

To the extent that one assumes zero initial real net worth of the central bank, $Qb_M^L = x$. Then, with no QE in the steady state, $Qb_M^L = x = 0$. Further, under the assumption that (exogenous) government debt issuance policy satisfies the households' maturity preference in the long run, $\frac{Qb_F^L}{b_F} = \delta$ and thus $R^L = R = \frac{\Pi}{\beta}$. Hence, $R^L - R = 0$. However, when steady-state QE is strictly positive ($Qb_M^L = x > 0$), combining the Euler equations above, one obtains the difference between the one-period return on a long-term bond and the return on short-term bond:

$$R^L - R = -\frac{\Pi}{\beta}\left[d\left(\frac{\delta(x+b_F)}{Q(b_F^L - b_M^L)} - 1\right)\frac{\delta(1-\lambda)}{Q(b_F^L - b_M^L)}\left(\frac{x+b_F}{Q(b_F^L - b_M^L)} + 1\right)\right]. \quad (55)$$

Recall that $\delta = \frac{Q\bar{b}_s^L}{\bar{b}_s} = \frac{Qb_F^L}{b_F}$. It follows that

$$\frac{\delta(x+b_F)}{Q(b_F^L - b_M^L)} - 1 > 0,$$

as $Qb_M^L = x > 0$. Clearly, other multiplicative terms inside the square brackets are strictly positive as well. Thus, the right-hand side of (55) is strictly negative, and therefore $R^L < R$. ∎

Appendix 4.B. The steady-state solution

This section describes how to solve for the steady state of the model. The main difficulty arising in the solution stems from the fact that the normalisation $y = 1$ is imposed. This requires choosing the steady-state productivity A such that it is consistent with the aggregate output $y = \frac{An}{D}$. However, in the recursive solution strategy, the solution for steady-state hours n depends on A. One thus has to choose a proposed value A_0 for A, solve for the steady state, and then in the end check whether the aggregate production relation holds, adjust A_0 accordingly, and recompute the steady state. This procedure is repeated until $error = |y_{implied} - y_{target}|$ is arbitrarily small, where $y_{target} = 1$ is the targeted normalisation. In what follows, I will choose $A_0 = 1$ as the initial value.

Given a proposed value for A, the computation of the steady state starts by imposing the following normalisations:

$$\begin{aligned} y &= 1 \\ \Pi &= 1, \end{aligned}$$

that is, the steady state output is normalised to one, and it is assumed that there is no trend inflation. In addition, the baseline assumption is that the central bank makes no asset purchases in the steady state, that is, $b_M^L = 0$, which implies that $x = 0$ by the assumption that the initial central bank net worth is zero, $\mathcal{N}_0 = 0$. The steady-state government short- and long-term bonds b_F and b_F^L are treated as exogenously given constants, as already mentioned in the subsection discussing the calibration of the model.

From the saver household's Euler equations, we can then solve for the steady-state short-term interest rate as well as the one-period holding return on the long-term bond:

$$\begin{aligned} R &= \beta^{-1} \\ R^L &= \beta^{-1}, \end{aligned}$$

and this then gives the steady-state long-term bond price:

$$Q = \frac{1}{R^L - \kappa} = \frac{1}{\beta^{-1} - \kappa}.$$

Once R^L and R are known, we can solve for the steady state lump-sum taxes from the fiscal authority's budget constraint:

$$\begin{aligned} \tau &= \left(\frac{R}{\Pi} - 1\right)b_F + \left(\frac{R^L}{\Pi} - 1\right)b_F^L - \tau_M \\ &= (R-1)b_F + (R^L - 1)b_F^L. \end{aligned}$$

where I have made use of the fact that, under zero QE in the steady state, the central bank capital gains are zero, and hence $\tau_M = 0$.

The optimality condition arising from the intermediate firms' price setting problem can be written more succinctly as

$$\Pi_t^* = \frac{\varepsilon}{\varepsilon - 1}\Pi_t \frac{G_t}{K_t},$$

where the auxiliary variables G_t and K_t are defined recursively as

$$\begin{aligned} G_t &= \Lambda_{s,t} y_t \mathcal{MC}_t + \theta\beta\,\mathbb{E}_t\left[G_{t+1}\Pi_{t+1}^{\varepsilon}\right], \\ K_t &= \Lambda_{s,t} y_t + \theta\beta\,\mathbb{E}_t\left[K_{t+1}\Pi_{t+1}^{\varepsilon-1}\right]. \end{aligned}$$

Then, in the steady state,

$$\begin{aligned} G &= \frac{\Lambda_s y \mathcal{MC}}{1 - \theta\beta\Pi^{\varepsilon}} = \frac{\Lambda_s \mathcal{MC}}{1 - \theta\beta}, \\ K &= \frac{\Lambda_s y}{1 - \beta\theta\Pi^{\varepsilon-1}} = \frac{\Lambda_s}{1 - \beta\theta} \end{aligned}$$

so that

$$\Pi^* = \frac{\varepsilon}{\varepsilon - 1}\Pi\frac{G}{K} = \frac{\varepsilon}{\varepsilon - 1}\mathcal{MC}.$$

Furthermore, evaluating (31) in the steady state and imposing $\Pi = 1$, it follows that $\Pi^* = 1$. We are then able to solve for the steady-state real marginal cost:

$$\mathcal{MC} = \frac{\varepsilon - 1}{\varepsilon}.$$

Using the fact that $\mathcal{MC} = \frac{w}{A}$, one can solve for the steady-state real wage:

$$w = A\mathcal{MC} = A\left(\frac{\varepsilon - 1}{\varepsilon}\right).$$

Given real wage and government transfers, we next solve for the steady-state consumption of the hand-to-mouth household using (21) and (22):

$$w^{1+\psi} c_r^{-\sigma} = \left(c_r + \tau_r\right)^{\psi},$$

where we recall that $\tau_r = \frac{\alpha}{\lambda}\tau$. Then, c_r can be solved from the above equation numerically using a standard nonlinear solver. After solving for c_r, one can obtain n_r from the intratemporal condition of the hand-to-mouth household:

$$n_r = \left(\frac{w}{c_r^{\sigma}}\right)^{\frac{1}{\psi}}.$$

Under zero steady-state central bank asset purchases, the portfolio costs are zero and aggregate resource constraint simply reads as

$$y = c$$

Given c_r, the consumption of the saver household can be solved using the aggregate consumption equation:

$$c_s = \frac{c}{1-\lambda} - \frac{\lambda}{1-\lambda} c_r.$$

Given c_s, the steady-state hours of the saver household can be solved using the intratemporal condition:

$$n_s = \left(\frac{w}{c_s^{\sigma}} \right)^{\frac{1}{\psi}}.$$

Given n_r and n_s, the aggregate hours are given by the labour market clearing condition:

$$n = (1-\lambda) n_s + \lambda n_r.$$

Since $\Pi = \Pi^* = 1$, it follows from equation (34) that in the steady state $\mathcal{D} = 1$. The steady state aggregate output is thus given by

$$y = \frac{An}{\mathcal{D}} = An.$$

Recall that the normalisation $y = 1$ was imposed, and the initial value for A was chosen to be $A_0 = 1$. Given the initial value A_0, we compute the implied error:

$$error = \left| y_{implied} - y_{target} \right|$$

where $y_{implied} = A_0 n$ is the implied value of y, and $y_{target} = 1$ is the target value. As long as the error exceeds some arbitrarily small number, A_0 is adjusted according to

$$A_{new} = A_0 - \frac{A_0 n - y_{target}}{n}$$

where the adjustment step follows from a straightforward application of Newton's method. The steady state is then recomputed using $A_0 = A_{new}$.

REFERENCES

Aiyagari, S. R. (1994). Uninsured idiosyncratic risk and aggregate saving. *The Quarterly Journal of Economics*, 109(3):659–684.

Andres, J., López-Salido, J. D., and Nelson, E. (2004). Tobin's imperfect asset substitution in optimizing general equilibrium. *Journal of Money, Credit and Banking*, pages 665–690.

Ascari, G., Colciago, A., and Rossi, L. (2016). Determinacy analysis in high order dynamic systems: The case of nominal rigidities and limited asset market participation. De Nederlandsche Bank Working Paper 511, Netherlands Central Bank, Research Department.

Benigno, P. and Nisticò, S. (2020). Non-neutrality of open-market operations. *American Economic Journal: Macroeconomics*, 12(3):175–226.

Bernanke, B. (2014). Central banking after the great recession: Lessons learned and challenges ahead: A discussion with Federal Reserve chairman Ben Bernanke on the Fed's 100th anniversary. *Brookings Institution (January)*.

Bernanke, B. S. (2009). The crisis and the policy response. *Stamp lecture, London School of Economics, January*, 13:2009.

Bilbiie, F. O. (2008). Limited asset markets participation, monetary policy and (inverted) aggregate demand logic. *Journal of Economic Theory*, 140(1):162–196.

Bilbiie, F. O. (2019). The New Keynesian cross. *Journal of Monetary Economics*.

Borio, C. and Disyatat, P. (2010). Unconventional monetary policies: an appraisal. *The Manchester School*, 78:53–89.

Bullard, J. and Mitra, K. (2002). Learning about monetary policy rules. *Journal of Monetary Economics*, 49(6):1105–1129.

Campbell, J. Y. and Mankiw, N. G. (1989). Consumption, income, and interest rates: Reinterpreting the time series evidence. *NBER Macroeconomics Annual*, 4:185–216.

Carlstrom, C. T., Fuerst, T. S., and Paustian, M. (2017). Targeting long rates in a model with segmented markets. *American Economic Journal: Macroeconomics*, 9(1):205–42.

Chen, H., Cúrdia, V., and Ferrero, A. (2012). The macroeconomic effects of large-scale asset purchase programmes. *The Economic Journal*, 122(564):F289–F315.

Colciago, A. (2011). Rule-of-thumb consumers meet sticky wages. *Journal of money, credit and banking*, 43(2-3):325–353.

Debortoli, D. and Galí, J. (2018). Monetary policy with heterogeneous agents: Insights from TANK models. Unpublished manuscript.

Eggertsson, G. B. and Woodford, M. (2003). Optimal monetary policy in a liquidity trap. Working Paper 9968, National Bureau of Economic Research.

Ellison, M. and Tischbirek, A. (2014). Unconventional government debt purchases as a supplement to conventional monetary policy. *Journal of Economic Dynamics and Control*, 43:199–217.

Galí, J., López-Salido, J. D., and Vallés, J. (2004). Rule-of-thumb consumers and the design of interest rate rules. Working Paper 10392, National Bureau of Economic Research.

Galí, J., López-Salido, J. D., and Vallés, J. (2007). Understanding the effects of government spending on consumption. *Journal of the European Economic Association*, 5(1):227–270.

Gertler, M. and Karadi, P. (2011). A model of unconventional monetary policy. *Journal of Monetary Economics*, 58(1):17–34.

Hall, R. E. and Reis, R. (2015). Maintaining central-bank financial stability under new-style central banking. Working Paper 21173, National Bureau of Economic Research.

Harrison, R. (2012). Asset purchase policy at the effective lower bound for interest rates. Working Paper 444, Bank of England.

Harrison, R. (2017). Optimal quantitative easing. Working Paper 678, Bank of England.

Huggett, M. (1993). The risk-free rate in heterogeneous-agent incomplete-insurance economies. *Journal of Economic Dynamics and Control*, 17(5-6):953–969.

Imrohoroğlu, A. (1989). Cost of business cycles with indivisibilities and liquidity constraints. *Journal of Political Economy*, 97(6):1364–1383.

Kaplan, G., Moll, B., and Violante, G. L. (2018). Monetary policy according to HANK. *American Economic Review*, 108(3):697–743.

Kaplan, G., Violante, G. L., and Weidner, J. (2014). The wealthy hand-to-mouth. Working Paper 20073, National Bureau of Economic Research.

Krusell, P. and Smith, Jr, A. A. (1998). Income and wealth heterogeneity in the macroeconomy. *Journal of Political Economy*, 106(5):867–896.

Leeper, E. M. (1991). Equilibria under 'active' and 'passive' monetary and fiscal policies. *Journal of Monetary Economics*, 27(1):129–147.

Lenza, M. and Slacalek, J. (2018). How does monetary policy affect income and wealth inequality? Evidence from quantitative easing in the euro area. Working Paper 2190, European Central Bank.

Maliar, L. and Naubert, C. (2020). Monetary policy and redistribution: A look under the hatch with TANK.

McKay, A., Nakamura, E., and Steinsson, J. (2016). The power of forward guidance revisited. *American Economic Review*, 106(10):3133–58.

McKay, A. and Reis, R. (2016). The role of automatic stabilizers in the us business cycle. *Econometrica*, 84(1):141–194.

Sargent, T. J. and Wallace, N. (1981). Some unpleasant monetarist arithmetic. *Federal Reserve Bank of Minneapolis Quarterly Review*, 5(3):1–17.

Sims, C. A. (1994). A simple model for study of the determination of the price level and the interaction of monetary and fiscal policy. *Economic Theory*, 4(3):381–399.

Wallace, N. (1981). A Modigliani-Miller theorem for open-market operations. *The American Economic Review*, 71(3):267–274.

Weale, M. and Wieladek, T. (2016). What are the macroeconomic effects of asset purchases? *Journal of Monetary Economics*, 79:81–93.

Woodford, M. (1995). Price-level determinacy without control of a monetary aggregate. In *Carnegie-Rochester Conference Series on Public Policy*, volume 43, pages 1–46. Elsevier.

Woodford, M. (1998). Doing without money: Controlling inflation in a post-monetary world. *Review of Economic Dynamics*, 1(1):173–219.

Woodford, M. (2001). Fiscal requirements for price stability. Working Paper 8072, National Bureau of Economic Research.

YHTEENVETO (FINNISH SUMMARY)

Tutkimuksia rahapolitiikasta

Väitöskirjassa tutkitaan rahapolitiikkaan ja sen taloudellisiin vaikutuksiin liittyviä kysymyksiä. Painopiste on erityisesti kysymyksissä, jotka ovat olleet viime vuosikymmenten aikana keskeisiä niin käytännön rahapolitiikan harjoittamisen kuin akateemisen tutkimuksenkin kannalta.

Väitöskirja koostuu johdantoluvusta seka kolmesta erillisestä tutkimuksesta. Kaksi väitöskirjan ensimmäista tutkimusta ovat empiirisiä, kun taas kolmas on luonteeltaan teoreettisempi. Luku 1 käy läpi ollenaisen tutkimuskirjallisuuden ja keskustelee väitöskirjan suhteesta siihen, kuvailee työssä käytettäviä tutkimusmenetelmiä, sekä käy läpi tutkimuskysymykset.

Luvun 2 tutkimus tarkastelee osake- ja valuuttamarkkinainformaation roolia 14 OECD-maan rahapolitiikkasäännöissä vuosina 1999–2016. Tutkimuksen kohteena olevien maiden rahapolitiikkaa kuvataan niin sanotulla Taylorin säännöllä, jonka yleisimmin käytetÿn muodon mukaan keskuspankki asettaa korkotason makrotaloudellisten muuttujien, kuten inflaation ja tuotantokuilun, perusteella. Tutkimus tarkastelee osake- ja valuuttamarkkinamuuttujien roolia tällaisessa rahapolitiikkasäännössä. Tuloksissa havaitaan, että niin osake- kuin valuuttamarkkinamuuttujatkin ovat olleet tilastollisesti merkitseviä selittäjiä usean tutkimuksen kohteena olevan OECD-maan rahapolitiikkasäännössä. Tämän lisäksi havaitaan, että osake- ja valuuttamarkkinamuuttujilla on mahdollisesti ollut epäsuora rooli usean OECD-maan rahapolitiikkasäännössä: tarjoamalla informaatiota tulevasta talouskehityksestä niillä on mahdollisesti ollut merkitystä rahapolitiikan kannalta.

Luvun 3 tutkimuksessa arvioidaan Yhdysvaltojen rahapolitiikan vaikutusta neljän pienen avotalouden rahapolitiikkaan. Tutkimuksen kohteena olevat maat ovat Kanada, Iso-Britannia, Norja ja Ruotsi. Tutkimuskysymystä tarkastellaan kahdesta eri näkökulmasta. Ensimmäisessa tarkastellaan Yhdysvaltojen rahapolitiikan systemaattista roolia pienten avotalouksien rahapolitiikassa estimoimalla rahapolitiikkasääntöjä, joissa Yhdysvaltojen korkotaso on yksi potentiaalinen selittäjä. Toinen lähestymistapa pyrkii selvittämään Yhdysvaltojen rahapolitiikkasokkien, eli odottamattomien rahapolitiikan muutosten, dynaamisia vaikutuksia pienten avotalouksien rahapolitiikkaan. Tutkimuksessa havaitaan, että Yhdysvaltojen rahapolitiikkapäätöksillä on ollut systemaattinen rooli erityisesti Kanadan ja Ison-Britannian harjoittamassa rahapolitiikassa. Havaitaan myös, että Yhdysvaltojen rahapolitiikkasokit ovat vaikuttaneet korkoihin Kanadassa, Norjassa ja Ruotsissa, vaikkakin tuloksen vahvuuden osoitetaan olevan riippuvainen käytettävästä tutkimusmenetelmästä. Tutkimuksessa tarkastellaan myös, ovatko pienet avotaloudet käyttäneet valuuttainterventioita lisätäkseen rahapolitiikkansa autonomiaa Yhdysvaltoihin nähden. Tälle hypoteesille ei löydetä tukea.

Luvun 4 tutkimuksessa kehitetään teoreettinen yleisen tasapainon malli, jonka avulla tutkitaan, missä määrin keskuspankin suorittaman määrällisen keventämisen talousvaikutukset riippuvat valtion harjoittamasta finanssipolitiikasta. Osoitetaan, että määrällisen keventämisen tehokkuus riippuu siitä, sopeuttaako valtio budjettirajoitteensa muuttamalla verotusta vai laskemalla liikkeeseen valtionlainoja. Havaitaan, että määrällisen keventämisen alkuvaikutus on vahvimmillaan ensin mainitussa tilanteessa, mutta vaikutukset ovat pidempikestoisia kun sopeuttaminen tehdään valtionlainojen kautta. Jälkimmäisessä tapauksessa määrällisen keventämisen osoitetaan olevan tehokkaimmillaan silloin, kun valtio laskee liikkeeseen juoksuajaltaan pitkiä velkakirjoja. Tutkimuksessa tarkastellaan lisäksi mallin teoreettisia ominaisuuksia numeeristen simulaatioiden avulla. Havaitaan, että realistisilla parametrien arvoilla mallin tasapainon yksikäsitteisyys ei riipu valtion harjoittamasta finanssipolitiikasta.