Three essays on

Unconventional Monetary Policies, Forward Guidance and Open Economies

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Dedication

To my wife and daughters.

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Contents

List of Figures

List of Tables

Introductory remarks

During the great financial crisis, various central banks resorted to unconventional monetary policies (UMP) in order to provide additional stimulus once their main instrument, the policy rate, hit the zero lower bound. As the reasoning and targets for these UMPs differed across central banks, so did the different UMP types. Several central banks run extensive asset purchase programmes with a focus on credit conditions or broader interest rates; others relied on, or complemented asset purchases with guidance on interest rates; while again others, primarily open economies, responded to spillovers from abroad and temporarily managed exchange rates by applying a temporary floor for the exchange rate and/or conducting foreign exchange interventions.

The present thesis focuses on two specific topics from this wide range of types and applications: The understanding, efficacy and (optimal) conduct of forward guidance, as one particular UMP type, and the interaction of unconventional monetary policies with open economies. The thesis uses both empirical and theoretical approaches to tackle these questions: The first chapter empirically addresses the impact of foreign UMPs on (the financial markets of) a small open economy, namely Switzerland. Chapters two and three analyze the (theoretical) efficacy and conduct of forward guidance in a closed and open economy in stylized DSGE models.

The first chapter analyzes the impact that UMP *announcements* by the four major central banks – the Federal Reserve, European Central Bank, Bank of England and Bank of Japan – have on four different asset prices in Switzerland, representing an advanced small open economy: Government and corporate bond yields, equities and exchange rates. The contributions of this part are fourfold: First, it focuses on the spillovers of UMPs from several central banks *to* one country, whereas other papers on spillovers often focus on the spillovers of UMPs *from* one country (or focused on domestic impacts only). Second, Switzerland as a highly globalized economy with a large financial sector and an internationally traded currency that is occasionally exposed to safe-haven demand provides a particularly interesting case; most studies on spillovers so far focus on emerging markets. Third, the minimum rate of 1.20 Swiss franc per Euro – enforced by the Swiss National Bank between 6 September 2011 and 15 January 2015 – allows to examine the effectiveness of domestic monetary policy responses to external financial shocks. Last but not least, this chapter provides an extensive, newly constructed data set of UMP announcements of the major central banks. This increases the number of observations sharply and allows for a more thorough analysis of the impact of different UMP programmes or features.

The second and third chapter tackle the identification issues with respect to the effects of particular UMPs types – induced by the wide range of different types, few observations and the fact that UMP announcements often comprise multiple UMP types – from a theoretical side and analyzes the efficacy of forward guidance in stylized (DSGE) models. Specifically, a closed economy (second chapter) or a open economy (third chapter) is hit by negative shocks that drive interest rates to zero or lead to negative spillovers from abroad. The central bank may then revert to forward guidance in order to offset the negative impact of such shocks. The contributions of this part are fourfold: First, it analyzes forward guidance for a closed and an *open economy*, whereas the majority of the academic literature on forward guidance so far focuses on closed economies. Second, it analyzes and compares *various specifications* of forward guidance, besides the common 'low for long' interest rate announcement. For instance, it also covers a temporary overshooting of inflation through a more expansionary policy rule, or so-called state-contingent forward guidance. In doing so, it also provides an idea about the 'best' specification, or conduct, of forward guidance in a stylized DSGE model. Third, forward guidance in the open economy can also *target exchange rates*, not only interest rates. The central bank of the small open economy may pre-announce a temporary management of the exchange rate, for instance through a temporary floor for the exchange rate. Last but not least, the open economy part also evaluates the *spillovers* of foreign shocks (potentially exacerbated by foreign forward guidance) to a small open economy; a topic shared with the empirical analysis in the first chapter.

The analysis of the three chapters leads to the following main conclusions. First, forward guidance is (highly) effective in providing stimulus to the economy, in theory at least. This particularly holds for a closed economy, but also for a small open economy. Second, forward guidance and other UMP programmes lead to considerable and harmful spillovers to other countries, not only in theory but also in reality. Specifically, exchange rates of small open economies appreciate in response to expansionary UMP policies abroad, with potentially negative effects on inflation and demand from abroad. Third, central banks of small open economies are able to at least partly offset such spillovers from abroad through domestic (unconventional) monetary policies. Last but not least, the common low-for-long forward guidance specification is generally the most effective, but also most sensitive with respect to a potential mis-specification of the duration or future shocks. Alternatives such as a temporarily higher inflation target, or a temporary exchange rate peg in the open economy, are much more stable through their endogenous response without loosing too much effectiveness.

The following sub-sections provide non-technical overviews of the methodology and additional results for the three chapters.

Chapter 1: Cross-border Spillover Effects of Unconventional Monetary Policies on Swiss Asset Prices

This first chapter analyzes of UMP *announcements* by the central banks of the four major currency areas (the U.S., Euro area, U.K. and Japan) on four types of Swiss asset prices (government and corporate bond yields, equities and exchange rates).

The empirical strategy adopted follows a time-series approach and is based on two core elements: First, the chapter evaluates the daily changes in Swiss asset prices on days with UMP announcements by foreign central banks. The timing of the announcements is pinpointed by an extensive, newly constructed event set. The second element is the extent to which financial markets anticipate the content of these UMP statements. We identify the surprise part of these statements using a market-based surprise measure that relies on the daily changes in the price of 10y government bond futures. Controlling for market anticipation proves necessary to properly identify the financial market impact of UMP announcements. For instance, on the day of its announcement, an increase in the size of an asset purchase programme – at face value arguably an expansionary policy – may exert contractionary (expansionary) financial market effects, if markets have anticipated a larger (smaller) increase of the programme.

The chapter finds that UMP announcements by the four major advanced central banks significantly affect Swiss financial assets. The size and direction of the impact depend on the degree of policy anticipation and the specific asset class under consideration. An expansionary foreign UMP shock induces a decrease in Swiss long-term government bond yields, a decrease in Swiss long-term corporate bond yields, a decline in the Swiss equity index and an appreciation of the Swiss franc against the Euro and the U.S. dollar. The effects are strongest for UMP announcements by the ECB and, among Swiss government bonds, for those with residual maturities of 7-10 years. The implementation of the minimum rate of 1.20 CHF per EUR tends to attenuate the spillover effects on bond yields and exchange rates but not those on Swiss equities. This result indicates that the domestic monetary policy stance can exert some limited effect on the cross-border financial spillover impact of foreign monetary policy decisions.

The chapter further confirms the finding of Glick and Leduc (2012) that the sign of spillover effects differs between positive and negative UMP surprises, whereas it cannot lend support to their conclusion that the strength of spillover effects is larger for positively surprising announcements.

Chapter 2: The optimal conduct of forward guidance (in a closed economy)

This chapter analyzes the theoretical efficacy of forward guidance in a stylized DSGE model for a closed economy. Amid the differences in forward guidance applications by major central banks, this paper furthermore evaluates and compares various forward guidance specifications in order to provide some guidance about the *'best' conduct* of forward guidance. The chapter measures the effectiveness of such announcements twofold: The positive analysis compares impulse response functions of different forward guidance policies on key variables of interest, the normative analysis instead compares welfare proxied by utility.

Forward guidance always represents a credible and pre-announced temporary change in the regular policy rule, varying in three dimensions: Timing (duration and start), trigger (a specific date or a condition), and specification (the central bank may announce *low* interest rates, or *lower* interest rates than usual, through a more dovish reaction function with a temporarily higher inflation target or higher sensitivities regarding inflation or output). We reduce the set of possible combinations to three main cases: First, the chapter analyzes calendar-based forward guidance, inspired by that of the Federal Reserve in 2011 and 2012 (until a specific date). Second, the chapter follows the Federal Reserve in December 2012 and replaces the calendar-based duration with a condition (inflation must exceed a specific threshold). Third, the chapter addresses the effect of guidance on policy normalization, i.e. the promise to allow for higher inflation for a specific number of periods, *as soon as* interest rates lift off from the zero lower bound. Any 'gradual' approach in raising interest rates may come close to this. In all three cases, the chapter evaluates the two main specifications: low or lower interest rates.

The chapter shows that forward guidance is generally effective at providing policy accommodation at the zero lower bound. Calendar-based forward guidance expressed as a constant interest rate over a given period is especially effective, but also most prone to a mis-specification of the duration (or future shocks). Forward guidance that allows inflation to temporarily overshoot can achieve similar results, and additionally provides a 'hedge' against duration mis-specification or future shocks. In contrast, state dependent forward guidance and forward guidance with higher (inflation or output gap) sensitivities yield much less policy accommodation. State dependent forward guidance reveals to be highly sensitive to the parameters announced by the central bank: If the threshold requires an overly aggressive monetary policy easing, the central bank may be expected to give up its accommodative stance too early, thereby undermining its intentions to stabilize the economy. This reduces the feasible set of parameter values and its efficacy. Allowing for an overshooting of the conditions for an extended periods (e.g. inflation must exceed the threshold for one year) can, however, offset this shortcoming. Finally, forward guidance concerning the path of interest rate normalization can be as effective as guidance extended during the zero lower bound period.

Chapter 3: Forward guidance in a small open economy: the transmission of international shocks

The third chapter combines elements of the two previous chapters and analyzes the (theoretical) efficacy of forward guidance in an small open economy. The central bank of the small open economy may apply forward guidance in two cases: In response to a large negative domestic shock that drives domestic interest rates to zero, or in response to spillovers from abroad, induced by a large negative shock abroad. The first case reveals the effect that international linkages (e.g. the exchange rate) have on (the effectiveness of) forward guidance. The second case addresses the international transmission of shocks and the ability of forward guidance to counter (the transmission of) such shocks.

The central bank of the small open economy may announce three types of forward guidance. First, the central bank may announce *low* interest rates for an extended period, by means of a constant interest rate path. Second, it may announce *lower* interest rates than usual, by means of a more expansionary policy rule with a higher inflation target. These first two cases are simplified versions of the closed economy analysis in the second chapter (forward guidance always starts today, and we consider calendar-based triggers only). Additionally, the central bank may not only announce forward guidance on interest rates, but also on exchange rates: It may announce a *temporary peg* for the exchange rate. Technically, we implement such a temporary peg via a modified interest rate rule that responds to exchange rate deviations. The entire analysis takes place in a stylized two-country (DSGE) model.

The chapter shows that forward guidance is effective in both cases, whether the small open economy suffers from a domestic shock or faces negative spillovers from abroad. One major channel for its efficacy is the exchange rate, besides the general effects of lower interest rates (such as higher inflation expectations). One additional equation of open economies with complete international markets, the international risk sharing condition, however seems to dampen the effect of forward guidance on consumption; the response is much smaller than in the closed economy. Forward guidance is also successful in altering the international transmission of foreign shocks, such that spillovers to the domestic economy are less pronounced (or even positive for long forward guidance durations). Among the three forward guidance types, results are similar to the second chapter: The promise of low interest rates is the most effective but also most sensitive type, a temporarily higher inflation target and the temporary peg are somewhat less effective, but provide sort of a hedge against an excessive overshooting of output gap and inflation. Note that the implementation of the temporary peg reveals questionable effects on interest rates, for specific periods towards the end of forward guidance, an explicit modeling of foreign exchange interventions seems due in this respect. At present, these results should be taken with a grain of salt.

Chapter 1

Cross-border Spillover Effects of Unconventional Monetary Policies on Swiss Asset Prices

Abstract

Unconventional monetary policies (UMPs) announced by the Federal Reserve, the European Central Bank, the Bank of England and the Bank of Japan exert important spillover effects on asset prices in Switzerland. Using a broad UMP event set and a long-term bond-futures based measure of market anticipation, we show that surprisingly expansionary UMPs lower Swiss government and corporate bond yields, induce the Swiss franc to appreciate, and dampen Swiss equity prices. Four extensions provide further insights. First, the estimated effects are strongest for announcements by the ECB. Second, the impact on government bonds is largest for bonds with residual maturities of 7-10 years. Third, the impact of foreign UMP shocks on exchange rates and Swiss bond yields is less pronounced after the introduction of the minimum rate of 1.20 Swiss franc per Euro by the Swiss National Bank on September 6, 2011, indicating that domestic monetary policy action partially affects the impact of external monetary shocks on domestic financial markets. Fourth, the sign of spillover effects differs for positive and negative UMP surprises, but their strength does not.

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1.1 Introduction

Empirical evidence strongly suggests that unconventional monetary policies (UMPs) implemented by core advanced economy central banks in response to the financial crisis exert significant spillover effects on global financial markets. Globally, yields on short- and long-term bonds issued by governments and corporates decline in response to expansionary UMP announcements (Glick and Leduc (2012), Neely (2015), Chen et al. (2012), and IMF (2013b)). Further, the spot exchange rates appreciate relative to the currency of the central bank implementing an expansionary UMP (Diez and Presno (2013), Glick and Leduc (2015), and Neely (2015)), whereas the evidence on the spillover effects on global equity prices and on capital flows is mixed (IMF (2013a), Berge and Cao (2014), Fratzscher et al. (2013), Glick and Leduc (2012), and Ahmed and Zlate (2014)). In general, the observed size of spillover effects depends on push factors such as the specific characteristics of the UMP programme implemented (Fratzscher et al. (2013), Chen et al. (2012), Christensen and Rudebusch (2012), and IMF (2013b)). At the same time, and unsurprisingly, domestic pull factors are important to explain differences across recipient economies of the observed size and scope of cross-border effects of foreign monetary policies.[2] In this regard, both structural and cyclical factors are important, such as the degree of global financial and economic integration, the presence of imperfections in domestic financial markets, the domestic business cycle as well as dometic macroeconomic policy choices (IMF (2013b), Chen et al. (2014), Fratzscher et al. (2013), and Caruana (2012)).[3]

To date, analytical contributions and policy debates focus predominantly on the spillover effects of UMPs to emerging economies (e.g. Bowman et al. (2015), and Chen et al. (2012)) or on those among large advanced economies (e.g. Bauer and Neely (2014), Glick and Leduc (2012), Rogers et al. (2014), and Neely (2015)), while only limited evidence has been provided on UMP spillovers on financial markets in small advanced countries as of yet.

In an effort to fill this gap, we empirically assess the impact of UMP announcements by the central banks of the four major currency areas (the U.S., Euro area, U.K. and Japan) on a broad range of Swiss asset prices (government and corporate bond yields, equities and exchange rates). In doing so, our study complements the empirical literature on the financial market impact of unconventional monetary policies in four respects: First, Switzerland, a highly globalized economy, with a large financial sector and an internationally traded currency that is occasionally exposed to safe-haven demand, provides a particularly interesting case to discuss global implications of foreign monetary policy. While analyses of the asset price impact of domestic UMPs are available for Switzerland, this does not hold for an assessment of the effects of foreign UMPs (Kettemann and Krogstrup (2014), and Christensen and Krogstrup (2014)). Second, due to the minimum rate of 1.20 Swiss franc (CHF) per Euro (EUR) that was enforced by the Swiss National Bank between 6 September 2011 and 15 January 2015, the Swiss case also allows us to examine the ef-

[2]Throughout this study, we denote the economies hosting the central bank originating an UMP as *foreign* and the economy potentially affected – namely Switzerland – by the spillovers emenating from these policies as *domestic*.

[3]This corroborates the evidence for the important role of pull factors in case of conventional monetary policy (Ehrmann and Fratzscher (2009)).

fectiveness of domestic monetary policy responses to external financial shocks. Third, we rely on a newly constructed set of nearly 100 UMP statements by the Fed, ECB, BoJ and BoE from 2008 to 2014, whereas a large part of the literature analyses only the first asset purchase program of the Fed. In this regard, the studies by Chen et al. (2012), Diez and Presno (2013), and Rogers et al. (2014) are closest to ours. However, their analyses rely on a different event selection scheme and focus mainly on the domestic effects and U.S. dollar (USD) exchange rate effects of UMP announcements. Fourth, this extended set of UMP events allows us to re-assess the results by Glick and Leduc (2012), who find that both the direction and strength of cross-border asset price effects differs between positive and negative UMP surprises.

The empirical strategy adopted follows the linear time-series approach of Glick and Leduc (2012). It is based on two core elements: First, we evaluate the daily changes in Swiss asset prices on days with UMP announcements by foreign central banks. The timing of the announcements is pinpointed by our newly constructed event set. By this choice, we focus our analysis on the immediate effects of policy announcements, but abstain from assessing longer-term effects (e.g. Wright (2012), Neely (2014), and Chen et al. (2015)). The second element is the extent to which financial markets anticipate the content of these UMP statements. We identify the surprise part of these statements using a market-based surprise measure that relies on the daily changes in the price of 10y government bond futures. We thus closely follow the approach proposed by Wright (2012). Controlling for market anticipation proves necessary to properly identify the financial market impact of UMP announcements. For instance, on the day of its announcement, an increase in the size of an asset purchase programme – at face value arguably an expansionary policy – may exert contractionary (expansionary) financial market effects, if markets have anticipated a larger (smaller) increase of the programme.[4] In the following, we classify announcements that are more expansionary than expected or those that are less restrictive than expected as a *positive surprise* and announcements that are more restrictive or less expansionary than expected as a *negative surprise*.

We find that UMP announcements by the four major advanced central banks significantly affect Swiss financial assets. The size and direction of the impact depend on the degree of policy anticipation and the specific asset class under consideration. An expansionary foreign UMP shock equivalent to a 25-basis-point decline in foreign long-term bond yields induces an approximately 6-basis-point decrease in Swiss long-term government bond yields, a 4.5-basis-point decrease in Swiss long-term corporate bond yields, a 1-percentage-point decline in the Swiss equity index, an approximately 0.6-percentage-point appreciation of the Swiss franc against the Euro and an approximately 0.9-percentage-point appreciation against the U.S. dollar. Qualitatively, our estimates for Swiss assets corroborate the spillover effects estimated for comparable assets in other advanced economies (Glick and Leduc (2012), Diez and Presno (2013), and Rogers et al. (2014)). For Swiss assets, the effects are strongest for UMP announcements by the ECB and, among Swiss government bonds, for those with residual maturities of 7-10 years. We further confirm the finding of Glick and Leduc (2012) that the sign of spillover effects differs between positive and negative UMP surprises, whereas we cannot lend support to their conclusion that the strength

[4]The same logic applies to announcements intended to be restrictive: If markets anticipated an even more (less) restrictive policy than announced, then an announcement would lead to expansionary (contractionary) effects on the day of the announcement.

of spillover effects is larger for positively surprising announcements. The implementation of the minimum rate of 1.20 CHF per EUR tends to attenuate the spillover effects on bond yields and exchange rates but not those on Swiss equities. This result indicates that the domestic monetary policy stance can exert some limited effect on the cross-border financial spillover impact of foreign monetary policy decisions.

The remainder of the chapter is structured as follows. Section 2 reviews the theoretical literature on UMP spillover channels. Section 3 outlines the empirical set-up and data, section 4 describes the UMP event selection strategy and section 5 explains the approach relied upon to identify monetary policy surprises. The empirical results are discussed in Section 6, followed by a discussion of their robustness in section 7. Section 8 concludes.

1.2 UMP spillover effects in theory

We start by reviewing the theoretical literature on the channels through which UMPs – both asset purchases (quantitative easing or credit easing) and forward guidance statements by central banks – can affect international financial markets. We focus on a set of four UMP spillover channels relevant for the remainder of this chapter, without claiming to be exhaustive: an international portfolio re-balancing channel, an international liquidity channel, an international signalling channel and an exchange rate channel.[5]

The *international portfolio re-balancing channel* applies in particular to government bonds. It is based on the notion that investors have a preference for bonds with certain characteristics such as their maturity (Vayanos and Vila (2009), and Greenwood and Vayanos (2010)). Given a foreign UMP focuses on purchasing such preferred bonds, thereby reducing their supply and hence their yield, then optimizing investors will seek to re-balance their portfolio internationally to bonds with sufficiently similar characteristics. As a consequence, a foreign UMP focused on purchasing foreign long-term government bonds tends to lower yields of domestic long-term government bonds. Such portfolio re-balancing effects need not be confined exclusively to the closest substitutes only. Alternatively, if optimizing investors act upon a pre-determined return goal, a decline in foreign government bond yields could induce them to shift their portfolio holdings also towards more risky assets – for instance domestic and foreign corporate bonds – thereby driving up (down) the prices (yields) of those assets both locally and internationally (Krishnamurthy and Vissing-Jorgensen (2011), Gagnon et al. (2011), and Bauer and Neely (2014)).

Second, and related, the *international liquidity channel* emphasises the fact that asset purchases by a central bank increase the amount of liquidity available to the counterparties of the trade (Krogstrup et al. (2012), and Korniyenko and Loukoianova (2015)). Optimizing agents will seek to invest the newly available liquidity profitably by increasing their demand for a broad spectrum of assets, thereby pushing up their prices. In a similar vein, more ample availability of liquidity lowers expected average risk-free interest rates

[5]Unlike in the literature on conventional monetary policy channels, no settled consensus has been reached so far on the distinction and nomenclature of transmission channels of unconventional monetary policies. The channels selected here are varieties of a core set of channels discussed recurrently in the literature, see, among others, D'Amico et al. (2012), Haldane et al. (2016), Joyce et al. (2012), Bauer and Neely (2014), Miyajima et al. (2014), and Chen et al. (2012).

and tends to increase the risk-taking capacity of market participants. The latter implies that risk premia fall and hence asset prices rise across the board. Importantly, there is nothing specifically local to these effects. The main complication arising in the international case is the fact that investors must take the currency risk into account. However, while the currency risk premium may alter the size of the effect an UMP has on global risky assets relative to local risky assets, this does not imply that the liquidity channel is muted completely.

Third, foreign UMP announcements exert domestic financial market effects through an *international signalling channel*. This channel relates to the notion that monetary policy announcements convey relevant information regarding the commitment of a central bank to a given path of the policy rate as well as regarding its assessment of the economic situation (Eggertsson and Woodford (2003), Bauer and Rudebusch (2014), and Bauer and Neely (2014)). The underlying mechanisms apply similarly both within a given economy as well as across borders. The latter holds in particular for announcements by central banks of core economies of the global economy, i.e. exactly those central banks focused on in this study. Specifically, a policy decision in a major foreign economy can signal to market participants that the domestic central bank in a small economy will subsequently implement comparable policies thereby driving up domestic asset prices through standard domestic transmission channels, as discussed in Taylor (2013), Chen et al. (2012), or Caruana (2012). Further, it may also signal to market participants that the major central bank has changed its assessment of the *global* economic outlook or its assessment of *global* risk.

Through these signalling mechanisms, a foreign UMP announcement may induce adjustments in the pricing of domestic financial assets. Importantly, the net effect of a foreign UMP announcement on domestic asset prices and yields through the signalling channel is ambiguous. It crucially depends on whether markets coordinate on an optimistic or pessimistic interpretation of the policy announcement. For *government bonds*, a positively surprising foreign UMP tends to lower yields, as it signals a lower and flatter expected path of the domestic policy rate. The same holds if the foreign UMP announcement indicates a less benign economic outlook, as the latter tends to compress the domestic term premium. Both effects (lower expected short-term rate, lower term premium) imply a downward shift in the domestic government bond yields in response to a foreign UMP through the signalling channel. For *corporate bonds*, essentially the same narrative applies. An additional, offsetting effect is conceivable if markets interpret the foreign UMP announcement as negative news regarding the domestic corporate default risk, i.e. if the default risk premium increases. For *equities*, such a default risk premium effect may apply as well. Furthermore, if a foreign UMP is read as indicating a downgrading of the global economic outlook, then expected earnings are negatively affected globally, which also weighs on domestic equity prices. These negative signalling effects may be compensated by a positive effect through lower than expected discount rates due to a lower and flatter than expected path of the domestic policy rate. For *exchange rates*, signalling effects tend to dampen the appreciation pressures on the domestic currency through their impact on the expected domestic policy reaction. However – and this holds specifically for the Swiss case as well as other safe haven currencies – if the foreign UMP announcement signals higher risk and a downgrading of the global economic outlook, the CHF tends to appreciate (e.g. Ranaldo and Söderlind (2010)).

Forth, foreign monetary policy announcements – both conventional and unconventional – can have a significant bearing on domestic financial assets through an *exchange rate channel*. Standard monetary models imply that a more expansionary foreign monetary policy in one economy induces a depreciation of the nominal spot exchange rate of the foreign currency – or, consequently, an appreciation of the domestic currency (Krugman et al. (2011, chapter 14)).[6] In general terms, similar effects ensue in the case of expansionary unconventional monetary policy abroad.

Through the appreciation of the spot exchange rate, which implies that domestic monetary conditions become more restrictive, a foreign UMP also affects other domestic asset prices: For *government bonds*, more restrictive monetary conditions will lead to, ceteris paribus, lower expected short rates, whereas the term premium is not necessarily affected. In sum, an appreciation thus tends to lower government bond yields. For *corporate bonds*, the same holds true. In addition, the impact on the default risk premium needs to be considered. As long as the exchange rate appreciation does not alter the perceived default risk of domestic corporates, then expected effects for corporate bond yields do not differ from those on government bond yields. For *equities*, an appreciation of the domestic currency has the main effect of negatively affecting expected earnings as it reduces the competitiveness of internationally exposed firms. It thus weighs on their share price.[7] Finally, for all assets considered, an appreciation of the domestic currency may have two further, possibly offsetting effects: On the one hand, an appreciation of the spot exchange rate implies that the price of domestic assets increases relative to comparable assets abroad. This again dampens domestic equity prices and increases domestic bond yields. On the other hand, if investors believe the domestic currency to appreciate further over time, they expect domestic assets to provide appreciation-induced valuation gains, making them relatively more attractive.

The *net spillover effect* induced by foreign UMPs comprises the sum of individual effects through each of these distinct channels. As the discussion so far showed, the impact of foreign UMPs can differ substantially for different domestic assets, possibly even in direction. Disentangling and quantifying the relative importance of the individual spillover channels poses a set of methodological challenges and asks for specific empirical models for each asset under consideration (Krishnamurthy and Vissing-Jorgensen (2011), Fratzscher et al. (2016), Bauer and Neely (2014), Neely (2015), Bhattarai and Neely (2016), and Bauer and Rudebusch (2014)). As such, a formal analysis of the question which channel dominates under which circumstances and for which asset in the Swiss case goes beyond the scope of this chapter. Yet, by uncovering the overall impact of foreign UMPs on a set of different domestic assets, and squaring the results obtained with the theoretical mechanisms outlined here, this study allows us to draw some tentative conclusions on this question in qualitative terms.

[6] This is a consequence of Mundell's "trilemma": in economies with open capital accounts, exchange rate fluctuations ensue in response to foreign monetary policy shocks (e.g. Obstfeld et al. (2005)).

[7] This is the transaction effect of exchange rate changes on firms' financial statements.
In the context of our study, it is important to recognize that the firms listed in the Swiss Market Index (SMI) generate on average about 90% of their turnover abroad, whereas more significant parts of their cost arise domestically. The latter is indicated by the fact that, on average, almost 25% of the employees of the SMI-listed firms are Swiss-based (Rasch (2015)).

1.3 Empirical framework and data

We estimate the UMP spillover effects on Swiss asset prices using the econometric model described by equation (1.1) based on daily data. We apply the time-series set-up as in Glick and Leduc (2012), using an explicit measure of the surprise component of policy announcements, following Wright (2012).[8]

$$\Delta y_t = \alpha + \beta \Delta s_t d_{t,events} + \boldsymbol{\gamma}' \mathbf{z}_t + \varepsilon_t \tag{1.1}$$

The dependent variable Δy_t represents the one-day change in the following Swiss asset prices: the main Swiss equity price index (Swiss Market Index, SMI), bilateral nominal Swiss franc exchange rates versus the U.S. dollar (Dollar) and the Euro (Euro), yields on Swiss government bonds with 10-year maturity (Gov.) and yields on Swiss franc denominated bonds of AAA-BBB rated domestic corporates with 7-10-year maturity (Corp.).[9] The dummy variable $d_{t,events}$ takes the value of one on all days specified as foreign UMP announcement days and zero otherwise. The strategy adopted to designate specific days as UMP announcement days is explained in section 1.4. Δs_t represents a quantitative measure of monetary policy surprise, that is, the extent to which a policy announcement differs from market expectations. The baseline measure used as a proxy for monetary policy surprise is the one-day change in the price of longer-term government bond *futures* (approximately 10y, active contract). The underlying motivation for the use and the quality of this proxy is discussed in detail in section 1.5. The surprise measure for each central bank is set to its market-derived value on corresponding UMP announcement days. The vector $\mathbf{z}_t$ denotes the vector of control variables. The baseline set of controls comprises the one-day lagged values of the dependent variable, the one-day lagged change in the VIX, and the lagged change in the U.S. 10y treasury yield.

In extensions, we interact the explanatory variable $\Delta s_t d_{t,events}$ with a dummy for the implementation of the minimum exchange rate ($d_{t,mer}$, taking the value of one after 6 September 2011 and zero otherwise), dummies for each central bank ($d_{t,cb}$, taking the value of one on days with announcements by the corresponding central bank), or a dummy for positive and negative surprises ($d_{t,\Delta s>0}$ and $d_{t,\Delta s<0}$, taking the value of one for announcements that surprise markets positively and negatively, respectively), with positive surprises being defined as announcements that are more expansionary than expected.

We estimate equation (1.1) by OLS, accounting for heteroscedasticity based on White (1980). We do not expect serial correlation to be a crucial problem for changes in asset prices and is indeed dismissed by preliminary checks.[10]

[8] The approach is closely related to the event study approach commonly relied upon in the empirical UMP literature. An event study using a one-day event window and the same control variables as here, yields comparable results.

[9] Exchange rates are represented as Swiss francs per unit of foreign currency (i.e. EURCHF and USDCHF, respectively), such that an increase (decrease) indicates a CHF depreciation (appreciation).

[10] The assumption of normally distributed coefficients seems robust, although asset price changes per se follow a t-distribution rather than the normal. While tests for normally distributed asset prices changes do indeed reject the null of normal distribution, corresponding tests for non-parametric bootstrapped coefficients do not – we are thus confident in assuming this distribution for the coefficients. At the same time, estimation based on a GARCH specification of the variance structure yields qualitatively similar results.

Two sources of bias are conceivable when assessing the impact of monetary policy on asset prices using such an event study-inspired set-up.[11] First, reverse causality must be taken into consideration. In general, monetary policy decisions are taken as a function of economic and financial conditions. Hence, market developments may influence monetary policy decisions, as shown, e.g., by Rigobon and Sack (2003). Second, other important news, such as GDP releases or labour market data released during the measurement window (in our case, on the same day as a monetary policy announcement) may simultaneously affect asset prices and the market-based measure of monetary policy surprise. In other words, ex ante, we cannot rule out an omitted variable bias.

We address these issues as follows. On the one hand, we use control variables to take account of previous trends in asset prices and market developments, which could be triggers of subsequent policy interventions and asset price changes. Integrating the baseline controls contributes to effective containment of potential endogeneity issues. Moreover, testing for Granger causality in our data set suggests that the surprise measure relied upon is not driven by past asset price developments. In any case, from a central banking practice perspective, policy decisions are unlikely to be made based on short-run developments in asset prices, which by itself reduces the relevance of the endogeneity bias.[12] On the other hand, by measuring the daily change in asset prices, we allow markets sufficient time to process policy news without contaminating the measurement with too much noise.[13]

The financial market data are obtained from Bloomberg. We compute one-day changes as differences in basis points for bond yields ($x_t - x_{t-1}$), and changes in percentage points for equities and exchange rates ($(x_t - x_{t-1})/x_{t-1} \times 100$).[14] The sample data set spans from January 2008 to December 2014, containing 1827 non-weekend observation days. Depending on trading holidays and data availability, the effective number of observations entering the analysis varies among the individual assets, ranging from 1688 to 1763.

Due to Swiss trading hours, announcements by the Fed released after 10.45 a.m. local time (ET) are assumed to affect Swiss equity and bond yields one day after the announcement is made, whereas exchange rates are affected on the announcement day.[15]

[11] Gürkaynak and Wright (2013) provides an overview of the strengths and limits of the event-study approach.

[12] Endogeneity should be even less of an issue in the small open economy case considered in this study. Swiss asset price developments are very unlikely to affect foreign monetary policy decisions or foreign asset markets more generally.

[13] This is in line with the event-study literature that indicates a one-day window to be a reasonable length for measuring the financial market impact of monetary policies (e.g. Gürkaynak et al. (2005), Glick and Leduc (2012), Rogers et al. (2014), and Wright (2012)). More generally, the literature focused on estimating the asset price effects of conventional monetary policy suggests that both endogeneity and the omitted variable bias are minor issues (Rigobon and Sack (2004), Rosa (2011), and Gürkaynak et al. (2005)).

[14] Two-day changes are computed accordingly (x_t replaced by x_{t+1}).

[15] Swiss equity and bond market closure times, which are the cut-off points for daily values, vary between 5 p.m. and 6 p.m. Swiss time, in contrast to the market close for daily exchange rates, which is 10 or 11 p.m. Swiss time. For the purpose of our analysis, we assume that U.S. announcements made after 4.45 p.m. Swiss time affect Swiss equity and bond prices on the day following the announcement. One UMP event (a TALF extension on 10 February, 2009, which was released at 5 p.m. Swiss time) would be affected by a shift in the cut-off threshold from 5 p.m. to 6 p.m. An alternative approach to circumvent time zone-related issues is to rely on a two-day measurement window, see section 1.7.

BoJ announcements are consistently released before markets open in Switzerland. Therefore, they are assumed to affect Swiss asset markets on their release day. For ECB and BoE announcements, time zone differences do not matter in the Swiss case. Two ECB statements are released on a Sunday and are thus assumed to affect Swiss asset markets on the subsequent Monday.

1.4 UMP event selection

Estimating the impact of unconventional monetary policy announcements requires an appropriate, robust identification of unconventional monetary policy shocks. Identification entails two steps. First, a definition of the analysed policy 'events'. That is, we must determine when information about a specific policy was released (Faust et al. (2007)). Second, once the timing of the policy events is pinned down, we need a valid and robust measure of the extent of policy surprise – in other words, we need a measure of the size of the policy shocks. This section explains the strategy underlying the designation of UMP events, and section 1.5 explains the strategy used to identify the extent of policy surprise.

When selecting UMP events, we rely on the narrative approach of policy shock identification outlined in Romer and Romer (1989, 2004). To viably conduct such an approach, we have to outline the narrative of the crisis and the unconventional policy responses it evoked. To this purpose, annex tables A.1 and A.2 provide short descriptions of the key unconventional monetary policy programmes implemented by the Fed, ECB, BoE and BoJ between 2008 and 2014.[16]

Building on these programme descriptions, we identify the specific set of UMP announcements based on a thorough analysis of statements by the four central banks through press releases, media conferences and speeches of their governors. In doing so, we apply the following criteria to designate an announcement as an UMP event.

First, because our study focuses on measures aimed at securing monetary and macroeconomic stability, only those liquidity measures implemented predominantly for monetary policy reasons are included in our definition of UMP programmes; those focused mainly on financial stability are excluded. Hence, the first announcement entering as an UMP event dates in 2008. Obviously, it is not always easy to make an unambiguous distinction between liquidity provision programmes implemented as financial stability policies and those implemented for monetary policy reasons. To make the distinction, we rely on the crisis response narrative outlined above and an analysis of the key objectives of individual policy programmes as stated in their official descriptions.

Second, among the monetary policy announcements entering this group, announcements that do not include any changes in wording – i.e., contain no intended 'news' – regarding an UMP programme (for instance, a mere confirmation that a previously announced programme will continue as planned) are not included in our baseline event set. In this regard, our approach differs from Diez and Presno (2013), and Rogers et al. (2014), who base their analyses of exchange rate effects on all official (and scheduled) governing board

[16] Fawley and Neely (2013), Lenza et al. (2010), Cour-Thimann and Winkler (2012), and Rogers et al. (2014) provide detailed narratives of the financial crisis and the policy responses.

meeting statements over the course of the crisis. The key advantage of the more restrictive approach applied here is that it mitigates the problem caused by a large number of no news' events, i.e., it reduces the inclusion of noise, which weakens identification. One might argue that disregarding these events excludes the conceivable situation in which markets are expecting a central bank to move, but no move is announced. Although this argument is clearly important in theory, practical experience suggests that this problem is contained during the crisis because policy makers worked hard to ensure that markets knew in advance that policy would be changed on a specific day; the issue of surprise mainly concerns the scale of an announced policy change, not the change per se. In any case, we check the robustness of our event set selection by estimating the spillover effects based on an event set containing all monetary policy-related statements of the policy-setting bodies of the four central banks during our sample period.

The baseline event selection approach yields 97 UMP policy announcements: 34 by the Fed, 20 by the ECB, 16 by the BoE, and 27 by the BoJ. In seven instances, two different central banks release a statement on the same day; hence, the event set entering the estimation comprises 90 identified unique event days. The enlarged event set used for robustness contains 379 announcements, of which 73 were announced by the Fed, 98 by the ECB, 92 by the BoE, and 104 by the BoJ.

1.5 Measuring monetary policy surprise in the UMP era

The comparatively large number of announcements in our event set mitigates a crucial limitation of most studies on the impact of UMP announcements, namely, restrictions on inference and interpretation due to the small number of observations. However, given our expanded set of announcements, it is no longer plausible to argue that all events are fully surprising to market participants. Rather, it is appropriate to assume that market anticipation of unconventional policy announcements improves over time (e.g. McLaren et al. (2014)).[17] We therefore need an explicit measure of the anticipation of the content of a monetary policy announcement to correctly gauge the impact of policy statements on asset prices.[18]

[17]To circumvent this issue, many studies on UMP effects focus exclusively on the early rounds of UMP announcements, such as the QE1 or Fed LSAP1 programmes, arguing that these announcements can confidently be assumed to be fully surprising (e.g., Gagnon et al. (2011), Joyce et al. (2011), or Neely (2015)).

[18]Although there is broad consensus on the best (market-based) measure to capture the surprise content of conventional monetary policy announcements – the change in the federal funds rate futures in combination with the change in a somewhat longer-term financial instrument such as term federal funds, term eurodollars, or eurodollar futures (Gürkaynak et al. (2007), Gürkaynak et al. (2005), Poole et al. (2002), Rigobon and Sack (2004), and Piazzesi and Swanson (2008)) – a consensus has not yet emerged for measuring UMP surprises. A wide range of alternative measures is proposed in the literature. Quantitatively, one alternative is to take account of pre-event developments in financial markets (e.g. Fratzscher et al. (2013)). A second alternative is to use changes in the lagged dependent variable under scrutiny. In this spirit, Aït-Sahalia et al. (2012) use the difference between the asset price change on event day and its average daily change on the twenty days preceding the policy event. A third alternative that is similar but not identical to our baseline measure is the use of longer-term government bond forward rates (e.g., Chadha et al. (2013)). Fourth, changes in shadow policy rate estimates may prove useful for

We use the daily change in the price of 10-year government bond futures as a proxy for the extent of market surprise linked to unconventional monetary policy announcements and standardize this measure according to equation (1.2) by their standard deviation to ensure comparability among the measures for different economies. A positive change of the surprise measure – i.e., an increase in the price of the longer-term bond future – indicates that the policy is more expansionary than expected by market participants (and vice versa). Specifically, on average, a one-standard-deviation increase in the surprise measure implies a reduction in the corresponding foreign 10-year government bond yield of approximately 6 bp for U.S., German and U.K. yields and approximately 2 bp for Japanese yields.

$$\Delta s_t = \frac{f_t^{10y} - f_{t-1}^{10y}}{\sigma_\Delta f_t} \tag{1.2}$$

Our UMP surprise measure is closely related to the measure proposed by Wright (2012), which is also relied upon in Diez and Presno (2013) and Glick and Leduc (2012). However, we reduce its complexity threefold. First, we disregard the extraction of common factors from a broad range of futures contracts. Second, we rely on the change in these medium-term futures prices as a simplified approximation of their yields. Third, whereas Wright (2012) calculates intra-day changes in the futures yield, we rely on day-to-day changes. These simplifications allow us to use the same policy surprise proxy for all central banks and to circumvent issues regarding the limited scope of non-U.S. bond futures and the differences among futures contract specifications across economies.[19]

Because we rely on a market-based measure, it is not inconceivable that other market developments in addition to the policy announcement induce changes in this measure, particularly because we consider its daily changes. As previously discussed in section 1.3, this possibility potentially reduces the quality of this measure as clean identifier of monetary policy surprise. To verify that this issue is minor, we show that bond futures are a good proxy for 'news' in general and thus are a good proxy for 'monetary policy news' during the UMP period.

By construction, the announcements days selected in our event set contain news or a surprise regarding UMP. Hence, any good surprise proxy must – on average – exhibit stronger dispersion on these days than on days not selected as event days. As shown in

capturing the change in the monetary policy stance in an UMP/ZLB environment (Wu and Xia (2014), and Lombardi and Zhu (2014)). Qualitative measures of UMP expectations include survey-based data, such as the Reuters survey of London City economists (used, e.g., in Joyce et al. (2011) for the analysis of BoE UMPs), the Primary Dealer Survey (PDS) conducted by the New York Fed one week before each FOMC announcement (used, e.g., in Cahill et al. (2013)) and an ex-post analysis of newspaper articles on the market assessment of policy announcements (used, e.g., in Rosa (2012) and Lambert and Ueda (2014)).

[19] Wright (2012) uses two-, five-, ten- and thirty-year U.S. government bond futures contracts to compute changes in the yields of these futures in a short window spanning 15 minutes before to 1 hour and 45 minutes after a policy announcement. The futures yield change is approximated by dividing returns by the duration of the cheapest-to-deliver underlying bond. The first principal component of these changes in futures yields is then used as a proxy for the monetary policy shock. By definition, our simplifications reduce the information content entering the construction of the surprise measure. However, comparing the values of our surprise measure with those extracted by Wright (2012) for Fed announcements reveals that the statistical properties of these two series are similar in qualitative terms.

Panels 1, 2 and 3 of Table 1.1, descriptive statistics reveal that unconditional means and standard deviations of the daily change in long-term bond futures prices are considerably higher on event days than on non-event days. With the exception of BoJ announcements, dispersion is roughly 1.5 to 2 times higher on event days suggesting that the change in long-term government bond futures is a fairly well-suited proxy for market surprise on these days.

TABLE 1.1: DESCRIPTIVE STATISTICS: UMP SURPRISE MEASURE

Country/region	*US*	*EA*	*UK*	*JP*
Panel 1: All UMP event days (90 obs.)				
Mean	0.18	0.13	0.15	0.23
Standard dev.	1.69	1.34	1.10	1.05
Panel 2: UMP event days of corresponding central bank				
Mean	0.77	-0.25	0.19	0.35
Standard dev.	2.06	1.43	1.50	0.90
Panel 3: Non-UMP days (1656 obs.)				
Mean	0.01	0.04	-0.01	0.01
Standard dev.	0.94	0.98	1.00	0.98
Panel 4: Correlation with change in 10y gov. bond yield				
UMP event days of corr. central bank	-0.97	-0.98	-0.99	-0.79
Non-UMP days	-0.85	-0.91	-0.72	-0.63

Table reports descriptive statistics of the baseline surprise measure – the change in U.S., German (as proxy for the euro area), U.K., and Japanese longer-term government bond futures price for a sample running from 1 January 2008 to 31 December 2014. Panel 1 reports the statistics on all UMP event days, whereas Panel 2 focuses on the UMPs announced by the corresponding central bank, and Panel 3 on the days in the sample without a UMP announcement. Panel 4 reports the correlation of the change in the surprise measure with the corresponding local government bond yields. For example, on days with a Fed announcement, the first element in the 'US' column provides the correlation coefficient of the change in U.S. 10y government bond yields and the standardised change in the U.S. long-term bond futures price.

In addition, Panel 4 of Table 1.1 shows the correlation between changes in bond futures prices – the baseline proxy for market surprise – and changes in the corresponding foreign long-term interest rate – the implicit policy target in the UMP era. Overall, reported correlations are close to 1 in absolute terms. Moreover, the correlations are higher on event days than on non-event days. Considering these two facts together suggests that the baseline surprise measure is not only a good proxy for market surprise in general but also particularly well-suited for capturing news regarding unconventional monetary policies. Relatedly, using the publicly stated intention of the central banks implementing UMPs as a gauge, most announcements in our event set would be classified as expansionary. However, as Table 1.2 reveals, almost half of these announcements were in fact negatively surprising, i.e. less expansionary than expected. This underscores the importance of controlling for market anticipation.

Before turning to the empirical results, a remark on the ECB surprise measure is due.

Table 1.2: Announcements: Central banks' intention and market perception

Intention		*Expansionary*	*Neutral*	*Restrictive*	Σ
Perception	*Expansionary*	48	3	4	**55**
	Restrictive	36	1	4	**41**
	Σ	**84**	**4**	**8**	

Table compares the UMP announcement events in our data set classified by two different schemes: the first classification relies on the change in the policy stance as intended by the announcing central bank (expansionary, neutral or restrictive), whereas the second scheme relies on the policy stance as perceived by the markets based on our measure of policy surprise (expansionary = positive surprise, restrictive = negative surprise) described in section 1.5).

Summary statistics provided in Table 1.1 indicate that ECB announcements are, on average, less expansionary than expected, in contrast to the average announcement by the other central banks. This feature of ECB announcements can be linked to the fundamental challenge of implementing policies that have similar effects in every economy within a heterogenous monetary union. For instance, in response to the 'Whatever it takes' statement by ECB president Mario Draghi in July 2012, yields on German 10y bonds increased, whereas Italian and other periphery country long-term bond yields dropped. Put differently, in such a case, a decrease in the price of German bond futures indicates a more restrictive stance for safe assets, but it does not necessarily imply the same for more risky assets. This reasoning suggests that, to gauge the impact of ECB announcements on comparatively safe assets (such as Swiss assets), it is more appropriate to rely on the German long-term bond futures price than on a surprise measure derived from the movements of relatively risky assets, such as changes in Italian bond futures. We return to this issue in the robustness section.

1.6 Empirical results

1.6.1 Asset price summary statistics

As a starting point of the empirical analysis, we report key stylised facts on the one-day changes in Swiss asset prices and yields in our sample data set. Panel 1 of Table 1.3 reveals that the changes in all Swiss asset prices considered are substantially larger in absolute numbers on days with UMP announcements than on days without UMP announcements. The conclusion that the days designated as events are 'special' – that is, that they are surprising or reflect news of some sort – is also supported by higher standard deviations of asset price changes on event days.

Panel 2 of Table 1.3 shows that the introduction of the exchange rate floor in September 2011 by the Swiss National Bank (often referred to as 'minimum exchange rate', MER) has exerted an important impact on the average asset price reaction to foreign UMP announcements: after the MER has been put in place, the average changes are clearly smaller in absolute value for all assets. Moreover, with the exception of 10y government bond yields, the unconditional asset price changes on announcement days are positive on average, whereas they are negative in the 'before-MER' sample. Additionally, the dispersion of asset price reactions on days of foreign UMP announcements is more muted

Table 1.3: Descriptive statistics: Changes in Swiss asset prices

Asset price	*SMI*	*Euro*	*Dollar*	*Gov.*	*Corp.*
Panel 1: Whole sample (1 Jan 2008 to 31 Dec 2014)					
UMP event days (90 obs.)					
Mean	-0.18	-0.16	-0.14	-0.42	-0.43
Standard dev.	1.59	0.60	0.97	4.32	3.57
Non-event days (between 1598 and 1651 obs.)					
Mean	0.02	-0.01	0.00	-0.13	-0.14
Standard dev.	1.22	0.52	0.73	3.52	3.14
Panel 2: UMP event days before vs days during minimum exchange rate regime					
Before MER (47 obs.)					
Mean	-0.53	-0.31	-0.31	-0.71	-0.89
Standard dev.	1.89	0.77	1.11	5.05	4.36
During MER (43 obs.)					
Mean	0.25	0.01	0.04	-0.08	0.07
Standard dev.	1.04	0.18	0.73	3.16	2.33
Panel 3: Positively surprising versus negatively surprising UMP event days					
Positive surprise (51 obs.)					
Mean	-0.43	-0.26	-0.24	-2.51	-2.06
Standard dev.	1.32	0.65	1.05	3.38	3.20
Negative surprise (38 obs.)					
Mean	0.17	-0.02	-0.04	2.39	1.76
Standard dev.	1.84	0.47	0.81	3.75	2.86

Table reports summary statistics of the daily changes in the following Swiss asset prices: Swiss equity market index (SMI), bilateral exchange rates of the Swiss franc vs. the Euro (Euro) and U.S. dollar (Dollar), 10 year Swiss government bonds yields (Gov.) and the yields on CHF-denominated bonds of Swiss corporates with maturity between 7 and 10y, rated at least BBB (Corp.). Panel 1 compares the respective changes on UMP event days and on non-UMP days in the sample running from 1 January 2008 to 31 December 2014. Panel 2 compares the statistics of the asset price changes on UMP event days between 1 January 2008 and 5 September 2011 with the statistics for the event days in the period running from 7 September 2011 to 31 December 2014. On 6 September 2011, the Swiss National Bank introduced its minimum exchange rate policy (MER). Panel 3 compares the statistics of the asset price changes on days with positively surprising UMP announcements with those on days with negatively surprising announcements.

after the implementation of the MER. Thus, at first glance, the summary statistics support the hypothesis that the temporary change in the Swiss monetary policy regime had a containing impact on the spillover of foreign policies on Swiss asset prices.

Panel 3 of Table 1.3 indicates that examining positively and negatively surprising foreign UMP announcements separately is worthwhile. Taking the descriptive statistics at face value, positive surprises induce a fall in bond yields and equity prices and induce the Swiss franc to appreciate. In contrast, negative surprises push bond yields and equity prices higher and induce only very contained appreciation of the Swiss franc. In absolute terms, the unconditional means suggest that negative surprises have a more muted impact on all Swiss assets analysed.

1.6.2 The key role of market expectations

We start the empirical analysis by gauging the response of Swiss asset prices to foreign UMP announcements days without controlling for the extent of the surprise entrenched in such announcements. Panel 1 of Table 1.4 reveals that foreign UMP announcements have no significant impact on Swiss bond yields and equity prices, whereas the Swiss franc bilateral exchange rates appreciate, on average, on days with UMP announcements by foreign central banks. However, as discussed in section 1.5, the estimates tend to be biased if we do not control for market expectations regarding the policy announcements. In sufficiently efficient financial markets, only unexpected changes ('news') of monetary policy should have a systematic impact on asset prices. It is therefore likely that the empirical model used for the first regression mis-measures the true extent of anticipation and thus the true effect of foreign policy announcements on Swiss asset prices.

Results change considerably as soon as we include our benchmark proxy for market surprise – the change in the price of long-term government bond futures – as an explanatory variable instead of relying exclusively on a UMP day dummy, i.e. if we estimate equation (1.1).

Panel 2 of Table 1.4 provides the point estimates using the UMP event set as specified in section 1.4. Swiss long-term government and corporate bond yields and Swiss equity prices decrease in response to a positively surprising UMP announcement, and the Swiss franc appreciates against the U.S. dollar and the Euro. All estimates reported are significantly different from zero on a fairly high level.[20]

In qualitative terms, the spillover effects on bond yields obtained corrobarate the cross-border impact of UMPs uncovered by studies focusing on different sets of advanced or emerging economies (Glick and Leduc (2012), Rogers et al. (2014), and Bowman et al. (2015)). The effect on long-term Swiss government bond yields suggests that this specific asset class tends to be an adequate substitute for foreign long-term government bonds, i.e., the international portfolio channel appears to be important to explain how foreign UMPs spillover to Swiss government bonds.[21] Similarly, thedirection of the reaction in corporate

[20]Statistically, the overall explanatory power of our model for the variation in asset prices as measured by R^2 is small. This is not surprising, given the specification applied (a time-series approach with dummies) and the low ratio of event days to non-event days in our sample.

[21]Section 1.6.6 discusses the impact on the entire Swiss government bond yield curve in more detail.

Table 1.4: Foreign UMPs: Spillover effects on Swiss asset prices

Asset price	*SMI*	*Euro*	*Dollar*	*Gov.*	*Corp.*
Panel 1: All UMP events, not controlled for surprise					
Constant	0.04	-0.01	0.01	-0.13	-0.13†
	(0.199)	(0.453)	(0.762)	(0.134)	(0.083)
UMP event day dummy	-0.24	-0.14†	-0.24*	-0.34	-0.29
	(0.175)	(0.060)	(0.021)	(0.457)	(0.470)
No. obs.	1694	1763	1763	1718	1692
Panel 2: All UMP events, baseline surprise					
Constant	0.03	-0.01	0.00	-0.12	-0.13†
	(0.287)	(0.259)	(0.910)	(0.159)	(0.089)
UMP surprise (90 obs.)	-0.26**	-0.14*	-0.22**	-1.46**	-1.07**
	(0.007)	(0.017)	(0.002)	(0.000)	(0.000)
VIX	-0.03**	0.00†	0.00	0.03†	0.04**
	(0.000)	(0.094)	(0.520)	(0.054)	(0.001)
US Gov bonds	0.02**	0.00	0.00	0.15**	0.14**
	(0.003)	(0.629)	(0.879)	(0.000)	(0.000)
Lagged dep.	-0.08	0.04	-0.01	-0.06†	-0.02
	(0.225)	(0.361)	(0.642)	(0.093)	(0.505)
No. obs.	1694	1741	1741	1706	1692
Panel 3: All UMP events distinguished by origin of monetary shock, baseline surprise					
Federal Reserve UMPs (34 obs.)	-0.11	-0.16†	-0.38**	-1.28**	-0.96**
	(0.225)	(0.052)	(0.000)	(0.000)	(0.000)
European Central Bank UMPs (20 obs.)	-0.84**	-0.25*	-0.02	-2.06**	-1.34**
	(0.005)	(0.047)	(0.792)	(0.000)	(0.000)
Bank of England UMPs (16 obs.)	-0.17	-0.06	0.09†	-1.72**	-1.54**
	(0.333)	(0.333)	(0.081)	(0.001)	(0.000)
Bank of Japan UMPs (27 obs.)	-0.40*	0.05	-0.03	-1.16*	-0.39
	(0.014)	(0.578)	(0.866)	(0.044)	(0.442)
(Constant and controls omitted)					
No. obs.	1694	1741	1741	1706	1692

Table reports the main regression results. Significance levels are 1% (∗∗), 5% (∗), and 10% (†). Values in parentheses represent p-values. Panel 1 relies on a UMP event day dummy, whereas Panel 2 includes our baseline surprise measure. Panel 3 reports results obtained when separating the underlying event set by announcing central bank. Dependent variables reported are the Swiss equity market index (SMI), bilateral exchange rates of the Swiss franc vs. Euro (Euro) and U.S. dollar (Dollar), the yields on 10 year Swiss government bonds (Gov.) and the yields on CHF-denominated bonds of Swiss corporates with maturity between 7 and 10 years, rated at least BBB (Corp.). Asset prices enter as daily changes, measured either in percentage points (SMI, exchange rates) or in basis points (bond yields). UMP surprises are measured in units of standard deviations of the daily change in longer-term government bond futures. The sample runs from 1 January 2008 to 31 December 2014. The UMP event set comprises 97 statements (34 Fed, 20 ECB, 16 BOE and 27 BoJ), 14 of which were announced pairwise on the same day, yielding a total of 90 days on which at least one of the central banks released an UMP statement. The total number of observations for the assets may differ due to missing values on non-event days.

bond yields suggests that foreign UMPs spill over through international portfolio re-balancing and liquidity channels. The smaller size of the impact on corporates compared to long-term government bond yields is consistent with the reading that corporate bonds are less close substitutes to foreign risk-free bonds, as suggested by theory. In addition, it may also indicate that markets read the foreign UMP predominantly as a negative signal for the economic outlook and, consequently, may ask for a higher default risk premium.

The negative response of the Swiss equity index to foreign UMP announcements is consistent with the results obtained by Glick and Leduc (2012) for equity markets in other advanced economies. This result suggests that the negative variety of the exchange rate channel (appreciation weighing on expected earnings) and the international signalling channel (risk-off, negative economic outlook) outweigh the price-boosting impact induced through the international portfolio re-balancing and liquidity channels.

The estimated effects on bilateral exchange rates (FX) are in line with theoretical predictions and empirical results for other currency pairs (Glick and Leduc (2015), and Diez and Presno (2013)). Arbitrage conditions for currency triangles, e.g. for the Euro, U.S. dollar and Swiss franc, and the different sizes of bilateral exchange rate markets may affect the bilateral foreign exchange rate impact. Therefore, caution is warranted in interpreting the FX coefficients.

The control variables influence Swiss asset prices as expected. An increase in overall market uncertainty – indicated by an increase in the VIX – lowers the prices of risky Swiss assets. The U.S. long-term bond yield covaries positively with Swiss government and corporate bond yields, providing further evidence of the importance of cross-border financial market interlinkages. The lagged dependent variables do not affect changes in same-day asset prices, as suggested by the efficient market hypothesis. Nonetheless, these variables are included for identification reasons, as described in section 1.3.

1.6.3 Spillover effects by announcing central bank

Thus far, announcements by the various central banks have been analysed together. Bilateral asset price effects may be disguised. A more granular analysis separating the announcements by corresponding central banks – i.e., multiplying $\Delta s_t d_{t,events}$ in equation (1.1) with a dummy $d_{t,cb}$ for each foreign central bank – provides a better reading of bilateral effects.[22]

The coefficients reported in Panel 3 of Table 1.4 broadly indicate that the depth of financial linkages to be an important determinant of the strength of cross-border spillover effects. ECB announcements exert the strongest and broadest impact on Swiss asset prices, followed by U.S. and U.K. announcements, whereas BoJ events have only limited or no impact on the Swiss assets considered. This result is consistent with evidence obtained for other economies with close ties to, but outside, the euro area (e.g. Falagiarda et al. (2015)) and indicates that the degree of financial and economic integration matters for the exposure of an economy to foreign monetary policy shocks. Moreover, the

[22]The resulting surprise series takes the value of the foreign surprise measure on the day of an UMP announcement by the corresponding central bank and is set to zero otherwise. The number of events per central bank ranges from 16 to 34.

coefficients for bilateral exchange rates indicate that UMPs announced by corresponding central banks are most relevant for the respective effects. As an aside, the analysis reveals that indirect FX effects are present as well, with Fed events affecting the EURCHF and BoE events affecting the USDCHF exchange rate. This result is in line with predictions from monetary models of the FX (see e.g. Jackson et al. (2005)) and is supportive to the view that the FX estimates measured in our framework should be interpreted prudently.

Less intuitively, Fed and BoE statements do not have significant effects on Swiss equities, whereas BoJ events do. The U.S. and U.K. results indicate either that the effects of different channels (e.g., signalling and liquidity effects) cancel each other out in the Swiss case or that that the announcement effects per se are in fact negligible. The BoE result specifically may be explained, at least to some degree, with the comparatively low relevance of the U.K. economy for Swiss enterprises. The BoJ result, on the other hand, is largely driven by the initial announcement of the Quantitative and Qualitative Monetary Easing (QQME) program on 4 April 2013. BoJ events have no significant effect on the SMI when controlling for this outlier, which is more in line with expectations based on rather weak economic and financial links between Switzerland and Japan.[23]

1.6.4 Impact of SNB's minimum exchange rate policy

The introduction of an exchange rate floor of 1.20 Swiss franc per Euro by the Swiss National Bank on 6 September 2011 provides a perfect setting to test the impact of domestic monetary regime change on the size and scope of spillover effects of foreign monetary policy shocks on domestic financial markets.

To evaluate whether the UMP spillover effects are significantly affected by this exceptional change in policy in the recipient country, we interact the $\Delta s_t d_{t,events}$ term in equation (1.1) with a dummy $d_{t,mer}$. This dummy takes the value of 1 for the time period during which the minimum exchange rate was in place.

The results reported in Table 1.5 reveal that the direction of the reported spillover effects is not affected by the MER introduction. However, the average size of UMP spillover effects on bond yields and exchange rates is attenuated after the introduction of the MER. In particular, bilateral exchange rates no longer respond significantly to foreign UMP announcements. In contrast, the Swiss stock price index is more strongly affected by foreign UMPs after the MER introduction, and the effect is more significant. This outcome is consistent with the asymmetric design of the MER policy, which allowed the Swiss franc to depreciate freely, but capped its appreciation. This reading is also supported by more analyses (not reported to conserve space), which indicate that positive UMP surprises exerted substantially smaller and less significant effects during the MER period, whereas spillover effects related to negative surprises remained largely intact. That said, for all assets considered, F-tests do not allow us to reject the null of equality of the 'before'-MER and 'during'-MER coefficients.

[23] The QQME announcement marked an important change in the BoJ monetary policy regime by substantially increasing its efforts to fight deflation. The QQME is a comprehensive programme, encompassing a change in the main operating target from an overnight call rate to monetary base and a substantial increase in the size of asset purchases.

Table 1.5: Foreign UMPs: Minimum exchange rate (MER)

Asset price	*SMI*	*Euro*	*Dollar*	*Gov.*	*Corp.*
UMP events before MER (47 obs.)	-0.24*	-0.17*	-0.27**	-1.52**	-1.13**
	(0.041)	(0.043)	(0.000)	(0.000)	(0.000)
UMP events during MER (43 obs.)	-0.33**	-0.05†	-0.04	-1.27**	-0.85**
	(0.000)	(0.065)	(0.629)	(0.000)	(0.000)
(Constant and controls omitted)					
No. obs.	1694	1741	1741	1706	1692
F-test	0.33	1.91	3.50†	0.54	0.76
	(-0.56)	(-0.17)	(-0.06)	(-0.46)	(-0.38)

Table reports results obtained when spitting the sample on the day of the implementation of the minimum exchange rate (MER) by the Swiss National Bank on 6 September 2011. The F-test tests the null of equality of the coefficients obtained for the UMP surprise variable before and during the minimum exchange rate. For values in parentheses, significance levels, and units see Table 1.4.

The estimates obtained for spillover effects observed during the MER period suggest that the channels of international UMP transmission likely to be important for different asset classes – portfolio re-balancing and liquidity channels for government and corporate bonds; signalling and exchange rate channels for equities – remained operational. However, their relative weight may have changed to some extent with the introduction of the MER.

The relatively more contained effect on bond yields suggests that Swiss government and corporate bonds have lost some of their appeal during the MER period, as they no longer provided expected appreciation-induced valuation gains for foreign investors – thus spillover effects through portfolio re-balancing and liquidity channels tend to be less important.[24]

For equities, the same logic applies. In addition, however, we would also expect earnings of SMI-listed companies to be less negatively affected through the exchange rate channel. Although our empirical set-up does not allow for measuring the individual impact of these two counterbalancing effects, the obtained coeffcient for the SMI suggests that the 'loss of attraction' tends to outweigh the effect of an improved outlook for earnings in the Swiss case.In fact, the 'loss of attraction' argument may be most relevant for risky Swiss assets as they do not provide any specific characteristics that would make them more valuable compared to foreign risky assets. Swiss government bonds may still be of value to investors as safe assets, even without providing any expected appreciation gains.

1.6.5 Spillover effect asymmetry

The average effects reported thus far do not account for the fact that certain UMP announcements surprise markets positively whereas others are read as a disappointment (see Table 1.2). Hence, results based on the average extent of surprise only tell part of the

[24] It is important to note that this interpretation hinges crucially on the assumption that the average investor's risk aversion did not change with the MER introduction. Otherwise, it would be difficult to reconcile the reported estimates with the proposed narrative. For instance, if investors become more risk averse, we would expect Swiss government bonds to become relatively more attractive and their yields to fall more pronouncedly, given the role of Swiss government bonds as safe assets.

story. In this section, we discuss whether UMP spillover effects on Swiss asset prices differ between positively and negatively surprising announcements, as suggested in the analysis of Glick and Leduc (2012) with respect to other advanced economies. The question of asymmetric effects has two components: first, it is a question of whether the sign of the spillover effects differs between the two sub-groups of announcements. Second, it is a question of whether the strength of the corresponding spillovers differs between positively and negatively surprising announcements.

To address these two questions, we interact the main explanatory variable ($\Delta s_t d_t$) of equation 1.1 with a dummy for positive surprises ($d_{t,\Delta s_t>0}$) and a dummy for negative surprises ($d_{t,\Delta s_t<0}$). The first dummy takes the value of 1 if the surprise measure is positive, whereas the second dummy is set to 1 if the measure returns a negative value.[25]

To check whether the signs of spillover effects differ, we interact the absolute value of the explanatory variable of interest with two dummies for positive and negative surprises. In line with the results in Glick and Leduc (2012) for other advanced economies, Panel 1 of Table 1.6 indicates that Swiss equity prices and bond yields react negatively to positive surprises and positively to negative surprises and that the Swiss franc appreciates versus the Euro in the former case and depreciates in the latter. The Swiss franc appreciates against the US dollar in the case of positive surprises, but shows no significant reaction to negative surprises. F-test results indicate that the differences between the coefficients are indeed significant.

From a policy perspective, it is not only crucial to understand whether announcement effects differ in direction but also to know whether the size of the spillovers differs between positive and negative surprises. Therefore, we compare the coefficients from an estimation based on the the interaction of the dummies with the surprise measure as such, $\Delta s_t d_t$, not on its absolute values. The corresponding results reported in Panel 2 of Table 1.6 suggest that the SMI and all bond yields considered respond more strongly to announcements that do not meet the expected degree of expansion, whereas the opposite holds for the bilateral exchange rates.[26] F-test results imply that the long-term yields of both Swiss government and Swiss corporate bonds, as well as the USDCHF exchange rate, are more strongly affected by negative surprises than by positive surprises, whereas the impacts for the other asset prices do not significantly differ in terms of size.

The difference-in-size result contrasts markedly with the conclusion of Glick and Leduc (2012) that in a number of advanced economies, the spillover effects on asset prices induced by UMP announcements by the Fed and BoE are more important for positive monetary surprises than for negative surprises. This discrepancy can be attributed to various reasons. Glick and Leduc seem to draw their conclusion based on a set-up that allows for assessing the equality of coefficients in general but not the equality of the size of the estimated effects. Moreover, although the general estimation set-up is similar, crucial details differ in the specification and data base used. Most importantly in this regard, Glick and Leduc (2012) focus on the Fed's LSAP programmes and BoE's APP, relying

[25] Recall for interpretation purposes that in our classification, we denote as positive those announcements that are perceived as more expansionary and as negative those perceived as more restrictive relative to expectations.

[26] Note for purposes of interpreting the coefficient of the interaction with the negative surprise dummy: a negative value indicates a positive asset price change because it implies the multiplication of two negative values (a negative coefficient times a negative value of the surprise measure).

Table 1.6: Foreign UMPs: Spillover effect asymmetry

Asset price	*SMI*	*Euro*	*Dollar*	*Gov.*	*Corp.*
Panel 1: All UMP events distinguished by surprise direction (abs. value of surprise)					
Positive Surprise (51 obs.)	-0.20*	-0.15†	-0.30**	-1.27**	-0.97**
	(0.036)	(0.055)	(0.000)	(0.000)	(0.000)
Negative Surprise (38 obs.)	0.48*	0.11**	-0.07	2.13**	1.38**
	(0.016)	(0.002)	(0.439)	(0.000)	(0.000)
(Constant and controls omitted)					
No. obs.	1694	1741	1741	1706	1692
F-test	9.63**	9.56**	4.31†	65.70**	47.39**
	0.00	0.00	-0.04	0.00	0.00
Panel 2: All UMP events distinguished by surprise direction (baseline surprise)					
Positive Surprise (51 obs.)	-0.20*	-0.15†	-0.30**	-1.27**	-0.97**
	(0.036)	(0.055)	(0.000)	(0.000)	(0.000)
Negative Surprise (38 obs.)	-0.48*	-0.11**	0.07	-2.13**	-1.38**
	(0.016)	(0.002)	(0.439)	(0.000)	(0.000)
(Constant and controls omitted)					
No. obs.	1694	1741	1741	1706	1692
F-test	1.55	0.15	10.99**	4.15†	1.35
	-0.21	-0.7	0.00	-0.04	-0.25

Table reports regression results obtained when separating the underlying UMP event set into expansionary and restrictive UMP announcements. An announcement is classified as expansionary (restrictive) if the corresponding surprise measure is positive (negative). Panel 1 uses the absolute value of the surprise measure, thus allowing to test whether the sign of the coefficients differ among the sub-samples. Panel 2 relies on the standard surprise measure allowing for a test in the difference in size of the coefficients (see text for more details). For values in parentheses, significance levels, and units see Table 1.4. The F-tests test the null of equality of the coefficients for positively and negatively surprising announcements.

only on 15 announcements in total and a commensurately smaller number of negatively and positively surprising announcements.

1.6.6 Spillover effects along the Swiss yield curve

This section assesses the impact of foreign UMP announcements on Swiss government bond yields more thoroughly by extending the set of bonds examined along the maturity spectrum covering maturities of two, three, five, seven, nine, and ten years.[27]

The estimation results reported in Table 1.7 are again based on equation (1.1) and indicate that the impact of foreign UMP announcements on Swiss government bond yields increases with maturity until approximately 10 years. All estimated coefficients point to a dampening effect of foreign UMPs on yields and are highly significant.[28]

[27] We rely on generic ("benchmark") government bond yield series derived from Bloomberg, which does not provide trade volumes. By using these data, we assume that bonds are actually traded and that volumes - and therefore precision - are comparable. Qualitatively, the results are similar when using yield changes derived from a term-structure model calculated based on Swiss Government bond data.

[28] Note that the number of observations is similar for all bonds. For the 30y bonds, several missing

Table 1.7: Foreign UMPs: Spillover effects along the Swiss yield curve

Maturity	*2y*	*3y*	*4y*	*5y*	*7y*	*9y*	*10y*
Constant	-0.08	-0.1	-0.11	-0.12	-0.12	-0.12	-0.12
	(0.463)	(0.231)	(0.174)	(0.143)	(0.145)	(0.167)	(0.159)
UMP surprise	-0.69*	-0.82*	-1.02**	-1.15**	-1.16**	-1.55**	-1.46**
	(0.030)	(0.011)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
(Controls omitted)							
No. obs.	1707	1662	1707	1708	1615	1663	1706

Table reports regression results for Swiss government bond yields at different maturities using the baseline surprise measure. The underlying event set comprises all UMP events. For values in parentheses, significance levels, and units see Table 1.4.

Combining the result that the effect on Swiss government bond yields is largest at 7-10 year maturities with the fact that foreign bond purchase programmes focus predominately on precisely those maturities supports the view that Swiss government bonds are seen as close substitutes for foreign government bonds. This reasoning in turn lends support to the interpretation that an international portfolio re-balancing channel is important to an explanation of the transmission of foreign monetary policy shocks to the Swiss yield curve, whereas government bonds at different maturities within Switzerland seem to be imperfect substitutes.

Taking a more granular look, Figure 1.1 suggests that the MER introduction dampened the spillover effect along the entire Swiss yield curve and that negatively surprising announcements exert a stronger effect than positive surprises on government bond yields - the latter result being particularly relevant at 7 to 10 year maturities.

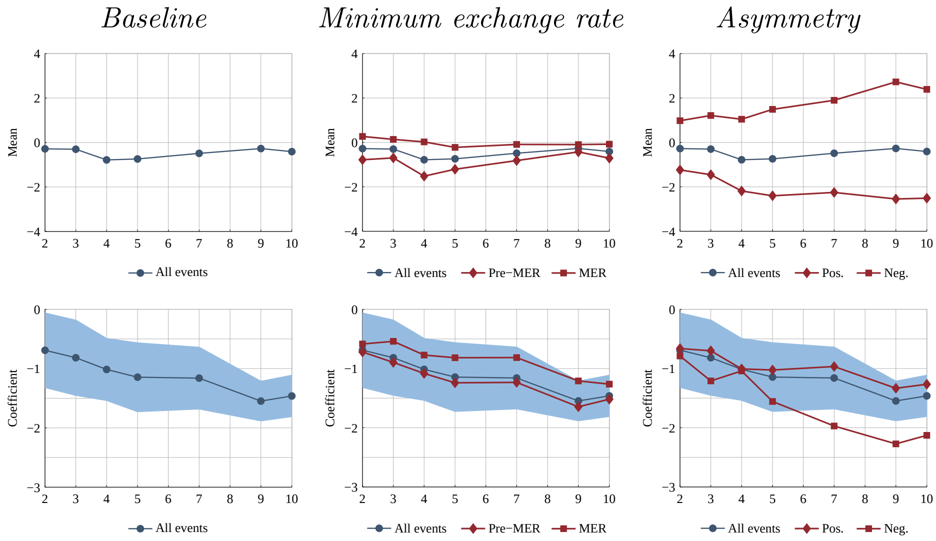
In the figure, the upper row of panels depicts the unconditional average yield changes on event days for the respective group of announcements and the lower row depicts the estimated coefficients obtained by the corresponding least squares regressions. For all government bond yields considered, the reported coefficients are smaller in absolute values in the sample that considers UMPs since the MER introduction. However, F-tests do not allow us to reject the null of equality between pre- and during-MER announcement coefficients for any maturity. Regarding the question of spillover effect asymmetry, the reported coefficients indicate, as they did in section 1.6.5 above, that the sign of the spillover differs between positive and negative surprises for yields at all maturities considered. Corresponding tests for asymmetry in the strength of spillover effects suggest, as above, that longer-term yields (7y to 10y) are slightly more affected by negative surprises than by positive surprises.

1.7 Robustness

The results reported in section 1.6 are robust to alternative choices of the event set, the policy surprise proxy, control variables, and the length of the sample and of the

values are reported primarily at the beginning of the sample. The results are qualitatively unchanged in an analysis based on a balanced sample of events (i.e., if the number of observations is balanced across maturities).

FIGURE 1.1: SPILLOVER EFFECTS ALONG THE YIELD CURVE



The charts in the first row depict the average change (vertical axis) of Swiss government bond yields at different maturities (specified on the horizontal axis in years) on event days. The charts in the second row depict the coefficients of the corresponding regressions using the baseline surprise measure. The charts on the left are based on all foreign UMP announcements; the charts in the middle separate these announcements into pre- and post-6 September 2011 (when the SNB announced the EURCHF-floor) samples; the charts on the right group the announcements by the sign of the surprise measure. Blue shaded areas represent the 95% confidence bands for the coefficient estimated based on all announcements.

measurement window, as well as to alternative specifications of the econometric set-up. We report the most important checks here.

First, following Rogers et al. (2014) and Diez and Presno (2013), we conduct the empirical exercise using an enlarged set of monetary policy events that contains *all monetary policy statements* between 2008 and the end of 2014, for a total of 379 announcements, including several instances of policy rate changes. Specifically, in addition to the baseline event set, this enlarged event set comprises all press releases or press conferences following regular, scheduled monetary policy council meetings that do not contain news regarding UMP programmes. The results of this exercise, reported in Panel 1 of Table 1.8, indicate that the estimates reported in the results section are in general robust to the inclusion of this broader set of policy announcements, with the exception of the impact of ECB annoucements on the USDCHF exchange rate, which is significantly larger in this case. This lends further support to our prudent approach when interpreting the exchange rate coefficients, as discussed in section 1.6.3.

< Table 1.8 about here >

Second, the discussion in section 1.5 indicate that the surprise measure used may be unreliable for *BoJ announcements*. Thus their inclusion may have detrimental effects on the statistical significance of our results. Excluding all BoJ announcements from the event set does not materially alter either the point estimates or their statistical significance.

Third, using the change in foreign 10y government bond yields on announcement days

Table 1.8: Robustness

Asset price	*SMI*	*Euro*	*Dollar*	*Gov.*	*Corp.*
Panel 1: Alternative event set: All monetary policy events, baseline surprise					
Constant	0.03	-0.02	0.00	-0.13	-0.13†
	(0.394)	(0.169)	(0.794)	(0.118)	(0.068)
Federal Reserve events (73 obs.)	-0.05	-0.11	-0.28**	-1.57**	-1.02**
	(0.703)	(0.117)	(0.001)	(0.000)	(0.000)
European Central Bank events (98 obs.)	-0.77**	-0.25**	0.22*	-1.99**	-1.32**
	(0.000)	(0.002)	(0.015)	(0.000)	(0.000)
Bank of England events (92 obs.)	-0.11	-0.03	-0.07	-0.95**	-1.50**
	(0.321)	(0.536)	(0.529)	(0.009)	(0.000)
Bank of Japan events (104 obs.)	-0.26†	-0.04	-0.07	-1.26**	-1.20**
	(0.070)	(0.473)	(0.457)	(0.001)	(0.000)
(Controls omitted)					
No. obs.	1694	1741	1741	1706	1692
Panel 2: Alternative surprise: sum of foreign futures changes					
Constant	0.03	-0.02	0.00	-0.12	-0.13†
	(0.335)	(0.199)	(0.797)	(0.143)	(0.086)
Federal Reserve UMPs (34 obs.)	-0.08	-0.07*	-0.12*	-0.56**	-0.47**
	(0.101)	(0.023)	(0.044)	(0.000)	(0.000)
European Central Bank UMPs (20 obs.)	-0.35*	-0.13*	-0.04	-0.73**	-0.59**
	(0.011)	(0.048)	(0.374)	(0.001)	(0.000)
Bank of England UMPs (16 obs.)	-0.05	-0.02	0.04†	-0.64*	-0.47**
	(0.524)	(0.481)	(0.061)	(0.017)	(0.000)
Bank of Japan UMPs (27 obs.)	-0.13*	-0.02	0.05	-0.47**	-0.33*
	(0.026)	(0.614)	(0.378)	(0.002)	(0.014)
(Controls omitted)					
No. obs.	1694	1741	1741	1706	1692
Panel 3: Alternative specification: Two-day event window, baseline surprise					
Constant	0.04	-0.03†	-0.01	-0.29*	-0.29**
	(0.365)	(0.055)	(0.698)	(0.015)	(0.007)
Surprise	-0.38**	-0.15*	-0.33**	-2.12**	-1.64**
	(0.009)	(0.028)	(0.003)	(0.000)	(0.000)
(Controls omitted)					
No. obs.	1717	1741	1741	1729	1715

Table reports results of main robustness checks. Panel 1 reports the coefficients obtained in a regression based on an extended policy event set containing all monetary policy announcements during the sample (1 Jan 08 to 31 Dec 14). Panel 2 reports the results based on the sum-of-surprise' measure described in the text. Panel 3 reports the results when measuring the impact on asset prices over a two day window around UMP announcements. For values in parentheses, significance levels, and units see Table 1.4.

instead of the change in the bond futures price as *alternative surprise measure* indicates that a positively surprising shock – a decline in the foreign bond yield – induces a fall in the SMI and the Swiss long-term bond yields, and a depreciation of the US dollar against the Swiss franc, thus confirming the results obtained in the baseline exercise in qualitative terms. On a per-central-bank basis, the baseline results are consistently confirmed for Fed, ECB and announcements individually. For the BoJ, the use of government bond yield changes as a proxy for market surprise indicates that BoJ announcements do not exert significant effects on Swiss equities – in line with the relatively weak economic and financial links between the two economies.

Forth, due to the lack of Euro area-wide bonds, we use the change in the price of the 10y German Bund futures as a proxy for measuring the surprise in ECB policy announcements. To address potential mis-measuring issues, Rogers et al. (2014) rely instead on the change in the *spread* between yields on Italian (relatively risky) and German (relatively safe) 10y government bonds, and interpret a lower spread as a positive UMP surprise. Using this spread as an explanatory variable, we do not find any significant spillovers on Swiss assets induced by ECB events. This result is similar to the international effects reported in Rogers et al. (2014), indicating that ECB announcements do not have an impact on bond yields in the US, Japan and France. This result is unsurprising, given that a decline in the aforementioned bond spread can be due to an increase or due to a decrease in the price of relatively safe assets. Moreover, it lends further support to our prior assumption that it is more appropriate to rely on a surprise measure derived from the reaction of a relatively safe euro-denominated asset, such as German long-term government bonds, if we are to gauge the announcement effect of ECB UMPs on relatively safe Swiss assets.

Fifth, although our estimates hint at significant effects of UMP announcements, we cannot guarantee that these estimates reveal the *direct impact* on Swiss asset prices exclusively from the origin country. The indirect effects of foreign policy announcements through their impact on asset prices in a third country could possibly dampen or magnify the bilateral effects on Swiss assets, because policy shocks may induce asset price co-movements around the world. The possibility of *indirect effects* potentially hampers the measurement of the true size of the cross-border asset price effects of monetary policy. To account for this possibility, we sum the individual changes in long-term government bond futures prices in all four foreign economies considered – that is, we assume that a event drives changes in futures prices in all four economies. For instance, on a BoE event day, we consider not only the change in value of the Gilt future but also the changes in the Bund future, Treasury future and Japanese long-term bond future price. This process is conducted for each event day accordingly, and the resulting sum of surprise' series is used as an explanatory variable in the regression. Summing all four foreign surprise measures on any UMP announcement day in this manner broadly confirms the baseline results. More specifically, as Panel 2 of Table 1.8 reveals, using this 'sum of surprise' measure returns coefficient values that are 2 to 3 times lower than those in the baseline analysis. The smaller size of the coefficients is related to the fact that the individual surprises are positively correlated, particularly on UMP announcement days, and hence the sum-of-surprise measure is larger than the individual surprise measure, on average. This allows us to interpret the size of the baseline results as an *upper bound* and the size of the sum-of-surprise-based estimates as a *lower bound* of the average spillover effect of foreign UMP announcements on Swiss asset prices.

Sixth, in qualitative terms, the estimations of the effect of monetary policy surprises on

Swiss asset prices based on one-day asset price changes can be repeated using a *two-day window*, see Panel 3 of Table 1.8. The coefficients tend to be larger than in the one-day window suggesting that markets may need a prolonged period of time to fully digest the UMP news.[29]

1.8 Concluding remarks

This study shows that UMP announcements by major central banks since 2008 have substantial spillover effects on asset prices in Switzerland. Specifically, an expansionary foreign UMP shock equivalent to a 25-basis-point decline in foreign long-term bond yields induces an approximately 6-basis-point decrease in Swiss long-term government bond yields, a 4.5-basis-point decrease in Swiss long-term corporate bond yields, a 1-percentage-point decrease in the Swiss Market Index, an approximately 0.6-percentage-point appreciation of the Swiss franc against the Euro and an approximately 0.9-percentage-point appreciation against the US dollar. Qualitatively, these estimates of immediate spillovers to Swiss assets corroborate the results regarding cross-border effects of UMPs on asset prices reported by Glick and Leduc (2012), Neely (2015) (selected advanced), Diez and Presno (2013) (bilateral and effective US dollar exchange rate effects), Chen et al. (2012) (Asian emerging markets), and Fratzscher et al. (2013) (groups of advanced and emerging economies, respectively).

Four extensions provide further insights. First, the degree of economic and financial linkages matters. Quantitatively, UMPs announced by the ECB have the most important impact on Swiss asset prices. In particular, bilateral exchange rates respond more strongly to announcements of corresponding central banks. Second, in contrast to Glick and Leduc (2012), our results suggest that the size of spillover effects does not differ materially between negatively and positively surprising announcements. Third, using the implementation of the minimum exchange rate policy, we show that even decisive domestic policy action only partially mitigates the spillover effects of foreign UMP announcements on domestic asset prices and bond yields. Fourth, a more granular bond market analysis suggests that Swiss 7-10y government bonds are fairly close substitutes for foreign long-term government bonds. Although substantial, the degree of substitutability is weaker for Swiss long-term corporate bonds and particularly for Swiss government bonds of shorter maturity.

A comparison of the spillover effects predicted by our estimates with the observed change in the corresponding Swiss asset prices on foreign UMP announcement days indicates that the estimated spillover effects are economically important: On the days of their announcement, foreign UMPs are by and large responsible for the observed decline in Swiss longer-term government and corporate bond yields, whereas they account for approximately 60% of the decline in the SMI and for approximately 35% and 40% of the appreciation of the Swiss franc against the Euro and the US dollar, respectively.

The reported results must be interpreted with appropriate prudence. A first note of cau-

[29] The two-day change is measured as the difference between the end-of-day value on the day after the announcement and the end-of-day value of the corresponding asset price on the day before the announcement.

tion concerns the role of market functioning and its potential impact on the reported results. The estimated effects of UMP statements are based on observations in a period during which markets may not have functioned fully or properly. Applying similar policies may not be as effective in more 'normal' times. Second, the jury is still out on the best approach to capture the surprise part of an unconventional monetary policy announcement. Third, this chapter approach does not allow for assessing quantitatively the contribution of individual transmission channels to the overall asset price effects. Nevertheless, our estimates tentatively suggest that a portfolio re-balancing channel is important for explaining spillover effects to Swiss government and corporate bond yields, in line with evidence provided by Bauer and Neely (2014) for other economies. For Swiss equity prices, on the other hand, negative effects through international signalling and exchange rate channels seem to outweigh the price-boosting effect of more abundant global liquidity and lower global discount rates. However, a formal assessment of the relative importance of the distinct spillover channels at work for different Swiss financial assets is left for future research.

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Chapter 2

The optimal conduct of forward guidance (in a closed economy)

Abstract

During the great financial crisis, various central banks resorted to forward guidance to provide additional policy accommodation at the zero lower bound. Yet, providing empirical evidence is difficult, as instances of forward guidance are few and have been deployed very differently over time and across countries. This chapter takes a theoretical approach to analyze the overall effectiveness and the 'optimal' specification of forward guidance, and compares the outcome of several types of forward guidance in a stylized DSGE model for a closed economy. These types cover promises to keep interest rates low until a specific date or until a specific condition is met, alternatively with a promise to simply keep interest rates *lower* than usual (through a more expansionary policy rule), or to conduct a more accommodative policy during interest rate normalization. Technically, the chapter distinguishes such types by specification (low interest rates vs more dovish rule), timing (immediately vs pre-announced), and triggers (calendar-based vs state-dependent). The effects of each type are compared on the basis of impulse response functions and utility-based welfare. Overall, guidance based on calendar dates emerges as more effective, as long as the central bank does not deviate too much from its traditional Taylor rule. Credibly delivering temporarily higher inflation can replicate the effects of committing to low interest rates. Guidance over the normalization path of interest rates can almost be as effective as immediately responding to an adverse demand shock.

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2.1 Introduction

When monetary policy hit the zero lower bound and purchases of assets no longer seemed sufficient, central banks reverted to an old instrument: forward guidance. This instrument involved no action, only words, nevertheless many thought it could be the most powerful yet. Central banks tried to convince markets they would keep interest rates low(er) for an extended period and allow for a little higher inflation in the future, in order to decrease real long-term interest rates deemed pivotal for the economic recovery.

In hindsight, gauging the actual effects of this new instrument is difficult: It was used to different extents, by different central banks, had different goals in different countries, and nearly always coincided with news of other policies, such as asset purchases. Some central banks tried to clarify their traditional reaction functions to market participants (as did the ECB in 2014), others tried to convince markets they would opt for a more aggressive reaction function temporarily, until the recovery was well established. Some expressed the deviation from their traditional rules over a given calendar period (as did the U.S. Federal Reserve between August 2011 and December 2012), others linked the new policy action to the evolution of one or several key variables (as did the Fed starting in December 2012).[2] Given this heterogeneity and the few instances of unique forward guidance announcements, empirical analysis is fraught with hurdles – not only regarding the overall effectiveness of forward guidance, but particularly with respect to the different types implemented by central banks.

This chapter tackles these two questions – the overall effectiveness and the 'optimal' specification of forward guidance – through the lens of a stylized DSGE model for a closed economy. The chapter first simulates the response of the economy to several types of forward guidance, then compares the outcome of the different types to each other, and to the baseline without forward guidance. Each forward guidance type represents a credible and pre-announced temporary change in the regular policy rule, followed by the central bank in normal times. A first dimension to alter the rule is timing: Deviations can last to different extents, and begin today or in the future. A second dimension is the trigger: The central bank can either announce a specific date for the start or end ('calendar-based') or make them conditional on certain economic conditions ('state contingent'). A third dimension is the specification: The central bank may commit to keep interest rates *low*, in our case at zero, or *lower*, as the adoption of a more dovish reaction function by temporarily raising either the inflation target or the sensitivities regarding inflation or output.[3]

We reduce the plethora of potential types to three main examples. First, we analyze a calendar-based forward guidance type, inspired by that of the Federal Reserve in 2011 and 2012. In addition to the Fed's promise to keep interest rates low, the chapter also evaluates lower interest rates than usual, by means of a more expansionary policy rule. Second, we follow the Federal Reserve in December 2012 and replace the calendar-based duration with

[2]See Woodford (2013) for an overview and the following examples, for instance. Alternatively, Charbonneau and Rennison (2015) or Moessner et al. (2015) also provide excellent overviews.

[3]A fourth possible dimension over which forward guidance can evolve is credibility: The central bank's policy announcement can be more or less credible in the eyes of market participants. We leave this last iteration for future work, building on the intuition and methodologies developed to study the first two possible variations.

a condition: Inflation must exceed a specific threshold, before the central bank returns to the usual policy rule (state-dependent duration). Throughout the chapter, this case is referred to as 'state-dependent' forward guidance. In order to reduce complexity, we assume that this type of forward guidance always starts today. Third, we address the effect of guidance on policy normalization, i.e. the promise to allow for higher inflation for a specific number of periods, *as soon as* interest rates lift off from the zero lower bound (state-dependent start). This case has no precise equivalent in reality, but might be linked to any 'gradual' approach in raising interest rates. Technically, the central bank replaces the calendar-based start with a condition, but announces the duration ex ante.

The chapter assesses both the positive and normative effects of such policies. The positive analysis compares impulse response functions of different forward guidance policies on key variables of interest: inflation, the output gap, and nominal and real interest rates, the normative analysis compares welfare – proxied by utility – resulting from different forward guidance policies. In each case, forward guidance is deployed in response to an aggregate demand shock large enough to temporarily bring nominal interest rates to the zero lower bound.

The method to solve the model and generate impulse response functions is chosen to account for two sources of non-linearities. The first is the zero lower bound, which imposes a non-linear constraint on the policy interest rates. And the second is the actual formulation of forward guidance, which also involves a non-linear path of interest rates: either remaining at zero for an extended period, or generated by switching between different Taylor rules. The model is thus solved using the perfect foresight approach, based on Newton methods, assuming the economy returns to steady state in finite time and that future shocks equal their expected value. The model is solved without recourse to linearization, so as not to affect solution paths away from steady state. Other papers discussed further below have tackled the hurdle of non-linear constraints differently, by either feeding shocks into the model after it is solved so as to respect the zero lower bound constraint, through piece-wise linear approximation, or through policy function iteration methods.

This chapter finds that forward guidance is generally effective at providing policy accommodation at the zero lower bound. In particular, calendar-based forward guidance expressed as a constant interest rate over a given period is especially effective at increasing welfare, measured by utility. Forward guidance can achieve the same results if the central bank convinces the markets it will allow inflation to temporarily overshoot its target. This is akin to the effects of a price-level target. State dependent forward guidance is sensitive to the parameters announced by the central bank. This is more than a technical point. Intuitively, if the central bank announces a threshold to return to its traditional Taylor rule that requires an overly aggressive monetary policy easing, it may be expected to give up its accommodative stance too early, thereby undermining its intentions to stabilize the economy. This reduces the feasible set of parameter values to those that allow for a measured, and sufficiently long, period of policy accommodation and, as a result, state-contingent forward guidance yields lower utility. This shortcoming can, however, easily be offset by announcing an overshooting of the conditions for a specific number of periods. Finally, forward guidance concerning the path of interest rate normalization can be as effective as guidance extended during the zero lower bound period. All results should be considered against their technical background: the perfect foresight solution method.

The usage of other solution methods, in particular stochastic methods, may affect and alter the results.

The chapter is structured as follows. The next section reviews the relevant literature. Section 2.3 reviews the solution methods and forward guidance specifications. Section 2.4 then summarizes results from the numerical simulations for i) calendar-based forward guidance, ii) state-dependent forward guidance, and iii) forward guidance related to normalization of monetary policy after lift-off from zero lower bound. Section 5 takes a closer look at state-contingent forward guidance, to explore sources of instability and the set of parameters allowing for model convergence. The last section concludes.

2.2 Related literature

The literature on forward guidance can be roughly split into two camps, corresponding to the two types of forward guidance discussed earlier. The first is Delphic guidance, and the second Odyssean, as defined in Campbell et al. (2012). Delphic guidance provides information on the central bank's existing reaction function or Taylor rule. The goal of Delphic guidance is to improve the signal to noise ratio of central bank actions, allowing markets to refine their expectations of monetary policy responses to specific shocks hitting the economy. Odyssean guidance, instead, aims to introduce a temporary deviation in the central bank's reaction function, often with the goal of providing additional policy accommodation at the zero lower bound. The literature on Delphic guidance is older and well developed, generally underscoring the efficiency gains from having a better understood reaction function. Eggertsson and Woodford (2003) provide a useful summary.[4]

The literature on Odyssean guidance – more relevant for this chapter – has instead attracted significant attention more recently, following its use by various central banks including the Fed, Bank of Canada and Bank of England, as reported in Woodford (2013). Early papers include Levin et al. (2010), and Carlstrom et al. (2012b,a, 2013, 2014). These papers study the effect on inflation and output of credibly committing to a more expansive monetary policy stance for a temporary period. In general, the effects of fixing interest rates a zero for an extended period led to implausibly large effects on inflation and output, as suggested in Negro et al. (2012).

Various papers have tried to understand why the effects of forward guidance are so large. A first strand of the literature alters the effectiveness of forward guidance through changes to the model specification. de Graeve et al. (2014), Kiley (2014) and Chung et al. (2015) show that sticky prices cause a large part of the huge responses, and introduce sticky information to dampen market responses to a central bank announcement. One channel for this dampening is that "agents may confuse the exogenous expansive nature of the policy announcement with (an endogenous policy response to) a worse outlook for the

[4] Moessner et al. (2015) notice that researchers and practitioners often talk differently about Odyssean forward guidance: Researchers often assume perfect credibility (or time-consistency), while practitioners seldom promise a deviation from their usual policy rule, if applicable, but are rather unusually transparent about their policy response in order to achieve at least some policy accommodation (that is, without publishing interest rate paths on a regular basis, such as the Reserve Bank of New Zealand or Norges Bank). Moessner et al. call the latter Aesopian forward guidance.

economy".[5] McKay et al. (2015) obtains similar results after introducing imperfect markets and precautionary savings. Cole (2015, 2016) shows that the expectation formation and financial frictions also dampen the effectiveness of forward guidance (in particular during a crisis where policy accommodation is heavily needed). The effectiveness of forward guidance can also be mitigated strongly if agents have heterogenous interpretations about the forward guidance, see Andrade et al. (2015). Another strand alters the effectiveness through changes to the solution methods or technical implementation of forward guidance. Chen (2014) or Boneva et al. (2015) attribute a considerable share of the effects to the (non-) stochastic environment, while Bundick and Smith (2016) show that the implementation of forward guidance may also explain part of the difference.[6] Last but not least, Harrison (2015) questions the assumption of modest policy interventions being still appropriate for models using forward guidance, given large deviations from the usual policy rate.

Fewer papers have studied state-contingent forward guidance and guidance provided on the path of normalization. Campbell et al. (2012), Christiano et al. (2014), Chung et al. (2015), and de Graeve et al. (2014) each introduce different thresholds to which forward guidance responds to successfully support the recovery. Florez-Jimenez and Parra-Polania (2016) and Schmitt-Grohé and Uribe (2014) find that rules leading to an overshooting of inflation during the normalization period yield a faster economic recovery. More recently, Boneva et al. (2015) show that state-contingent forward guidance is successful in both providing accommodation and providing a hedge against future (positive or negative) shocks.

The literature is also venturing into the field of forward guidance with imperfect credibility. Bodenstein et al. (2012) and Dennis (2014) assume, as in the Calvo framework, an exogenous probability that the central bank may revert back to its traditional monetary policy rule. As a result, forward guidance loses some effectiveness, and central banks promise especially aggressive monetary policy easing.

Finally, this literature should be distinguished from that on optimal monetary policy at the zero lower bound. Such papers aim to uncover a unique policy rule that is optimal both outside of, and at, the zero lower bound, as in Eggertsson and Woodford (2003), Jung et al. (2005), Nakov (2008), Levin et al. (2010), Adam and Billi (2006), Werning (2011), or Hasui et al. (2016). This aim is inherently different from that pursued by the literature on Odyssean forward guidance that explicitly allows for central banks to switch between two or more policy rules. Proponents of this literature are, for instance, well-known price-level targeting.[7] Bilbiie (2016) is an interesting extension in this regard – deriving an analytical expression for the *optimal* forward guidance length – while most aforementioned papers derive the 'best' solution by evaluating different specifications of forward guidance. Additionally, we should also separate this literature from that on the

[5]Quote from de Graeve et al. (2014). In consequence, the fall in the (nominal) long rate must not necessarily be due to forward guidance, and furthermore, the real rate drops less. Overall, imperfect information "limits the ability of the announcement to generate a boom".

[6]The former argue that deterministic solution methods, e.g. perfect foresight, lead to implausibly large effects. The latter show that implementing the *desired* policy rate as an inertia term into the policy rule proves sufficient to dampen the responses considerably.

[7]This literature also heavily relies on, and contributes to the question of discretion vs. commitment, and is thus related to the paragraph above.

optimal rate of inflation in the light of the zero lower bound, for instance as in Coibion et al. (2012).

This chapter distinguishes itself from the literature on Odyssean forward guidance in three ways. First, the model studies a variety of different forward guidance specifications with the same model, allowing for utility based comparisons. Second, this chapter gives particular weight to state-contingent forward guidance, and is among the first – to our knowledge – to investigate the conditions under which forward guidance is effective and feasible.[8] Third, the model is solved non-linearly, so that solution paths away from steady state – as they naturally emerge from interest rates remaining at the zero lower bound for an extended period – can be considered. Last but not least, the chapter puts particular emphasis on the mechanics, and comparison, of different varieties of forward guidance.

2.3 Methodology

In this section, we briefly outline the model, solution method, and various forward guidance specifications considered in this chapter.

2.3.1 Model and calibration

Our baseline model is a simple, stylized DSGE model with quadratic price adjustment costs à la Rotemberg (1996). Upon linearization (around a zero inflation steady state), this model is equivalent to the Calvo (1983) pricing framework, yet does not exhibit endogenous state variable price dispersion.[9] This is convenient in our non-linear model; in Calvo set-ups, dispersion usually disappears upon linearization.

We closely follow Braun et al. (2012) for the specification of the model. Briefly summarized, the model features a representative household with consumption, labour and inter-temporal bonds issued by the government, but no capital accumulation, investment or habit formation. Final good producers are perfectly competitive, intermediary good producers monopolistically competitive facing quadratic price adjustment costs. The final good producers have a CES production function with intermediate goods as only inputs, and producers of such goods have a linear production function with labour as the only input. Factor markets are perfectly competitive. The government runs a balanced budget with lump-sum transfers adjusted to the issuance of new bonds and (exogenous fraction of output) government purchases.

In this section, we only highlight the conditions that are different to the Calvo pricing framework, and refer to appendix B.1 for the full set of equilibrium conditions. Specifically, firms face individual (real) adjustment costs $\kappa_t(j)$ per unit produced

$$\kappa_t(j) \equiv \frac{\gamma}{2}\left(\frac{p_t(j)}{p_{t-1}(j)} - 1\right)^2$$

[8] As of 2015, this chapter was indeed the first. Since then, the paper from Boneva et al. (2015) addresses very similar questions.

[9] See Ascari and Rossi (2012) for a thorough comparison of the two frameworks, in particular if steady-state inflation is non-zero.

where γ the price adjustment cost parameter and $p_t(j)$ the (optimal) price set by the individual firm. Optimal pricing then leads to the following equilibrium condition

$$mc_t = \frac{\epsilon - 1}{\epsilon} + \frac{\gamma}{\epsilon}(\pi_t - 1)\pi_t - \mathbb{E}_t \frac{\gamma}{\epsilon}\left[\beta d_{t+1}\left(\frac{c_{t+1}}{c_t}\right)^{-\sigma}\pi_{t+1}(\pi_{t+1} - 1)\frac{y_{t+1}}{y_t}\right]$$

where mc_t are real marginal costs (equal across firms), π_t is gross inflation and ϵ is the elasticity of substitution.

Due to the (aggregate) price adjustment costs, aggregate output generally does not correspond to Gross Domestic Product (GDP).[10] Aggregate (real) price adjustment costs are $\kappa_t y_t$, and the fraction of output that the government consumes is η_t. As a result:

$$y_t = c_t + g_t + \kappa_t y_t = c_t + \eta_t y_t + \kappa_t y_t \qquad \leftrightarrow \qquad c_t = (1 - \eta_t - \kappa_t)y_t$$
$$\tilde{y}_t \equiv c_t + g_t = (1 - \kappa_t)y_t$$

The model is calibrated using standard parameters. Inter-temporal substitution is set to one, implying log-utility for consumption. This is somewhat lower than values in Levin et al. (2010), but if anything should dampen the response of economic conditions to forward guidance.[11] We further set $\nu = 0.2$ (inverse elasticity of labour supply), $\epsilon = 6$ (elasticity of substitution), $\beta = 0.994$ (discount factor), and set the labour weight ψ such that the share of steady-state hours worked corresponds to a third.

2.3.2 Monetary policy and forward guidance

To simplify the reading, we use two variables for the central bank's interest rates. Z_t denotes the *desired* interest rate, which may get negative (or smaller than one, using gross interest rates). This can either be the interest rate implied by the regular Taylor rule (Z_t^n), or an expansionary alternative, stemming from any particular type of forward guidance (Z_t^e). R_t instead denotes the *realized* interest rate, the interest rate that the central bank can achieve on money markets respecting the zero lower bound.

$$R_t = \max\{1, Z_t\}$$

The normal policy rule Z_t^n is a common Taylor rule, responding to an inflation and output gap based on the gross domestic product $\tilde{y}_t$. The Taylor rule parameters ϕ_π and ϕ_x are set to standard values 1.5 and 0.5, inertia ρ_r is set to zero unless specified otherwise.

$$Z_t^n = R_{t-1}^{\rho_r}\left[R\left(\frac{\pi_t}{\pi^\star}\right)^{\phi_\pi}\left(\frac{\tilde{y}_t}{\tilde{y}}\right)^{\phi_x}\right]^{1-\rho_r}$$

[10] This is the Rotemberg (1996) 'friction'. In contrast, the Calvo (1983) framework generates different prices and output levels across firms, which leads to inefficiencies, measured by an additional variable: price dispersion. Price dispersion generally follows a recursive process and is often accompanied by two auxiliary equations – the Calvo framework thus often carries two additional equilibrium conditions. Economically, price dispersion drives a wedge into the aggregate labour demand equation $a_t h_t = y_t$. In contrast, in the Calvo framework aggregate output corresponds to GDP.

[11] Nakov (2008), for instance, also considers values below unity.

Forward guidance, represented by the expansionary rule Z_t^e, can take different specifications. The promise of *low* interest rates corresponds to a constant interest rate path, denoted as c below (technically, the central bank could announce an arbitrary interest rate path). The promise of *lower* interest rates than usual refers to the Taylor rule, but raises either the inflation target ($\pi^e > \pi^\star$), the inflation sensitivity ($\varphi_\pi^e > \varphi_\pi$) or the output gap sensitivity ($\varphi_x^e > \varphi_x$) in order to provide additional stimulus given equal economic conditions.

$$Z_t^e = \begin{cases} c\ (IRP_t) & \text{constant interest rate path} \\ Z_t^n \text{ with } \pi^e > \pi^\star & \text{expansionary rule: higher inflation target} \\ Z_t^n \text{ with } \varphi_\pi^e > \varphi_\pi & \text{expansionary rule: higher sensitivity to inflation} \\ Z_t^n \text{ with } \varphi_x^e > \varphi_x & \text{expansionary rule: higher sensitivity to output gap} \end{cases}$$

Timing is also key for forward guidance. The central bank follows the expansionary rule Z_t^e for a specific period of time, from a starting date T_1 to an end date T_2, with $t \leq T_1 < T_2$, where t is today. In all other periods, the central bank follows the regular policy rule Z_t^n. Both dates are announced at the beginning (with the specification of the forward guidance), in accordance with the triggers below.

$$Z_t = \left\{ \begin{array}{ll} Z_t^e & \text{for } t \in \{T_1, \ldots, T_2\} \\ Z_t^n & \text{otherwise} \end{array} \right\}$$

Finally, the expansive monetary policy rule is set, or dropped, in response to specific triggers. In the case of calendar-based forward guidance, the triggers are specific dates, credibly announced at the beginning. These dates change to a value of chosen variables, say $d_t = \bar{d}$, for state-dependent forward guidance. The same holds for forward guidance over the normalization path, which is triggered once the economy has sufficiently recovered. In short, the start and end dates for forward guidance are set according to

$$T_1,\ T_2 = \begin{cases} t & t+K & \text{calendar-based} \\ t+j & t+j+K & \text{pre-announced calendar-based} \\ t & t(d_t > \bar{d}) & \text{state-dependent} \\ t(d_t > \bar{d}) & t(d_t > \bar{d}) + K & \text{guidance over the normalization path} \end{cases}$$

Each forward guidance type thus draws one element from the last three equations arrays. For all rules, we assume that the information set of the central bank and the public are identical and common knowledge.

2.3.3 Channels of forward guidance

Forward guidance works by affecting the real interest rate. This follows intuition: at the zero lower bound, policy can only provide further accommodation by decreasing the real interest rate through higher inflation expectations, or expectations of lower future interest rates. Forward guidance affects both. The relationship is clearly seen by iterating forward the (linearized) dynamic IS equation. Today's output gap is affected by future real interest rates, composed of the difference between nominal rates i_{t+j} and inflation π_{t+j+1}, as in

$$x_t = -\sigma\,\mathbb{E}_t \sum\nolimits_{i=0}^{\infty} \left(i_{t+j} - \pi_{t+j+1} - r^n_{t+j}\right)$$

It is thus important to underscore that forward guidance only works through the signaling channel of monetary policy. Most DSGE models abstract from term premia (long-term rates are merely the expectation of future short-term rates) and thus do not leave room for the portfolio rebalancing channel.

Under forward guidance, the expected short-term interest rates i_{t+j} are either fixed (in the constant interest rate path case) or follow a more expansionary policy rule (in the inflation target or sensitivities case) while forward guidance lasts. In the former case, there is no feedback from economic conditions to interest rates, while interest rates may respond in the latter case: they are *lower* given the same economic conditions, but not necessarily *low*. If forward guidance is overly effective, interest rates may thus also rise from the zero lower bound even before forward guidance ends. This feedback, the endogenous reaction to changes in economic conditions following the expansionary policy rule, is what de Graeve et al. (2014) refer to as the *endogenous channel*. Notably, such an endogenous reaction will alter the effectiveness of forward guidance.

2.3.4 Solution method

The model is solved using the perfect foresight (PF) approach, using Dynare (Adjemian et al., 2011). This approach assumes that the economy returns to its steady-state in finite time, and that agents replace future expected shocks with their expected value, so that certainty equivalence applies. As a result, the perfect foresight method numerically solves a finite set of equations using Newton methods.

For our analysis, this approach has several advantages. First, it accommodates the non-linear zero lower bound constraint, and the design of non-linear policy rules. Second, the method also allows for rules to be defined with indicator functions based on conditions with inequalities (such as $d_t \geq \bar{d}$). This is particularly convenient to study state-contingent forward guidance. Third, the full non-linear model can be solved. This allows us to study solution paths that are away from steady state, following a lengthy period at the zero lower bound, for instance. The main draw-back from this method is the inability to account for the uncertainty over future shocks (a fully stochastic environment).[12]

Alternatives to the PF method exist. The most common, introduced in Laséen and Svensson (2011), feeds anticipated shocks, known to agents at t, into the model to ensure that the zero lower bound restriction and the announced interest rate path will hold in equilibrium. However, the introduction of shocks is not innocuous, and can bias results as these become increasingly larger. Harrison (2015) finds that for large deviations from the

[12] Adjemian and Juillard (2014) introduce a solution method, the stochastic extended path (SEP), that allows for a limited degree of stochastic effects: It considers shocks during k periods ahead and reverts to the perfect foresight beyond. The computational burden, however, increases substantially for even small numbers of k. Since (our) forward guidance often lasts for several periods, the method did not prove useful for our purpose.

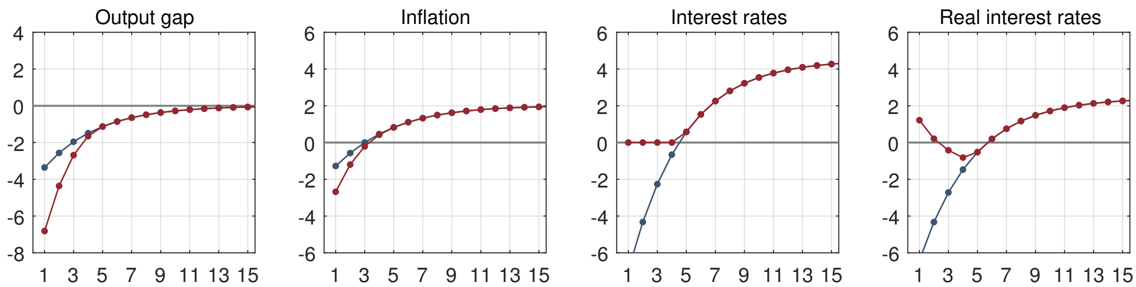
usual policy path, the underlying assumptions of 'modest policy interventions' (and/or rational expectations), and by these means the results seem questionable. Guerrieri and Iacoviello (2015), Jung et al. (2005) and Levin et al. (2010) instead rely on a piece-wise linear approximation – around the normal steady-state, and the steady-state where the constraint is binding. Papers focused on optimal policy at the zero lower bound resort to policy function iteration, value function iteration, and projection methods. While these methods are well-suited to investigate optimal policy, their use for (Odyssean) forward guidance has been limited so far, notable recent exceptions are Boneva et al. (2015), Gavin et al. (2013, 2014) or Keen et al. (2015).

The baseline scenario in the subsequent analysis is a large adverse shock, pushing the economy to the ZLB for four quarters (without forward guidance). This follows from a shock to the stochastic discount factor, as in Fernández-Villaverde et al. (2015).

2.4 Simulation results

We start the analysis by illustrating the effects of the zero lower bound on nominal interest rates. Figure 2.1 shows the response of the economy to a (large) negative shock on the discount factor, once without (blue), and once with the ZLB (red).

FIGURE 2.1: EFFECT OF ZLB TO A LARGE NEGATIVE DEMAND SHOCK



This figure depicts the impact of a large negative demand shock to the economy. If the zero lower bound does not bind (blue line), the central bank slashes nominal interest rates deeply into negative territory and dampens the negative of the shock somewhat. As soon as zero lower bound binds (red line), nominal interest rates remain at zero for four periods, real interest rates remain positive and exacerbate the slump in the economy. All units are percentage points, with inflation and interest rates in annualized terms.

Economic conditions deteriorate considerably when the zero lower bound binds. Without the ZLB, policy responds by cutting interest rates into negative territory for four periods, thereby generating negative real interest rates to stimulate the economy. As the ZLB binds, nominal interest rates remain at zero for four periods. Due to negative inflation, this yields positive real interest rates, and thus a more pronounced decline in output gap and inflation. Note that the response without the ZLB is by far not the optimal response to the negative shock – we do not consider optimal monetary policy in this chapter – the central bank merely follows the normal, unconstrained Taylor rule.

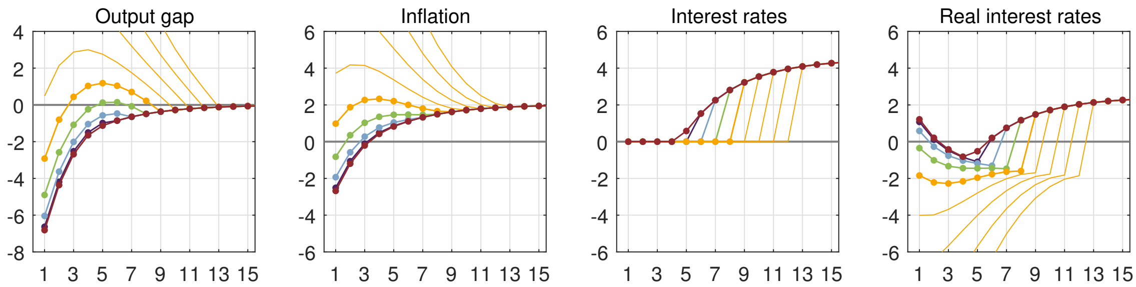
2.4.1 Date-based forward guidance

In the entire date-based forward guidance exercise, the date T_2 must be chosen larger than the ZLB would hold without forward guidance – otherwise forward guidance has no effect at all (the central bank would like to be more expansionary, but cannot since ZLB binds).

Constant-interest rate forward guidance

Constant-interest rate (CIR) forward guidance, if not overly extended, allows central banks to effectively stimulate the economy. We assume $Z_t^e = 1$ for all $t \in \{T_1, T_2\}$, where T_2 is chosen such that it is greater than the period up to which the ZLB is binding. Forward guidance clearly improves economic outcomes up to a certain point (orange, blue and green lines in Figure 2.2). But as forward guidance is extended over longer horizons, economic conditions explode (thin orange lines).[13] The response based on CIR forward guidance also outperforms the response to the regular Taylor rule without the ZLB.

FIGURE 2.2: CONSTANT-INTEREST RATE FORWARD GUIDANCE



This figure depicts the impact of calendar-based, constant-interest rate forward guidance, where the central bank promises to keep interest rates at zero for a prolonged period of time. In the baseline ZLB scenario (red line), negative inflation leads to positive real interest rates and a pronounced drop in output gap and inflation. Already a few periods of additional stimulus (violet to orange solid-dotted lines) lead to a decrease in real interest rates and increases in the output gap and inflation. However, economic conditions explode with longer durations (thin orange lines). All units are percentage points, with inflation and interest rates in annualized terms.

The sensitivity of results – and the power of forward guidance – come from the forward looking nature of the model and perfect credibility of central bank communication. Future real interest rates decrease with forward guidance, and have an immediate effect on the output gap and thus inflation. In a model with additional stickiness, such as habit formation, forward guidance might loose some of its impact, though the channels of transmission and basic takeaways remain unchanged. Models with imperfect central bank credibility also exhibit smaller effects of forward guidance. But the central bank might merely offset these hurdles with longer commitments to keep interest rates low.

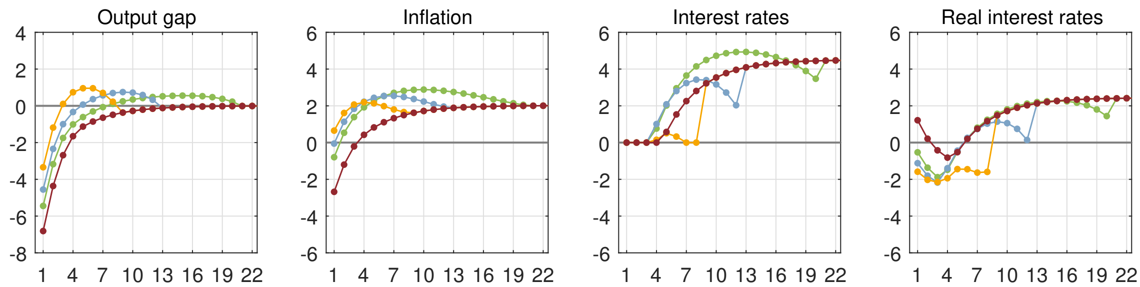
Raised inflation target forward guidance

A temporary rise in the inflation target ($\pi^e > \pi^\star$ for $t \in \{T_1, T_2\}$), credibly announced by the central bank, leads to lower interest rates given equal economic conditions ($Z_t^e < Z_t^n$) and also considerable amelioration of the recession. An immediate announcement that the

[13]Results do not change qualitatively if we allow forward guidance to start in the future ($T_2 > T_1 > 0$, graphs omitted). This is true for sufficiently short periods of forward guidance to warrant a smooth return to steady state.

inflation target is raised to 6% for two years (tripling the inflation target of 2%, orange line in figure 2.3) leads to zero nominal interest rates for most of the forward guidance duration and, through deeply negative real interest rates, a noticeable stimulus and overshooting of output gap and inflation. Increasing the duration while reducing the rise in the temporary inflation target (4% for three and 3% for five years, blue and green lines) has diverging effects: output gap overshoots less but longer, inflation overshoots more and longer, but overall, there is less amelioration today. Generally, this type of forward guidance is akin to announcing an overshooting of inflation in the return to steady state and, by these means, similar to price-level targeting.[14]

FIGURE 2.3: RAISING THE INFLATION TARGET



This figure depicts the impact of calendar-based forward guidance based on a more expansionary policy rule, where the central bank announces a temporarily higher inflation target for a prolonged period of time. Relative to the baseline ZLB scenario, the promise of a higher inflation target of 6% for two years (orange line), 4% for three years (blue line) or 3% for five years (green line) leads to overshooting inflation, lower real interest rates (at least partly) and an improvement and overshooting of the output gap. The economic conditions improve such that nominal interest rates lift off from the zero lower bound even before it ends to bind in the baseline scenario. All units are percentage points, with inflation and interest rates in annualized terms.

The responses differ from the constant interest rate case in two ways: First, in none of the cases, economic conditions explode as in the previous section. Second, the central bank raises interest rates even before the ZLB would end. Both are consequences of the *lower than otherwise* feature of inflation-target forward guidance, compared to the *low* (or zero) interest rate promise in the constant-interest rate case. Formally, this is a result of the *endogenous channel* introduced in section 2.3: The central bank responds endogenously to the improved economic conditions – themselves a result of the forward guidance announcement – while it keeps interest rates at zero no matter what in the constant-interest rate case. Put differently, the central bank mitigates the effectiveness of its own forward guidance.[15]

Additional remarks are noteworthy: First, the inflation target forward guidance can almost replicate the zero-interest rate forward guidance if the parameters are chosen accordingly, for instance a short but steep rise in the inflation target. Second, real interest rates are often equivalent to the case without forward guidance, they are lower only at the beginning and toward the end of the forward guidance. As we approach the end of forward guidance, the agents expect less remaining periods with expansionary monetary

[14]We assume that inflation in steady state returns to the 'normal' inflation target, i.e. (long-term) inflation expectations are not affected.

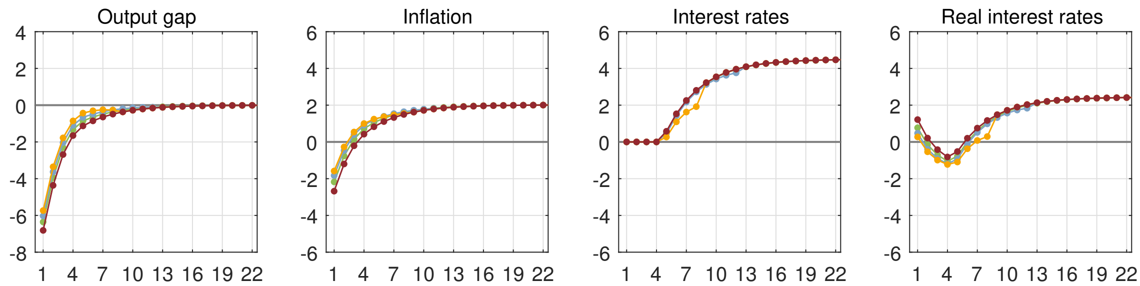
[15]For the sake of completeness, note that de Graeve et al. consider the effect of a pre-announced one-period shock, which would be akin to pre-announced date-based CIR forward guidance with length one in our case. Until the pre-announced shock takes place, the central bank of de Graeve et al. follows the regular Taylor rule. In contrast, we consider a more expansionary Taylor rule applied from period one, or today, to a specified period in the future.

policy, respond more mutedly, and the central bank sets a lower nominal interest rate (which leads to lower real interest rates). Third, it is unclear yet which specification of inflation target forward guidance is preferable. It seems that a high inflation target and a short duration provides the benefits of ameliorating the recession without the costs of an over-shooting inflation for several periods, but section 2.6 will shed more light on this.

Inflation and output gap sensitivity forward guidance

In sharp contrast to previous results, raising the sensitivity parameters for inflation and/or output gap ($\varphi_\pi^e > \varphi_\pi$ or $\varphi_x^e > \varphi_x$) does not yield noticeable policy accommodation, see figure 2.4. This is somewhat surprising at first sight, given another *less than otherwise* promise of the central bank. But, the purely forward-looking behaviour of the baseline model explains most of these disappointing results. First, both output gap and inflation return relatively quickly to their steady-state values. The scope for additional accommodation, relying on their deviation from their steady-state values, is thus limited. Second, the endogenous channel further mitigates any effect of the forward guidance. Last but not least, and in contrast to the previous results, output gap and inflation never overshoot. Due to the symmetric impact of the sensitivities, this type of forward guidance would even penalize such an overshooting.

FIGURE 2.4: RAISING SENSITIVITY ON INFLATION

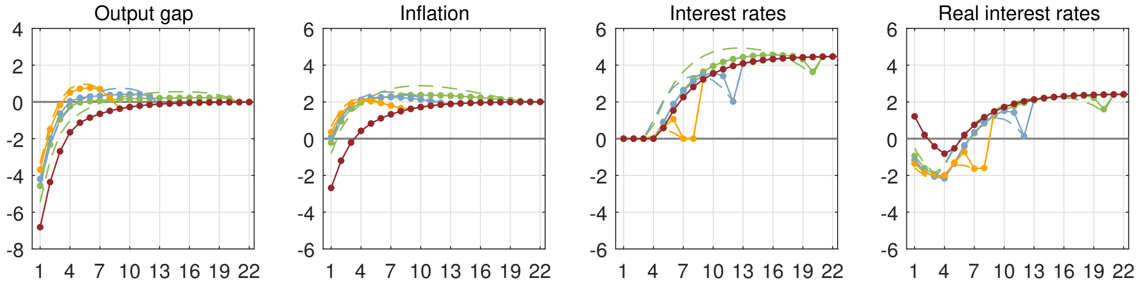


This figure depicts the impact of calendar-based forward guidance based on a more expansionary policy rule, where the central bank announces a temporarily higher sensitivity on inflation (results for the output gap sensitivity are essentially equivalent and omitted). Relative to the baseline ZLB scenario, raising the sensitivity by three for two years (orange line), two for three years (blue line) or one for five years (green line) has no noticeable impact on economic conditions. All units are percentage points, with inflation and interest rates in annualized terms.

Combined inflation target and sensitivity forward guidance

If per se not effective, can inflation or output gap sensitivities assist in improving other types of forward guidance? Yes and no, see Figure 2.5. Solid-dotted lines represent combined (both inflation target and sensitivities raised), thin dashed lines the corresponding inflation-target only forward guidance. Announcing higher sensitivities for both output gap and inflation thus dampens the overshooting of inflation and output gap, particularly for longer durations, but, at first sight, cannot provide additional amelioration of the recession today compared to the inflation-target only forward guidance case. The overall effect thus remains unclear at this stage (section 2.6 provides corresponding results for utility).

FIGURE 2.5: RAISING SENSITIVITY AND INFLATION VS INFLATION ONLY

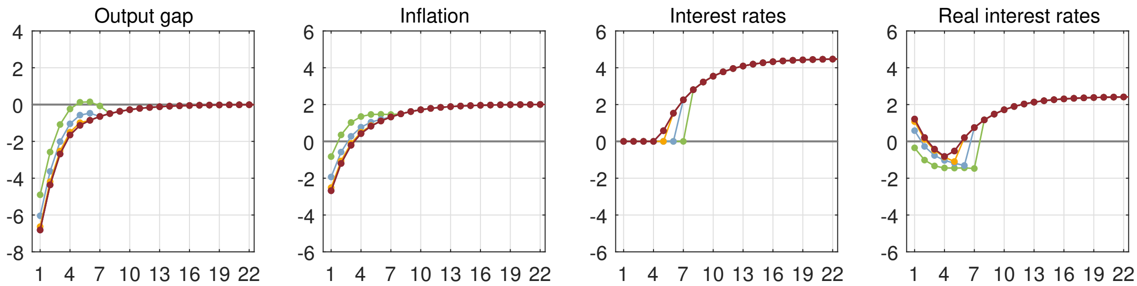


This figure depicts the impact of calendar-based forward guidance based on a more expansionary policy rule, where the central bank announces a temporarily higher inflation target (c.f. figure 2.3 for durations and levels) *and* higher sensitivities on inflation and output gap (both increased by two). Compared to the inflation target case only (dashed lines), raising the sensitivity contemporaneously (solid-dotted lines) considerably reduces overshooting of inflation and the output gap, yet without losing too much stimulus. In contrast, for longer durations (e.g. green line), combining the target and sensitivities proves rather beneficial. All units are percentage points, with inflation and interest rates in annualized terms.

2.4.2 State-dependent forward guidance

In December 2012, the Federal Reserve moved from date-based towards state-dependent forward guidance: Interest rates shall remain low until unemployment drops below a certain threshold while inflation must remain below a specified value. In our terminology, the forward guidance specification – the expansionary policy rule (Z_t^e) – will be applied until one or multiple conditions ($d_t > \bar{d}$) are met.[16]

FIGURE 2.6: ZERO INTERST RATES UNTIL INFLATION EXCEEDS A THRESHOLD



This figure depicts the impact of state-dependent forward guidance, where the central bank promises zero interest rates until inflation exceeds thresholds of approximately 1% (orange line), 1.2% (blue line), and close to 1.5% (green line). Compared to the ZLB baseline and previous figures, the impact on economic conditions of such forward guidance is visible but limited; three periods of additional stimulus (green) is the best the central bank can achieve.

Overall, state-dependent forward guidance seems rather limited in providing policy accommodation. Figure 2.6 shows, for instance, the effect of promising to keep interest rates at zero until inflation reaches a certain threshold. Different colours imply different (possible) thresholds, however, none of them provides nearly as much accommodation as previous forward guidance specifications did. The most accommodative (feasible) forward guidance specification (green line) implies three additional periods of zero interest rates – one or two periods less than implied by the most successful specifications so far. One

[16] A simple way to implement state-dependent forward guidance is to calculate forward guidance for several durations and check for each duration whether economic outcomes meet their conditions at the corresponding duration. Using the perfect-foresight solution method in Dynare, we can circumvent this manual selection process and impose the condition directly by using an index function. In addition, we replace unemployment conditions with output gap conditions, similar to Chung et al. (2015).

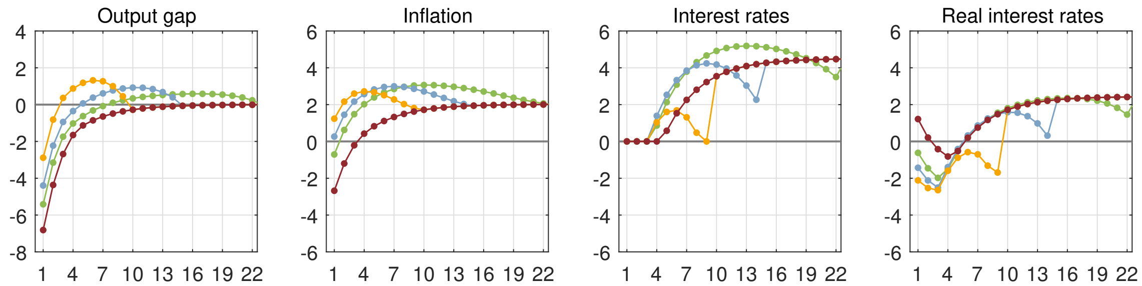
potential explanation is that the inflation condition is not sufficient. However, adding a second condition for the output gap does not improve the outcome, if not worsen (results omitted). Since the response of the output gap to forward guidance announcements is also very strong, if not stronger than that of inflation, the set of feasible specifications (in terms of determinacy of equilibrium) seems even more limited than in the inflation-only condition case.

Note that this sub-section showed feasible specifications only. Section 2.5 provides additional details on the mechanics and determinacy of equilibria for this type of forward guidance, and thereby on the efficacy of state-dependent forward guidance.

2.4.3 Guidance over the normalization path

Our third type of forward guidance provides guidance over the normalization path. For instance, the central bank promises to follow a higher inflation target for two years once it lifts off interest rates from zero. The main difference to previous specifications is the trigger of forward guidance: The central bank promises accommodation *once* a condition has been met, instead of promising accommodation *until* a pre-specified time or condition being fulfilled. This type of forward guidance relies upon the fact that forward guidance is entirely ineffective during the period where the zero lower bound binds – the efficacy of forward guidance generally stems from promises made for periods beyond the zero lower bound. In our terminology, the aforementioned example promises a temporary increase in the inflation target ($Z_t^e < Z_t^n$, with $\pi^e > \pi^\star$) for a specific duration K (until $T_2 = T_1 + K$) once the condition, a lift-off as suggested by the regular Taylor rule, is met ($T_1 = t(d_t > \bar{d}) = t(Z_t^n > 1)$).[17]

FIGURE 2.7: GUIDANCE ON NORMALIZATION



This figure depicts the impact of guidance on normalization, where the central bank announces a more expansionary policy rule, by raising the inflation target temporarily, once interest rates lift off from the zero lower bound. Overall, the findings are almost equivalent to raising the inflation target as of today, c.f. figure 2.3. The promise of a higher inflation target of 6% for two years (orange line), 4% for three years (blue line) or 3% for five years (green line) leads to overshooting inflation, lower real interest rates (at least partly) and an improvement and overshooting of the output gap. Compared to the ZLB baseline, nominal interest rates lift off one period earlier (and trigger the forward guidance). All units are percentage points, with inflation and interest rates in annualized terms.

Guidance on normalization is also highly effective, with appropriate parametrization. All three cases considered and depicted in figure 2.7 – an increase in the inflation target to 6% for two years, to 4% for three years or to 3% for five years – provide accommodation by

[17]Certain specifications are inherently problematic. For instance, a promise to apply zero interest rates after a lift-off from the ZLB, as measured by the implemented interest rate, is not feasible since we would never leave the ZLB. Formally, there is no equilibrium for most specifications of this type.

means of an amelioration of today's economic conditions. The results are, by construction, very similar to the results for date-based temporary rises in the inflation target.

2.4.4 Preliminary summary of simulation results

Various specifications of forward guidance are highly effective in providing accommodation when needed. Date-based forward guidance with a constant interest rate seems most effective, but also most sensitive. Inflation-target based specifications can equal their performance, if the parameters are set accordingly. Note, however, that the results are conditional on the deterministic solution method. In a stochastic set-up, rules with an endogenous component or with an endogenous condition (either to trigger or end forward guidance) may serve as a hedge against (un)favourable shocks occurring after the forward guidance has been promised and thus yield different outcomes (in particular if different specifications are compared to each other). Among others, see Appendix A of Boneva et al. (2015) for a comparison of deterministic and stochastic set-ups.

2.5 State-dependent: Mechanics, determinacy and improvement

State-dependent forward guidance is among the least effective types of forward guidance. This section first provides an explanation by means of its mechanics and determinacy, then shows a simple way to improve the efficacy: A promise to overshoot the condition for a specific time.

2.5.1 Mechanics and limitations

An announcement of forward guidance always has two instant implications[18]

Step 1: The central bank releases an forward guidance *announcement* with an explicit (date-based) or implicit (condition) *duration* (K_1).

Step 2: The *agents respond* to the initial announcement (and its implied duration K_1), assumed to be fully credible, and economic conditions adjust accordingly.

These two steps are sufficient for specifications with date-based triggers, such as the constant interest rate specification: The central bank announces forward guidance, the agents respond. There is no feedback (or second round) and hence no further adjustment. In specifications with endogenous triggers, such as state-dependent forward guidance, additional steps take place.

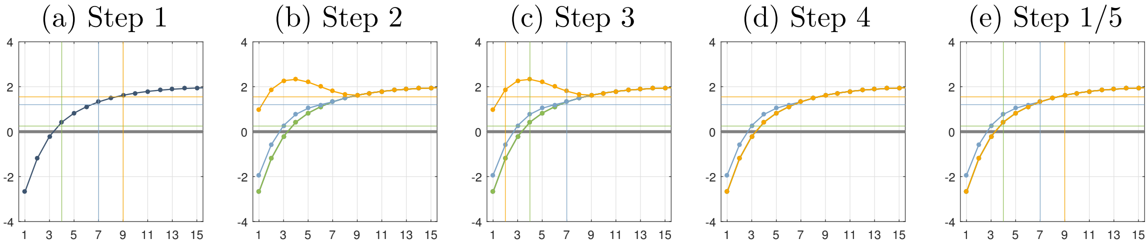
[18] Note that the general equilibrium feature of DSGE models implies that these are implicit steps only. Nevertheless, they serve well for the purpose of this section: explaining the mechanics and limitations of state-dependent forward guidance.

Step 3: The response of Step 2 leads to an update of the *implied duration* (K_2) of the (unchanged) promise of the central bank.
Step 4: The *agents respond* to the updated implied duration (K_2).

The following example shows that these additional two steps are crucial for explaining how and why state-dependent forward guidance can fail. If the threshold of the initial announcement is too high (inflation above 5%, for instance), the central bank would be forced to keep interest rates at zero for a long period (Step 1). This, in turn, would imply a very large response of agents today (Step 2). In our exercise, the central bank would need to keep interest rates at zero for ten periods such that inflation exceeds five percent ($K_1 = 10$, according to figure 2.2, second thin orange line). This strong response, however, implies that the conditions of the announcements would already be met today and that the central bank would not need to run forward guidance at all ($K_2 = 0$, Step 3 conditional on Step 2). This updated implied duration of zero, however, mitigates the response of agents of the response in the case without forward guidance (Step 4) and thereby implies the same duration as in the beginning ($K_{1 \text{ or } 3} = 10$, back to Step 1).

The implied durations K_1 and K_2 are thus essential for the determinacy of the equilibrium. If the central bank announces a threshold which is too high, the implied durations of Step 1 and 3 differ ($K_1 > K_2$) and we keep running through Steps 1-4 over and over; there is no equilibrium. The opposite, a very low threshold, aught to be feasible from a technical point of view, but neither desirable from an economic point of view: The implied duration K_1 is so low that there is no or very little stimulus for the economy (recall that any duration lower than the duration of the zero lower bound yields no stimulus at all).

FIGURE 2.8: THE MECHANICS OF STATE-DEPENDENT FORWARD GUIDANCE



This figure illustrates the implicit steps that determine the equilibrium of state-dependent forward guidance. All plots depict annualized inflation rates and different colors represent different inflation thresholds (horizontal lines). The steps represent different implied durations of forward guidance (vertical lines) and different responses of agents (solid-dotted lines). Only if the durations of (a) and (c) match, we find an equilibrium. If the central bank announces an overly aggressive threshold (orange), implied forward guidance duration jumps (a) and economic conditions improve (b) such that in the next implicit step, the central bank would need to run hardly any forward guidance at all (c), which leads to an adjusted response in (d), and we are back in (a): there is no equilibrium.

Figure 2.8 illustrates this issue for three different thresholds. In plot (a), the central bank announces three thresholds (horizontal lines) with corresponding implied durations (vertical lines).[19] This triggers the response of the agents in step 2, depicted in plot (b). In the orange case (high threshold), the response would be so strong that its updated implied duration falls to one (step 3, plot (c)), i.e. the central bank would not even need to run forward guidance given this response. The durations and responses for the lower two thresholds are much weaker (blue and green). Plot (d) depicts the fourth step, the updated response of the agents conditional on the new implied duration. The implied

[19]Note that the duration of the forward guidance is one period less than the position of the vertical line. The central bank lifts interest rates as soon as the condition is met.

one-period forward guidance from the third step (orange) destroys any benefit from early steps, and the central bank is 'forced' to run its forward guidance for the initial implied duration (plot (e)). The implied duraation jumps from forth and back between eight and one; technically, there is no equilibrium. For the blue and green cases the response is so weak that the implied durations do not change; technically we have an equilibrium, which is, however, no desirable either given the weak responses.

2.5.2 Determinacy and improving state-dependent forward guidance

The previous paragraph showed that the choice of the threshold is crucial, and sensitive. This section thus derives the feasible ranges for the inflation threshold. We derive the ranges graphically in figure 2.9, but the results are confirmed by a numerical grid search (results omitted).

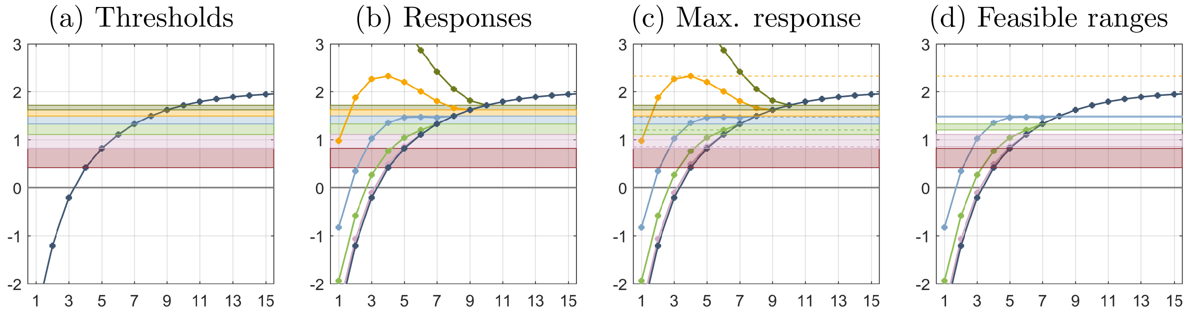
We proceed in two steps. First, we calculate the implied duration for each threshold that could be announced by the central bank (omitting the responses of the agents at this stage). Equivalently, we can plot the thresholds that correspond to specific implied durations, as in plot (a). Each shaded area corresponds to a different implied duration, and the blue-dotted line depicts the response of the economy without forward guidance. Plot (b) shows the responses of the agents to each of the implied duration, or threshold respectively; the colors of the lines matches the one of the corresponding thresholds. These responses are equivalent to those of the date-based constant-interest rate case, as in figure 2.2 (due to the promise of keeping interest rates at zero until the condition is met). The next required item are the maximum of the responses, see the dashed lines in plot (c). If the response exceeds the threshold range of plot (a) before the last period of the duration, the strong response would imply a shorter updated duration in Step 3 above, a weaker response in Step 4 and no equilibrium. In the orange case, for instance, the response exceeds the range already in period two; see the previous paragraph for the unfavorable outcome. Only if the maximum lies within the threshold range, we have an equilibrium. The feasible range for each implied duration then covers values from the corresponding maximum (lower bound) to the upper range of the threshold range. These final, feasible ranges are depicted in plot (d).

We clearly see that the range of feasible thresholds quickly narrows for longer durations (due to the concave shape of the inflation response in the zero-lower bound case). In this deterministic setup, the choice of an appropriate threshold is thus not only delicate, but its delicacy even increases with the efficacy of the state-dependent forward guidance. One presumed problem of state-dependent forward guidance is the strong response of the agents in the second step, or plot (b) in figure 2.9. Yet, reducing the efficacy of the response might do little good:[20] The implied duration of step one should increase with decreasing efficacy and might thereby offset any gains from the reduction in the response. We thus expect this finding to also hold in other, potentially larger models with additional rigidities or stickiness.[21]

[20]For instance through lowering the sigma, according to the discussion in Levin et al. (2010).

[21] Again, a stochastic setup may change this conclusion considerably or even twist the findings – see for instance Boneva et al. (2015).

Figure 2.9: State-dependent: Threshold regions for equilibria



This figure derives feasible ranges for the inflation threshold if the central bank announces state-dependent forward guidance. All plots depict annualized inflation rates. Horizontal lines and areas depict different thresholds, solid-dotted lines the response of the economy to different implied durations (on the horizontal axis). Each area in (a) corresponds to one implied duration and is determined by the response of the baseline ZLB case at this duration. For instance, the light green area yields an implied duration of six periods and is determined by the two dark-blue dots at six and seven. The corresponding response of the agents to this implied forward guidance duration is depicted in (b). If the green response exceeds the green area at any time (the dashed lines in (c) represent the maximum of the response), the implied duration would shorten and we do not get an equilibrium (c.f. figure 2.8). The feasible range for forward guidance (d) is thus the range from (a), corrected for the maximum response of (c) if the latter lies within the former.

A simple and effective way to improve the state-dependent forward guidance, however, is to announce an overshooting of the conditions for several periods.[22] Such overshooting lifts the potential efficacy of state-dependent forward guidance considerably (results omitted): to the levels of date-based equivalents or guidance over normalization. This improvement is no surprise: If the Fed promises to keep interest rates at zero until inflation has exceeded a specific threshold for eight periods (or increase the inflation target by x%), the response is so strong that the conditions are met soon, if not today, and the overshooting state-dependent announcement gets akin to a date-based promise for eight periods. Detailed results based on utility follow in the next section.

2.6 Utility-based evaluation

This section underlines the previous results – based on impulse response functions – with an appropriate 'welfare' measure: the utility of the representative household.[23,24] For each specification, we calculate the utility according to the households (discounted) utility function, as provided in equation (2.1) (for details see section B.1.1). An approximation of utility by a quadratic loss function – commonly used in the literature, for the derivation see e.g. Woodford (2003, chapter 6) – is neither necessary nor consistent with the non-

[22]Noticeably, this had been suggested by the International Monetary Fund to the Federal Reserve Board in their 2016 Article IV Consultation with the United States of America: "[..] the path for policy rates should accept some modest, temporary overshooting of the Feds inflation goal to allow inflation to approach the Feds 2 percent medium-term target from above." Available at https://www.imf.org/en/News/Articles/2015/09/28/04/52/mcs062216.

[23]Note that given the deterministic solution method, we refrain from calling this utility 'welfare' in the following and stick to the term 'utility'.

[24]Linear (perturbation) approaches would have provided similar impulse response functions so far, since household know about the uncertainty but do not adjust their behavior amid the uncertainty (their response is linear, i.e. certainty equivalence holds). This similarity, however, only holds for situations that are close to the steady-state. If the economy is far away from the zero lower bound, perturbation methods may lead to different results. In this section, results may additionally differ due to uncertainty.

linear solution method. To facilitate comparison of utility levels, we show utilities relative to that of the zero lower bound case (without forward guidance).

$$U_t = \mathbb{E}_t \left[\sum_{j=0}^{\infty} \beta^j \left(\prod_{k=0}^{j} d_{t+k} \right) \left(\frac{c_{t+j}^{1-\sigma}}{1-\sigma} - \varphi \frac{h_{t+j}^{1+\nu}}{1+\nu} \right) \right] \tag{2.1}$$

Table 2.1 shows the highest utilities achievable with a certain forward guidance specification. The left panel depicts date-based, the right panel state-dependent and guidance over normalization. Within each panel, we show the highest utility level for different specifications. Note that this table does *not* provide guidance on the parameter constellation that leads to the corresponding utility levels, and that the table only provides a ranking of the different forward guidance specifications (the numbers have no direct economic interpretation).

TABLE 2.1: HIGHEST UTILITY ACHIEVABLE

Specification that yields highest utility

Date-based forward guidance	Rel. utility	State-dependent	Rel. utility
Constant-interest rate	2.27	Constant-interest rate, condition for inflation	1.41
Inflation target	2.23	Constant-interest rate, condition for output gap	0.16
Inflation sensitivity	0.89	Constant-interest rate, condition for both	1.41
Output-gap sensitivity	1.08		
Inflation target and both sensitivities	2.27	State-dependent with overshooting	Rel. utility
		Constant-interest rate, condition for inflation	2.27
		Inflation target, condition for inflation	2.23
		Guidance on normalization	Rel. utility
		Inflation target, cond. on desired interest rate	2.06
		Inflation target, cond. on interest rate being set	0.91

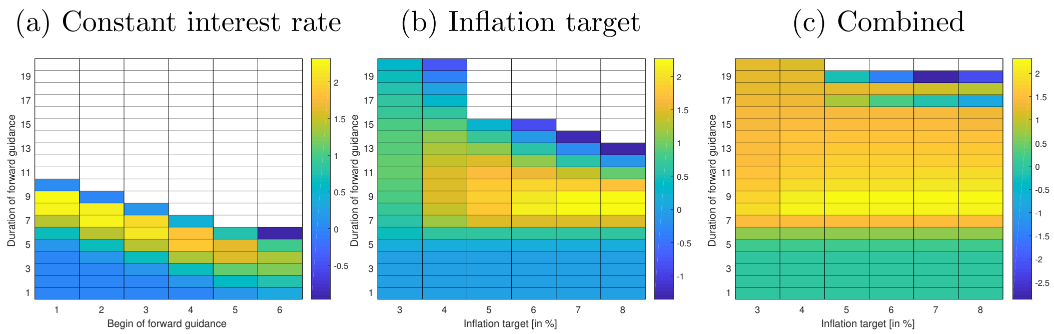
This table shows the utility of forward guidance specifications relative to the ZLB scenario: Positive numbers imply higher utility with than without forward guidance. The numbers do have only one purpose, the ranking the specifications, and have no (other) economic interpretation. For each forward guidance type provided, the table only shows highest utility achievable. Guidance on normalization is shown for two triggers: Lift-off from the regular Taylor rule (Z_t), or lift-off from the interest rate set by the central bank (R_t, affected by forward guidance). Clearly, forward guidance is beneficial in all cases, but the differences among the types are substantial.

The table broadly confirms the results derived from the impulse-response section. Date-based forward guidance is, overall, most powerful in offsetting a negative shock leading to the zero lower bound. Among the date-based triggered forward guidance types, the constant-interest rate case takes the lead, closely followed by the inflation-target specification and, surprisingly, tied by the combined date-based forward guidance (a rise in inflation-target and sensitivities). In contrast, individual results for inflation or output gap sensitivities are rather disappointing. Communicating a temporary rise in inflation and/or output gap sensitivities thus seems only desirable in combination with other forward guidance specifications (to provide sort of a hedge against a strong overshooting).

Table 2.1 also confirms previous results for the state-dependent forward guidance and guidance on normalization. State-dependent forward guidance with a contemporaneous condition is limited in its efficacy, while guidance on normalization benefits from its resemblance to (date-based) inflation-target forward guidance and thus comes close to the results for the date-based case. As expected, announcing an overshooting of the inflation condition for a specified amount of periods enhances the efficacy of state-dependent forward guidance substantially: it now matches the performance of the best specifications so far.

How sensitive are the utility results to the selection of (forward guidance) parameters, such as the announced duration, or the temporary rise in the inflation target? Figure 2.10 provides guidance on this question. It shows the utility, colored by level (high utility levels are yellow, low levels are blue), for three specifications of date-based forward guidance: constant-interest rate, inflation target, and combined, i.e. a contemporaneous rise in inflation target and sensitivities. In all three plots, the vertical axis depicts the duration of forward guidance. For the constant-interest rate case, the horizontal axis depicts the start of the forward guidance (pre-announced or immediate), for the other two the rise in the inflation target. If there are additional parameters which are not plotted, such as the sensitivities in the right plot, the plot depicts the highest utility achievable for each axis value combination (i.e. the sensitivities may differ across the plotted values). The white areas contains both negative utility beyond -2 and no determinacy cases. Note that the colouring is relative within each plot and hence not fully comparable across the plots.

FIGURE 2.10: SENSITIVITY OF DATE-BASED FORWARD GUIDANCE UTILITY



This figure depicts the relative utility of various date-based forward guidance types, compared to the ZLB baseline. Yellow colored cells represent high utility, dark blue low utility. Different to table 2.1 that shows the highest utility per type, utility might get negative in this case, i.e. forward guidance be harmful in terms of utility. Colors are relative within each plot and not necessarily comparable across plots. To enhance readability of the charts, specifications with very low utility levels had been removed (missing, white).

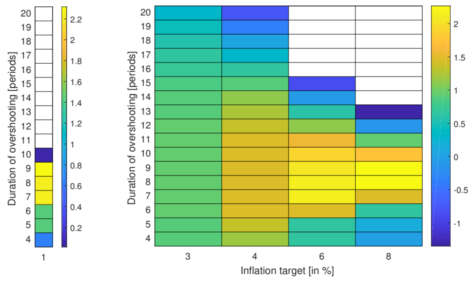
The sensitivity charts for date-based forward guidance confirm the results from the impulse-response section. Date-based constant-interest rate forward guidance is highly effective, but also very sensitive with regard to the duration. Utility quickly drops if the duration is set either too long or too short. Furthermore, pre-announced forward guidance appears to be somewhat less effective.[25] In terms of rising the inflation target, a short but steep rise in the inflation target indeed seems favorable to a longer duration with lower inflation target. Negative aspects of a prolonged overshooting of inflation and output gap hence outweigh the obvious benefits of a higher output gap. Rising the sensitivities at the same time, however, seems very favorable: It enhances the efficacy slightly (see table 2.1) while strongly reducing the sensitivity by mitigating the persistent overshooting of inflation and output gap. In other words, the range of close-to-optimal specifications widens and

[25]Potential reasons are the strong overshooting of the economy, but also the endogenous response of the central bank to this overshooting: a rise in interest rates before forward guidance actually starts – it sets the interest rates according to the Taylor rule until forward guidance starts – that mitigates the overshooting.

the error margin for a policymaker facing decisions under uncertainty narrows. The results are similar for the state-dependent forward guidance and guidance on normalization: constant-interest rate specifications are extremely sensitive, while inflation target variants are overall somewhat less powerful but also less sensitive.

Figure 2.11: Sensitivity of state-dependent forward guidance

(a) CIR (b) Inflation target



Notes

This figure depicts the relative utility of state-dependent forward guidance, where the central bank announces zero interest rates (a) or an expansionary policy rule by means of a higher inflation target (b, inflation target on horizontal axis) as long as inflation does not exceed a certain threshold for a specific number of periods (vertical axis). Utility is always compared to the ZLB baseline. Comments from figure 2.10 on negative utility, colors and removed values also apply.

Figure 2.11 illustrates these results for the state-dependent forward guidance case (with overshooting). The left bar, plot (a), shows that utility rises substantially if inflation is required to overshoot between seven and nine periods (the difference in colors to figure 2.2 stems from different scales). Adding one period, however, drastically reduces the utility of the agents. In contrast to this sharp drop, the yellowish ranges are larger for the inflation target case: Both different periods or lower inflation targets do reduce utility, but less sharply than in the constant-interest rate case.

2.7 Concluding remarks

The present chapter tackles the question whether forward guidance is an effective instrument to counteract a large negative shock, and if, which specification of forward guidance seems preferable. In order to assess these questions, we employ a standard DSGE model with the standard Taylor rule representing the central bank's policy rule (in regular times), and solve the model non-linearly using a deterministic framework. In response to a large negative shock, we evaluate forward guidance specifications along three dimensions: timing (immediate vs pre-announced relative to the path of normalization), specification (commitment to zero interest rates vs a more dovish reaction function), and triggers (calendar-based guidance vs state-contingent guidance). The effects of each combinations are compared on the basis of impulse response functions and utility-based welfare.

We find that forward guidance is generally effective at providing policy accommodation at the zero lower bound. In particular, calendar-based forward guidance expressed as a constant interest rate over a given period is especially effective at increasing welfare utility. Forward guidance can achieve the same results if the central bank convinces the markets it will allow inflation to temporarily overshoot its target. This is akin to the effects of a price-level target. State dependent forward guidance efficacy is limited, i.e. sensitive to the parameters announced by the central bank. This is more than a technical point. Intuitively, if the central bank announces a threshold to return to its traditional Taylor rule that requires an overly aggressive monetary policy easing, it may be expected to give up its accommodative stance too early, thereby undermining its intentions to stabilize the economy. This reduces the feasible set of parameter values to those that allow for a measured, and sufficiently long, period of policy accommodation. As a result, state-contingent forward guidance yields lower utility. Finally, forward guidance concerning the path of interest rate normalization can be as effective as guidance extended during the zero lower bound period.

The sensitivity of utility for different forward guidance specifications varies along the three dimensions timing, specification and trigger. First of all, constant-interest rate path forward guidance is always highly sensitive to the duration initially announced. One additional period can turn a highly effective and beneficial into a harmful announcement – always compared to the standard Taylor rule response. On the other side, forward guidance with a temporary rise in the inflation target is less sensitive to both duration and the rise in the target. Increasing the sensitivities for inflation and output gap at the same time yields additional margin with respect to mis-specifications of parameters: The range of beneficial specifications broadens considerably.

The limited efficacy of state-dependent forward guidance specifications is partly explained by the responsiveness of the economy to the initial announcement (and the perfect foresight solution method). Reducing this responsiveness, however, does not appear useful in increasing its efficacy: The promise *until* would now imply a longer duration, potentially offsetting the lower responsiveness. Another, simple yet effective way to increase the efficacy of state-dependent forward guidance is overshooting. In this case, the central bank announces that interest rates remain low not only until inflation exceeds a specific threshold, but rather that inflation must exceed (overshoot) this threshold for a specific number of periods, say one year. Such overshooting yields utility levels almost fully comparable to those of date-based forward guidance.

All results must be considered against the deterministic framework applied in this chapter. A stochastic setup, such as in Boneva et al. (2015), may change the results and the interpretation thereof. In a stochastic setup, all forward guidance types that enclose an endogenous factor – rule, trigger or duration – may provide a hedge against these shocks. Date-based constant interest rate forward guidance, instead, might either provide too much or too little accommodation.

Future work should focus on three issues regarding forward guidance in a closed economy. First, any comparison of different specifications should cover a stochastic environment and solution method. Second, credibility is crucial and requires additional work. Third, Third, adding Quantitative Easing or other unconventional monetary policy tools, may provide interesting insights, potentially also to enhance credibility. Last but not least, forward guidance may work differently in an open economy.

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Chapter 3

Forward guidance in a small open economy: the transmission of international shocks

Abstract

The literature on forward guidance so far has put little emphasis on open economies. This paper contributes to this area and analyzes the extent to which forward guidance looses its potency in an open economy – in three aspects. First, the paper analyzes the efficacy of forward guidance in response to a large negative domestic shock, and sheds light on the interplay of international linkages and forward guidance. Second, the paper analyzes its impact on the transmission of international shocks, i.e. its efficacy in dampening or offsetting spillovers from a large negative shock abroad. Third, the paper not only analyzes forward guidance on interest rates, but also on the exchange rate: The central bank may announce a temporary peg for the exchange rate. We use a stylized two-country New Keynesian (DSGE) model to analyze these questions, where central banks follow their policy rules in normal times and revert to three types of forward guidance if interest rates are constrained by the zero lower bound: A fixed interest rate path (low interest rates), a temporary rise in the inflation target (lower interest rates through a more expansionary rule) or a temporary peg for the nominal exchange rate. The paper shows that forward guidance is a powerful tool – both against domestic or foreign shocks – and thus successfully alters the international transmission of shocks from abroad. Forward guidance based on constant interest rates (low for long) is generally most effective, but also most sensitive to a mis-specification of the duration. Forward guidance based on a temporarily higher inflation target or a temporary peg for the exchange rate is much more stable and yet still effective.

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3.1 Introduction

The recent academic literature on forward guidance has grown rapidly, with a particular emphasis on ways to explain and mitigate the incredibly large effect that theory often suggests. But, the majority of this research considers closed economies only, whereas contributions on forward guidance in open economies are yet scarce.[1] This paper contributes to this area in analyzing the extent to which forward guidance looses its potency in an open economy – in three steps. First, we analyze the efficacy of forward guidance in response to a large negative *domestic* shock. Second, we analyze its impact on the transmission of international shocks, i.e. its efficacy in dampening or offsetting spillovers from a large negative shock *abroad*. Third, we analyze not only forward guidance on interest rates, but also on the exchange rate: The central bank may announce a temporary peg for the exchange rate. The entire analysis takes place in a stylized two-country (DSGE) model.

The applications of forward guidance by central banks of open economies vary considerably. The Swedish Riksbank or Bank of Canada, for instance, used forward guidance on interest rates in order to provide additional monetary policy stimulus.[2] Similarly, the Bank of Japan, as a larger open economy, also relied on forward guidance (as long until inflation exceeds a threshold) and recently even announced that it aims at controlling the steepness and/or level of the yield curve. Taking a different but related approach, the Norges Bank or the Reserve Bank of New Zealand, among others, publish the path of their unconditional interest rate forecast in order to provide as much information as possible about their usual policy rule, instead of explicitly announcing a deviation from their usual rule. Last but not least, the Czech Central Bank and the Swiss National Bank also applied some sort of forward guidance: Both central banks announced a lower bound for their currencies against the Euro.[3]

In this chapter, we extract and analyze three stylized forward guidance types. First, central banks may credibly announce *low* interest rates for an extended period, by means of a constant interest rate path. Second, central banks may announce *lower* interest rates than usual and follow a more expansionary policy rule with a higher inflation target for an extended period. These first two cases are equivalents to the closed economy case in the second chapter, but simplified given the additional complexity of the open economy model: Forward guidance always starts today and we consider calendar-based triggers only (no state-dependent triggers).[4] Third and last, the central bank may announce a *temporary peg* for the nominal exchange rate. Technically, we implement such via a modified interest rate rule that responds to exchange rate deviations.

[1]The open economy literature often focuses on different issues regarding the zero lower bound in open economies that may drag attention away from forward guidance of interest rates, not least induced by the greater complexity of open economy models with respect to additional variables, equations or spillovers. The presence of the zero lower bound itself, for instance, leads to different spillovers between the economies and thereby represents an entire research field per se. Another example is (the ordering of) exchange rate regimes at the zero lower bound.

[2]See Svensson (2015) or Woodford (2013) for examples.

[3]Clearly, many of the aforementioned (forward guidance) statements accompanied or complemented other unconventional monetary policies, particularly quantitative easing.

[4]In a non-stochastic environment, these additional triggers provide little additional insight, see the conclusion of the second chapter for a detailed discussion.

Central banks may choose to apply forward guidance in two cases. First, the small open economy is hit by a large negative domestic shock and interest rates are bound by the zero lower bound. Is forward guidance an effective tool to provide additional monetary policy accommodation in such case? This case is closely linked to the analysis for the closed economy in the second chapter and highlights the feedback from international linkages to domestic forward guidance. Second, the foreign economy is hit by a large negative shock and foreign interest rates are bound by the zero lower bound. What is the international transmission of this shock, or spillovers to the domestic economy, and to what extent can domestic forward guidance affect or offset such? Furthermore, do results change if the foreign central bank itself runs forward guidance amid restricted interest rates? Throughout the chapter, we measure the effect of forward guidance through impulse response functions of key variables of interest: Output gap, inflation, exchange rates and interest rates.

The model is a standard stylized micro-founded new open economy DSGE model for two economies. Model frictions include price-adjustment costs for firms à la Rotemberg (1982) or incomplete pass-through at the CPI level due to home bias. A relative size parameter allows for both the small and large open economy case, we analyze the former unless stated otherwise. In normal times, both central banks set interest rates according to a Taylor rule, at the zero lower bound the central banks may revert to (fully credible) forward guidance. The method to solve the model and derive impulse response functions is identical to that of the closed economy case in the second chapter, providing full non-linearity with respect to the zero lower bound and arbitrary forward guidance formulations, with the major back-draw of a non-stochastic solution. Specifically, we solve the model with the perfect-foresight method, assuming that the economy returns to the (good) steady-state and assuming that certainty equivalence holds.

The chapter shows that forward guidance is effective in both cases, whether the small open economy suffers from a domestic shock or faces negative spillovers from abroad. One major channel for its efficacy is the exchange rate: Lower interest rates (ceteris paribus) lead to a depreciation or mitigate the appreciation of the domestic currency, and thereby drag world demand to the domestic economy. Domestic output (gap) and inflation in turn both rise. In the first case, a domestic shock, forward guidance specifically offsets the initial appreciation of the domestic currency that may occur once the zero lower bound binds, induced by a ‘perverse response’ of relative prices. Yet, the international risk sharing condition leads to a rather muted response of consumption and final good output to lower interest rates in all cases, a finding in contrast to the closed economy case. In consequence, the question of whether forward guidance is more or less effective in an open economy than in the closed economy remains subject to further research. The second case shows that forward guidance is also successful in altering the international transmission of foreign shocks, such that spillovers to the domestic economy are less pronounced (or even positive for long durations). Spillovers get worse with forward guidance of the foreign central bank, but remain comparable in qualitative terms.

Among the three forward guidance types, the promise of low interest rates is the most effective but also most sensitive type, in line with findings from the closed economy case. A temporarily higher inflation target and the temporary peg are somewhat less effective, but provide sort of a hedge against an excessive overshooting of output gap and inflation, a feature which might be particularly desirable in a stochastic environment.[5] The implementation of the temporary peg reveals questionable effects on interest rates, for specific periods towards the end of forward guidance, an explicit modeling of foreign exchange interventions seems due in this respect. At present, these results should be taken with a grain of salt.

The chapter is structured as following. Section 3.2 reviews the literature on forward guidance or more generally monetary policy at the zero lower bound in open economies. Section 3.3 introduces the baseline model, the different forward guidance specifications and the solution model. Section 3.4 presents the simulation results based on impulse response functions. Section 3.5 concludes and outlines further potential research.

3.2 Related literature

The introduction highlighted that the most directly relevant literature – theoretical contributions on interest-rate based forward guidance or temporary exchange rate pegs – is somewhat scarce. This literature review thus extends the scope to the more general question of (optimal) monetary policy at the zero lower bound in an open economy and, given the international dimension of the model and research question, also briefly introduces the question of the (optimal) exchange rate regime at the zero lower bound. Note that due to the wider complexity of the open economy models, various papers below may ignore the zero lower bound or refer to simpler models than fully-fledged DSGE models. But unless stated otherwise, papers do cover the zero lower bound.

Spillovers at the zero lower bound

First and foremost, recent literature shows that the spillovers of foreign shocks to the domestic economy may alter with the zero lower bound. Bodenstein et al. (2010) for instance show (in a two-country DSGE model) that at the zero lower bound, 'the effects of foreign demand shocks on the home country are greatly amplified', even for less open economies. In addition, foreign shocks may extend the duration of the zero lower bound.[6] Bäurle and Kaufmann (2014) get similar results, the response of the exchange rate and changes in prices are stronger under the zero lower bound. Cook and Devereux (2013, 2014) and Bhattarai and Egorov (2016) show that one potential key feature (for these dynamics) is home bias: For certain degrees of home bias, relative prices can respond perversely in response to demand shocks, lead to an (over-) appreciation of the home terms of trade and exacerbate the slump in the home country. Obviously, this has a considerable impact on (optimal) monetary policy.[7]

In a similar vein, Haberis and Lipinska (2012) show that changes to foreign monetary policy, or foreign central bank preferences in general, may affect (i.e. spill over to) domestic monetary policy. A more stimulatory foreign policy worsens the home policymakers' trade-

[5] Please refer to the second chapter for a thorough discussion on this topic.

[6] The opposite also holds true: Positive foreign shocks may lead to an 'early exit' of the zero lower bound.

[7] De Paoli (2009) also analyzes optimal monetary policy for a small open economy and considers the impact of the economy's openness, though without the zero lower bound.

off between stabilizing inflation and the output gap, if home and foreign goods are close substitutes.[8] This reflects the fact that looser foreign policy leads to a relatively more appreciated home real exchange rates. Last but not least, (unconventional) monetary policy abroad may itself lead to spillovers. Alpanda and Kabaca (2015) for instance show that large scaled asset purchases of one country lead to spillovers to the other country – the compression of long-term yields stimulates economic activity in both countries – and that these spillovers are even stronger than conventional monetary policy shocks with the same impact on (domestic) output.[9]

In this chapter, we briefly touch and confirm the finding of changes in the spillovers at the zero lower bound in the baseline scenario, but do not deepen the analysis further. We also analyse the spillovers of *unconventional* monetary policy (forward guidance) of the foreign central bank.

Responses of the (domestic) central bank

Turning to responses of the domestic central bank to such spillovers (or domestic shocks), a first question is that of the exchange rate regime. The literature generally agrees that without a zero lower bound, flexible exchange rates are preferable to fixed exchange rates. In contrast, as Cook and Devereux (2014) point out, a currency area can be better at the zero lower bound than flexible exchange rates, if there are no additional tools available for the central bank. The reason behind is the aforementioned 'perverse' response of relative prices to a negative shock and the appreciation of the terms of trade. We briefly confirm this finding by applying a permanent exchange rate peg via interest rates.

Given de-jure flexible exchange rates, we enter the vast literature on 'usual' monetary policy. In normal times, monetary policy is often represented by interest rate based policies, but central banks more and more commonly extended this toolkit with unconventional monetary policies since the great financial crisis: Among others, these include (large-scaled) asset purchases, forward guidance on interest rates or a temporary management of exchange rates (i.e. interventions on foreign exchange markets). First contributions of the literature on such (unconventional) policies at the zero lower back may be traced back to the Japanese experience. Svensson (1999, 2001, 2003, 2004) for instance suggests a combination of policy accommodation and a temporary exchange rate management – also denoted as 'the fool-proof way'.[10,11] Policy accommodation in the fool-proof way is

[8]In a similar spirit, Lipińska et al. (2011) show that the pricing of imports, local or producer currency pricing, further affects this 'spillover' to domestic stabilization trade-off.

[9]From an empirical point of view, the results from the first chapter show that, for instance, Swiss asset prices indeed react to foreign unconventional monetary policies (to be precise, even the announcement of a policy is sufficient): the Swiss franc generally appreciates in response to an expansionary announcement and Swiss bond yields decrease. The domestic economy, in turn, may respond to these (financial) spillovers – e.g. the appreciation may lead to lower exports and thereby output – and trigger changes to domestic policy.

[10]Other contributions in this regard include Krugman (1998), Bernanke (2000), Posen (1998), McCallum (2000) or Meltzer (1999b,a), arguing for increases in the inflation target (recently renewed by Blanchard et al. (2010)), policy and/or targeting rules that carry along a commitment to hold interest rates lower than usual, depreciation of exchange rates, exploiting portfolio balance effects, or combinations thereof.

[11]Svensson's 'foolproof way' formally consists of three elements that shall guarantee an exit from the liquidity trap: commitment for a higher future price level, concrete action that demonstrates the central bank's commitment (devaluation of the currency) and a temporary exchange rate peg.

achieved through price level targeting, where expectations of a higher future price level lead to increased inflation expectations, lower long real interest rates and a real depreciation of the domestic currency, thereby to a 'jump-start' for the economy.[12]

Interest-rate based policies / responses

The finding that price-level targeting is an effective way to mitigate the impact of a large negative shock has been confirmed by a variety of other authors. Coenen and Wieland (2004) provide full support, 'the central bank may improve performance substantially by devaluing the exchange rate and switching to an exchange-rate peg or by committing to a price-level target path and interest-rate rule that will close the price gap in the future.' However, they also stress the 'lack of immediate verifiability' in practice that will hamper credibility and reduce effectiveness. Iwamara et al. (2005) show (combining optimal rules with *optimal monetary policy*) that optimal monetary policy under commitment (i.e. assuming full credibility) can be implemented via a inflation targeting framework, augmented with a history dependent inflation target.[13] Nakajima (2008) shows that the paths for inflation, output gap and interest rates under optimal monetary policy are similar to those achieved by Eggertsson and Woodford (2003) for the closed economy (or the second chapter). Interestingly, the authors find that contrary to aforementioned results from Svensson, the nominal exchange rate of the country in a liquidity trap appreciates under optimal policy.[14] Bhattarai and Egorov (2016) also show that optimal monetary policy under commitment significantly outperforms its counterpart discretion. The solution under discretion is a function of an inflation target, without history dependence, and leads to a so-called overvaluation bias: The real exchange rate is 'relatively more appreciated'. In contrast, optimal monetary policy under commitment can be represented by a time-varying price-level target.[15,16]

[12] As a neat extension, Jeanne and Svensson (2007) introduce balance sheet concerns of the central bank as one tool to enhance the (crucial but questionable) credibility assumption of the foolproof-way approach.

[13] The authors then compare this finding to the conduct of monetary policy in Japan in the early zeros and find that 'the BOJ rule lacks history dependence in the sense that the BOJ had no intention of revising the target level of inflation in spite of the occurrence of various additional shocks to the Japanese economy' and thus 'failed to have sufficient influence on the markets expectations about the future course of monetary policy'. In addition, the authors state that 'findings suggests that the Japanese government deviated from Ricardian fiscal policy toward fiscal tightening.'

[14] The author adds a caveat though: The exchange rate appreciates *except possibly* at the initial date. Additionally, the author partly questions the results from Svensson (2004) in criticizing one specific assumption of the latter: That productivity is unexpectedly high at period zero, but normal afterwards. The author concludes that if 'the shock lasts for more than one period so that the expected growth rate of productivity is negative', then 'the currency would appreciate [..] under optimal policy commitment'.

[15] More precisely, the authors state that "under optimal policy under commitment, the central bank promises a more depreciated real exchange rate" and "is able to promise low real interest rates and a higher output gap in future, which helps mitigate the extent of the negative output gap during the initial periods". The authors also put a large emphasis on the importance of the elasticity of substitution on the outcome and show that the liquidity trap (and adverse effects) gets worse, the lower the elasticity of substitution of between domestic and foreign goods. Last but not least, the authors also consider optimal fiscal policy.

[16] Contributions on optimal monetary policy without the zero lower bound include, for instance, Dib et al. (2008), where 'optimal price level targeting regime substantially reduces the welfare cost of business cycle fluctuations' (compared to the historical inflation targeting rule), or De Paoli (2009), where optimal monetary policy in a small open economy 'can be written as a function of domestic inflation, output gap and real exchange rate'. De Paoli (2009) also addresses the importance of the elasticity of substitution:

Given a counterpart in the foreign economy, various contributions particularly analyze the aspect of cooperation. Nakajima (2008) puts an emphasis on coordination and world welfare and shows that the aforementioned findings require (precisely: assume) active policy coordination across countries. Without the zero lower bound, in contrast, the optimal inflation targeting rule has exactly the same form as in a closed economy (and thus no international dependence). Fujiwara et al. (2013) confirm previous findings that history dependence is an essential feature of optimal monetary policy and that price-level targeting per se is also beneficial, and show that this holds even if applied by one of the two countries only. Any cooperation of the two central banks in determining optimal monetary policy provides additional benefit. Fujiwara et al. (2015) deepen this research question and show that (optimal) monetary policy under cooperation exhibits 'an incentive feasibility problem'. In other words, policymakers might have an incentive to deviate from cooperation under certain circumstances. A similar result occurs if the countries differ in size.[17] Last but not least, Cook and Devereux (2013) also achieve a clear result for optimal monetary policy: Commitment beats discretion by far, independent of the currency regime. Under commitment, optimal monetary policy can re-establish the general result on exchange rate regimes that flexible exchange rates are generally more beneficial than a currency union.[18,19]

History dependence and commitment (or credibility) are thus essential for an effective monetary policy at the zero lower bound and particularly reduce the appreciation 'bias' of the exchange rate.[20] Coordination is, in general, also seen as beneficial but but of lower importance. In contrast to most of the aforementioned references, we consider explicit deviations *from* a rule. In order to do so, we follow most papers in assuming that the announcements are fully credible. Since central banks usually follow their Taylor rules, we do not model any form of cooperation, though implicitly cover cooperation by evaluating contemporaneous forward guidance at home and abroad.[21] To the best of our knowledge, the (theoretical) coverage of such explicit forward guidance in a (small) open economy is very limited. Garcia-Cicco (2011) seems the notable exception. The author analyzes balance sheet and interest rate policies in a small open economy model and shows that maintaining the policy rate at zero for a prolonged period can be greatly expansionary, particularly after contractionary shocks (at the zero lower bound).[22] Again, (a lack in)

When domestic and foreign goods are close substitutes for each other, the optimal policy rule implies lower real exchange rate volatility than a domestic inflation targeting regime. The reverse is true when the elasticity of substitution between goods is low.

[17] The authors thus analyze (and suggest) a *sustainable cooperation* regime, history dependent, that encloses 'a cross-country, state-contingent contract between policymakers'.

[18] The authors sometimes refer to 'forward guidance'. Yet, their usage is somewhat misleading compared to this chapter: The authors refers to optimal monetary policy under commitment, while we refer to an explicit deviation of a given rule.

[19] A noteworthy contribution without the zero lower bound is Fujiwara and Wang (2016) who focus on the pricing of goods (local vs producer currency) and cooperation and show that cooperation always leads to welfare gains, but that those gains are not very large.

[20] Differences in models and assumptions may however affect the findings, even lead to opposite findings. See, for instance, the discussion of the findings regarding the appreciation bias in Nakajima (2008) (vs the depreciation as in Svensson (2004)).

[21] While central banks certainly communicate with each other in practice, they seem to rarely cooperate in determining their actual monetary policy *rate* (or, as another example, the pace or their asset purchases).

[22] The author implements these policies via three ad-hoc frictions: a liquidity premium, deviations from

credibility can severely undermine these effects. Similar to the closed economy case, the effect primarily relies on higher expected price levels. Our first type of forward guidance is thus similar to the approach of Garcia-Cicco (2011), but differs e.g. in the approaches considered (forward guidance through the inflation target or temporary exchange rate pegs) or the structure and solution methods of the model (non-linear, allowing for different relative size of the economies, perfect foresight). Related but yet different in the approach, Svensson (2015) and Woodford (2013) provide narrative overviews for various examples of implicit and explicit forward guidance applied by the Swedish Riskbank, Bank of Canada, Reserve Bank of New Zealand or the Federal Reserve Board. In doing so, the authors neatly illustrate the problems regarding credibility measured by the distance of the projected interest rate path from markets' expectations or by intraday market responses.[23]

Exchange-rate based policies / responses

Turning towards the interaction of exchange rates and monetary policy, a first question is related to aforementioned policy rules: Should the central bank respond to exchange rate movements while setting interest rates, i.e. add the exchange rate to its policy rule? Another question addresses the implementation of the (temporary) exchange rate management if the the central bank decides to do so, as proposed by Svensson (2004) or discussed in McCallum (2000).

Regarding the former, adding the exchange rate to the policy rule has one convenient implication: If the corresponding parameter (i.e. the penalty on any deviation of the variable from its target) is large enough, it will lead to an exchange rate peg. Any (forward) guidance on this exchange rate parameter, for instance a temporary increase, would also allow for a *temporary* peg. Among others, Wang (2010) addresses the general question whether the central bank should add the exchange rate to the policy rule or not, while Benigno et al. (2007) and Corsetti et al. (2011) target the link of policy rules and exchange rate pegs.[24] This is the technique we apply in this chapter, for the sake of simplicity.[25]

The second approach to implement a (temporary) management of exchange rates is to explicitly model foreign exchange interventions, a task a variety of papers addressed recently for (DSGE) models. A caveat is due upfront, however: Most of the following papers do *not* model the zero lower bound explicitly. The common and obvious way to

the uncovered interest rate parity and a premium in the term structure of interest rates.

[23]Among empirical contributions – forward guidance is hard to isolate from other announcements, such as quantitative easing – we might mention that of Okina and Shiratsuka (2004), discussing the effectiveness of the Bank of Japan's forward guidance from March 1998 to February 2003, primarily by analyzing the yield curve. The policy-duration effect is found to be highly effective in stabilizing market expectation for the path of short-term interest rates, but fails to reverse deflationary expectations in financial markets.

[24]Wang (2010) e.g. analyzes the benefit of adding the exchange rate to the policy rule on welfare (additionally, the author evaluates the benefits from cooperation). Overall, the findings suggest that the monetary authority should not seek to vigorously stabilize exchange rate fluctuations. The model does not detect relevant welfare gains from international monetary cooperation.

[25]Note that the uncovered interest rate parity – commonly used in small models – will lead to equal interest rates across borders during an (temporary) exchange rate peg applied through the policy rule. Clearly, this approach has the disadvantage of not being able to model forward guidance on interest rates and exchange rates contemporaneously (for the same periods).

model such interventions are foreign exchange reserves (or international bond reserves). Imperfect substitution across money, domestic and/or foreign bonds usually creates the wedge such that (even) sterilized interventions can be effective. Escudé (2013), Castillo (2014) or Benes et al. (2015) analyze the merits of having two policy rules, one setting interest rates, the other targeting exchange rates (in some form) via foreign exchange interventions. Escudé (2013) e.g. shows that the losses of the central bank are systematically lower if both rules are used simultaneously. Castillo (2014) adds the caveat that the 'central bank should coordinate the timing on and monetary policy stance on its two instruments in order to simultaneously achieve both goals; otherwise it could send opposite signals to economic agents, and endanger the achievement of one of its targets, particularly, its inflation target'. Benes et al. (2015) analyze how interventions affect the economy through portfolio balance sheet effects in the financial sector and show that they can help to insulate the economy against certain shocks.[26]

The following papers analyze *optimal* interventions (and monetary policy). Canzoneri and Cumby (2014) show that optimal monetary policy with interventions is rather complex: Leaning against the wind can be less beneficial than traditional inflation targeting (via a Taylor rule), and foreign exchange interventions in an inflation targeting regime may outperform sterilized interventions.[27] Optimal monetary policy in Cavallino (2016) (also) encloses both foreign exchange interventions and (regular) monetary policy; in other words, foreign exchange interventions shall 'lean against the wind' and are not a substitute of but complement (regular) monetary policy. Fanelli and Straub (2016) also show that leaning against the wind interventions are optimal against global liquidity shocks, and that they should be small and frequent. In addition, the authors show that 'forward guidance' of future interventions (through smoothing interventions) is beneficial. Last but not least, simple coordination rules (among central banks) may avoid over-accumulation of reserves (in a world with emerging markets engaging in currency wars) and depressed world interest rates.

In a similar vein, Amador et al. (2017) develop a simple two-period and two-country model with the zero lower bound to provide a simple way to measure costs associated with exchange rate policies. Specifically, the authors analyze how a central bank can pursue an exchange rate objective at the zero lower bound with limits to arbitrage in international capital markets. At the zero lower bound, 'all changes in external conditions that increase inflows of capital toward the country are detrimental, while policies like negative nominal interest rates or capital controls can reduce the costs [..]'.[28] Ghosh et al. (2016) also use a small, non-DSGE model – modelling foreign exchange interventions through the (foreign) reserves in the balance of payments – and show that interventions can be optimal for a sudden surge in capital inflows that negatively affect the domestic economy. This finding holds even under an inflation targeting regime. More generally, 'if two policy instruments

[26]However, the authors stress the fact that 'foreign exchange interventions may also hinder necessary exchange rate adjustments, e.g. in the presence of terms of trade shocks'.

[27]The central bank does not necessarily sterilize interventions via open market operations of the same amount on domestic bond markets, it may also conduct open market operations such that interest rates follow the path suggested by the policy (Taylor) rule. The latter is what the authors refer to as an inflation targeting regime.

[28]The authors underline their theoretical findings with empirical findings that show that when interest rates are close to zero, violations in interest parity are more likely, and those violations are associated with reserve accumulation by Central Banks'.

are available, then they should be used in tandem to achieve both price-stability and exchange-rate objectives'.[29]

Overall, a temporary management of the exchange rate through foreign exchange interventions seems to provide additional benefit, at least from a theoretical point of view.[30] Similar to the interest-rate forward guidance case, precise equivalents for the exchange rate management part are scarce: The recent (theoretical) literature often focuses on permanent pegs or *optimal* interventions (without the zero lower bound), whereas we are interested in an explicit deviation from the general (floating) regime. Fanelli and Straub (2016)'s approach of analyzing 'forward guidance' on foreign exchange interventions (via intervention smoothing) is probably one of the closer recent contributions, though differences are manifold, such as the implementation of foreign exchange interventions (we take the basic policy rule approach) or the pre-announcement of the interventions (we specify a fixed number of periods instead of a smoothing process). Clearly, Franta et al. (2014) also discuss related issues (a pre-announced floor) from a narrative and partly theoretical approach.

Literature wrap-up

In total, there is much less specific literature than in the closed economy case that is (directly) related to our research question, the fool-proof way of Svensson (2004) may still come closest and the work from Garcia-Cicco (2011) is very similar in the interest-rate forward guidance approach. Surely, all literature analyzing *optimal* monetary policy or interventions is also close, though we aim at analyzing an *explicit deviation* from a given rule. The main back-draw of our approach relative to the idea of Svensson (2004) is that we cannot analyse forward guidance on interest rates and exchange rates contemporaneously, i.e. for the same periods.[31] Our advantage is that we apply and solve a non-linear DSGE model. For the sake of completeness, we also do not model any quantitative easing (though it would be similar to interventions in various aspects), fiscal policy or balance sheet concerns.[32]

[29]For the sake of completeness, the authors also stress that the interventions should be two-way.

[30]For empirical contributions on foreign exchange interventions, see e.g. Fratzscher et al. (2015), Dabrowski et al. (2015), Forbes and Klein (2015), Blanchard et al. (2015), Fatum and Yamamoto (2012), Fatum (2010), or Fatum and Hutchison (2010). We also like to mention two particular cases in this regard, both suffering from interest rates being constrained by the zero lower bound and from an appreciation of the home exchange rate: the Czech or Swiss case. See e.g. Franta et al. (2014) or Alichi et al. (2015) for the former or various speeches from the Swiss National Bank for the latter.

[31]We could, however, analyze the switch from one to another at a specific period.

[32]We nevertheless may highlight some recent contributions in this regard (not least because some of aforementioned papers discuss these topics). For quantitative easing, see e.g. Garcia-Cicco (2011) or Alpanda and Kabaca (2015). Typically, foreign exchange interventions are often applied via foreign bonds, while asset purchase programs would primarily target domestic bonds. Interestingly, Alpanda and Kabaca (2015) for instance show that spillovers are larger for asset purchase programs than for conventional monetary policy. For fiscal policy, see e.g. Iwamara et al. (2005), Cook and Devereux (2011) (optimal fiscal policy at the zero lower bound), Corsetti et al. (2011) (fiscal policy and currency pegs), Cook and Devereux (2013) (optimal fiscal and monetary policy at the zero lower bound), Müller et al. (2015) (fiscal policy coordination in currency unions), Gomes et al. (2015) (fiscal policy and cooperation at the zero lower bound), or Bhattarai and Egorov (2016) (interaction of optimal monetary policy and fiscal policy).

3.3 Methodology

In this section, we briefly outline the model, the solution method, and the types of forward guidance considered in this chapter.

3.3.1 Model and calibration

Our baseline model is a standard two-country DSGE model with quadratic price adjustment costs à la Rotemberg (1996) and three production sectors operating under perfect competition (final good producers and importers/retailers) or monopolistic competition (intermediary good producers).[33] Intermediary good producers price their goods in their currency (producer currency pricing, PCP), can re-optimize prices in each period but face prices adjustment costs. The law of one price holds at the intermediary good level, but home bias at the final good level leads to deviations from the law of one price, captured by the real exchange rate. The production function for intermediary goods is linear with labor as the only input, technology is known and equal across individual firms. Capital markets are perfect, both countries can access both bond markets (while governments do *not* issue bonds). Governments follow a simple one-period budget rule with government expenditures (exogenous fraction of domestic final good output), wage taxes and lump-sum transfers. Finally, the model incorporates a parameter for the relative size of the two economies – inspired by De Paoli (2009), among others – and is thus able to simulate anything between the small open economy and a large open economy case (with two symmetric countries). Unless stated otherwise, the small open economy is the baseline.

The complete model, equilibrium conditions and steady-state values are available in the appendix C.1. At this place, we only highlight selected equations.

Price adjustment costs. Intermediary good producers are free to update prices every period, but face price adjustment costs whenever they do so. The adjustment costs are a function of the change in prices, a cost parameter γ and, following Ascari and Rossi (2012), an indexation variable $\chi_t \equiv \left(\pi_{t-1}^{\chi}\right)^{\mu} \left(\pi^{t,\chi}\right)^{1-\mu}$ that allows for different indexations, the baseline assumes full indexation to the inflation target.

$$\kappa_t(j) \equiv \frac{\gamma}{2} \left(\frac{p_{h,t}(j)}{p_{h,t-1}(j)} \frac{1}{\chi_t} - 1 \right)^2$$

Optimal price setting. With symmetric technology, all intermediary good producers re-optimize to the same price. The Rotemberg (1996) price adjustment costs thus yield the following optimal price setting equation for prices of local intermediary goods $p_{h,t}$.[34]

$$0 = (1-\epsilon)\frac{p_{h,t}}{p_t}\tilde{y}_t + \epsilon mc_t \tilde{y}_t - \gamma \left(\frac{\pi_{h,t}}{\chi_t} - 1\right)\frac{\pi_{h,t}}{\chi_t} y_t + \gamma\beta E_t \left[\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{\pi_{h,t+1}}{\chi_{t+1}} - 1\right)\frac{\pi_{h,t+1}}{\chi_{t+1}} y_{t+1}\right]$$

[33] The three former types are often modeled by the households directly, through CES utility functions and expenditure minimization. In our case, firms maximize profits and minimize expenditures on inputs under perfect competition (leading to zero profits). The result, however, is equivalent.

[34] The Calvo framework, instead, faces a recursive formulation for the price index, often accompanied by two auxiliary equations.

Home bias. Final good producers combine domestic and foreign inputs $x_{h,t}$ and $x_{f,t}$ to a final good y_t, purchased by the household at price p_t. The composition of the two inputs follows a CES production function where the elasticity of substitution v consists of two parameters and conforms two assumptions:[35] First, it incorporates a degree of openness (α), that leads to home bias if $\alpha < 1$. Second, the foreign country only consumes foreign goods if $n \to 0$, but the smaller economy always consumes foreign goods. The definitions that satifsy these requirements are $v \equiv 1-(1-n)\alpha$ for the domestic economy and $v^\star \equiv n\alpha$ for the foreign economy. The final good production function finally gets

$$y_t = \left[v^{\frac{1}{\theta}} x_{h,t}^{\frac{\theta-1}{\theta}} + (1-v)^{\frac{1}{\theta}} x_{f,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$$

Gross domestic product. Price adjustment costs drive a wedge between domestic output and gross domestic product, as in the closed economy case. In addition to the price adjustment costs, the (nominal) gross domestic product (GDP) $\tilde{y}_t$ in an open economy is also a function of exports and imports. Note that we do not model investments in this model.

$$p_{h,t}\tilde{y}_t = p_t c_t + p_t g_t - p_t \kappa_t y_t + \frac{1-n}{n} p_{h,t} x^\star_{h,t} - p_{f,t} x_{f,t}$$

International risk sharing and *uncovered interest rate parity.* The Euler equations for the two households yield two common expressions, an international risk sharing condition and the well-known uncovered interest rate parity (where $\Delta e_{t+1} \equiv e_{t+1}/e_t$)

$$c_t = (d_t/d_t^\star)^{1/\sigma} q_t^{1/\sigma} c_t^\star \qquad\qquad R_t = \Delta e_{t+1} R_t^\star$$

The model is calibrated using standard parameters, for details and references see appendix C.3. Inter-temporal substitution σ is set to two, home bias α set to 0.4 and the discount factor β set to 0.9975, implying a real interest rate of roughly 1% in annualized terms. The intratemporal elasticity of substitution between domestic and foreign goods θ is set to 3 and that between intermediary goods ε to 6. Price adjustment cost parameter γ is set to 100, the inverse elasticity of labor supply ν is 0.2 and monetary policy parameters follow standard Taylor rule parameters: ϕ_π and ϕ_x are set to standard values 1.5 and 0.5. Interest rate inertia, although technically available, is set to zero.

3.3.2 Monetary policy and forward guidance

We use two different variables for the central bank's interest rates. Z_t denotes the *desired* interest rate, which may get negative (or smaller than one, using gross interest rates). This can either be the interest rate implied by the regular Taylor rule (Z_t^n), an expansionary alternative, stemming from any particular type of forward guidance (Z_t^e). R_t instead denotes the *realized* interest rate, the interest rate that the central bank can achieve on

[35] See, for instance, De Paoli (2009).

money markets respecting the zero lower bound.[36]

$$R_t = \max\{1, Z_t\}$$

The normal policy rule Z_t^n is a common Taylor rule, responding to inflation and the output gap based on the gross domestic product $\tilde{y}_t$. The Taylor rule parameters ϕ_π and ϕ_x are set to standard values 1.5 and 0.5, inertia ρ_r is set to zero unless specified otherwise. Following a major part of the literature, we do not explicitly add the exchange rate.

$$Z_t^n = R_{t-1}^{\rho_r}\left[R\left(\frac{\pi_t}{\pi^\star}\right)^{\phi_\pi}\left(\frac{\tilde{y}_t}{\tilde{y}}\right)^{\phi_x}\right]^{1-\rho_r}$$

Forward guidance, represented by the expansionary rule Z_t^e, can take three different specifications, including the distinction between interest-rate or exchange-rate based (temporary peg) forward guidance. First, the promise of *low* interest rates corresponds to a constant interest rate path, denoted as c below (technically, the central bank could announce an arbitrary interest rate path IRP_t). Second, the promise of *lower* interest rates than usual refers to the Taylor rule, but raises the inflation target ($\pi^e > \pi^\star$) temporarily in order to provide additional stimulus given equal economic conditions. Third, we impose that the central bank implements a *temporary exchange rate peg* via a policy rule based on exchange rate deviations (instead of modeling interventions separately).[37]

$$Z_t^e = \begin{cases} c\ (IRP_t) & \text{constant interest rate path} \\ Z_t^n \text{ with } \pi^e > \pi^\star & \text{higher inflation target} \\ Z_t^n \text{ with } \Delta e_t \text{ instead of } (\pi_t, \tilde{y}_t) & \text{temporary peg} \end{cases}$$

Specifically, the interest-rate rule for the temporary peg case gets (Δe_t^e could again be any arbitrary path for the nominal exchange rate, but is a constant in the baseline case)

$$Z_t^e = R_{t-1}^{\rho_r}\left[R\left(\frac{\Delta e_t}{\Delta e_t^e}\right)^{\phi_e}\right]^{1-\rho_r}$$

Finally, the central bank applies the corresponding forward guidance rule from today t to a credible date T. In difference to the closed economy case of the second chapter, we assume that forward guidance always starts today.

$$Z_t = \begin{Bmatrix} Z_t^e & \text{for } t \in \{t, \ldots, T\} \\ Z_t^n & \text{otherwise} \end{Bmatrix}$$

For all rules, we assume that the information set of the central bank and the public are identical and common knowledge.

[36] We are fully aware that the literature distinguishes between the zero and effective lower bound and intensifies the research on the latter. For the sake of readability, we nevertheless omit this distinction and argue that the precise threshold should not matter for the dynamics of forward guidance. If anything, if the effective lower bound was known, we could conveniently reduce the zero lower bound to a lower value (below one for gross rates).

[37] Technically, this implies that the zero lower bound does not hold as long as a temporary peg lasts, but continues to hold afterwards. The parameter for this rule is set high enough to penalize (and prevent) any deviation from the peg.

3.3.3 Solution method

The solution method for the model is identical to that of the closed economy case in the second chapter: the perfect foresight (PF) approach, using Dynare (Adjemian et al., 2011). This approach assumes that the economy returns to its steady-state in finite time, and that agents replace future expected shocks with their expected value, so that certainty equivalence applies. As a result, the perfect foresight method numerically solves a finite set of equations using Newton methods. The main advantages are again an accommodation of the non-linear zero lower bound constraint and the design of non-linear policy rules, and being able to solve the full non-linear model. This allows us to study solution paths that are away from steady state, following a lengthy period at the zero lower bound, for instance. The main draw-back from this method is the inability to account for the uncertainty over future shocks (a fully stochastic environment). See the second chapter for a discussion of alternatives.

The baseline scenario in the subsequent analysis is a large adverse demand shock for the first case (domestic shock), pushing the economy to the ZLB for four quarters (without forward guidance), and a large adverse expenditure shock abroad for the second case (foreign shock).

3.4 Simulation results

As outlined in the introduction, the (simulation) analysis is split into two parts, providing answers to the following questions

1. Is forward guidance an effective tool for a small open economy if the domestic economy is hit by a large negative shock and domestic interest rates are bound at zero?
2. How does forward guidance affect (or offset) the international transmission of a shock to the foreign economy?

In both parts, the chapter assesses the effects of forward guidance by comparing impulse response functions of different forward guidance policies on key variables of interest: Inflation, output gap, interest and exchange rates. The first few charts depict a somewhat broader set of variables to highlight the impact in more detail, but subsequent charts focus on the aforementioned four variables.

3.4.1 Is forward guidance an effective tool for a small open economy?

This first part addresses the efficacy of forward guidance to counter a domestic liquidity trap. A large negative demand shock hits the small open economy and drives interest rates down to zero or, if unconstrained, into negative territory.[38] The foreign economy,

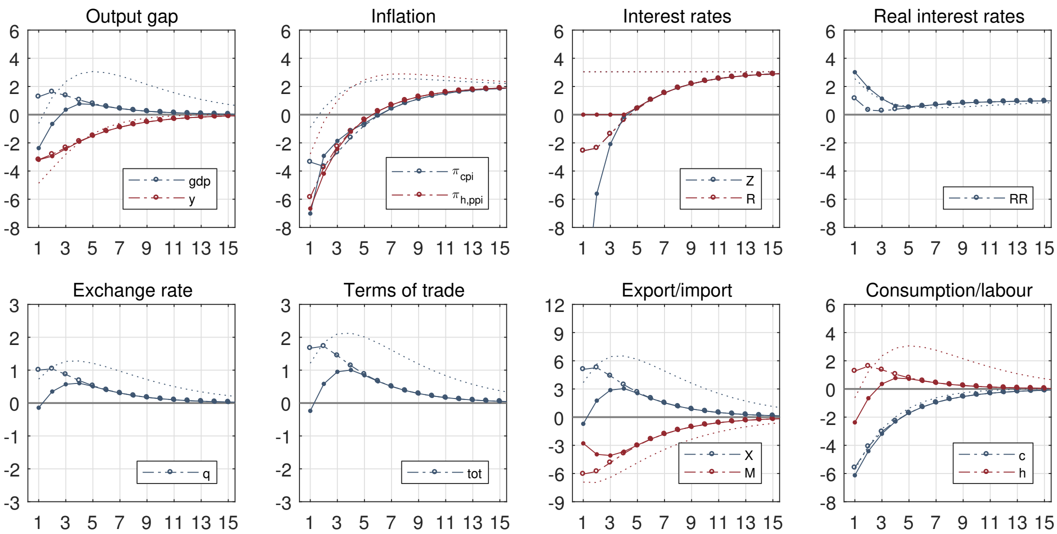
[38]Technically, this corresponds to a shock to the discount factor of d_t, calibrated such that interest rates remain at the zero lower bound for four periods.

also referred to as the rest of the world, remains unaffected by both the shock and the response of the small open economy. The domestic central bank may then announce forward guidance in an attempt to counter this shock. A comparison to the closed economy case highlights the implications of having an open economy, i.e. the impact international linkages may have on forward guidance.

The effect of the zero lower bound

Figure 3.1 illustrates the effect of the shock and the zero lower bound in the domestic economy, without forward guidance. The shock to the discount factor leads to a strong decrease in consumption (via the Euler equation), output of final goods and inflation. Without the zero lower bound (solid line with empty dots), this forces the central bank to slash interest rates deeply into negative territory, down to more than minus two percentage points, inducing a depreciation in the exchange rate. In turn, domestic terms of trade also depreciate and net exports (exports minus imports) increase, supporting domestic aggregate production (gross domestic product). In other words, the response of the domestic central bank drags world output to the domestic economy through the exchange rate channel. The linear production function finally leads to additional hours worked.

FIGURE 3.1: THE DOMESTIC LIQUDITY TRAP



The figure depicts the response of a small open economy to a large negative (domestic) demand shock. Foreign variables are omitted. Colors represent variables, patterns specifications: Lines with empty dots depict the situation without the zero lower bound, lines with filled dots the case with the zero lower bound and, for comparison, thin dotted lines the case with a permanent peg for the *nominal* exchange rate. The values are deviations from the steady-state in percent for output, exchange rates, terms of trade, consumption and labor, and annualized rates for interest and inflation (the model uses gross rates). Wherever applicable, values are measured per-capita to account for the different sizes of the economy.

The presence of the zero lower bound (solid line with filled dots) restricts the interest rates to dive into negative territory and leads to ceteris paribus higher real interest rates, similar to the closed economy case. In combination with a similar impact on inflation, the depreciation of the (real) exchange rate turns into a temporary appreciation, which confirms recent findings from the literature.[39] The lack in policy accommodation and

[39] According to the literature, different values for the home bias α should lead to different findings at this place, see section 3.2 for a discussion and references.

the appreciation of the real exchange rate leads to a more pronounced drop in inflation rates (more than minus six percentage points) and a rather negative contribution from net exports: The appreciation now rather dispels world demand from the domestic economy. In turn, gross domestic product drops in the first periods, the output gap turns negative, and hours worked initially decrease. Note that the desired interest rates Z_t are now deeply negative, compared to the case without the zero lower bound (in the case without the zero lower bound, the blue line is fully covered by the red line), further illustrating the negative impact of the zero lower bound on the domestic economy.

The muted response of consumption to the presence of the zero lower bound, and to various applications of forward guidance below, seems somewhat at odds with intuition. Changes in interest rates should generally lead to changes in the intertemporal consumption profile. However, the international risk sharing condition from section 3.3.1 – a new condition compared to the closed economy case – provides an additional, tight band for consumption. Foreign consumption is basically exogenous in the small open economy case, domestic consumption thus may only change with the (exogenous) discount factor and the real exchange rate. Unless the intertemporal elasticity of substitution σ is very high, the impact of the real exchange rate on consumption via this condition is rather limited.[40]

Running a fixed exchange rate regime at the zero lower bound (thin dotted line) can indeed be beneficial, in line with the literature. The domestic central bank is forced to keep interest rates at the levels from abroad, which remain unaffected from the shock to the small open economy, and nominal exchange rates in turn remain identical. The real exchange rate, however, depreciates considerably amid inflation differentials and leads to a similar (positive) outcome as in the case without the zero lower bound. Noteworthy is the much more persistent impact on the real exchange rate.

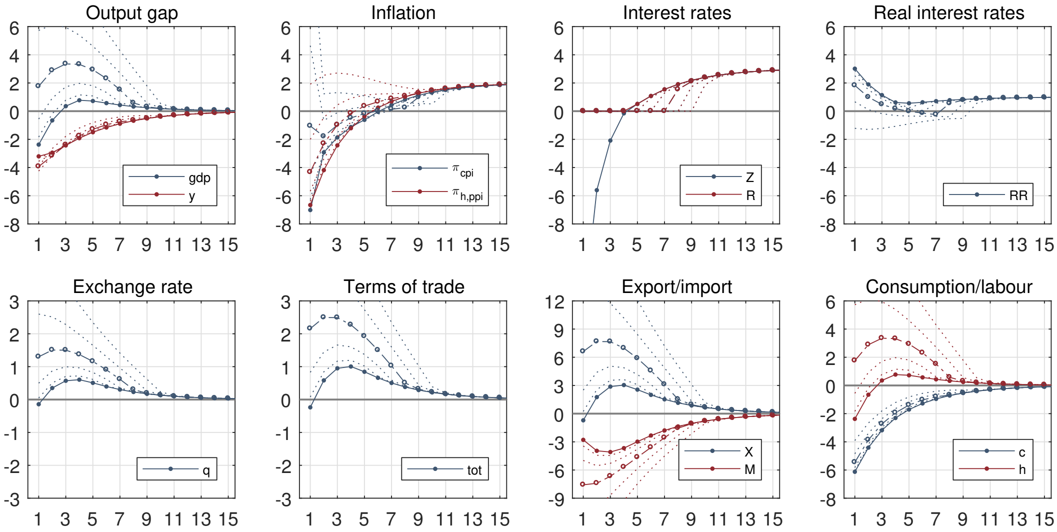
The efficacy of forward guidance in a liquidity trap

Shall the domestic central bank counter such a negative shock through forward guidance if the economy is constrained by the zero lower bound? We henceforth analyze the three types of forward guidance defined in section 3.3.2 and compare it to the zero lower bound case (always the solid line with filled-dots): (i) constant-interest rates, (ii) higher inflation-target and (iii) a temporary peg for the nominal exchange rate. Different patterns of the lines now imply different forward guidance specifications or durations.

A promise to keep interest rates at zero for an extended period, illustrated by figure 3.2, is indeed effective in stimulating the domestic economy. The initial appreciation of the real exchange rate disappears and real interest rates drop compared to the zero lower bound case. Finally, consumption slightly rises from its low levels. The depreciation again drags external demand to the domestic economy and at least partly offsets the initial drop in the gross domestic product, and pressure on prices decreases. This stimulus, however, quickly turns into an excessive overshooting of the economy with longer durations. Already a promise of two years leads to implausibly large effects (prices do no longer drop anymore). Yet, even the largest stimulus cannot offset the most direct impact of the shock: the drop in consumption. As in the baseline scenario, hours worked increase with the gross domestic product.

[40] A different σ will lead also to different real exchange rate responses; the overall impact of a higher value of σ on consumption thus remains unclear.

Figure 3.2: Constant interest-rate fwd guidance in a domestic liquidity trap

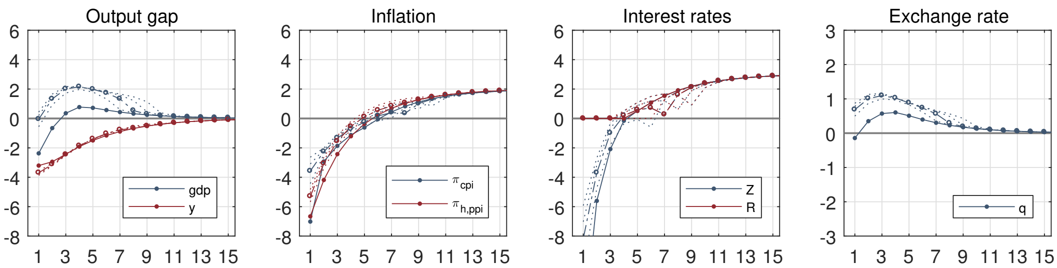


The figure depicts the effect of constant-interest rate forward guidance of a small open economy in response to a large negative (domestic) demand shock. The central bank promises to keep interest rates at zero for several periods (up to nine periods). For a description of the variables and units see figure 3.1. The solid-dotted line represents the baseline scenario where the zero lower bound binds but no forward guidance is applied. The dotted lines represent different durations of the constant-interest rate forward guidance, the dashed line highlights forward guidance for seven periods.

The effect of a promise to raise the inflation target temporarily by approximately 2% is, as shown in figure 3.3 for the core variable set, overall somewhat less effective but more stable in terms of overshooting. If conditions improve too strongly, the central bank may even rise interest rates before the zero lower bound 'ends', the so-called *endogenous channel* of the second chapter. As in the constant interest rate case, it decreases the real interest rates and repeals the initial appreciation of the real exchange rate, with according effects on all variables.

Finally, the central bank may announce a temporary peg of nominal exchange rates via the interest rates, illustrated in figure 3.4. The peg restricts changes to the nominal exchange rate to zero for eight to sixteen periods, starting today, and thereby equals domestic to foreign interest rates, with the notable exception of the last period of the peg where interest rate sharply drop, at odds with intuition. This drop in the interest rate seems to be a

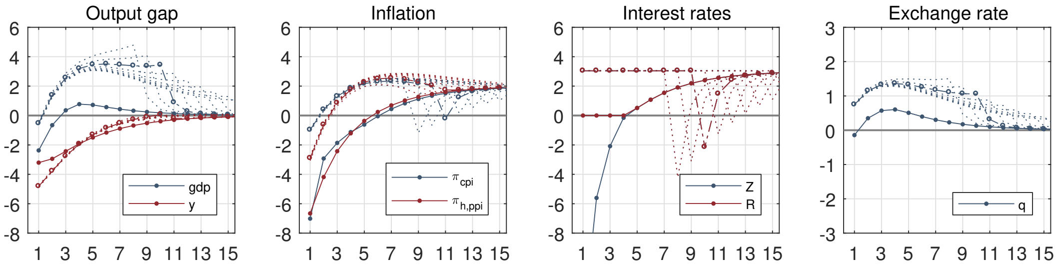
Figure 3.3: Inflation-target fwd guidance in a domestic liquidity trap



The figure depicts the effect of an inflation target forward guidance of a small open economy in response to a large negative (domestic) demand shock. The inflation target is raised by approximately two percentage points for six to nine periods. For a description of the variables and units see figure 3.1. The solid-dotted line represents the baseline scenario where the zero lower bound binds but no forward guidance is applied. The dotted lines represent different durations of the inflation-target rate forward guidance, the dashed line highlights forward guidance for seven periods.

consequence of the construction of the peg (via interest rates) and cannot be avoided in this set up.[41] The set of restrictions implied by the construction of the peg, a temporary nominal exchange rate peg and the Taylor rule with the zero lower bound afterwards, seems to be too strict to be consistent with the structure of the model, particularly the relationship between the exchange rate and the interest rate. Modeling foreign exchange interventions might greatly help in this regard, providing a second instrument for the central bank. Notably, the drop decreases with longer durations – the need for post-peg adjustments seems to decrease (with the shock fading out) – and the responses get more and more similar to the permanent peg from figure 3.1. Furthermore, agents anticipate this one-off drop and smooth out their behavior accordingly.

FIGURE 3.4: A TEMPORARY PEG IN A DOMESTIC LIQUIDITY TRAP



The figure depicts the effect of a temporary exchange rate peg in response to a large negative (domestic) demand shock. The nominal exchange rate is kept at its current level for eight to sixteen periods, starting today, and interest rates are set accordingly during the peg. See text for a discussion of the one-off drop in interest rates once the peg ends. For a description of the variables and units see figure 3.1. The filled-dotted line represents the baseline scenario where the zero lower bound binds but no peg is applied. The dotted lines represent different durations of the peg, the empty-dotted line highlights a peg for then periods.

Taking the results as given (and with a grain of salt), the real exchange rate depreciates due to lower domestic inflation. This leads to well-known and positive results for terms of trade, net exports and domestic GDP. Overall, a pre-announced temporary peg (via interest rates) thus successfully ameliorates the recession.

The relevance of international linkages

In essence, the results for the open economy are comparable to the closed economy case in the second chapter. Forward guidance on interest rates yields highly desired monetary stimulus, pushing up domestic production and inflation. Major differences arise in two aspects: external demand via exchange rates, and consumption.

First, the impact of the exchange rate – and thereby external demand – is two-faced. Generally, a depreciation of the exchange rate, either induced by the negative shock itself or by forward guidance, drags demand from abroad to the domestic economy, with *positive* effects on domestic production. However, the zero lower bound may lead to an (initial) appreciation if the central bank refrains from forward guidance, with *negative* effects on domestic variables. With the zero lower bound case as the baseline in reality, it is well conceivable that such an appreciation may occur occasionally in open economies.

[41]Today's interest rates are set such that today's change in the nominal exchange rate is zero (implementation of the peg), but today's interest rates also directly affect tomorrow's exchange rate via the uncovered interest rate parity. Tomorrow's interest rates, in turn, are set by the Taylor rule (the peg is over) and the zero lower bound binds again. Note that for the duration of the peg, we temporarily allow for negative interest rates.

Second, consumption overall responds much less to forward guidance than in the closed economy case, presumably due to the international risk sharing condition (which is, in turn, affected by the assumption of complete international markets). Positive effects of forward guidance thus primarily stem from domestic production, or GDP, and muted disinflation.

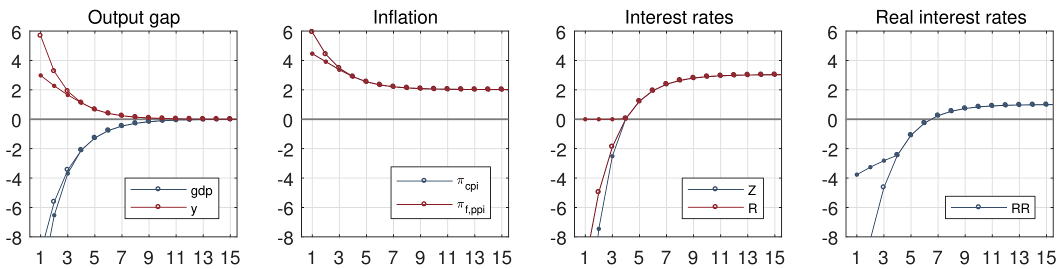
3.4.2 How does forward guidance affect the international transmission of shocks?

This second part addresses how domestic forward guidance affects the international transmission of foreign shocks. A large negative expenditure shock hits the foreign economy and drives foreign interest rates down to zero or, if unconstrained, into negative territory.[42] The negative shock abroad, and the response of the foreign central bank thereto, leads to spillovers to the small open economy which the domestic central bank may counter with forward guidance, if desired.

The international transmission of shocks

The negative expenditure shock affects the foreign economy noticeably, as shown by figure 3.5. Aggregate demand, or gross domestic product, sharply drops and the central bank responds with a deep cut in interest rates, to zero or below depending on whether the zero lower bound binds. Interest rates remain at or below zero for approximately four periods. Consumption and final good output rise amid lower interest rates, whereas hours worked drops considerably with lower production. Lower interest rates lead to a depreciation of the foreign exchange rate and terms of trade (variables omitted in the chart), despite an increase in inflation, but these responses are virtually irrelevant for the de-facto closed foreign economy. The zero lower bound exacerbates the negative impact on output and hours worked, and mitigates the rise in consumption and final good production.

FIGURE 3.5: THE EXPENDITURE SHOCK ABROAD



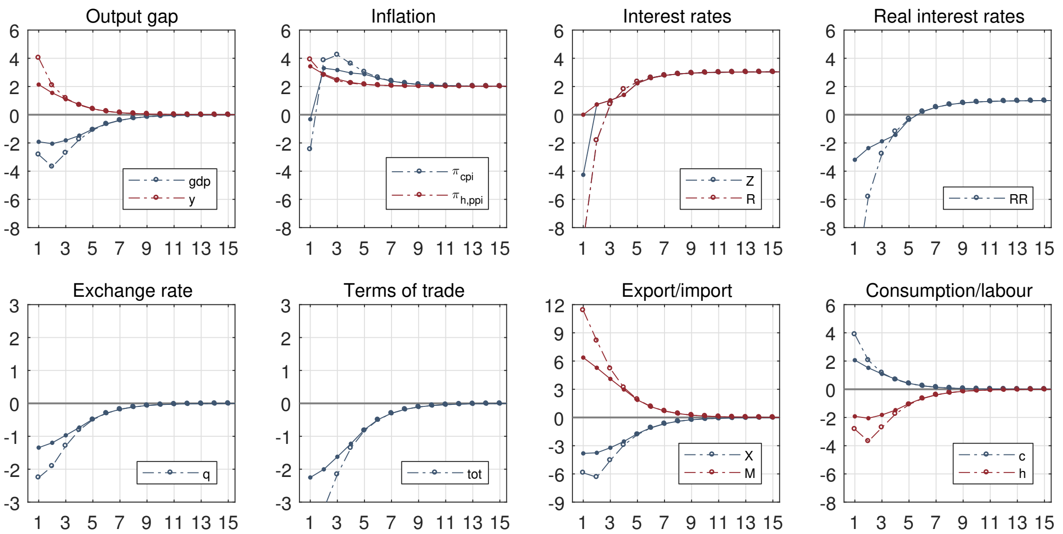
The figure depicts the response of the foreign economy (rest of the world) to a large negative expenditure shock abroad. For a description of the variables and units see figure 3.1. Solid lines with empty (filled) dots represent the case without (with) the zero lower bound.

Figure 3.6 shows how the expenditure shock abroad leads to pronounced, negative spillovers to the domestic small open economy, irrespective of whether the zero lower bound holds (filled dots) or not (empty dots). First and foremost, the appreciation of the domestic currency amid low interest rates abroad leads to a drop in external demand, gross domestic

[42] Technically, this corresponds to a shock to the foreign aggregate demand $\tilde{y}_t^\star$, specified in equation (C.37), calibrated such that interest rates remain at the zero lower bound for four periods.

product and (initially) in CPI inflation. Producer prices, instead, increase slightly. The domestic central bank responds according to the policy rule and reduces interest rates also to zero or, if unconstrained, into negative territory. Consumption profits from both low interest rates and consumption abroad and rises considerably. Overall, the spillovers appear rather harmful to the domestic economy. Interestingly, the zero lower bound – binding in both economies – mitigates the spillovers somewhat; relatively higher interest rates abroad lead to a less pronounced appreciation of the domestic currency. Fixed exchange rates are, in this case, akin to domestic constant interest rate forward guidance (mirroring interest rates abroad), which is covered by the following forward guidance analysis and hence omitted in this chart.

FIGURE 3.6: THE INTERNATIONAL TRANSMISSION OF THE FOREIGN SHOCK

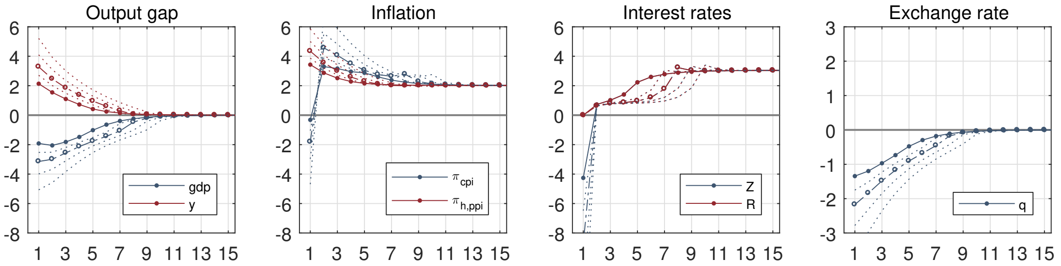


The figure depicts the response of a small open economy to a large negative expenditure shock abroad. For a description of the variables and units see figure 3.1. Colors represent variables, patterns different cases. Empty-dotted lines represent the case without the zero lower bound, solid-dotted lines the case with a zero lower bound and, for comparison, thin dotted lines the case with fixed exchange rates.

So far, the foreign central bank merely followed its policy rule, constrained by the zero lower bound or not, and refrained from using forward guidance. In reality, however, various central banks of large (foreign) economies resorted to forward guidance themselves. How do spillovers to the small open economy change if the foreign central bank decides to run (calendar-based) constant-interest rate forward guidance? Figure 3.7 shows that spillovers to the domestic economy worsen considerably.

The promise of low interest rates abroad leads to an amelioration of economic conditions abroad (charts omitted); as expected for a de-facto closed economy. With sufficiently long forward guidance, the drop in the output gap due to the expenditure shock decreases and inflation rises, and even overshoots for longer forward guidance durations. This response has two opposite effects on the domestic, small open economy: On the one hand, exports of the small open economy profit from higher demand abroad, providing additional demand for domestic goods. On the other hand, ceteris paribus lower interest rates abroad lead to a (much more) pronounced appreciation of the domestic currency and terms of trade, with well-known effects by now: Exports drop while imports rise, leading to an overall negative contribution of demand from abroad, lower domestic GDP and an initial disinflation. Overall, spillovers remain similar in their pattern, but get

FIGURE 3.7: EXACERBATING THE SPILLOVERS: FOREIGN FORWARD GUIDANCE



The figure depicts the spillovers of constant interest-rate forward guidance abroad – in response to a large negative expenditure shock abroad - to the domestic, small open economy. For a description of the variables and units see figure 3.1. Filled dots represent the case with the zero lower bound but no forward guidance. The dotted lines represent different durations of the constant interest-rate forward guidance abroad, the line with the empty-dots highlights foreign forward guidance for seven periods.

considerably worse with foreign forward guidance.

Given qualitatively comparable spillovers, we henceforth continue with the no forward guidance case to reduce complexity of charts and results.

How does forward guidance affect the international transmission of the shock?

The central bank of the small open economy responds to these spillovers and reverts to the three forward guidance types specified in section 3.3.2. The first row in figure 3.8 depicts the impact of constant interest-rate forward guidance, the second row the impact of lower than usual interest rates – applied through a temporarily higher inflation rate. Figure 3.9 instead analyses the impact of a pre-announced temporary peg of the domestic currency. In all cases, lines with filled dots represent the regular policy case, lines with empty dots the case of seven periods and dotted lines other forward guidance durations.

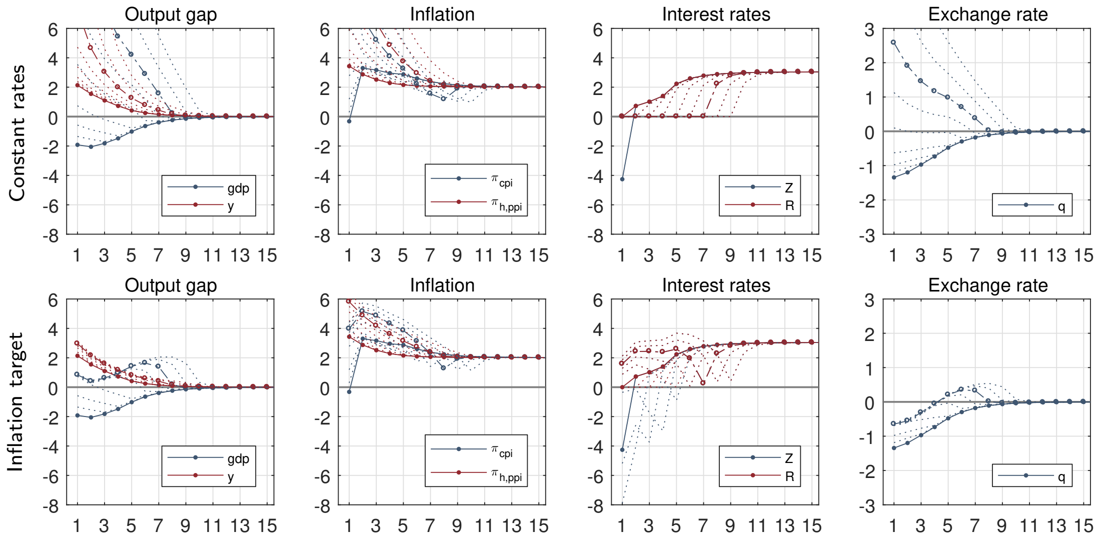
The results are overall comparable to those of the previous part. Forward guidance based on a constant-interest rate promise is both the most powerful but also most sensitive type. A few periods of zero interest rates are already able to offset the appreciation of the exchange rate and (at least partly) the drop in domestic output, seven periods (line with empty dots) lead to a pronounced depreciation of the domestic currency and a considerable overshooting of domestic production and inflation.

Raising the inflation target temporarily is again somewhat less effective but much more stable due to the endogenous response of interest rates to economic conditions. Raising the inflation target for a few periods already improves economic conditions such that interest rates are positive and higher than in the case without forward guidance. The longer the forward guidance, the earlier and higher interest rates rise. This type of forward guidance thus (again) provides a cap on the overshooting of output gap and inflation, but does not fully prevent the domestic currency from an appreciation.[43] Overall, this type of forward guidance remains effective and provides a hedge against an implausible overshooting of output gap and inflation.

Last but not least, the domestic central bank promises to keep nominal exchange rates

[43]Different changes in the inflation target might change these results, as they imply even lower or relatively higher interest rates. On the other hand, economic conditions should respond also differently amid different interest rates. The net effect of different rises in the inflation target remains thus unclear.

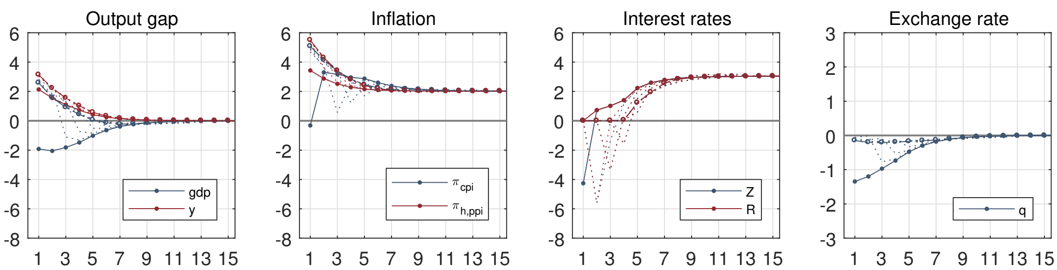
Figure 3.8: Domestic forward guidance and the international transmission of shocks



The figure depicts the effect of interest-based forward guidance of a small open economy in response to a negative expenditure shock abroad. The central bank promises to temporarily keep interest rates at zero (first row) or to temporarily raise the inflation target by approximately 4% (second row). For a description of the variables and units see figure 3.1. The lines with filled dots represent the baseline scenario without forward guidance, dotted lines represent different durations of forward guidance and the line with empty dots highlights forward guidance for seven periods.

unchanged for an extended period in response to the spillovers from abroad. Figure 3.9 depicts the outcome on core variables. Due to the implementation of the peg through interest rates, the domestic central bank mirrors interest rates from abroad while the temporary peg lasts.[44] Foremost, ceteris paribus lower interest rates lead to a less pronounced appreciation of the domestic currency (though never completely offset the appreciation) with positive effects on output and (initial) CPI inflation. The mirroring of foreign interest rates also provides sort of a hedge against overshooting of domestic economic conditions for longer durations, as domestic interest rates will simply mirror the normalization of interest rates abroad after four periods (the duration the zero lower bound binds abroad).

Figure 3.9: A temporary peg and the international transmission of shocks



The figure depicts the effect of a temporary peg in response to a negative expenditure shock abroad. The central bank promises to keep nominal exchange rates unchanged for an extended period. For a description of the variables and units see figure 3.1. The lines with filled dots represents the baseline without any peg (but the zero lower bound), the dotted lines different durations of the peg, and the lines with empty dots highlights a temporary peg for seven periods.

Overall, the message regarding forward guidance and the international transmission of

[44]See the discussion of figure 3.4 regarding the drop in interest rates towards the end of the temporary peg. Foreign interest rates are bound by the zero lower bound for four periods and then gradually rise.

shocks is clear: Forward guidance considerably affects the international transmission of the foreign shock and is able to ameliorate economic conditions at home, if the duration of forward guidance is chosen appropriately. First and foremost, domestic forward guidance in any of the three types leads to (ceteris paribus) lower interest rates than in the case without forward guidance and thereby reduces, offsets or even overcompensates the appreciation of the domestic currency. This, in turn, reduces the negative impact of the appreciation on domestic output gap through a drop in external demand and mitigates or offsets the initial drop in CPI inflation.

3.5 Concluding remarks

This chapter evaluates the effectiveness of forward guidance in an open economy, in response to either a large negative shock at home or abroad. The central bank of the domestic economy may revert to three different types of forward guidance, two related to interest rates, one to the (nominal) exchange rate. To conduct this analysis, we use a stylized two-country DSGE model and adjust the relative size of the economies such that the domestic economy resembles a small open economy, and measure the impact of forward guidance by means of impulse response functions.

Forward guidance shows to be effective in both cases, either providing additional stimulus if domestic interest rates are bound by the zero lower bound, or by offsetting spillovers from the negative shock abroad. Among the three forward guidance types, low for longer interest rates (a promise of zero interest rates for an extended period) is always the most effective, but also most sensitive choice. A promise of lower interest rates, applied through a more expansionary policy rule, is somewhat less effective – despite providing substantial stimulus – but also much more stable in terms of overshooting of economic conditions. This is a consequence of the endogenous response of interest rates; they are low*er* given equal conditions. The third type, a temporary exchange rate peg modeled via a modified policy rule, is qualitatively similar to the lower for longer type: somewhat less effective, but more stable. The implementation of this type however leads to implausible interest rate behavior for specific periods, strongly suggesting an explicit modeling of interventions in order to provide a second instrument. The results for forward guidance with constant interest rates are also consistent with those of Garcia-Cicco (2011).[45]

One major channel for the efficacy of forward guidance in an open economy is the exchange rate, besides the 'traditional' interest rate channel as in closed economies (and thereby inflation expectations): Ceteris paribus lower interest rates lead to a depreciation of, or mitigate the appreciation of the domestic currency and thereby drag world demand to the domestic economy. Domestic output gap and inflation in turn both rise. In the first case of this chapter, forward guidance specifically offsets the initial appreciation of the domestic currency that may occur once the zero lower bound binds, induced by a 'perverse response' of relative prices. On the other hand, the international risk sharing condition implied by complete international capital markets leads to a rather muted response of

[45] Garcia-Cicco (2011) states (e.g. page 77) that "keeping the rate at zero for a longer period significantly reduces the problem originated by the zero bound, and if kept fixed long enough, it can even improve the responses obtained when the policy rate is allowed to be negative." The author also stresses the importance of credibility, discussed below.

consumption and final good output to lower interest rates in all cases, a finding that constrasts somewhat with those for closed economies. In consequence, the question of whether forward guidance is more or less effective in an open economy than in the closed economy remains subject to further research.

As in the closed economy case of the second chapter, all results must be considered against the deterministic framework applied in this chapter. A stochastic setup may change the results and the interpretation thereof, not least the comparison of the three forward guidance types: In a stochastic setup, all forward guidance types that enclose an endogenous factor may provide a hedge against these shocks. Forward guidance based on constant interest rates, instead, might either provide too much or too little accommodation.

Future work on forward guidance in an open economy should include the following issues. First, any comparison of different specifications should cover a stochastic environment and solution method. Second, the implementation of the temporary exchange rate peg strongly calls for an explicit modeling of foreign exchange interventions to avoid implausible interest rate behavior. Third, uncertainty or a lack of credibility about the end of the temporary peg seems due to reduce the potential speculative aspect of such a pre-announced end for the peg. Last but not least, credibility is generally crucial and requires additional work.

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Appendix A

List of Unconventional Monetary Policies Announcements

This appendix provides the announcements of unconventional monetary policies of the four central banks for chapter 1, referred to as events. Table A.1 provides the events for the Federal Reserve Board and the European Central Bank, table A.2 for the Bank of England and Bank of Japan.

Table A.1: Fed and ECB UMP programmes

Start	*End*	*Programme*	*Description*
Federal Reserve Board			
25.11.2008	31.03.2010	Large-scale asset purchases (LSAP 1)	Purchases of MBS, agency-related securities and longer-term Treasury securities up to a total of $1.75 trillion
10.08.2010	30.06.2011	Large-scale asset purchases (LSAP 2)	Additional purchases of longer-term Treasury securities of $600 billion and reinvestment of principal repayments of LSAP1 purchases into longer-term Treasury securities
09.08.2011	31.12.2012	Maturity extension programme (MEP, Operation Twist) and calendar-based Forward Guidance (FG)	Extension of the average maturity of FOMC holdings of securities and calendar-based forward guidance on policy rate path
13.09.2012	17.12.2013	Large-scale asset purchases (LSAP 3) and threshold-based FG	Open-ended purchases of agency mortgage-backed securities and longer-term Treasury securities at a pace of $40 billion and $45 billion, respectively, and threshold-based forward guidance on policy rate path
18.12.2013	31.10.2014	Tapering and threshold-based FG	Step-wise phasing-out of asset purchases (reduction of purchases by $10bn per month)
European Central Bank			
27.03.2008	01.04.2010	Extension of liquidity provision	Allocation of liquidity through fixed-rate, full-allotment tender and broadening of eligible collateral basket
07.05.2009	30.06.2010	Covered bond purchase programme (CBPP 1)	Purchases of EUR 60 billion of covered bonds
10.05.2010	06.09.2012	Securities market programme (SMP)	Sterilized purchases of sovereign debt securities
10.05.2010	running	Extension of liquidity provision	Re-establishment of liquidity allocation through fixed-rate, full-allotment tender
04.08.2011	01.03.2012	Extension of liquidity provision	Extension of maturity of liquidity provision operations (6m, 1y and 3y)
06.10.2011	31.10.2012	Covered bond purchase programme (CBPP 2)	Additional purchases of EUR 40 billion of covered bonds
06.09.2012	running	Outright monetary transactions (OMT)	Unlimited purchases of sovereign debt securities
05.06.2014	running	"Draghi Swarm"	Package of expansionary measures, including 4y liquidity operation and preparation for the purchase of asset-backed securities (ABSPP) and other covered bonds (CBPP3)
22.01.2015	running	Public sector purchase programme (PSPP)	Purchases of public sector securities amounting to a total of EUR 60 billion per month, including ABSPP and CBPP3

Table A.2: BoE and BoJ UMP programmes

Start	*End*	*Programme*	*Description*
Bank of England			
19.01.2009	10.06.2011	Asset purchase programme (QE1)	Purchases of private sector assets and public sector bonds of 225 billion
06.10.2011	03.07.2013	Asset purchase programme (QE2)	Additional purchases of private sector assets and public sector bonds of 150 billion
13.07.2012	running	Funding for lending (FLS)	Scheme incentivizing bank lending to households and businesses
04.07.2013	running	Forward Guidance	Threshold-based forward guidance on the policy rate path
Bank of Japan			
02.12.2008	31.03.2010	Liquidity provision: Special fund supplying operations (SFSO)	Expansion of the range of corporate debt as eligible collateral in liquidity operations
19.12.2008	31.12.2009	Asset purchase programme	Annual purchases of government bonds and commercial papers/corporate bonds of Y21.6 trillion and Y3 trillion, respectively
01.04.2010	29.10.2012	Liquidity provision (FRO - replacing SFSO)	Fixed-rate allotment of liquidity in 3m and 6m operations amounting to Y30 trillion
05.10.2010	03.04.2013	Asset purchase programme (Comprehensive monetary easing - CME)	Purchase of government securities, commercial paper (CP), corporate bonds, exchange-traded funds (ETFs), and Japan real estate investment trusts (J-REITs), up to a total amount of Y101 trillion
21.05.2011	running	Growth supporting funding facility (GSFF)	Scheme to support to fund-provisioning by private financial institutions
30.10.2012	running	Stimulating bank lending facility (SBLF)	A fund-providing scheme to stimulate bank lending
04.04.2013	running	Quantitative and qualitative monetary easing (QQME) and calendar-based FG	Purchases of JGBs, ETFs and J-REITs with the goal of increasing the monetary base by approximately Y80 trillion annually and intending to meet the 2 percent price stability target over 2 years

Appendix B

Baseline model for a closed economy

The closed economy model is a stylized DSGE model with quadratic price adjustment costs à la Rotemberg (1996). The model features a representative household that decides upon consumption, labour and inter-temporal bonds issued by the government. We exclude investment, capital accumulation, or habit formation.

The economy contains two types of firms. Final good producers transform intermediary goods into the final good according to a CES production function. Profits are zero due to perfect compentition. Intermediary good producers transform labour, as the only input, to intermediary goods according to known and symmetric technology. They operate under monopolistic competition facing quadratic price adjustment costs, profits are distributed to the owner: the household. Factor markets are perfectly competitive. The government plays a limited role only: It runs a balanced budget with lump-sum transfers adjusted to the issuance of new bonds and (exogenous fraction of output) government purchases.

The differences of Rotemberg and Calvo models are, for our case, twofold. First, upon linearization (around a zero inflation steady state), the Rotemberg framework is equivalent to the Calvo (1983) pricing framework, yet does not exhibit endogenous state variables like price dispersion. This is convenient in our non-linear model; in Calvo set-ups, dispersion usually disappears upon linearization. Second, aggregate output generally does not correspond to Gross Domestic Product (GDP) in the Rotemberg framework, due to the (aggregate) price adjustment costs.

B.1 Baseline model

B.1.1 Households

The representative household draws (dis-) utility for consumption and labour. The one-period utility function is

$$U(c_t, h_t) = \frac{c_t^{1-\sigma}}{1-\sigma} - \varphi \frac{h_t^{1+\nu}}{1+\nu}$$

where φ is a scaling term to ensure a specific steady-state hours level. The household consumes c_t, buys new real bonds b_t, receives real labour income (after taxes) $w_t(1-\tau_{w,t})h_t$, receives pay-off from bonds from $t-1$, in real terms $R_{t-1}b_{t-1}/(\pi_t)$, and receives transfers from the government T_t and profits through Π_t. This yields the following real budget constraint (in terms of p_t)

$$c_t + b_t = w_t(1-\tau_{w,t})h_t + \frac{R_{t-1}b_{t-1}}{\pi_t} + T_t + \Pi_t$$

The household thus maximizes discounted (life-time) utility

$$\begin{aligned} \max_{c_t, h_t, b_t, \lambda_t} \quad & \mathbb{E}_t \left[\sum_{j=0}^{\infty} \beta^j \left(\prod_{k=0}^{j} d_{t+k} \right) \left(\frac{c_{t+j}^{1-\sigma}}{1-\sigma} - \varphi \frac{h_{t+j}^{1+\nu}}{1+\nu} \right) \right] \\ \text{s.t.} \quad & c_t + b_t = w_t(1-\tau_{w,t})h_t + \frac{R_{t-1}b_{t-1}}{\pi_t} + T_t + \Pi_t \end{aligned}$$

The first order conditions of this optimization problem are (λ_t is the Lagrangian multiplier for the budget constraint)

$$d_t c_t^{-\sigma} = \lambda_t \tag{B.1}$$

$$\varphi d_t h_t^{\nu} = \lambda_t w_t (1-\tau_{w,t}) \tag{B.2}$$

$$\lambda_t = \mathbb{E}_t \left(\beta \lambda_{t+1} \frac{R_t}{\pi_{t+1}} \right) \tag{B.3}$$

$$c_t + b_t = w_t(1-\tau_{w,t})h_t + \frac{R_{t-1}b_{t-1}}{\pi_t} + T_t + \Pi_t \tag{B.4}$$

B.1.2 Final good producers

Final good producers choose their inputs, intermediate goods $y_t(j)$, in order to maximize their profits (or, equivalently, minimize costs), with respect to the following CES production function

$$y_t = \left(\int_0^1 y_t(j)^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}} \tag{B.5}$$

and profits $\Pi_t \equiv p_t y_t - \int_0^1 p_t(j) y_t(j) dj)$. The first order condition of this maximization problem yields the demand of the intermediary good $y_t(j)$

$$y_t^d(j) = \left(\frac{p_t(j)}{p_t}\right)^{-\epsilon} y_t \tag{B.6}$$

Using the production function, we can derive an expression for the price of the final good, p_t

$$p_t = \left(\int_0^1 p_t(j)^{1-\epsilon} di\right)^{\frac{1}{1-\epsilon}} \tag{B.7}$$

B.1.3 Intermediate good producers

The intermediary good producers use labour as (the only) input and produce their intermediary good variety $y_t(j)$ with a linear production function. Productivity a_t is common to all producers

$$y_t(j) = a_t h_t(j) \tag{B.8}$$

The producers determine their optimal quantity (or the optimal price that leads to this quantity) in two steps: First, they minimize costs given a certain level of production, i.e. derive the optimal level of labour input, then maximize profits by choosing the appropriate price. Note that we assume complete labour markets, thus wages are equal for all firms ($w_t(j) = w_t$), and that firms take aggregate variables (such as prices or output) as given. In the following, we already propose market clearing for the intermediary good.

Step 1: Cost minimization (real marginal costs)

First, intermediaries minimize nominal costs $w_t p_t h_t(j)$ such that the production/supply (B.8) of the intermediary good producer satisfies demand (B.6) from the final good producers. Formally, intermediary good producers minimize

$$\min_{h_t(j)} \quad w_t p_t h_t(j) \quad \text{s.t.} \quad a_t h_t(j) = \left(\frac{p_t(j)}{p_t}\right)^{-\epsilon} y_t$$

The corresponding Lagrangian adds a multiplier $\psi_t(j)$ to the restriction, which represents nominal marginal costs. The two first order conditions of this maximization problem are

$$\frac{\partial \mathcal{L}}{\partial h_t(j)}: \quad 0 = w_t p_t - \psi_t(j) a_t \qquad\qquad \frac{\partial \mathcal{L}}{\partial \psi_t(j)}: \quad 0 = a_t h_t(j) - \left(\frac{p_t(j)}{p_t}\right)^{-\epsilon} y_t$$

With equal wages and technology across firms, so are nominal marginal costs ($\psi_t(j) = \psi_t$). In the following, we replace nominal with a definition for real marginal costs mc_t. Although we will see that optimal prices are equal across firms, c.f. step 2, they are not yet. The two equilibrium conditions from the first step thus are real marginal costs and individual production level

$$mc_t \equiv \frac{\psi_t}{p_t} = \frac{w_t}{a_t} \tag{B.9}$$

$$a_t h_t(j) = \left(\frac{p_t(j)}{p_t}\right)^{-\epsilon} y_t \tag{B.10}$$

Step 2: Profit maximization (optimal price setting)

Second, the intermediaries maximize profits. In this model, the firms face quadratic real price adjustment costs $\kappa_t(j)$ à la Rotemberg (1982) per unit of y_t, as in Braun et al. (2013).

$$\kappa_t(j) \equiv \frac{\gamma}{2}\left(\frac{p_t(j)}{p_{t-1}(j)} - 1\right)^2 \tag{B.11}$$

The firms receive nominal revenues $p_t(j)y_t(j)$, face nominal total costs $p_t mc_t y_t(j)$ and (total) nominal adjustment costs $\kappa_t(j)p_t y_t$. (Nominal) profits of firm j then are

$$\Pi_t(j) = \underbrace{p_t(j)y_t(j)}_{\text{Earnings}} - \underbrace{p_t mc_t(j) y_t(j)}_{\text{Nominal costs}} - \underbrace{\frac{\gamma}{2}\left(\frac{p_t(j)}{p_{t-1}(j)} - 1\right)^2 p_t y_t}_{\text{Nominal adj. costs}} \tag{B.12}$$

The firms then maximize (real) discounted profits with respect to $p_t(j)$

$$\max \ \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \Pi_{t+s}(j) \frac{1}{p_t}$$

where the firms, owned by the household, use the (stochastic) nominal discount factor $\Lambda_{t,t+1}$ from the household (derived from equation (B.3)) to discount expected future profits

$$\Lambda_{t,t+1} = \beta \frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\pi_{t+1}} = \beta\left(\frac{d_{t+1}}{d_t}\frac{c_{t+1}}{c_t}\right)^{-\sigma}\frac{1}{\pi_{t+1}}$$

The first order condition with respect to $p_t(j)$ yields

$$\begin{aligned} 0 = &\left[p_t(j)\frac{\partial y_t(j)}{\partial p_t(j)} + y_t(j)\right] - p_t mc_t(j)\frac{\partial y_t(j)}{\partial p_t(j)} - \gamma\left(\frac{p_t(j)}{p_{t-1}(j)} - 1\right)\left(\frac{1}{p_{t-1}(j)}\right) p_t y_t \\ &- E_t\left[\beta d_{t+1}\left(\frac{c_{t+1}}{c_t}\right)^{-\sigma}\frac{1}{\pi_{t+1}}\left[\gamma\left(\frac{p_{t+1}(j)}{p_t(j)} - 1\right)\left(-\frac{p_{t+1}(j)}{p_t(j)^2}\right) p_{t+1} y_{t+1}\right]\right] \end{aligned}$$

The (marginal) demand with respect to a particular price $p_t(j)$ is, from equation (B.6)

$$\frac{\partial y_t(j)}{\partial p_t(j)} = -\epsilon p_t(j)^{-\epsilon-1} p_t^{\epsilon} y_t = -\epsilon \frac{1}{p_t(j)}\left(\frac{p_t(j)}{p_t}\right)^{-\epsilon} y_t = -\epsilon\frac{1}{p_t(j)} y_t^d(j)$$

and the first order condition above turns into an equation where the only firm-specific variable is the (optimal) price $p_t(j)$, and hence all optimal prices will be equal.[1] Using the price index for the final good, equation (B.7), we thus know

$$p_t = \left(\int_0^1 p_t(j)^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}} = p_t(j)$$

Using the partial demand expression above, replacing all $p_t(j)$ with p_t, cancelling out all possible price terms, dividing by y_t and using the definition for inflation ($\pi_t \equiv \frac{p_t}{p_{t-1}}$) yields a very much simplified optimal price setting equation

$$\begin{aligned} 0 = & \left[p_t(-\epsilon)\frac{1}{p_t}y_t + y_t \right] - p_t mc_t \left[-\epsilon \frac{1}{p_t} y_t \right] - \gamma \left(\frac{p_t}{p_{t-1}} - 1 \right) \left(\frac{p_t}{p_{t-1}} \right) y_t \\ & + E_t \left[\beta d_{t+1} \left(\frac{c_{t+1}}{c_t} \right)^{-\sigma} \frac{1}{\pi_{t+1}} \left[\gamma \left(\frac{p_{t+1}}{p_t} - 1 \right) \left(\frac{p_{t+1}}{p_t} \right)^2 y_{t+1} \right] \right] \\ = & 1 - \epsilon + \epsilon mc_t - \gamma \left(\pi_t - 1 \right) \pi_t \\ & + E_t \left[\beta d_{t+1} \left(\frac{c_{t+1}}{c_t} \right)^{-\sigma} \left[\gamma \left(\pi_{t+1} - 1 \right) \left(\pi_{t+1} \right) \frac{y_{t+1}}{y_t} \right] \right] \end{aligned}$$

We finally get an expression for marginal costs mc_t from the optimal price setting equation

$$mc_t = \frac{\epsilon - 1}{\epsilon} + \frac{\gamma}{\epsilon}(\pi_t - 1)\pi_t - \frac{\gamma}{\epsilon} E_t \left[\beta d_{t+1} \left(\frac{c_{t+1}}{c_t} \right)^{-\sigma} \pi_{t+1} \left(\pi_{t+1} - 1 \right) \frac{y_{t+1}}{y_t} \right] \tag{B.13}$$

B.1.4 Government and central bank

Government expenditures are (assumed) a (stochastic) fraction η_t of aggregate output y_t

$$g_t \equiv \eta_t y_t \tag{B.14}$$

We assume a government that runs a balanced (real terms) budget each period. It faces real expenditures g_t, proportionally linked to aggregate output y_t, receives (real) labour income taxes $\tau_{w,t} h_t w_t$, pays back its old bonds with interests $R_{t-1} d_{t-1}/\pi_t$, and issues new debt d_t. Finally, it provides transfers T_t to households. Its budget constraint in real terms gets

$$\underbrace{g_t}_{\text{gov. exp.}} + \underbrace{\frac{R_{t-1} d_{t-1}}{\pi_t}}_{\text{pay back bonds}} + \underbrace{T_t}_{\text{transfers}} = \underbrace{w_t \tau_{w,t} h_t}_{\text{tax income}} + \underbrace{d_t}_{\text{issue new bonds}} \tag{B.15}$$

The central bank follows a standard Taylor rule for its desired interest rate Z_t, considering inflation and output gap based on Gross Domestic Product.[2] Once we apply forward

[1] Note that this is the main implication and thus difference of the Rotemberg (1982) model: all firms adjust, and all firms adjust to their optimal level.

[2] The latter differs from final good production y_t in the Rotemberg model, and will be defined further below.

guidance, we relax this interest rate setting behavior. The interest rate set by the central bank, R_t, has to obey the zero lower bound

$$\frac{Z_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_r} \left[\left(\frac{\pi_t}{\pi^\star}\right)^{\phi_\pi} \left(\frac{\tilde{y}_t}{\tilde{y}}\right)^{\phi_x}\right]^{1-\rho_r} \tag{B.16}$$

$$R_t = \max\{1, Z_t\} \tag{B.17}$$

B.1.5 Gross domestic product

In the Rotemberg set-up, aggregate output y_t does not correspond to the Gross Domestic Product (GDP): The (aggregate) price adjustment costs create a 'wedge' between output and GDP. We thus define GDP as

$$\tilde{y}_t \equiv c_t + g_t = (1 - \kappa_t) y_t \tag{B.18}$$

Note that our model does nit inherit investments and, since it is a closed economy, there are no exports or imports either.

B.1.6 Aggregation and market clearing

Market clearing

We have four markets to clear: (a continuum of) intermediary good markets, the final good market, the labour market, and the bond market.

- We already used the market clearing condition for the intermediary good to derive the optimal price setting equation (B.13) and individual labour demand (B.10).
- Labour markets clear if

$$h_t^s = \int_0^1 h_t^d(j) dj$$

- Bond markets clear if government issued bonds equal household's bonds (there is no foreign country to exchange bonds with)

$$b_t = d_t \tag{B.19}$$

- Final good market clears if production equals the (aggregate) consumption of the household and government, and aggregated (real) adjustment costs

$$y_t \geq c_t + g_t + \int_0^1 \kappa_t(j) dj = c_t + g_t + \int_0^1 \frac{\gamma}{2} \left(\frac{p_t(j)}{p_{t-1}(j)} - 1\right)^2 y_t dj$$

Using the intermediary good producers' production function (B.10) (and equal prices $p_t(j) = p_t$), we get the aggregate labour demand from the labour market clearing condition[3]

$$h_t \equiv h_t^s = \int_0^1 h_t^d(j)dj = \int_0^1 \frac{y_t}{a_t}dj = \frac{y_t}{a_t} \tag{B.20}$$

Final good market clearing can be rewritten, using equal prices and the definition for inflation, to get the aggregate resource constraint

$$y_t = c_t + g_t + \frac{\gamma}{2}(\pi_t - 1)^2 y_t = c_t + \eta_t y_t + \kappa_t y_t \tag{B.21}$$

which can be re-written as

$$c_t = y_t(1 - \eta_t - \kappa_t)$$

Aggregate resource constraint / budget constraints

According to Walras' law, we know that one (market clearing) condition is redundant. In our case, this corresponds to the aggregate resource constraint (B.21) derived above. We derive this condition alternatively, by using the budget constraints of the household and the government, profits and taxes.

Aggregate (real) profits in t are

$$\begin{aligned}\Pi_t &= \int_0^1 \Pi_t(j)dj = \int_0^1 \frac{p_t(j)y_t(j)}{p_t} - mc_t(j)y_t(j) - \frac{\gamma}{2}\left(\frac{p_t(j)}{p_{t-1}(j)} - 1\right)^2 y_t dj \\ &= y_t - mc_t y_t - \kappa_t y_t\end{aligned}$$

Take the budget constraint of the household (B.4), plug in aggregate real profits and the government budget constraint (solved for transfers T_t), use aggregate labour demand (B.20) and real marginal costs (B.9) to get the alternative (and identical) aggregate resource constraint

$$\begin{aligned}c_t + b_t &= w_t(1-\tau_{w,t})h_t + \frac{R_{t-1}b_{t-1}}{\pi_t} + T_t + \Pi_t \\ c_t + b_t &= w_t(1-\tau_{w,t})h_t + \frac{R_{t-1}b_{t-1}}{\pi_t} + \left[b_t + \tau_{w,t}w_t h_t - g_t - \frac{R_{t-1}b_{t-1}}{\pi_t}\right] \\ &\quad + (y_t - mc_t y_t - \kappa_t y_t) \\ c_t &= w_t h_t - g_t + y_t - mc_t y_t - \kappa_t y_t \\ c_t &= g_t + y_t - \kappa_t y_t \end{aligned} \tag{B.22}$$

B.1.7 Equilibrium conditions

From the household, we have three optimality conditions left, (B.1), (B.2), and (B.3), while the budget constraint (B.4) entered the aggregate resource constraint (B.22). The

[3]Note that in the Calvo set-up, this equation does not hold anymore, as price dispersion leads to inefficiency. In the Calvo setup, we (often) get three equations for optimal pricing; one recursive formula and two 'auxiliary' equations. In the Rotemberg set-up, we only require pricing equation (B.13). The Rotemberg 'friction', price adjustment costs, will become apparent below in the distinction of y_t and $\tilde{y}_t$.

optimality conditions from the final good producing firm, demand for intermediary goods (B.6) and the price index (B.7), entered other equations and thus do not longer represent equilibrium conditions. From the intermediary good producing firm, we have marginal costs (B.9), aggregate labour demand (B.10), and optimal price setting (B.13). From the government, we still require the definitions of government expenditures (B.14), while we used its budget constraint (B.15) to derive the aggregate resource constraint (B.22). The central bank provides the Taylor rule and the (zero) lower bound equation, (B.16) and (B.17) The aggregation led to the aggregate resource constraint (B.22), the definition of Gross Domestic Product (B.18) and (the definition for) aggregate price adjustment costs (B.11) (which have shown to be equal across firms).

In sum, we have the following 12 equations and 12 (endogenous) variables.

- Households equations (B.1), (B.2), (B.3)
  Final firm none
  Intermediary firm (B.10), (B.9), (B.13)
  Government (B.14)
  Definition of price adjustment costs (B.11)
  Taylor rule and ZLB (B.16), (B.17)
  Definition of GDP (B.18)
  Aggregate resource constraint (B.22)
- Endogenous variables $c_t,\ h_t,\ \lambda_t,\ R_t,\ Z_t,\ w_t,\ \pi_t\ mc_t,\ \kappa_t,\ y_t,\ g_t,\ \tilde{y}_t$
- Exogenous variables $d_{t+1},\ \eta_t,\ a_t,\ \tau_{w,t}$

In addition, we need to specify a process for each exogenous variable. Productivity enters the production function linearly. Hence, we need to ensure that production cannot get zero due to productivity. Similarly for the stochastic discount shock (one in steady state or without shocks), government expenditure share and taxes on labour income

$$a_t = a^{1-\rho_a} a_{t-1}^{\rho_a} \exp\{\sigma_a \varepsilon_{a,t}\} \tag{B.23}$$
$$d_{t+1} = d^{1-\rho_d} d_t^{\rho_d} \exp\{\sigma_d \varepsilon_{d,t}\} \tag{B.24}$$
$$\eta_t = \eta^{1-\rho_\eta} \eta_{t-1}^{\rho_\eta} \exp\{\sigma_\eta \varepsilon_{\eta,t}\} \tag{B.25}$$
$$\tau_{w,t} = \tau_w^{1-\rho_\tau} \tau_{w,t-1}^{\rho_\tau} \exp\{\sigma_\tau \varepsilon_{\tau,t}\} \tag{B.26}$$

with variance parameters σ_a, σ_d, σ_η, and σ_τ.

B.2 Steady state

The Taylor rule (B.16) requires – assuming that we are in the 'good' steady state ($R = Z$) – that inflation returns to its steady state value (inflation target) $\pi = \pi^\star$ such that the rule holds.

Using $\pi = \pi^\star$ in the steady-state expression of (B.3) and the adjustment costs (B.11) we get

$$R = \frac{1}{\beta}\pi^\star \tag{B.27}$$

$$\kappa = \gamma/2\left(\pi^\star - 1\right)^2 \tag{B.28}$$

Use $\pi = \pi^\star$ for marginal costs mc and wages w, derived through equation (B.13) and (B.9)

$$mc = \frac{\epsilon - 1}{\epsilon} + \frac{\gamma}{\epsilon}(\pi^\star - 1)\pi^\star\left(1 - \beta d\right) \tag{B.29}$$

$$w = mc\ a \tag{B.30}$$

Equations (B.10), (B.14), (B.22), and (B.18) give us four ratios which are all determined

$$\frac{h}{y} = 1/a \qquad \frac{g}{y} = \eta \qquad \frac{c}{y} = 1 - \eta - \kappa \qquad \frac{\tilde{y}}{y} = 1 - \kappa$$

Combining the steady-state equations for (B.1) and (B.2) yields, with the ratios above

$$h^\nu c^\sigma = \frac{w(1-\tau_w)}{\varphi} \quad \rightarrow \quad y^{\nu+\sigma}\left(\frac{h}{y}\right)^\nu\left(\frac{c}{y}\right)^\sigma = \frac{w(1-\tau_w)}{\varphi} \rightarrow \quad y^{\nu+\sigma} = \frac{a^\nu w(1-\tau_w)}{\varphi\left(1-\eta-\kappa\right)^\sigma}$$

and, finally, get the steady-state expression for output y

$$y = \left[\frac{a^\nu w(1-\tau_w)}{\varphi\left(1-\eta-\kappa\right)^\sigma}\right]^{\frac{1}{\nu+\sigma}} \tag{B.31}$$

Given y, we can derive the other variables using the ratios again

$$h = y/a \tag{B.32}$$

$$g = \eta\ y \tag{B.33}$$

$$c = y(1 - \eta - \kappa) \tag{B.34}$$

$$\tilde{y} = c + g = y(1 - \kappa) \tag{B.35}$$

The preference parameter φ on labour is often implemented (and set) to scale down steady-state labour, e.g. to set steady-state hours to a third. This implies the following value for φ

$$\frac{1}{3} \overset{!}{=} h = y/a = \left[\frac{a^\nu w(1-\tau_w)}{\varphi\left(1-\eta-\kappa\right)^\sigma}\right]^{\frac{1}{\nu+\sigma}}/a \quad \rightarrow \quad \varphi = \left[\frac{a}{3}\right]^{\nu+\sigma}\frac{\left(1-\eta-\kappa\right)^\sigma}{a^\nu w(1-\tau_w)} \tag{B.36}$$

Last but not least, the steady-state value for the Lagrangian multiplier gets

$$\lambda = c^{-\sigma} \tag{B.37}$$

B.3 Calibration

We calibrate the model as following. Certain parameters may matter substantially for forward guidance, such as the intertemporal elasticity of substitution, and we provide somewhat more detail on these choices. Others, in contrast, matter less and we rely on standard parameters.

- *Intertemporal elasticity of substitution*
  We implicitly use log-utility and set the (inverse) intertemporal elasticity of substitution to $\sigma = 1$. In doing so, we follow Braun et al. (2013) or Fernández-Villaverde et al. (2015). Note that Levin et al. (2010) and Nakov (2008) analysis a wide range of values for σ, Nakov e.g. considers values from 1/6 to 6. Generally, a lower σ generally reduces the responsiveness of forward guidance.
- *(Inverse) elasticity of labor supply*
  The value for the (inverse) elasticity of labor supply ν often ranges from 0.1 to 1. We set $\nu = 0.2$ and are thus quite close to Braun et al. (2013).
- *Discount factor*
  The discount factor β determines the steady-state level of the real interest rate. We set it to $\beta = 0.994$, such that real interest rate equals roughly 2.5% in annualized terms.
- *Elasticity of substitution between intermediary goods*
  The range of values for the elasticity of substitution values often varies between six and ten. We set this value to $\varepsilon = 6$.
- *Price adjustment costs*
  We set the price adjustment parameter to a hundred, $\gamma = 100$
- *Government expenditure share and taxes*
  We set both taxes and government consumption share to 20%, $\eta = 0.2$ and $\tau_w = 0.2$
- *Monetary policy parameters*
  We set the Taylor rule coefficients to standard values: $\phi_\pi = 1.5$ and $\phi_\pi = 0.5$. In the baseline simulations, we set inertia to zero, i.e. $\rho_r = 0$. The inflation target is set to 2% in annualized terms, i.e. $\pi^\star = 1.005$ (gross inflation)
- *Steady-state hours worked*
  We set the weight on labour disutility φ such that the steady-state hours equal one third $h = 1/3$. This choice should not matter for the effectiveness of forward guidance.

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Appendix C

Baseline model for an open economy

The two economies are symmetric in terms of most functions, preferences and parameters. We denote foreign variables with a * and, wherever applicable, domestic goods (also inflation) with a h and foreign goods with a f. This yields, for instance, $p_h^\star$ as the foreign price (in foreign currency) for domestically produced goods. For the sake of readability, we provide the derivation of the equations for the domestic economy, but only the final equations for the foreign economy.

Note, foremost, that the economies are similar in most things, but may possess different population sizes n, following, for instance, De Paoli (2009). Technically, n is the fraction of $[0, 1]$ that lives in the domestic economy, and $(1 - n)$ the fraction that lives in the foreign economy. A single household gets the suffix (j), aggregate variables are corresponding variables without. This size variable creates a 'wedge' between aggregate, per-capita and individual variables; aggregation will matter considerably, but allows us to contemporaneously asses the small open economy $(n \to 0)$ and the large open economy case $(n \approx 1/2)$.

The economy consists of three types of firms: final good producer(s), retailed/imported good producer(s) and intermediary good producers. The first two operate under perfect competition and thus could easily be replaced by a corresponding CES consumption bundle function for the household. The intermediary good producers operate under monopolistic competition. The law of one price holds at the individual level. In other words, the producer chooses one price and both the domestic and foreign buyer pay in the producers' currency, without any price discrimination – also referred to as producer currency pricing (PCP). Home bias in the composition of the final good, however, implies that the law of one price only holds at a lower level: for individual intermediary goods and retailed or imported good bundles. At the final good level, home bias implies that the pass-through is incomplete, deviations thereof are captured by the real exchange rate.

The production function of the intermediary good producers is linear, with common and known technology and labour as the only input. There is no capital and thus no investment in this model. Different to the majority of DSGE models, the (intermediary) good producers face price adjustment costs á la Rotemberg (1982) and no pricing lottery à la Calvo (1983). The price adjustment costs are, however, indexed to past and steady-state or target inflation, following Ascari and Rossi (2012), in order to provide a better comparison with any Calvo model (at least from a theoretical point of view).[1]

Ricardian equivalence holds, the government's role is thus very limited. Lump-sum transfers offset wage taxes and government expenditures in each period, the government is not allowed to issue bonds. This simplifies the bond handling considerably without loosing too much intuition. In the baseline model, the central bank follows a standard Taylor rule.

[1]The authors conclude that, despite common understanding, the two modeling approaches face considerable differences if steady-state inflation is not zero. With full indexation, however, "the two models are again equivalent as in the case of no trend inflation".

C.1 Baseline model

C.1.1 Definitions and aggregates

In this introductory section, we define several variables that will simplify the formal language below (and, formally, also replace the variables they are based upon). A first set of variables concerns inflation variables that will replace (changes in) price variables. The first two columns represent (CPI) inflation, the last two columns (PPI) inflation.

$$\pi_t \equiv \frac{p_t}{p_{t-1}} \qquad \pi_t^\star \equiv \frac{p_t^\star}{p_{t-1}^\star} \qquad \pi_{h,t} \equiv \frac{p_{h,t}}{p_{h,t-1}} \qquad \pi_{f,t}^\star \equiv \frac{p_{f,t}^\star}{p_{f,t-1}^\star} \tag{C.1}$$

Another variable the real exchange rate q_t that relates the nominal exchange rate e_t with (CPI) prices p_t and $p_t^\star$.

$$q_t \equiv e_t \frac{p_t^\star}{p_t} \tag{C.2}$$

In standard models with unity size of economies, aggregated, per-capita and individual variables are (mostly) identical, at least under symmetry. In our case, however, the size of the economies may differ from one (determined by the parameter for the relative size n) and thus affect aggregates. Domestic and foreign aggregates are

$$\hat{c}_t \equiv \int_0^n c_t(j)dj = nc_t(j) \qquad \hat{c}_t^\star \equiv \int_n^1 c_t(j)dj = (1-n)c_t(j) \tag{C.3}$$

where the second step follows by symmetry. Obviously, aggregates approach zero for the small open economy case ($n \to 0$), which complicates the interpretation and comparison of domestic and foreign variables. In contrast, the following per-capita figures remain comparable.

$$c_t \equiv \frac{1}{n}\int_0^n c_t(j)dj = c_t(j) \qquad c_t^\star \equiv \frac{1}{1-n}\int_n^1 c_t^\star(j)dj = c_t^\star(j) \tag{C.4}$$

Henceforth, we rely on per-capita figures unless stated otherwise.

C.1.2 Households

Each individual household j draws (dis-) utility from consumption and labour. The one-period utility function for the domestic household j is

$$U(c_t, h_t)(j) = \frac{c_t(j)^{1-\sigma}}{1-\sigma} - \psi\frac{h_t(j)^{1+\nu}}{1+\nu}$$

where ψ is a scaling term to allow for a specific steady-state hours level.

The consumption c_t stems from the (non-tradable) final good, acquired at price p_t from the domestic final good producer. In addition, the household may buy (or sell) nominal domestic $B_t(j)$ and foreign bonds $F_t(j)$. Prices of these bonds at t are one, the payoff determined by corresponding interest rates. The household receives nominal labour income (after taxes), $W_t(1-\tau_{w,t})h_t(j)$ from providing its labour supply $h_t(j)$ to the domestic intermediary good producers, receives nominal pay-off from $t-1$ domestic and foreign bond holdings, $R_{t-1}B_{t-1}(j)$ and $R^\star_{t-1}F_{t-1}(j)$, nominal transfers from the government $T_t(j)$ and nominal profits $\Pi^n_t(j)$ from domestic intermediary good producers. Note that bond prices and dividends are denominated in local currencies and the household needs to transfer those via the nominal exchange rate e_t (price of foreign in local currency). Otherwise, we assume perfect international capital markets, i.e. all households have access to all bonds.

These incomes and expenditures determine the following nominal budget constraint

$$c_t(j) + \frac{B_t(j)}{p_t} + e_t\frac{F_t(j)}{p_t} = \frac{W_t}{p_t}(1-\tau_{w,t})h_t + \frac{R_{t-1}B_{t-1}(j)}{p_t} + e_t\frac{R^\star_{t-1}F_{t-1}(j)}{p_t} + T_t(j) + \Pi^n_t(j)$$

To derive the real budget constraint, we define real terms of wages, bonds, taxes and profits as $w_t \equiv W_t/p_t$, $b_t \equiv B_t/_t$, $f_t \equiv F_t/p^\star_t$, $\tau_t \equiv T_t/p_t$ and $\Pi_t \equiv \Pi^n_t/p_t$ and use the definitions for CPI inflation (C.1) and the real exchange rate (C.2).

$$c_t(j) + b_t(j) + q_t f_t(j) = w_t(1-\tau_{w,t})h_t + \frac{R_{t-1}b_{t-1}}{\pi_t} + q_t\frac{R^\star_{t-1}f_{t-1}(j)}{\pi^\star_t} + \tau_t(j) + \Pi_t(j)$$

Optimization of individual households

The domestic household then maximizes discounted (life-time) utility

$$\max_{c_t(j),h_t(j),b_t(j),f_t(j)} \quad \mathbb{E}_t\left[\sum_{k=0}^{\infty}\beta^k\left(\prod_{l=0}^{k}d_{t+l}\right)\left(\frac{c_{t+k}(j)^{1-\sigma}}{1-\sigma} - \psi\frac{h_{t+k}(j)^{1+\nu}}{1+\nu}\right)\right]$$
$$\text{s.t.} \quad c_t(j) + b_t(j) + q_t f_t(j) = w_t(1-\tau_{w,t})h_t(j) + \frac{R_{t-1}b_{t-1}}{\pi_t} + q_t\frac{R^\star_{t-1}f_{t-1}(j)}{\pi^\star_t} + \tau_t(j) + \Pi_t(j)$$

where d_t is a preference shock that may affect the households' discount factor β. The first order conditions with respect to consumption, labour, domestic and foreign bonds are

$$d_t c_t(j)^{-\sigma} = \lambda_t(j) \qquad d^\star_{t+1}c_t(j)^{\star,-\sigma} = \lambda^\star_t(j) \tag{C.5}$$
$$\psi d_t h_t(j)^\nu = \lambda_t(j)w_t(1-\tau_{w,t}) \qquad \psi d^\star_{t+1}h^{\star,s}_t(j)^\nu = \lambda^\star_t(j)w^\star_t(1-\tau^\star_{w,t}) \tag{C.6}$$
$$\lambda_t(j) = \mathbb{E}_t\left(\beta\lambda_{t+1}(j)\frac{R_t}{\pi_{t+1}}\right) \qquad \lambda^\star_t(j) = \mathbb{E}_t\left(\beta\lambda^\star_{t+1}(j)\frac{q_t}{q_{t+1}}\frac{R_t}{\pi^\star_{t+1}}\right) \tag{C.7}$$
$$\lambda_t(j) = \mathbb{E}_t\left(\beta\lambda_{t+1}(j)\frac{q_{t+1}}{q_t}\frac{R^\star_t}{\pi^\star_{t+1}}\right) \qquad \lambda^\star_t(j) = \mathbb{E}_t\left(\beta\lambda^\star_{t+1}(j)\frac{R^\star_t}{\pi^\star_{t+1}}\right) \tag{C.8}$$

Last but not least, the Lagrangian multipliers $\lambda_t(j)$ and $\lambda^\star_t(j)$ impose the real budget constraints as additional conditions

$$
\begin{aligned}
c_t(j) + b_t(j) + q_t f_t(j) &= w_t(1-\tau_{w,t})h_t(j) \\
&+ \frac{R_{t-1}b_{t-1}(j)}{\pi_t} + q_t \frac{R^\star_{t-1} f_{t-1}(j)}{\pi^\star_t} + \tau_t(j) + \Pi_t(j) \qquad \text{(C.9)}
\end{aligned}
$$

$$
\begin{aligned}
c^\star_t(j) + \frac{1}{q_t} b^\star_t(j) + f^\star_t(j) &= w^\star_t(1-\tau^\star_{w,t})h^\star_t(j) \\
&+ \frac{1}{q_t}\frac{R_{t-1}b^\star_{t-1}(j)}{\pi^\star_t} + \frac{R^\star_{t-1} f^\star_{t-1}(j)}{\pi^\star_t} + \tau^\star_t(j) + \Pi^\star_t(j) \qquad \text{(C.10)}
\end{aligned}
$$

Households' aggregated optimality conditions

Per-capita first order conditions for households with respect to consumption and labour are straightforward (and identical), given symmetry

$$d_t c_t^{-\sigma} = \lambda_t \qquad d^\star_{t+1} c_t^{\star,-\sigma} = \lambda^\star_t \qquad \text{(C.11)}$$

$$\psi d_t h_t^\nu = \lambda_t w_t (1-\tau_{w,t}) \qquad \psi d^\star_{t+1} h_t^{\star s,\nu} = \lambda^\star_t w^\star_t (1-\tau^\star_{w,t}) \qquad \text{(C.12)}$$

The same holds for per-capita conditions for domestic and foreign bonds

$$\lambda_t = \mathbb{E}_t\left(\beta\lambda_{t+1}\frac{R_t}{\pi_{t+1}}\right) \qquad \lambda^\star_t = \mathbb{E}_t\left(\beta\lambda^\star_{t+1}\frac{q_t}{q_{t+1}}\frac{R_t}{\pi_{t+1}}\right) \qquad \text{(C.13)}$$

$$\lambda_t = \mathbb{E}_t\left(\beta\lambda_{t+1}\frac{q_{t+1}}{q_t}\frac{R^\star_t}{\pi^\star_{t+1}}\right) \qquad \lambda^\star_t = \mathbb{E}_t\left(\beta\lambda^\star_{t+1}\frac{R^\star_t}{\pi^\star_{t+1}}\right) \qquad \text{(C.14)}$$

and the per-capita budget constraints[2]

$$c_t + b_t + q_t f_t = w_t(1-\tau_{w,t})h_t + \frac{R_{t-1}}{\pi_t}b_{t-1} + q_t\frac{R^\star_{t-1}}{\pi^\star_t}f_{t-1} + \tau_t + \Pi_t \qquad \text{(C.15)}$$

$$c^\star_t + \frac{1}{q_t}b^\star_t + f^\star_t = w^\star_t(1-\tau^\star_{w,t})h^\star_t + \frac{1}{q_t}\frac{R_{t-1}}{\pi^\star_t}b^\star_{t-1} + \frac{R^\star_{t-1}}{\pi^\star_t}f^\star_{t-1} + \tau^\star_t + \Pi^\star_t \qquad \text{(C.16)}$$

Note how these conditions could change if we used aggregate variables, for instance for the aggregate optimal consumption decision for domestic households

$$d_t c_t(j)^{-\sigma} = \lambda_t(j) \quad \rightarrow \quad d_t\left(\frac{\hat{c}_t}{n}\right)^{-\sigma} = \frac{\hat{\lambda}_t}{n} \quad \rightarrow \quad d_t n^{1+\sigma}\hat{c}_t^{-\sigma} = \hat{\lambda}_t$$

In this case, the relative size parameter does not cancel out.

[2] In most models, a set of specific assumptions, among which Ricardian equivalence and perfect capital markets, makes the the households' budget constraint redundant. This also holds in our case. For the sake of completeness, we carry on this equation and show that they are indeed redundant once we can refer to the government's budget constraint, profits and market clearing, see section (C.1.9).

C.1.3 Final good producers

The (domestic) final good producer combines domestic and foreign inputs $x_{h,t}$ and $x_{f,t}$ to a final good y_t, purchased by the household at price p_t. The final good producer takes the input prices $p_{h,t}$ and $p_{f,t}$, in local currency, as given. We assume a continuum of identical firms under perfect competition, hence profits are zero, but simplify by referring to one representative firm. The foreign firm is symmetric in the general set-up while preferences may vary. The composition of the two inputs follows a CES production function in each economy

$$y_t = \left[v^{\frac{1}{\theta}} x_{h,t}^{\frac{\theta-1}{\theta}} + (1-v)^{\frac{1}{\theta}} x_{f,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$$

$$y_t^\star = \left[v^{\star,\frac{1}{\theta}} x_{h,t}^{\star,\frac{\theta-1}{\theta}} + (1-v^\star)^{\frac{1}{\theta}} x_{f,t}^{\star,\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}}$$

The parameter v consists of two parameters and conforms two assumptions, following e.g. De Paoli (2009): First, it shall allow for home bias (α), a preference for home goods vs. foreign goods (home bias occurs if $\alpha < 1$). Second, it shall allow us to implement the fact that the foreign country – representing the rest of the world – only consumes foreign goods if $n \to 0$, but that the smaller economy always consumes foreign goods. The following table shows the specifications that satisfy these two assumptions

Household	*Goods*	*Definition*	*Case* $n \approx 1/2$	*Case* $n \to 0$
Domestic	Domestic	$v = 1-(1-n)\alpha$	$v = 1-\frac{1}{2}\alpha$	$v = 1-\alpha$
	Foreign	$1-v \equiv (1-n)\alpha$	$1-v = \frac{1}{2}\alpha$	$1-v = \alpha$
Foreign	Domestic	$v^\star \equiv n\alpha$	$v^\star = \frac{1}{2}\alpha$	$v^\star = 0$
	Foreign	$1-v^\star = 1-n\alpha$	$1-v^\star = 1-\frac{1}{2}\alpha$	$1-v^\star = 1$

Profit maximization

The (domestic) final good producer hence solves the following optimization problem

$$\max_{x_{h,t},x_{f,t}} \hat{\Pi}_t = p_t \left[v^{\frac{1}{\theta}} x_{h,t}^{\frac{\theta-1}{\theta}} + (1-v)^{\frac{1}{\theta}} x_{f,t}^{\frac{\theta-1}{\theta}} \right]^{\frac{\theta}{\theta-1}} - p_{h,t}x_{h,t} + p_{f,t}x_{f,t}$$

The first order conditions with respect to inputs $x_{h,t}$ and $x_{f,t}$ yield the two demand functions for locally retailed (first row) and foreign (second) intermediary goods

$$x_{h,t} = v \left(\frac{p_{h,t}}{p_t} \right)^{-\theta} y_t \qquad x_{f,t}^\star = (1-v^\star) \left(\frac{p_{f,t}^\star}{p_t^\star} \right)^{-\theta} y_t^\star \tag{C.17}$$

$$x_{f,t} = (1-v) \left(\frac{p_{f,t}}{p_t} \right)^{-\theta} y_t \qquad x_{h,t}^\star = v^\star \left(\frac{p_{h,t}^\star}{p_t^\star} \right)^{-\theta} y_t^\star \tag{C.18}$$

and, with the zero profit condition (earnings minus expenditures for inputs)

$$p_t y_t = p_{h,t}x_{h,t} + p_{f,t}x_{f,t} \qquad p_t^\star y_t^\star = p_{h,t}^\star x_{h,t}^\star + p_{f,t}^\star x_{f,t}^\star \tag{C.19}$$

we also retrieve the prices of the final good

$$p_t = \left(v p_{h,t}^{1-\theta} + (1-v) p_{f,t}^{1-\theta} \right)^{\frac{1}{1-\theta}} \qquad p_t^\star = \left(v^\star p_{h,t}^{\star,1-\theta} + (1-v^\star) p_{f,t}^{\star,1-\theta} \right)^{\frac{1}{1-\theta}} \tag{C.20}$$

Aggregated equilibrium conditions

With the assumption of a representative firm, we face no aggregation (issues) at this stage. The individual conditions correspond to the per-capita conditions.

C.1.4 Retailers and importers

The goods consumed by the final good producers are gathered, bundled and sold by two sorts of retailers facing perfect competition and zero profits: domestic retailers (which buy, bundle and sell local intermediary goods and sell to the local final good producer) and importers (which buy, bundle and sell foreign intermediary goods to the local final good producer).[3] For the sake of simplicity, we again refer to one representative firm only, for each type, that bundles using a CES production function. The retailers follow

$$\hat{y}_{h,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\epsilon}} \int_0^n x_{h,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}} \qquad \hat{y}_{f,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\epsilon}} \int_n^1 x_{f,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}$$

and the importers follow

$$\hat{y}^\star_{f,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\epsilon}} \int_n^1 x^\star_{f,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}} \qquad \hat{y}^\star_{h,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\epsilon}} \int_0^n x^\star_{h,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}$$

To simplify reading, we already impose market clearing of retailed and imported good ($x_{h,t} = y_{h,t}$ and similarly for the others), and use only $x_{h,t}$ henceforth.

Retailers

The retailer maximizes profits with respect to all inputs, $x_{h,t}(j)$, subject to a certain level of (aggregate) output/demand $\hat{x}_{h,t}$

$$\max_{x_{h,t}(j)} \; p_{h,t}\hat{x}_{h,t} - \int_0^n p_{h,t}(j)x_{h,t}(j)dj \quad \text{s.t.} \quad \hat{x}_{h,t} \leq \hat{y}_{h,t} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\epsilon}} \int_0^n x_{h,t}(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}$$

For each input, we get one first order condition that corresponds to the demand function for this particular intermediary good. Solving for variety j yields (using the production function), using aggregates on the first and per-capita figures on the second row

$$\begin{aligned} x_{h,t}(j) &= \frac{1}{n}\left(\frac{p_{h,t}(j)}{p_{h,t}}\right)^{-\epsilon} \hat{x}_{h,t} & x^\star_{f,t}(j) &= \frac{1}{1-n}\left(\frac{p^\star_{f,t}(j)}{p^\star_{f,t}}\right)^{-\epsilon} \hat{x}^\star_{f,t} \\ &= \left(\frac{p_{h,t}(j)}{p_{h,t}}\right)^{-\epsilon} x_{h,t} & &= \left(\frac{p^\star_{f,t}(j)}{p^\star_{f,t}}\right)^{-\epsilon} x^\star_{f,t} \end{aligned} \tag{C.21}$$

[3] This step could easily be covered by the households themselves (utility derived from a CES consumption bundle) or an extended final good producer that relies upon two inputs with a CES production function (and cost minimization).

and, with the zero profit condition, we also retrieve the price of the domestically retailed good

$$p_{h,t} = \left[\frac{1}{n}\int_0^n p_{h,t}(j)^{1-\epsilon}dj\right]^{\frac{1}{1-\epsilon}} \qquad p^\star_{f,t} = \left[\frac{1}{1-n}\int_n^1 p^\star_{f,t}(j)^{1-\epsilon}dj\right]^{\frac{1}{1-\epsilon}} \tag{C.22}$$

Importers

The importer maximizes profits with respect to all inputs, $x_{f,t}(j)$, subject to a certain level of (aggregate) output/demand $\hat{x}_{f,t}$

$$\max_{x_{f,t}(j)} \; p_{f,t}\hat{x}_{f,t} - \int_n^1 p_{f,t}(j)x_{f,t}(j)dj \quad \text{s.t.} \quad \hat{x}_{f,t} \leq \hat{y}_{f,t} = \left[\left(\frac{1}{1-n}\right)^{\frac{1}{\epsilon}}\int_n^1 x_{f,t}(j)^{\frac{\epsilon-1}{\epsilon}}dj\right]^{\frac{\epsilon}{\epsilon-1}}$$

For each input, we get one first order condition that corresponds to the demand function for this particular intermediary good. Solving for variety j yields (using the production function), using aggregates on the first and per-capita figures on the second row. Note that in this case, the parameter for the relative size of the economies (n) does *not* cancel out.

$$\begin{aligned} x_{f,t}(j) &= \frac{1}{1-n}\left(\frac{p_{f,t}(j)}{p_{f,t}}\right)^{-\epsilon}\hat{x}_{f,t} & x^\star_{h,t}(j) &= \frac{1}{n}\left(\frac{p^\star_{h,t}(j)}{p^\star_{h,t}}\right)^{-\epsilon}\hat{x}^\star_{h,t} \\ &= \frac{n}{1-n}\left(\frac{p_{f,t}(j)}{p_{f,t}}\right)^{-\epsilon}x_{f,t} & &= \frac{1-n}{n}\left(\frac{p^\star_{h,t}(j)}{p^\star_{h,t}}\right)^{-\epsilon}x^\star_{h,t} \end{aligned} \tag{C.23}$$

and, with the zero profit condition, we also retrieve the price of the domestically retailed good

$$p_{f,t} = \left[\frac{1}{1-n}\int_n^1 p_{f,t}(j)^{1-\epsilon}dj\right]^{\frac{1}{1-\epsilon}} \qquad p^\star_{h,t} = \left[\frac{1}{n}\int_0^n p^\star_{h,t}(j)^{1-\epsilon}dj\right]^{\frac{1}{1-\epsilon}} \tag{C.24}$$

Aggregated optimality conditions

These equilibrium conditions will enter the optimality conditions of the intermediary good producers (following section). In consequence, there is no need to provide aggregated equilibrium conditions.

C.1.5 Intermediate good producers

The intermediary good producers, a continuum of firms with mass identical to that of the households, convert labour (as the only input, bought from the households) to intermediary goods (sold to domestic and foreign retailers) and operate under monopolistic competition. Technology is identical and known across firms, but not necessarily across countries.

$$\tilde{y}_t(j) = a_t h_t(j) \qquad \tilde{y}^\star_t(j) = a^\star_t h^\star_t(j) \tag{C.25}$$

According to the Rotemberg framework, the intermediary good producers face quadratic (real) price adjustment costs $\kappa_t(j)$. These price adjustment costs are measured in units of y_t, following Braun et al. (2013), i.e. total (real) price adjustment costs per firm are $\kappa_t(j)y_t$. In addition, the price adjustment costs are indexed to past (and steady state or target) inflation to ensure a better comparability with Calvo models. The parameter χ represents the degree of price indexation (full indexation if $\chi = 1$) and μ the type of indexation 'usually employed in the Calvo literature' (quote from Ascari and Rossi (2012)). See the introduction of this appendix for additional information. To simplify notation below, we define $\chi_t \equiv \left(\pi_{t-1}^{\chi}\right)^{\mu}\left(\pi^{t,\chi}\right)^{1-\mu}$ as a sort of indexation variable

$$\begin{aligned}
\kappa_t(j) &\equiv \frac{\gamma}{2}\left(\frac{p_{h,t}(j)}{p_{h,t-1}(j)}\frac{1}{\left(\pi_{t-1}^{\chi}\right)^{\mu}\left(\pi^{t,\chi}\right)^{1-\mu}}-1\right)^2 = \frac{\gamma}{2}\left(\frac{p_{h,t}(j)}{p_{h,t-1}(j)}\frac{1}{\chi_t}-1\right)^2 \\
\kappa_t^{\star}(j) &\equiv \frac{\gamma}{2}\left(\frac{p_{f,t}^{\star}(j)}{p_{f,t-1}^{\star}(j)}\frac{1}{\left(\pi_{t-1}^{\star,\chi}\right)^{\mu}\left(\pi^{t\star,\chi}\right)^{1-\mu}}-1\right)^2 = \frac{\gamma}{2}\left(\frac{p_{f,t}^{\star}(j)}{p_{f,t-1}^{\star}(j)}\frac{1}{\chi_t^{\star}}-1\right)^2 \qquad \text{(C.26)}
\end{aligned}$$

The firms decide in two steps: First, they minimize costs given a certain level of production, then maximize profits by choosing the appropriate price. Beforehand, we define how firms set prices abroad (pass-through) and derive the total demand that each firm faces.

Pricing, law of one price and total demand

Cross-border pricing for individual goods is assumed to follow the law of one price (first row of equations below). This pricing implies that the price levels of retailed and imported goods also follow the law of one price and simplify (second row, plug equations (C.27) into (C.22) and (C.24) and extract the exchange rate e_t from the integral). Note, however, that the law of one price will not hold at the final good level due to home bias. The real exchange rate, equation (C.2), covers deviations at this final good (CPI) level.

$$p_{f,t}(j) = e_t p_{f,t}^{\star}(j) \qquad p_{h,t}^{\star}(j) = \frac{1}{e_t}p_{h,t}(j) \qquad \text{(C.27)}$$

$$p_{f,t} = e_t p_{f,t}^{\star} \qquad p_{h,t}^{\star} = \frac{1}{e_t}p_{h,t} \qquad \text{(C.28)}$$

The demand functions of the importers also simplify under the assumptions of the law of one price (plug equations (C.28) into (C.23))

$$\begin{aligned}
x_{f,t}(j) &= \frac{n}{1-n}\left(\frac{e_t}{e_t}\frac{p_{f,t}(j)}{p_{f,t}}\right)^{-\epsilon}x_{f,t} = \frac{n}{1-n}\left(\frac{p_{f,t}^{\star}(j)}{p_{f,t}^{\star}}\right)^{-\epsilon}x_{f,t} \\
x_{h,t}^{\star}(j) &= \frac{1-n}{n}\left(\frac{e_t}{e_t}\frac{p_{h,t}^{\star}(j)}{p_{h,t}^{\star}}\right)^{-\epsilon}x_{h,t}^{\star} = \frac{1-n}{n}\left(\frac{p_{h,t}(j)}{p_{h,t}}\right)^{-\epsilon}x_{h,t}^{\star} \qquad \text{(C.29)}
\end{aligned}$$

Total (per-capita) demand for an intermediary good consists of the demand from the local retailer and the importer abroad (plug equations (C.21) and (C.29) into the definition below)

$$x^t_{h,t}(j) \equiv x_{h,t}(j) + x^\star_{h,t}(j) = \left(\frac{p_{h,t}(j)}{p_{h,t}}\right)^{-\epsilon} \left(x_{h,t} + \frac{1-n}{n} x^\star_{h,t}\right)$$
$$x^{t\star}_{f,t}(j) \equiv x_{f,t}(j) + x^\star_{f,t}(j) = \left(\frac{p^\star_{f,t}(j)}{p^\star_{f,t}}\right)^{-\epsilon} \left(\frac{n}{1-n} x_{f,t} + x^\star_{f,t}\right) \tag{C.30}$$

Note the implications of the relative size of the economy: As the size of the domestic economy approaches zero (small open economy), the contribution of the domestic economy to the foreign demand (rest of the world) also approaches zero, even in per-capita terms.[4]

$$\frac{n}{1-n} x_{f,t} \quad \stackrel{n\to 0}{\longrightarrow} \quad 0$$

Optimization step 1: Cost minimization

Intermediary good producers minimize nominal costs such that the production/supply of the intermediary good (C.25) satisfies a specific (total) demand from the local retailers and importers abroad (C.30). Formally, this corresponds to

$$\min_{h_t(j)} \quad w_t p_t h_t(j) \quad \text{s.t.} \quad a_t h_t(j) = \tilde{y}_t(j) \geq x^t_{h,t}(j)$$

The corresponding Lagrangian adds a multiplier $\psi_t(j)$ to the restriction, which represents nominal marginal costs. The two first order conditions of this maximization problem are

$$\frac{\partial \mathcal{L}}{\partial h^d_t(j)} : \; 0 = w_t p_t - \psi_t(j) a_t \qquad\qquad \frac{\partial \mathcal{L}}{\partial \psi_t(j)} : \; 0 = a_t h_t(j) - \tilde{y}_t(j)$$

Nominal marginal costs $\psi_t(j)$ are thus equal given that wages and technology are equal across firms ($\psi_t(j) = \psi_t$). In the following, we replace nominal marginal costs with a definition for real marginal costs (mc_t). The two equilibrium conditions from the first step thus are real marginal costs and individual production level

$$mc_t \equiv \frac{\psi_t}{p_t} = \frac{w_t p_t}{a_t}\frac{1}{p_t} = \frac{w_t}{a_t} \qquad\qquad mc^\star_t \equiv \frac{\psi^\star_t}{p^\star_t} = \frac{w^\star_t p^\star_t}{a^\star_t}\frac{1}{p^\star_t} = \frac{w^\star_t}{a^\star_t} \tag{C.31}$$
$$a_t h_t(j) = \tilde{y}_t(j) \qquad\qquad a^\star_t h^\star_t(j) = \tilde{y}^\star_t(j) \tag{C.32}$$

Optimization step 2: Profit maximization (optimal price settings)

The firms receive revenues from selling their good (produced amount set such that it simply serves demand (C.30)), face (nominal) costs from buying labour (C.31) and face

[4] If we would work with a continuum of households that purchase intermediary goods directly (which is quite common given the no profits condition of retailers and final good producers), we would need to integrate over the mass of households, which is n for domestic households and $1-n$ for foreign households. The results would be identical.

price adjustment costs according to (C.26). Nominal (per-capita) profits per period then get

$$\Pi_t^n(j) \equiv p_{h,t}(j)\tilde{y}_t(j) - p_t mc_t(j)\tilde{y}_t(j) - p_t \frac{\gamma}{2}\left(\frac{p_{h,t}(j)}{p_{h,t-1}(j)}\frac{1}{\chi_t} - 1\right)^2 y_t \tag{C.33}$$

The firms maximize nominal discounted profits $\Pi_{t+s}^n(j)$ with respect to $p_{h,t}(j)$, discounting future expected profits according to the (stochastic) discount factor $(\Lambda_{c,t,t+s})$ from their owners, the households (derived from equation (C.13))

$$\max_{p_{h,t}} \quad \mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s}\Pi_{t+s}(j) \qquad \text{where} \quad \Lambda_{t,t+s} = \beta\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\pi_{t+1}}$$

The first order condition of the firms with respect to their price yields

$$\begin{aligned}
0 = &\left[p_{h,t}(j)\frac{\partial\tilde{y}_t(j)}{\partial p_{h,t}(j)} + \tilde{y}_t(j)\right] - p_t mc_t(j)\frac{\partial\tilde{y}_t(j)}{\partial p_{h,t}(j)} \\
&- \gamma\left(\frac{p_{h,t}(j)}{p_{h,t-1}(j)}\frac{1}{\left(\pi_{t-1}^{\chi}\right)^{\mu}\left(\pi^{t,\chi}\right)^{1-\mu}} - 1\right)\left(\frac{1}{p_{h,t-1}(j)}\frac{1}{\chi_t}\right)p_t y_t \\
&- \mathbb{E}_t\left[\left[\beta\frac{\lambda_{t+1}}{\lambda_t}\frac{1}{\pi_{t+1}}\right]\left[\gamma\left(\frac{p_{h,t+1}(j)}{p_{h,t}(j)}\frac{1}{\chi_{t+1}} - 1\right)\left(-\frac{p_{h,t+1}(j)}{p_{h,t}(j)^2}\frac{1}{\chi_{t+1}}\right)p_{t+1}y_{t+1}\right]\right]
\end{aligned}$$

The marginal demand/output with respect to the chosen price $p_{h,t}(j)$ is, according to (C.30)

$$\frac{\partial\tilde{y}_t(j)}{\partial p_{h,t}(j)} = \frac{\partial x_{h,t}^t(j)}{\partial p_{h,t}(j)} = -\epsilon\frac{1}{p_{h,t}}\left(\frac{p_{h,t}(j)}{p_{h,t}}\right)^{-\epsilon-1}\left(x_{h,t} + \frac{1-n}{n}x_{h,t}^{\star}\right) = -\frac{\epsilon}{p_{h,t}(j)}\tilde{y}_t(j)$$

and the first order condition above turns into an equation where the only firm-specific variable is the (optimal) price $p_{h,t}(j)$, and hence all optimal prices will be equal.[5]

$$p_{h,t}(j) = p_{h,t}(i) \qquad \forall j, i \tag{C.34}$$

and the price indices for the retailed (C.22) and imported goods (C.24) simplify to

$$p_{h,t} = p_{h,t}(j) \qquad\qquad p_{f,t}^{\star} = p_{f,t}^{\star}(j) \tag{C.35}$$

which, in turn, also simplifies total demand for intermediary goods (C.30) by replacing $p_{h,t}(j)$ with $p_{h,t}$ following (C.35)

$$\begin{aligned}
\tilde{y}_t(j) &= x_{h,t}^t(j) = \left(x_{h,t} + \frac{1-n}{n}x_{h,t}^{\star}\right) \\
\tilde{y}_t^{t\star}(j) &= x_{f,t}^{t\star}(j) = \left(\frac{n}{1-n}x_{f,t} + x_{f,t}^{\star}\right)
\end{aligned} \tag{C.36}$$

[5] Note that this is the main implication of the Rotemberg (1982) model: all firms adjust, and all firms adjust to their optimal level. In the Calvo (1983) framework, only a fraction can re-optimize prices, thus price dispersion leads to inefficiencies.

Aggregated equilibrium conditions

In the open economy, (aggregate) per-capita domestic production (to be denoted as $\tilde{y}_t$) is often different to the per-capita production of the final good (y_t). We define per-capita production $\tilde{y}_t$ following the CES production function of retailers and importers

$$\tilde{y}_t \equiv \left[\left(\frac{1}{n}\right)^{\frac{1}{\epsilon}} \int_0^n \tilde{y}_t(j)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}} = \left[\left(\frac{1}{n}\right)^{\frac{1}{\epsilon}} \int_0^n \left(x_{h,t} + \frac{1-n}{n} x^\star_{h,t}\right)^{\frac{\epsilon-1}{\epsilon}} dj\right]^{\frac{\epsilon}{\epsilon-1}}$$

which can be simplified to (exploiting symmetry of output, given symmetry of prices (C.34))

$$\tilde{y}_t = x_{h,t} + \frac{1-n}{n} x^\star_{h,t} \qquad \tilde{y}^\star_t \equiv \frac{n}{1-n} x^\star_{h,t} + x^\star_{f,t}$$

In order to achieve a simple way to simulate shocks to foreign (and/or domestic) demand, we add an exogenous shock ζ_t to aggregate demand

$$\tilde{y}_t = \zeta_t \left(x_{h,t} + \frac{1-n}{n} x^\star_{h,t}\right) \qquad \tilde{y}^\star_t \equiv \zeta^\star_t \left(\frac{n}{1-n} x^\star_{h,t} + x^\star_{f,t}\right) \tag{C.37}$$

Using the definition for (PPI) inflation (C.1) and per-capita output of domestically produced goods (C.37), we can simplify the optimal price setting equation from the previous paragraph (or, phrased differently, an expression for marginal costs). All variables are already per-capita

$$\begin{aligned}
0 &= (1-\epsilon)\frac{p_{h,t}}{p_t}\tilde{y}_t + \epsilon mc_t \tilde{y}_t - \gamma\left(\frac{\pi_{h,t}}{\chi_t} - 1\right)\frac{\pi_{h,t}}{\chi_t} y_t \\
&\quad + \gamma\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\frac{\pi_{h,t+1}}{\chi_{t+1}} - 1\right)\frac{\pi_{h,t+1}}{\chi_{t+1}} y_{t+1}\right] \\
0 &= (1-\epsilon)\frac{p^\star_{f,t}}{p^\star_t}\tilde{y}^\star_t + \epsilon mc^\star_t \tilde{y}^\star_t - \gamma\left(\frac{\pi^\star_{f,t}}{\chi^\star_t} - 1\right)\frac{\pi^\star_{f,t}}{\chi^\star_t} y^\star_t \\
&\quad + \gamma\beta E_t\left[\frac{\lambda^\star_{t+1}}{\lambda^\star_t}\left(\frac{\pi^\star_{f,t+1}}{\chi^\star_{t+1}} - 1\right)\frac{\pi^\star_{f,t+1}}{\chi^\star_{t+1}} y^\star_{t+1}\right]
\end{aligned} \tag{C.38}$$

Similarly, per-capita labour demand from (C.32) yields

$$a_t h_t = \tilde{y}_t \qquad a^\star_t h^\star_t = \tilde{y}^\star_t \tag{C.39}$$

Per-capita adjustment costs are also straightforward given equal choices across firms and the definition of (PPI) inflation (C.1)

$$\kappa_t = \frac{\gamma}{2}\left(\frac{\pi_{h,t}}{\chi_t} - 1\right)^2 \qquad \kappa^\star_t = \frac{\gamma}{2}\left(\frac{\pi^\star_{f,t}}{\chi^\star_t} - 1\right)^2 \tag{C.40}$$

Optimized per-capita (real) profits finally are

$$\Pi_t = \frac{p_{h,t}}{p_t} h_t a_t - w_t h_t - \kappa_t y_t \qquad \Pi^\star_t = \frac{p^\star_{f,t}}{p^\star_t} h^\star_t a^\star_t - w^\star_t h^\star_t - \kappa^\star_t y^\star_t \tag{C.41}$$

C.1.6 GDP and international relations

Gross domestic product

It seems worth pointing out the economic relevance of the aggregate (domestic, and per-capita) production: it also corresponds to the Gross Domestic Product (GDP). Another way to derive this expression is by using the aggregate resource constraint (C.52) from the market clearing section below and the zero-profit condition (C.19). Start with multiplying (C.37) with domestic PPI, then plug in (C.19) and then (C.52)

$$\begin{aligned} p_{h,t}\tilde{y}_t &= p_{h,t}x_{h,t} + \frac{1-n}{n}p_{h,t}x^\star_{h,t} \\ &= p_t y_t - p_{f,t}x_{f,t} + \frac{1-n}{n}p_{h,t}x^\star_{h,t} \\ &= p_t c_t + p_t g_t - p_t \kappa_t y_t + \frac{1-n}{n}p_{h,t}x^\star_{h,t} - p_{f,t}x_{f,t} \end{aligned} \tag{C.42}$$

and we get the common definition of GDP in an open economy: Domestic expenditures – such as consumption, government, price adjustment costs (we do not carry investments in this model) – plus exports minus imports, all in domestic currency. The term with the relative size parameter n (only) arises due to per-capita terms; we could multiply the equation by n and replace terms with aggregate terms.

International risk sharing

Combining the optimal bond holdings of the domestic household for foreign bonds and of the foreign household for domestic bonds, equations (C.14), yields

$$0 = \mathbb{E}_t \left(\beta \frac{R^\star_t}{\pi^\star_{t+1}} \left(\frac{\lambda_{t+1}}{\lambda_t}\frac{q_{t+1}}{q_t} - \frac{\lambda^\star_{t+1}}{\lambda^\star_t} \right) \right)$$

Simplify to (also ignoring the expectation parameter)

$$\frac{\lambda_{t+1}}{\lambda_t}\frac{q_{t+1}}{q_t} = \frac{\lambda^\star_{t+1}}{\lambda^\star_t}$$

This holds in each period, iterating backwards yields (in the last step, assume identical initial conditions and, as in the steady state, a real exchange rate of one)

$$\frac{\lambda^\star_t}{\lambda_t}\frac{1}{q_t} = \frac{\lambda^\star_{t-1}}{\lambda_{t-1}}\frac{1}{q_{t-1}} \overset{t\to 0}{\Longrightarrow} \frac{\lambda^\star_0}{\lambda_0}\frac{1}{q_0} \approx 1 \qquad \leftrightarrow \qquad \lambda_t = \frac{1}{q_t}\lambda^\star_t$$

Finally, we got the international risk sharing condition in terms of λ_t. To get the common form in terms of consumption, insert optimal consumption (C.11) and solve for

$$c_t = q_t^{1/\sigma}\left(\frac{d_t}{d^\star_t}\right)^{1/\sigma} c^\star_t \tag{C.43}$$

Uncovered interest rate parity

Combining the optimality conditions of the domestic household for domestic bonds and foreign bonds, equations (C.13) and (C.14), to get

$$0 = \mathbb{E}_t \left(\beta \frac{\lambda_{t+1}}{\lambda_t} \left(\frac{R_t}{\pi_{t+1}} - \frac{q_{t+1}}{q_t} \frac{R_t^\star}{\pi_{t+1}^\star} \right) \right)$$

Simplify to (also ignoring the expectation parameter)

$$\frac{R_t}{\pi_{t+1}} = \frac{q_{t+1}}{q_t} \frac{R_t^\star}{\pi_{t+1}^\star}$$

This is the uncovered interest rate parity in real terms. For nominal terms, recall and insert the definition of the real exchange rate (C.2) (even better, the following stationarized verion (C.57)) and replace nominal exchange rates (with $\Delta e_t \equiv e_t / e_{t-1}$)

$$R_t = \frac{e_{t+1}}{e_t} R_t^\star = \Delta e_{t+1} R_t^\star \tag{C.44}$$

Home bias vs law of one price

Due to home bias α, covered through the elasticity of substitution between domestic and foreign goods v, the law of one price does hold at the intermediary and retailed/imported good level, but not at the final good (or CPI) level. The law of one price at the CPI would hold if the real exchange rate (C.2) was one, or, equivalently. if $p_t = e_t p_t^\star$ holds. This corresponds to

$$\begin{aligned} 0 &= \left(v p_{h,t}^{1-\theta} + (1-v) \left(p_{f,t}\right)^{1-\theta} \right) - e_t^{1-\theta} \left(v^\star p_{h,t}^{\star,1-\theta} + (1-v^\star) \left(p_{f,t}^\star\right)^{1-\theta} \right) \\ &= \left(v p_{h,t}^{1-\theta} + (1-v) e_t^{1-\theta} p_{f,t}^{\star,1-\theta} \right) - \left(v^\star p_{h,t}^{1-\theta} + (1-v^\star) e_t^{1-\theta} p_{f,t}^{\star,1-\theta} \right) \\ &= (v - v^\star) p_{h,t}^{1-\theta} + (v^\star - v)\, e_t^{1-\theta} p_{f,t}^{\star,1-\theta} \end{aligned}$$

In the special case of $v = v^\star$, the law of one price also holds at final good (CPI) level. Otherwise, it will generally not be the case, i.e. $p_t \neq e_t p_t^\star$. This condition is fulfilled if $1 - (1-n)\alpha = n\alpha$, or $\alpha \equiv 1$, which corresponds to no home bias. The real exchange rate (C.2) captures deviations from the law of one price.

Terms of trade

We define terms of trades as (using relative prices that will be defined in section C.1.10)

$$s_t \equiv \frac{\tilde{p}_{f,t}}{\tilde{p}_{h,t}} \qquad s_t^\star \equiv \frac{\tilde{p}_{h,t}^\star}{\tilde{p}_{f,t}^\star} \qquad \text{where} \quad s_t = s_t^{\star -1} \quad \text{or} \quad \frac{\tilde{p}_{f,t}}{\tilde{p}_{h,t}} = \frac{\tilde{p}_{f,t}^\star}{\tilde{p}_{h,t}^\star} \tag{C.45}$$

We can re-write various conditions as a function of the terms of trade, such as the relative prices, based on final good price equations (C.20). Technically, these are no (additional) equilibrium conditions, but will prove particularly useful for the derivation of the steady-state conditions.

$$
\begin{aligned}
g(s_t) &\equiv \frac{p_t}{p_{h,t}} = \left[v + (1-v)\left(p_{f,t}/p_{h,t}\right)^{1-\theta}\right]^{\frac{1}{1-\theta}} = \left[v + (1-v)s_t^{1-\theta}\right]^{\frac{1}{1-\theta}} \\
h(s_t) &\equiv \frac{p_t}{p_{f,t}} = \left[v\left(p_{h,t}/p_{f,t}\right)^{1-\theta} + (1-v)\right]^{\frac{1}{1-\theta}} = \left[v s_t^{-(1-\theta)} + (1-v)\right]^{\frac{1}{1-\theta}} \\
g^\star(s_t) &\equiv \frac{p_t^\star}{p_{h,t}^\star} = \left[v^\star + (1-v^\star)\left(p_{f,t}^\star/p_{h,t}^\star\right)^{1-\theta}\right]^{\frac{1}{1-\theta}} = \left[v^\star + (1-v^\star)s_t^{1-\theta}\right]^{\frac{1}{1-\theta}} \\
h^\star(s_t) &\equiv \frac{p_t^\star}{p_{f,t}^\star} = \left[v^\star\left(p_{h,t}^\star/p_{f,t}^\star\right)^{1-\theta} + (1-v^\star)\right]^{\frac{1}{1-\theta}} = \left[v^\star s_t^{-(1-\theta)} + (1-v^\star)\right]^{\frac{1}{1-\theta}}
\end{aligned}
\tag{C.46}
$$

where the following relations hold

$$
h(s_t) = \frac{g(s_t)}{s_t} \qquad\qquad h^\star(s_t) = \frac{g^\star(s_t)}{s_t} = \frac{p_t^\star}{p_{h,t}^\star}\frac{p_{h,t}^\star}{p_{f,t}^\star}
$$

The real exchange rate is also a function of the terms of trade

$$
q_t = \frac{g^\star(s_t)}{g(s_t)} \qquad \text{from} \quad e_t\frac{p_t^\star}{p_t} = \frac{p_t^\star}{p_{h,t}^\star}\frac{e_t p_{h,t}^\star}{p_t} = g^\star(s_t)\frac{p_{h,t}}{p_t} = \frac{g^\star(s_t)}{g(s_t)} \tag{C.47}
$$

C.1.7 Government and central bank

Government expenditures are assumed to be a fraction η_t of the (per-capita) final good production y_t We assume a government that runs a balanced (real terms) budget each period. It faces real expenditures g_t that are (stochastic but) proportional to the (per-capita) final good production y_t, and receives (real) labour income taxes $\tau_{w,t}h_t w_t$. Finally, it provides transfers τ_t to households. The real government budget constraints get

$$
g_t \equiv \eta_t y_t \qquad\qquad g_t^\star \equiv \eta_t^\star y_t^\star \tag{C.48}
$$

$$
\tau_t = w_t \tau_{w,t} h_t - g_t \qquad\qquad \tau_t^\star = w_t^\star \tau_{w,t}^\star h_t^\star - g_t^\star \tag{C.49}
$$

In our baseline model, the central bank follows a standard Taylor rule for its desired interest rate Z_t, considering inflation and output gap. This rule will be relaxed – at least temporarily – once forward guidance or any other unconventional measure gets implemented. The interest rate set by the central bank, R_t, has to obey the zero lower bound

$$
\frac{Z_t}{R} = \left(\frac{R_{t-1}}{R}\right)^{\rho_r}\left[\left(\frac{\pi_t}{\pi^t}\right)^{\phi_\pi}\left(\frac{\tilde{y}_t}{\tilde{y}}\right)^{\phi_x}\right]^{1-\rho_r} \qquad \frac{Z_t^\star}{R^\star} = \left(\frac{R_{t-1}^\star}{R^\star}\right)^{\rho_r}\left[\left(\frac{\pi_t^\star}{\pi^{t\star}}\right)^{\phi_\pi}\left(\frac{\tilde{y}_t^\star}{\tilde{y}^\star}\right)^{\phi_x}\right]^{1-\rho_r} \tag{C.50}
$$

$$
R_t = \max\{1, Z_t\} \qquad\qquad R_t^\star = \max\{1, Z_t^\star\} \tag{C.51}
$$

C.1.8 Market clearing

Market clearing occurs in six different types of markets: labour, final good, retailed and imported goods, intermediary goods and international (domestic and foreign) bond markets.

Labour markets are already cleared by denoting all labour variables as h_t and, implicitly, by exploiting symmetry of households and firms. Formally, labour markets clear if

$$\int_0^1 h_t^s(j)dj = \int_0^1 h_t^d(j)dj$$

Final good markets clear if the production y_t equals demand, which consists of consumption c_t, government expenditures g_t and the price adjustment costs $\kappa_t y_t$. This condition is often also referred to as the aggregate resource constraint.

$$y_t = c_t + g_t + \kappa_t y_t \qquad y_t^\star = c_t^\star + g_t^\star + \kappa_t^\star y_t^\star \tag{C.52}$$

Market clearing of retailed and imported goods has already been applied by replacing $y_{h,t}$ with $x_{h,t}$, and equally for the other three markets, and does not impose additional conditions.

Market clearing for intermediary goods has also already been imposed while deriving the marginal (total) demand for intermediary goods, and referring to $y_t(j)$ instead as $x_{h,t}(j)$ or similar. Hence there are no additional conditions.

Finally, bond markets clear if

$$\tilde{b}_t + \tilde{b}_t^\star = 0 \quad \leftrightarrow \quad b_t + \frac{1-n}{n} b_t^\star = 0 \qquad \tilde{f}_t + \tilde{f}_t^\star = 0 \quad \leftrightarrow \quad \frac{n}{1-n} f_t + f_t^\star = 0 \tag{C.53}$$

C.1.9 Redundancy of budget constraint equations

Under a specific set of assumptions, such as Ricardian equivalence, various equations are irrelevant for the equilibrium. This commonly includes the budget constraints from the household and the government, profits and taxes.[6]

Start with the budget constraint (C.15) and replace profits Π_t with (C.41) and taxes/transfers τ_t with (C.49), cancel out labour terms, then use the aggregate resource constraint (C.52),

[6] In a two-country model, there always have to be a buyer and a seller in a bilateral market. For instance, the imports of one economy are the exports of the other, and vice versa. The constraint of one economy thus always also affects the other economy. This can be different in a standard small open economy where the rest-of-the-world is purely exogenous.

government expenditures (C.48)) and aggregate production/output (C.39).

$$
\begin{aligned}
c_t + b_t + q_t f_t &= w_t(1-\tau_{w,t})h_t + \frac{R_{t-1}}{\pi_t}b_{t-1} + q_t\frac{R^\star_{t-1}}{\pi^\star_t}f_{t-1} \\
&\quad + [w_t\tau_{w,t}h_t - g_t] + \left[\frac{p_{h,t}}{p_t}h_t a_t - w_t h_t - \kappa_t y_t\right] \\
c_t + b_t + q_t f_t &= \frac{R_{t-1}}{\pi_t}b_{t-1} + q_t\frac{R^\star_{t-1}}{\pi^\star_t}f_{t-1} - g_t + \frac{p_{h,t}}{p_t}h_t a_t - \kappa_t y_t \\
y_t + b_t + q_t f_t &= \frac{R_{t-1}}{\pi_t}b_{t-1} + q_t\frac{R^\star_{t-1}}{\pi^\star_t}f_{t-1} + \frac{p_{h,t}}{p_t}\tilde{y}_t
\end{aligned}
$$

For the foreign economy, the corresponding equation gets

$$
y^\star_t + \frac{1}{q_t}b^\star_t + f^\star_t = \frac{1}{q_t}\frac{R_{t-1}}{\pi_t}b^\star_{t-1} + \frac{R^\star_{t-1}}{\pi^\star_t}f^\star_{t-1} + \frac{p^\star_{f,t}}{p^\star_t}\tilde{y}^\star_t
$$

Proceed with applying the market clearing for bonds (C.53) to the second, foreign equation, multiply with the real exchange rate q_t and solve for $b_t + q_t f_t$.

$$
\begin{aligned}
q_t y^\star_t - \frac{n}{1-n}b_t - \frac{n}{1-n}q_t f_t &= -\frac{n}{1-n}\frac{R_{t-1}}{\pi_t}b_{t-1} - \frac{n}{1-n}q_t\frac{R^\star_{t-1}}{\pi^\star_t}f_{t-1} + q_t\frac{p^\star_{f,t}}{p^\star_t}\tilde{y}^\star_t \\
b_t + q_t f_t &= \frac{R_{t-1}}{\pi_t}b_{t-1} + q_t\frac{R^\star_{t-1}}{\pi^\star_t}f_{t-1} - \frac{1-n}{n}q_t\frac{p^\star_{f,t}}{p^\star_t}\tilde{y}^\star_t + \frac{1-n}{n}q_t y^\star_t
\end{aligned}
$$

Plug this expression into the first equation

$$
\begin{aligned}
y_t + \left[\frac{R_{t-1}}{\pi_t}b_{t-1} + q_t\frac{R^\star_{t-1}}{\pi^\star_t}f_{t-1} - \frac{1-n}{n}q_t\frac{p^\star_{f,t}}{p^\star_t}\tilde{y}^\star_t + \frac{1-n}{n}q_t y^\star_t\right] &= \frac{R_{t-1}}{\pi_t}b_{t-1} + q_t\frac{R^\star_{t-1}}{\pi^\star_t}f_{t-1} + \frac{p_{h,t}}{p_t}\tilde{y}_t \\
y_t + \frac{1-n}{n}q_t y^\star_t &= \frac{1-n}{n}q_t\tilde{y}^\star_t + \frac{p_{h,t}}{p_t}\tilde{y}_t
\end{aligned}
$$

and now use the zero profit condition (C.19) and aggregate demand (C.37)

$$
\begin{aligned}
&\left[\frac{p_{h,t}}{p_t}x_{h,t} + \frac{p_{f,t}}{p_t}x_{f,t}\right] + \frac{1-n}{n}q_t\left[\frac{p^\star_{h,t}}{p^\star_t}x^\star_{h,t} + \frac{p^\star_{f,t}}{p^\star_t}x^\star_{f,t}\right] \\
&\qquad = \frac{1-n}{n}q_t\frac{p^\star_{f,t}}{p^\star_t}\left[\frac{n}{1-n}x_{f,t} + x^\star_{f,t}\right] + \frac{p_{h,t}}{p_t}\left[x_{h,t} + \frac{1-n}{n}x^\star_{h,t}\right]
\end{aligned}
$$

Finally, using the law of one price (C.28) combined with the (definition of the) real exchange rate (C.2), all terms cancel out.

C.1.10 Stationary equilibrium conditions

In our model, growth is absent. However, amid a positive inflation target, all prices are non-stationary. In order to achieve stationary equations, we will use the definitions for CPI and PPI inflation from (C.1), if not already used before, and we additionally define relative prices for retailed and imported goods as

$$
\tilde{p}_{h,t} \equiv \frac{p_{h,t}}{p_t} \qquad \tilde{p}^\star_{f,t} \equiv \frac{p^\star_{f,t}}{p^\star_t} \qquad \tilde{p}_{f,t} \equiv \frac{p_{f,t}}{p_t} \qquad \tilde{p}^\star_{h,t} \equiv \frac{p^\star_{h,t}}{p^\star_t} \tag{C.54}
$$

With relative prices replacing $p_{h,t}$ and similar, we retrieve the following expressions for (the definitions of) PPI inflation (C.1)

$$\pi_{h,t} \equiv \frac{p_{h,t}}{p_{h,t-1}} = \frac{p_{h,t}}{p_{h,t-1}}\left[\frac{p_t}{p_t}\frac{p_{t-1}}{p_{t-1}}\right] = \frac{p_{h,t}}{p_t}\frac{p_{t-1}}{p_{h,t-1}}\frac{p_t}{p_{t-1}} = \frac{\tilde{p}_{h,t}}{\tilde{p}_{h,t-1}}\pi_t \tag{C.55}$$

$$\pi^\star_{f,t} \equiv \frac{p^\star_{f,t}}{p^\star_{f,t-1}} = \frac{p^\star_{f,t}}{p^\star_{f,t-1}}\left[\frac{p^\star_t}{p^\star_t}\frac{p^\star_{t-1}}{p^\star_{t-1}}\right] = \frac{p^\star_{f,t}}{p^\star_t}\frac{p^\star_{t-1}}{p^\star_{f,t-1}}\frac{p^\star_t}{p^\star_{t-1}} = \frac{\tilde{p}^\star_{f,t}}{\tilde{p}^\star_{f,t-1}}\pi^\star_t \tag{C.56}$$

The definition of the real exchange rate (C.2) also changes (with $\Delta e_t \equiv e_t/e_{t-1}$)

$$q_t \equiv e_t\frac{p^\star_t}{p_t} = e_t\frac{p^\star_t}{p_t}\left[\frac{e_{t-1}}{e_{t-1}}\frac{p^\star_{t-1}}{p^\star_{t-1}}\frac{p_{t-1}}{p_{t-1}}\right] = \frac{e_t}{e_{t-1}}e_{t-1}\frac{p^\star_{t-1}}{p_{t-1}}\frac{p^\star_t}{p^\star_{t-1}}\frac{p_{t-1}}{p_t} = \Delta e_t\frac{\pi^\star_t}{\pi_t}q_{t-1} \tag{C.57}$$

The equations for the households already satisfy stationarity. The demand functions of the final good producer (C.17) and (C.18) get

$$x_{h,t} = v\tilde{p}_{h,t}^{-\theta}y_t \qquad x^\star_{f,t} = (1-v^\star)\tilde{p}_{f,t}^{\star,-\theta}y^\star_t \tag{C.58}$$

$$x_{f,t} = (1-v)\tilde{p}_{f,t}^{-\theta}y_t \qquad x^\star_{h,t} = v^\star\tilde{p}_{h,t}^{\star,-\theta}y^\star_t \tag{C.59}$$

and the price levels of the final goods get (divide by p_t)

$$1 = \left(v\tilde{p}_{h,t}^{1-\theta} + (1-v)\tilde{p}_{f,t}^{1-\theta}\right)^{\frac{1}{1-\theta}} \qquad 1 = \left(v^\star\tilde{p}_{h,t}^{\star,1-\theta} + (1-v^\star)\tilde{p}_{f,t}^{\star,1-\theta}\right)^{\frac{1}{1-\theta}} \tag{C.60}$$

The price of the retailed goods (C.28) get, using the definition of real exchange rate (C.2)

$$p_{f,t}\frac{p_t}{p_t} = e_t p^\star_{f,t}\frac{p^\star_t}{p^\star_t} \;\rightarrow\; \tilde{p}_{f,t} = q_t\tilde{p}^\star_{f,t} \qquad p^\star_{h,t}\frac{p^\star_t}{p^\star_t} = \frac{1}{e_t}p_{h,t}\frac{p_t}{p_t} \;\rightarrow\; \tilde{p}^\star_{h,t} = \frac{1}{q_t}\tilde{p}_{h,t} \tag{C.61}$$

Optimal price setting equations (C.38) change slightly to (also using aggregate demand (C.37))

$$\begin{aligned}
0 &= (1-\epsilon)\tilde{p}_{h,t}\tilde{y}_t + \epsilon mc_t\tilde{y}_t - \gamma\left(\pi_{h,t}-1\right)\pi_{h,t}y_t + \gamma\beta E_t\left[\frac{\lambda_{t+1}}{\lambda_t}\left(\pi_{h,t+1}-1\right)\pi_{h,t+1}y_{t+1}\right]\\
0 &= (1-\epsilon)\tilde{p}^\star_{f,t}\tilde{y}^\star_t + \epsilon mc^\star_t\tilde{y}^\star_t - \gamma\left(\pi^\star_{f,t}-1\right)\pi^\star_{f,t}y^\star_t + \gamma\beta E_t\left[\frac{\lambda^\star_{t+1}}{\lambda^\star_t}\left(\pi^\star_{f,t+1}-1\right)\pi^\star_{f,t+1}y^\star_{t+1}\right]
\end{aligned} \tag{C.62}$$

C.1.11 Equilibrium conditions

The following conditions represent an equilibrium (38 equations)

- **Households** (7 equations)
  Optimal consumption (C.11)
  Labour supply (C.12)
  Optimal bond holdings / Euler equations (C.13) and (C.14)
  International risk sharing (C.43)

- **Final, retailed and imported good firms** (8 equations)
  Demand for retailed and imported goods (C.58) and (C.59)
  Price of final good (C.60)
  Price of imported good (under LOP) (C.61)
- **Intermediary good firms** (10 equations)
  Optimal price setting (C.62)
  Aggregate demand/production / Gross domestic product (C.37)
  Labour demand (C.39)
  Marginal costs (C.31)
  Price adjustment costs (C.40)
- **Government** (6 equations)
  Expenditures (C.48)
  Taylor rule (C.50)
  Zero lower bound (C.51)
- **Market clearing** (2 equations)
  Aggregate resource constraint (C.52)
- **Definitions** (5 equations)
  Real exchange rate (C.57)
  PPI inflation (C.55)
  Terms of trade (C.45)

with the following endogenous variables (38 variables)

- **Real variables** (14 variables)
  Consumption c_t, $c_t^\star$
  Labour h_t, $h_t^\star$
  Final goods y_t, $y_t^\star$
  Retailed and imported goods $x_{h,t}$, $x_{h,t}^\star$, $x_{f,t}$, $x_{f,t}^\star$
  Government expenditures g_t, $g_t^\star$
  Gross domestic product $\tilde{y}_t$, $\tilde{y}_t^\star$
- **Prices and financial variables** (12 variables)
  Relative prices $\tilde{p}_{h,t}$, $\tilde{p}_{h,t}^\star$, $\tilde{p}_{f,t}$, $\tilde{p}_{f,t}^\star$
  (CPI) inflation π_t, $\pi_t^\star$
  (PPI) inflation $\pi_{h,t}$, $\pi_{f,t}^\star$
  Interest rates (set and desired) R_t, $R_t^\star$, Z_t, $Z_t^\star$
- **Costs, wages etc.** (8 variables)
  Price adj. costs (final good) κ_t, $\kappa_t^\star$
  Wages w_t, $w_t^\star$
  Marginal costs mc_t, $mc_t^\star$
  Langrangian multiplier λ_t, $\lambda_t^\star$
- **International variables** (4 variables)
  Exchange rate q_t, Δe_t
  Terms of trade s_t, $s_t^\star$

In addition, we need to specify a process for each exogenous variable. Productivity enters the production function linearly. Hence, we need to ensure that production cannot get zero due to productivity. Similarly for the stochastic discount shock (one in steady state or without shocks), government expenditure share and taxes on labour income

$$a_t = a^{1-\rho_a} a_{t-1}^{\rho_a} \exp\{\sigma_a \varepsilon_{a,t}\} \tag{C.63}$$
$$d_{t+1} = d^{1-\rho_d} d_t^{\rho_d} \exp\{\sigma_d \varepsilon_{d,t}\} \tag{C.64}$$
$$\eta_t = \eta^{1-\rho_\eta} \eta_{t-1}^{\rho_\eta} \exp\{\sigma_\eta \varepsilon_{\eta,t}\} \tag{C.65}$$
$$\tau_{w,t} = \tau_w^{1-\rho_\tau} \tau_{w,t-1}^{\rho_\tau} \exp\{\sigma_\tau \varepsilon_{\tau,t}\} \tag{C.66}$$
$$\zeta_t = \zeta^{1-\rho_\zeta} \zeta_{t-1}^{\rho_\zeta} \exp\{\sigma_\zeta \varepsilon_{\zeta,t}\} \tag{C.67}$$

with standard deviations σ_a, σ_d, σ_η, σ_τ, and σ_ζ (and AR-terms ρ).

C.2 Steady state

Inflation-based steady-state variables

The Taylor rules (C.50) and the zero lower bound conditions (C.51) imply – under the assumption that we return to the 'good' steady state – that inflation returns to its steady state value (inflation target) such that the rule holds.

$$\pi = \pi^t \qquad \pi^\star = \pi^{t\star} \tag{C.68}$$
$$\pi = \pi^t \qquad \pi^\star = \pi^{t\star} \tag{C.69}$$

while the definition of PPI inflation (C.55) implies that PPI and CPI inflation are identical in steady state

$$\pi_h = \pi \qquad \pi_f^\star = \pi^\star \tag{C.70}$$

In combination with the real exchange rate (C.57), we get symmetric inflation across borders

$$\pi = \pi^\star \qquad \Longrightarrow \qquad \pi_h = \pi = \pi^t = \pi^{t\star} = \pi^\star = \pi_f^\star \tag{C.71}$$

Using $\pi = \pi^t$ in the steady-state expressions of the Euler equations (C.13) and (C.14) and the adjustment costs (C.40) we get

$$R = \frac{1}{\beta}\pi^t \qquad R^\star = \frac{1}{\beta}\pi^{t\star} \tag{C.72}$$
$$\kappa = \gamma/2\left(\pi^t - 1\right)^2 \qquad \kappa^\star = \gamma/2\left(\pi^{t\star} - 1\right)^2 \tag{C.73}$$

Given steady-state inflation (C.69), price adjustment costs (C.73) and government expenditures (exogenous process), consumption amounts to a constant fraction of final good output

$$y = c + \kappa y + \eta y \qquad \Longleftrightarrow \qquad c = (1 - \kappa - \eta)y$$
$$y^\star = c^\star + \kappa^\star y^\star + \eta^\star y^\star y \qquad \Longleftrightarrow \qquad c^\star = (1 - \kappa^\star - \eta^\star)y^\star \tag{C.74}$$

Symmetry of economies

Gali and Monacelli (2005) analytically show that under identical preferences, output is symmetric and real exchange rate and terms of trade equal one in steady-state. In this sub-section, we briefly re-confirm this finding (in the non-linearized case), then exploit it in the next section. Note that the Rotemberg (1982) framework (also) has slightly different implications, in particular with respect to price-setting. The aim of this section is to express everything as a function of the terms of trade, then show that this function holds only if terms of trade equal one.

Foremost, recall that both, the terms-of-trade functions for retailed and imported good prices (C.46) and the real exchange rate (C.47), are (already) functions of the terms of trades

$$g(s) = \tilde{p}_h^{-1} \qquad h(s) = \tilde{p}_f^{-1} \qquad g^\star(s) = \tilde{p}_h^{\star,-1} \qquad h^\star(s) = \tilde{p}_f^{\star,-1}$$
$$h(s) = \frac{g(s)}{s} \qquad h^\star(s) = \frac{g^\star(s)}{s} \qquad q = \frac{g^\star(s)}{g(s)} \tag{C.75}$$

We proceed with deriving two expressions for the ratio of domestic vs foreign aggregate output/production $\tilde{y}$, once derived from total labour demand and once from the demand for goods.

- Combine optimal consumption (C.11) with labour supply (C.12), then replace labour supply with labour demand (C.39) and wages with marginal costs (C.31) and solve for aggregate demand/production

  $$\psi h^\nu c^\sigma = w(1-\tau_w) \qquad \longrightarrow \qquad \psi \left(\frac{\tilde{y}}{a}\right)^\nu c^\sigma = mc\, a(1-\tau_w)$$

  which yields, under the assumption of identical steady-state values and preferences for technology ($a = a^\star$), taxes $\tau_w = \tau_w^\star$) and labour share (ψ)

  $$\left.\begin{array}{l} \tilde{y} = a^{\frac{1+\nu}{\nu}} c^{-\frac{\sigma}{\nu}} \psi^{-\frac{1}{\nu}} mc^{\frac{1}{\nu}} (1-\tau_w)^{\frac{1}{\nu}} \\ \tilde{y}^\star = a^{\star,\frac{1+\nu}{\nu}} c^{\star,-\frac{\sigma}{\nu}} \psi^{-\frac{1}{\nu}} mc^{\star,\frac{1}{\nu}} (1-\tau_w^\star)^{\frac{1}{\nu}} \end{array}\right\} \quad \frac{\tilde{y}}{\tilde{y}^\star} = \left(\frac{c}{c^\star}\right)^{-\frac{\sigma}{\nu}} \left(\frac{mc}{mc^\star}\right)^{\frac{1}{\nu}} \tag{C.76}$$

- The demand functions for retailed and imported goods (C.59) and (C.58) and aggregate demand/output (C.37) get

  $$\tilde{y} = v\tilde{p}_h^{-\theta} y + \frac{1-n}{n} v^\star \tilde{p}_h^{\star,-\theta} y^\star \qquad \tilde{y}^\star = \frac{n}{1-n}(1-v)\tilde{p}_f^{-\theta} y + (1-v^\star)\tilde{p}_f^{\star,-\theta} y^\star$$

  and yield another ratio of domestic vs foreign aggregate output $\tilde{y}$

  $$\frac{\tilde{y}}{\tilde{y}^\star} = \frac{v g(s)^\theta + \frac{1-n}{n} v^\star g^\star(s)^\theta \frac{y^\star}{y}}{\frac{n}{1-n}(1-v)h(s)^\theta + (1-v^\star)h^\star(s)^\theta \frac{y^\star}{y}} \tag{C.77}$$

Next, we derive the remaining expressions of the previous two ratios that are not directly related to terms of trade yet: marginal costs, consumption, aggregate demand/output vs final good output and final good output ratios.

- The optimal pricing equations (C.62) for marginal costs simplify to, in the steady state

  $$0 = (1-\epsilon)\tilde{p}_h\tilde{y} + \epsilon mc\tilde{y} - \gamma(\pi-1)\pi y + \gamma\beta(\pi-1)\pi y$$
  $$0 = (1-\epsilon)\tilde{p}_f^\star\tilde{y}^\star + \epsilon mc^\star\tilde{y}^\star - \gamma(\pi^\star-1)\pi^\star y^\star + \gamma\beta(\pi^\star-1)\pi^\star y^\star$$

  Solving for marginal costs under symmetry of inflation across borders (C.69)

  $$mc = \frac{\epsilon-1}{\varepsilon}\tilde{p}_h + \frac{\gamma}{\varepsilon}(\pi-1)\pi\frac{y}{\tilde{y}} - \frac{\gamma}{\varepsilon}\beta(\pi-1)\pi\frac{y}{\tilde{y}}$$
  $$mc^\star = \frac{\epsilon-1}{\varepsilon}\tilde{p}_f^\star + \frac{\gamma}{\varepsilon}(\pi-1)\pi\frac{y^\star}{\tilde{y}^\star} - \frac{\gamma}{\varepsilon}\beta(\pi-1)\pi\frac{y^\star}{\tilde{y}^\star}$$

yields the ratio for marginal costs given terms-of-trade functions (C.75)

$$\frac{mc}{mc^\star} = \frac{\frac{\epsilon-1}{\epsilon} g(s)^{-1} + (1-\beta)\frac{\gamma}{\varepsilon}(\pi-1)\pi\frac{y}{\tilde{y}}}{\frac{\epsilon-1}{\epsilon} h^\star(s)^{-1} + (1-\beta)\frac{\gamma}{\varepsilon}(\pi-1)\pi\frac{y^\star}{\tilde{y}^\star}}$$

- Aggregate demand/output (C.37) and the demand functions for retailed and imported goods (C.59) and (C.58) yield the following ratios of final good vs aggregate demand/output

$$\frac{\tilde{y}}{y} = v\tilde{p}_h^{-\theta} + \frac{1-n}{n} v^\star \tilde{p}_h^{\star,-\theta}\frac{y^\star}{y} = vg(s)^\theta + \frac{1-n}{n} v^\star g^\star(s)^\theta \frac{y^\star}{y}$$

$$\frac{\tilde{y}^\star}{y^\star} = \frac{n}{1-n}(1-v)\tilde{p}_f^{-\theta}\frac{y}{y^\star} + (1-v^\star)\tilde{p}_f^{\star,\theta} = \frac{n}{1-n}(1-v)h(s)^\theta\frac{y}{y^\star} + (1-v^\star)h^\star(s)^\theta$$

- The aggregate resource constraint (C.74) and the international risk sharing condition (C.43) yield, using symmetry across countries, $\kappa = \kappa^\star$ from (C.73), $\eta = \eta^\star$ and $d = d^\star$ (both exogenous processes), and the terms-of-trade expression (C.75) for the real exchange rate

$$\frac{y}{y^\star} = \frac{c}{c^\star}\frac{1-\kappa^\star-\eta^\star}{1-\kappa-\eta} = \frac{c}{c^\star} \qquad \frac{c}{c^\star} = q^{\frac{1}{\sigma}}\left(\frac{d^\star}{d}\right)^{-\frac{1}{\sigma}} = q^{\frac{1}{\sigma}} = \left(\frac{g^\star(s)}{g(s)}\right)^{\frac{1}{\sigma}}$$

which, in turn, enters the previous ratios for aggregate demand/output vs final good output

$$\frac{\tilde{y}}{y} = vg(s)^\theta + \frac{1-n}{n}v^\star g^\star(s)^\theta\left(\frac{g^\star(s)}{g(s)}\right)^{-\frac{1}{\sigma}}$$

$$\frac{\tilde{y}^\star}{y^\star} = \frac{n}{1-n}(1-v)h(s)^\theta\left(\frac{g^\star(s)}{g(s)}\right)^{\frac{1}{\sigma}} + (1-v^\star)h^\star(s)^\theta$$

Replacing the corresponding terms in the labour-sided expression of the aggregate demand/output ratio (C.76) yields an expression purely based on terms of trade

$$\frac{\tilde{y}}{\tilde{y}^\star} = \left(\frac{c}{c^\star}\right)^{-\frac{\sigma}{\nu}}\left(\frac{mc}{mc^\star}\right)^{\frac{1}{\nu}} = \left(\left(\frac{g^\star(s)}{g(s)}\right)^{\frac{1}{\sigma}}\right)^{-\frac{\sigma}{\nu}}\left(\frac{\frac{\epsilon-1}{\epsilon} g(s)^{-1} + (1-\beta)\frac{\gamma}{\varepsilon}(\pi-1)\pi\frac{y}{\tilde{y}}}{\frac{\epsilon-1}{\epsilon} h^\star(s)^{-1} + (1-\beta)\frac{\gamma}{\varepsilon}(\pi-1)\pi\frac{y^\star}{\tilde{y}^\star}}\right)^{\frac{1}{\nu}}$$

$$= \left(\frac{g^\star(s)}{g(s)}\right)^{-\frac{1}{\nu}} \left(\frac{\frac{\epsilon-1}{\epsilon} g(s)^{-1} + (1-\beta)\frac{\gamma}{\varepsilon}(\pi-1)\pi\left(vg(s)^\theta + \frac{1-n}{n}v^\star g^\star(s)^\theta\left(\frac{g^\star(s)}{g(s)}\right)^{-\frac{1}{\sigma}}\right)^{-1}}{\frac{\epsilon-1}{\epsilon} h^\star(s)^{-1} + (1-\beta)\frac{\gamma}{\varepsilon}(\pi-1)\pi\left(\frac{n}{1-n}(1-v)h(s)^\theta\left(\frac{g^\star(s)}{g(s)}\right)^{\frac{1}{\sigma}} + (1-v^\star)h^\star(s)^\theta\right)^{-1}}\right)^{\frac{1}{\nu}}$$

and replacing the corresponding terms in the demand-sided expression of the aggregate demand/output ratio (C.77) yields another expression purely based on terms of trade

$$\frac{\tilde{y}}{\tilde{y}^\star} = \frac{vg(s)^\theta + \frac{1-n}{n}v^\star g^\star(s)^\theta\left(\frac{g^\star(s)}{g(s)}\right)^{-\frac{1}{\sigma}}}{\frac{n}{1-n}(1-v)h(s)^\theta + (1-v^\star)h^\star(s)^\theta\left(\frac{g^\star(s)}{g(s)}\right)^{-\frac{1}{\sigma}}}$$

Next, recall (the definitions of) home bias from section C.1.9: $v = 1-(1-n)\alpha$, $1-v = (1-n)\alpha$, $v^\star = n\alpha$ and $1-v^\star = 1-n\alpha$. Insert these expressions into the second ratio. Finally, recall that all terms-of-trade functions (C.75) satisfy $f(s=1)=1$.

$$\frac{\tilde{y}}{\tilde{y}^\star} = \frac{(1-\alpha+n\alpha)g(s)^\theta + (1-n)\alpha g^\star(s)^\theta \left(\frac{g^\star(s)}{g(s)}\right)^{-\frac{1}{\sigma}}}{n\alpha h(s)^\theta + (1-n\alpha)h^\star(s)^\theta \left(\frac{g^\star(s)}{g(s)}\right)^{-\frac{1}{\sigma}}} \overset{s=1}{\Longrightarrow} \frac{(1-\alpha+n\alpha)+(\alpha-n\alpha)}{n\alpha+(1-n\alpha)} = 1$$

Hence, if terms of trade equal one, all terms-of-trade-functions disappear, all home bias terms cancel out and we have symmetry of aggregate output/demand across borders. This also holds for the first ratio

$$\frac{\tilde{y}}{\tilde{y}^\star} \overset{s=1}{\Longrightarrow} \left(\frac{1}{1}\right)^{-\frac{1}{\nu}} \left(\frac{\frac{\epsilon-1}{\epsilon} + (1-\beta)\frac{\gamma}{\varepsilon}(\pi-1)\,\pi\,((1-\alpha+n\alpha)+(\alpha-\alpha n))^{-1}}{\frac{\epsilon-1}{\epsilon} + (1-\beta)\frac{\gamma}{\varepsilon}(\pi-1)\,\pi\,(n\alpha+(1-n\alpha))^{-1}}\right)^{\frac{1}{\nu}} = 1$$

Summing up, both ratios equal one if terms-of-trade equal one, symmetry thus holds. Clearly, and in difference to Gali and Monacelli (2005), we provide no formal proof; without linearization this seems quite impossible, and we omit a numerical proof for the sake of simplicity and due to economic intuition: if the economies are symmetric in terms of preferences, exogenous variables and initial conditions, why should there be any difference (in per-capita terms)?

Remaining steady-state values (under symmetry)

We know and impose that steady-state terms of trade equal one, i.e. $s=1$ and $s^\star = s^{-1} = 1$. Both the real exchange rate and relative prices are a function of terms of trade and equal one if terms of trade are one

$$q = 1 \tag{C.78}$$

$$\hat{p}_h = \frac{1}{g(s)} = 1 \qquad \hat{p}_f = \frac{1}{h(s)} = 1 \qquad \hat{p}_h^\star = \frac{1}{g^\star(s)} = 1 \qquad \hat{p}_f^\star = \frac{1}{h^\star(s)} = 1 \tag{C.79}$$

Steady-state marginal costs are

$$mc = \frac{\epsilon-1}{\epsilon} + (1-\beta)\gamma(\pi_h-1)\pi_h \qquad mc^\star = \frac{\epsilon-1}{\epsilon} + (1-\beta)\gamma(\pi_f^\star-1)\pi_f^\star \tag{C.80}$$

Steady-state consumption is given by

$$c = \left[\frac{(1-\kappa-\eta)^\nu a^{1+\nu} mc(1-\tau_w)^\nu}{\psi}\right]^{\frac{1}{\sigma+\nu}}$$

$$c^\star = \left[\frac{(1-\kappa^\star-\eta^\star)^\nu a^{\star,1+\nu} mc^\star(1-\tau_w^\star)^\nu}{\psi}\right]^{\frac{1}{\sigma+\nu}} \tag{C.81}$$

Steady-state production of final good y and $y^\star$ yields

$$y = \frac{1}{1-\kappa-\eta}c = \left[\frac{a^{1+\nu} mc(1-\tau_w)^\nu}{\psi\,(1-\kappa-\eta)^\sigma}\right]^{\frac{1}{\sigma+\nu}}$$

$$y^\star = \frac{1}{1-\kappa^\star-\eta^\star}c^\star = \left[\frac{a^{\star,1+\nu} mc^\star(1-\tau_w^\star)^\nu}{\psi(1-\kappa^\star-\eta^\star)^\sigma}\right]^{\frac{1}{\sigma+\nu}} \tag{C.82}$$

aggregate demand yields

$$\tilde{y} = y \qquad \tilde{y}^\star = y^\star \tag{C.83}$$

and via steady-state consumption equality we get $y = \tilde{y} = y^\star = \tilde{y}^\star$. Note that the steady-state values for consumption and output do *not* depend on n, in per-capita terms.

Steady-state demand for imported and retailed goods x_h, x_f, $x_h^\star$, and $x_f^\star$ gets

$$x_h = vy \qquad x_f = (1-v)y \qquad x_h^\star = v^\star y^\star \qquad x_f^\star = (1-v^\star)y^\star \tag{C.84}$$

Steady-state government expenditures g are

$$g = \eta y \qquad g^\star = \eta^\star y^\star \tag{C.85}$$

Steady-state hours worked h (using aggregate labour demand (C.39)) and wages w (using marginal costs (C.31)) get

$$h = \frac{1}{a}\tilde{y} = \frac{1}{a}y \qquad h^\star = \frac{1}{a^\star}\tilde{y}^\star = \frac{1}{a^\star}y^\star \tag{C.86}$$

$$w = a\ mc \qquad w^\star = a^\star\ mc^\star \tag{C.87}$$

Last but not least, the steady-state value for the Lagrangian multiplier gets

$$\lambda = c^{-\sigma} \qquad \lambda^\star = c^{\star,-\sigma} \tag{C.88}$$

Given symmetry, bond markets are zero in steady-state (irrelevant, since we canceled all bond terms from all equilibrium conditions)

$$b = b^\star = f = f^\star = 0 \tag{C.89}$$

Scaling labour hours

We set labour weight ψ such that hours worked correspond to one third. Hence, we start with imposing $h = \xi = \frac{1}{3}$ and solve the determining formula (via final good output and/or consumption) for the scaling factor ψ. Note that marginal costs mc are not affected by any steady-state value that is itself affected by the scaling factor, and thus 'exogenous' to this scaling factor

$$\xi \stackrel{!}{=} h = \frac{\tilde{y}}{a} = \frac{y}{a} = \frac{1}{a}\left[\frac{a^{1+\nu} mc(1-\tau_w)^\nu}{\psi\,(1-\kappa-\eta)^\sigma}\right]^{\frac{1}{\sigma+\nu}} = \left[\frac{a^{1-\sigma} mc(1-\tau_w)^\nu}{\psi\,(1-\kappa-\eta)^\sigma}\right]^{\frac{1}{\sigma+\nu}}$$

Solving for ψ yields

$$\psi = \frac{a^{1-\sigma} mc(1-\tau_w)^\nu}{\xi^{\sigma+\nu}\,(1-\kappa-\eta)^\sigma}$$

Comparison with related papers

Without labour taxes ($\tau_w = 0$), government expenditures ($\eta = 0$), price adjustment costs ($\kappa = 0$, Calvo framework), no steady-state labour parameter ($\psi = 1$) and zero inflation ($\pi = 0$), consumption steady-state values simplify to

$$c = a^{\frac{1+\nu}{\sigma+\nu}} \left(\frac{\epsilon - 1}{\epsilon} \right)^{\frac{1}{\sigma+\nu}}$$

which is identical to the finding of Gali and Monacelli (2005, p.729) if we adjust notation ($\nu = \varphi$), impose subsidies τ instead of taxes, and impose $y^\star = c^\star$ (without government expenditures and price adjustment costs)

$$Y = Y^\star = A^{\frac{1+\varphi}{\sigma+\varphi}} \left(\frac{1 - \frac{1}{\epsilon}}{1 - \tau} \right)^{\frac{1}{\sigma+\varphi}}$$

C.3 Calibration

We calibrate the model as following.

- *Relatize size of the economies*
  The model supports relative sizes between zero (small open economy) and 1/2 (two-country model). Unless stated otherwise, we analyse the small open economy case and set $n = 0$.
- *Home bias/degree of openness*
  The preferences of households for domestic and foreign goods are determined by the relative size n and the degree of openness α. Home bias occurs if $\alpha < 1$, we follow De Paoli (2009) and set $\alpha = 0.4$, or to an import share of GDP/final good of 40%.
- *Intertemporal elasticity of substitution*
  As in the closed economy case, we implicitly use log-utility and set the (inverse) intertemporal elasticity of substitution to $\sigma = 1$. This corresponds to Braun et al. (2013) or Fernández-Villaverde et al. (2015), and is also covered by the ranges analyzed in Levin et al. (2010) or Nakov (2008). Generally, a lower σ reduces the responsiveness of forward guidance in a closed economy.
- *Discount factor*
  The discount factor β determines the steady-state level of the real interest rate. We set it to $\beta = 0.9975$, such that real interest rate equals roughly 1% in annualized terms.
- *(Inverse) elasticity of labor supply*
  We set the (inverse) elasticity of labor supply to $\nu = 0.2$.
- *Intratemporal elasticity of substitution between domestic and foreign goods*
  We set the intratemporal elasticity of substitution between the retailed and imported goods to $\theta = 3$, following De Paoli (2009). This seems broadly in line with other papers on open economies, though values can range between unity (or even below) and numbers around five or six.
- *Intratemporal elasticity of substitution across intermediary goods*
  We set the intratemporal elasticity of substitution across intermediary goods to $\varepsilon = 6$. This is, for once, somewhat lower than in De Paoli (2009) and closer to other papers, such as Wang (2010).
- *Price adjustment costs and indexation*
  We set the price adjustment parameter to a hundred, $\gamma = 100$. As baseline, we assume full indexation to the inflation target and set $\chi = 1$ and $\mu = 0$.
- *Government expenditure share and taxes*
  We set both taxes and government consumption share to 20%, $\eta = 0.2$ and $\tau_w = 0.2$
- *Monetary policy parameters*
  We set the Taylor rule coefficients to standard values: $\phi_\pi = 1.5$ and $\phi_\pi = 0.5$. In the baseline simulations, we set inertia to zero, i.e. $\rho_r = 0$. The inflation target is set to 2% in annualized terms, i.e. $\pi^\star = 1.005$ (gross inflation)
- *Steady-state hours worked*
  We set the weight on labour disutility φ such that the steady-state hours equal one third $h = 1/3$. This choice should not matter for the effectiveness of forward

guidance.

Persistence of exogenous shocks or processes amounts to 0.75 for all shocks. The usual standard deviation is irrelevant for the non-stochastic analysis, but enters the processes for the external variables and thus set to 0.0025 for all shocks (it primarily affects the size of the demand shocks).

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