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Disinflation and improved anchoring of long-term inflation expectations: The Icelandic experience

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Abstract

After rising sharply following the Global Financial Crisis, inflation in Iceland has been low and stable in recent years despite a strong cyclical recovery. This not only reflects good luck – stemming from low global inflation, declining commodity prices, and a currency appreciation – but also a significant improvement in monetary policy credibility as reflected in a large decline in long-term inflation expectations. To quantify these effects, a forward-looking, open-economy Phillips curve is estimated for the inflation-targeting period since 2001. The empirical results suggest a structural shift in the average relation between inflation and its key drivers occurring around 2012. It is argued that this reflects the convergence of long-term inflation expectations of households and firms towards the downward trending inflation expectations in financial markets. Long-term inflation expectations of households and firms are not observed, but using a Markov switching model and a time-varying parameter model suggests that this unobserved component of long-term inflation expectations has declined from an average of about 2 percentage points in 2003-2011 to zero in late 2016. Together with the large decline in imported inflation, the improved anchoring of long-term inflation expectations goes a long way towards explaining the large disinflation of the last five years and the low recent inflation despite the strong pickup in economic activity. It also seems that an important part of the persistent over-prediction of inflation in Iceland by most forecasters in recent years can be explained by the failure to take the gradual improvement in monetary policy credibility since 2012 into account. Finally, this combination of imported deflation and a firmer anchoring of inflation expectations can explain why the post-2012 disinflation episode did not coincide with any loss of output.

Keywords: Disinflation, inflation expectations, monetary policy credibility, sacrifice ratio, Iceland.

JEL classification: E31, E32, E37, E52.

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1. Introduction

Iceland has recently experienced an unusually long period of stable and low inflation. Inflation has averaged 1.8% since the start of 2014, compared to 5% since the start of the inflation-targeting regime in 2001. The focus of this paper is to analyse the factors behind this recent development. Is it simply "good luck" reflecting the imported deflation stemming from the global "missing inflation" phenomena (cf. IMF, 2016), or does it also reflect an improvement in domestic monetary policy performance manifesting itself in a firmer anchoring of long-term inflation expectations?

To answer this, a forward-looking, open-economy Phillips curve is estimated over the inflation-targeting period. The analysis suggests a structural shift in the average relation between inflation on one hand and inflation expectations, cyclical output, and relative import prices on the other hand. The data suggests that this structural shift occurred around 2012. Inflation had risen to over 6% in early 2012 before gradually declining to 1% in early 2015 despite a strong rebound in economic activity and continuous decline in unemployment. The disinflation coincided with a gradual decline in long-term bond market inflation expectations from roughly 5% towards the 2.5% inflation target. It is argued, however that the decline in this measure of long-term inflation expectations (the only one available over the whole sample period) actually underestimates the true improvement in the anchoring of inflation expectations over this period. While data on long-term expectations of households and firms is not available, a comparison of short-term inflation expectations suggests that inflation expectations of non-financial economic agents are much more persistent and backward looking than those in financial markets. The structural shift in the average relation between inflation and its key drivers is therefore interpreted as reflecting the convergence of long-term inflation expectations of price and wage setters towards the downward trending bond market expectations as households and firms have gradually become more convinced that the inflation regime has changed.

A simple way to capture this structural break is by using a shift dummy variable but a more intuitive approach is to think of it as an unobserved random variable to be extracted from the data. Two approaches are adopted. First, using a Markov switching model, it is modelled as a state-dependent random variable that can switch between a low- and high-inflation regime determined by an unobservable state variable. Second, it is modelled as an unobserved random walk using a time-varying parameter model. Both approaches suggest that this unobserved component of long-term inflation expectations declined from an average of about 2 percentage points in 2003-2011 towards zero in late 2016, suggesting a much steeper decline in long-term inflation expectations of actual price and wage setters over the sample period than is captured by the bond-market measure.

Taking the gradual decline in the unobserved component of long-term inflation expectations into account results in a stable and plausible specification of the Phillips curve. The empirical findings suggest that the combination of declining bond market inflation expectations and this slow-declining expectations component, together with a large imported deflation, play a key role in explaining the disinflation since 2012 and the continued low inflation despite the strong growth in economic activity. Furthermore, the failure to take the decline in the unobserved component of long-term inflation expectations since 2012 into account goes a long way in explaining the persistent over-prediction of inflation by most forecasters in recent years. Finally, this combination of imported deflation and a firmer anchoring of inflation expectations can explain why the recent disinflation episode did not coincide with any loss of output. So, to answer the question set out at the beginning: a fair slice of good luck and improved monetary policy credibility have combined to reduce inflation and anchor long-term inflation expectations over the last few years without the loss of output that would usually coincide with such a large disinflation.

The remainder of the paper is organised as follows. Section 2 briefly documents the developments of inflation in Iceland since 1970, with special focus on the inflation-targeting period since 2001. Section 3 presents the empirical results for different specifications of the Phillips curve. Section 4 discusses the key properties of the estimated Phillips curves and the role of gradually improved anchoring of long-term inflation expectations in explaining the recent decline in inflation and why it did not coincide with any loss of output. Section 5 concludes.

2. A brief history of inflation in Iceland

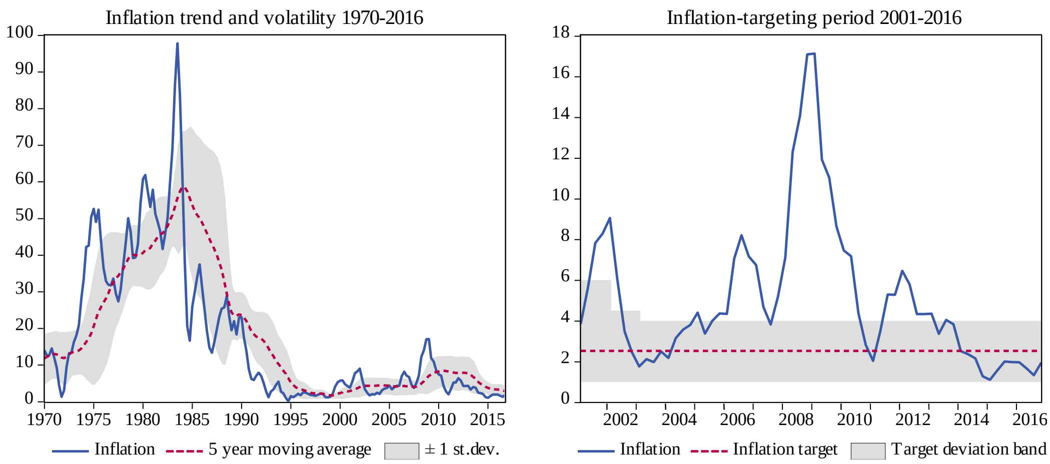
Much of Iceland's post-war economic history can be characterised as a period of chronically high and volatile inflation. Inflation averaged about 10% in the 1950s and 1960s but rose even further in the 1970s, fed by an extremely accommodative monetary policy and the two global oil price shocks (see Figure 1, left panel). Trend inflation, proxied by a 5-year (trailing) moving average of inflation, reached 20% in 1975 and rose further to 40% at the end of the decade. A complete lack of a nominal anchor and fiscal dominance of monetary policy meant that inflation escalated even further and reached almost 100% in late 1983. From then on, it gradually started to decline, with trend inflation reaching 23% by the end of the decade.[1] A recession in the early 1990s, triggered by a sharp tightening of monetary policy and negative external shocks, pushed inflation even further down (see Pétursson, 2002, and Zoega, 2002). It fell below 3% in 1994 and remained in the 1-3% range until mid-1999. However, demand pressures had started to build up again in the latter half of the 1990s, with wage growth reaching almost 10% in 1997. Inflation therefore started to pick up again at the turn of the century and these imbalances ultimately led to a collapse of the exchange rate peg in 2001. The currency fell sharply and inflation reached 9% in early 2002.

With an exit from the exchange rate peg, an inflation-targeting framework was introduced in March 2001 and the early signs were promising. Inflation started to decline again as the effects of the currency depreciation died out and past imbalances were gradually unwound (Figure 1, right panel). Inflation reached the 2.5% inflation target in late 2002 and remained close to target until mid-2004. However, macroeconomic imbalances had started to emerge again following the privatisation of the domestic banking system and liberalisation

[1] See Andersen and Gudmundsson (1998) for a discussion and analysis of the disinflation episode. Other empirical studies of inflation in Iceland include Gudmundsson (1990, 1998, 2002), Pétursson (1996, 1998, 2002), Gudmundsson and Zoega (1997), and Zoega (2002).

of the mortgage lending market that fuelled a rapid credit expansion (see, for example, Einarsson et al., 2015). Demand pressures mounted yet again and inflation overtook the 4% upper deviation limit in early 2005 and remained above it almost without interruption until the second half of 2010. Inflation reached 8% in mid-2006 and rose even further following a sharp depreciation of the currency in early 2008, reaching 17% when the financial crisis started in full force in late 2008. Inflation started falling again once the effects of the currency depreciation started to wane and the effects of the large contraction in economic activity began to take hold. By the end of 2009, inflation had fallen to just below 9%, before reaching the inflation target in late 2010. It remained close to target until spring 2011 whereupon it picked up yet again in the wake of a generous centralised wage bargaining settlement. Inflation rose above 6% in early 2012 but gradually eased back to target in early 2014. It remained at target until the end of 2014 when it fell still further, driven by a steep decline in global oil prices. From mid-2015, it has fluctuated between 1.5% and 2% for most of the period, and it has remained within the 1-4% deviation range of the inflation target for a longer period than any time before since the start of the inflation-targeting regime.

Figure 1. Inflation in Iceland 1970-2016



Note: Inflation is measured as the year-on-year change in the headline consumer price index (%).

Sources: Central Bank of Iceland, Statistics Iceland.

Taken as a whole, the inflation performance over the inflation-targeting period is underwhelming and a major disappointment. Inflation has averaged 5% over the whole period – twice the inflation target – and has been extremely volatile, with a standard deviation of more than 3 percentage points.[2] However, recent years have seen clear improvements, with trend inflation falling below 3% and the standard deviation of inflation halved by the end of the sample. There are signs that inflation and inflation expectations are becoming better aligned with the inflation target and that the credibility of the

[2] Iceland's experience with inflation targeting is a striking exemption from the experience in other inflation-targeting countries (see, for example, Pétursson 2008, 2010). Central Bank of Iceland (2017) discusses this experience in the context of monetary policy conduct.

framework has increased (cf. Central Bank of Iceland, 2017). We will return to this issue below in the context of our empirical analysis.

3. Empirical analysis

3.1. A Phillips curve specification of inflation dynamics

The Phillips curve is one of the core building blocks of macroeconomics, linking the nominal and real side of the economy through the relation between inflation and economic activity, as first observed by Phillips (1958). Inflation expectations were given a prominent role in the "expectations-augmented" version of the Phillips curve by Friedman (1968) and Phelps (1968), with the New-Keynesian literature providing the micro-foundations for the relationship through Calvo's (1983) model of staggered price adjustment (see, for example, Gali and Gertler, 1999).

The empirical analysis in this paper is based on the following expectations-augmented, open-economy specification of the Phillips curve:

$$\pi_t = \beta\pi_{t-1} + (1-\beta)\pi_t^e + \phi y_{t-1} + \lambda r_{t-1} + \epsilon_t \tag{1}$$

where π_t is consumer price inflation, π_t^e are long-term inflation expectations, y_t is the output gap, and r_t is relative import price inflation. This specification of the Phillip curve has become a standard workhorse for modelling inflation; for recent examples, see IMF (2013, 2016), and Blanchard et al. (2015). It encompasses the simple expectations-augmented ($\beta = 0$) and accelerationist ($\beta = 1$) Phillips curves and can also be interpreted in terms of the New-Keynesian Phillips curve, augmented with an assumption that some price setters index their prices to past inflation, e.g. through using rules of thumb for forecasting inflation (see, for example, Fuhrer and Moore, 1995, Gali and Gertler, 1999, and Christiano et al., 2005).

The lagged inflation term in Eq. (1) captures the inherent persistence typically found in inflation rates, presumably reflecting the fact that some wage and price setting is determined by past inflation developments. It can also be interpreted as capturing the effects of short-term inflation expectations on current inflation, to the extent that these short-term expectations depend on past inflation (cf. Blanchard, 2016). As in IMF (2013, 2016) and Blanchard et al. (2015), it is also assumed that current inflation is affected by long-term inflation expectations, capturing the notion that some workers and firms incorporate their expectations about the long-term future inflation rate when setting wages and prices. Long-term inflation expectations should also serve as a good proxy for the inflation target that economic agents believe that the authorities are aiming for. This should correspond to the official inflation target in a credible inflation-targeting regime, but can obviously differ from the publicly announced numerical target if the regime lacks credibility.[3] The β coefficient

[3] An additional benefit of using long-term rather than short-term inflation expectations is that the former is less subject to endogeneity problems in the estimation process. To check for any such problem, the Phillips curve was re-estimated using lagged inflation expectations as an instrument, but the results remained unchanged. To avoid any potential simultaneous problem, the output gap and relative import price inflation are also assumed to affect inflation with a one-quarter lag. Further lags of the explanatory variables could presumably be added

gives the relative weight of the backward and forward terms, with $1-\beta$ capturing the degree of "level anchoring" of inflation expectations (cf. Ball and Mazumder, 2011). The dynamic homogeneity restriction that the coefficients on lagged and expected inflation ensure that permanent changes in inflation do not affect output in the long run, i.e. that there is no permanent trade-off between inflation and output.

The cyclical effect of output on inflation is captured by the output gap, with ϕ measuring the slope of the Phillips curve. For a small, open economy, fluctuations in relative import prices are also important for inflation dynamics. Relative import prices capture the effects of global inflation and the effects of nominal exchange rate movements on headline consumer prices, with λ measuring these effects on consumer price inflation. Finally, the residual, ϵ_t, captures the effects of transitory supply shocks on inflation not reflected in movements in the output gap and relative import prices.[4]

Ideally, the measure of long-term inflation expectations used should capture the expectations of actual price and wage setters but such a measure is unfortunately not available. The only measure of long-term inflation expectations available for a sufficiently long period is from the bond market, extracted from the interest rate spread between nominal and inflation-indexed government bonds, which measures the expected inflation over the maturity of the bonds that would make a risk-neutral investor indifferent between holding either of the bonds – typically called the breakeven inflation rate. This measure of inflation expectations in the bond market is, however, an imperfect measure of inflation expectations of non-financial economic agents, such as households or firms.[5] In fact, a number of studies find that financial market inflation expectations tend to be better aligned to inflation targets and that the general population does not pay the same level of attention to monetary policy actions and signals as financial market participants and professional forecasters.[6] This is

to the Phillips curve, but they are found to be statistically insignificant. We also tried including the change in the output gap, but these "speed limit" effects were found to be statistically insignificant.

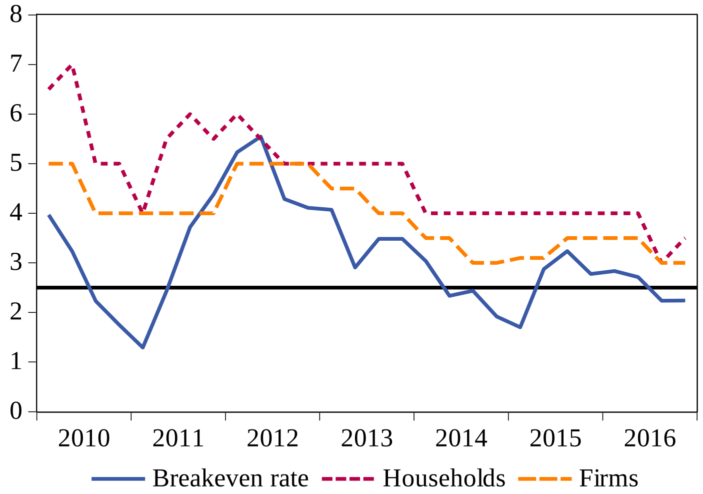
[4] Although relative import prices should capture the effects of global oil and commodity price shocks, Borio and Fillardo (2007) argue that import prices are not sufficient statistics for capturing the influence of global factors on domestic inflation. They suggest adding global factor utilisation as an independent explanatory variable to standard Phillips curves to capture the increasing relevance of globalisation for domestic price setting. We tested for this additional effect by adding the trading-partner output gap (using the deviations of trade-weighted foreign output from its Hodrick-Prescott trend) to our Phillips curve specifications and found it to be statistically insignificant. This is consistent with findings in Ihrig et al. (2010) and Mikolajun and Lodge (2016).

[5] Note also that the breakeven inflation rate does not directly measure bond markets inflation expectations as it can also contain a (possibly) time-varying risk premium for inflation and liquidity risks. Survey measures of bond market 10-year inflation expectations are only available since 2012 and are in fact very similar to the breakeven measure for that period. In any case, re-estimating the Phillips curve using inflation volatility as an instrumental variable did not affect the results in any material way. The possible implication of using this noisy measure of inflation expectations for our results is discussed in Section 4.1.

[6] See, for example, Truman Bewley's ongoing survey of pricing behaviour among American firms and the survey evidence in Kumar et al. (2015) of how poorly informed small-firm managers in New Zealand are about inflation and monetary policy. As Ball (2000, p. 6) argues when suggesting that some economic agents are inherently backward looking: "It is costly to gather and process the information needed for fully rational inflation forecasts. Some large firms pay these costs – they hire economists to build forecasting models and monitor the Fed. For the local pizza parlor, however, the costs of these activities are larger than the gains from improved inflation forecasts. So the pizza parlor uses the inexpensive and reasonably accurate rule of setting expected inflation equal to past inflation."

consistent with predictions from Carroll's (2003) epidemiological model where "expert opinion" on the inflation outlook spreads slowly through the news media to the general public which absorbs the new information probabilistically. It is also consistent with the sticky-information model of Mankiw and Reis (2002), where economic agents slowly accumulate information about macroeconomic variables, and with the rational inattention model of Sims (2011), where rational agents find it optimal to be selective about what new information to react to as their information-processing capacity is finite.

Figure 2. Different measures of 2-year inflation expectations



Note: 2-year breakeven inflation rate from the bond market and survey measures of 2-year inflation expectations of households and firms (all in %). The survey of firms' expectations measures the expectations of the 400 largest firms in Iceland (available at semi-annual frequency). The solid horizontal line gives the 2.5% inflation target.

Sources: Central Bank of Iceland, Gallup.

The different speed of adjustment of inflation expectations in the bond market and among non-financial economic agents can be seen from Figure 2, which compares the 2-year breakeven inflation rate to survey measures of 2-year inflation expectations (the longest horizon surveyed) of households and the 400 largest firms in Iceland over the period 2010-2016. The figure shows how all the measures of inflation expectations have gradually declined towards the inflation target during the recent disinflation episode, but at a different speed. Compared to financial market participants, households and firms appear to form their expectations in a more backward-looking manner and update their information set more gradually: their expectations have persistently remained higher than those in the bond market and have fallen much slower – although the difference has narrowed recently.[7] Households and firms therefore seem to take a longer time to change their view on the inflation outlook and to be convinced that the inflation regime has in fact changed. The Icelandic experience is therefore very similar to the Volcker disinflation period in the US.

[7] Inflation expectations of large firms lie between those of households and the breakeven rate. As argued by Coibion and Gorodnichenko (2015), inflation expectations of households are likely to be a good proxy for expectations of small- and medium sized firms, which are the most important price-setters in the economy.

Mankiw et al. (2003) show that as inflation declined in the early 1980s, some economic agents revised their expectations downwards, whereas others retained their pre-Volcker expectations. However, as the disinflation proceeded, a larger share of the population updated their believes and revised their inflation expectations downwards.

This suggests that using inflation expectations from financial market agents could lead to an underestimation of the actual decline of long-term inflation expectations in Iceland and that this can be a source of instability in the Phillips curve. To account for this potential mismeasurement of long-term inflation expectations, the Phillips curve in Eq. (1) is re-specified as:

$$\pi_t = \beta\pi_{t-1} + (1-\beta)(\pi_t^{uc} + \pi_t^b) + \phi y_{t-1} + \lambda r_{t-1} + \epsilon_t \tag{2}$$

where π_t^b is the 10-year breakeven inflation rate and π_t^{uc} is an unobserved component of long-term inflation expectations capturing the sticky component of long-term inflation expectations of households and firms. Long-term inflation expectations of wage and price setters are therefore given as $\pi_t^e = \pi_t^{uc} + \pi_t^b$. As we will show below, π_t^{uc} has fallen significantly in recent years and has become statistically insignificant, suggesting that inflation expectations of both non-financial economic agents and bond market participants have gradually become better anchored to the inflation target as inflation performance has improved.

3.2. A first attempt at the Phillips curve

We use quarterly data from 2003 (the first observation of the inflation expectations data) through 2016 to estimate the Phillips curve specification in Eq. (2). Inflation is measured as the year-on-year change in headline Consumer Price Index (CPI), the output gap is measured as the four-quarter (trailing) moving average of the quarterly difference between actual and potential GDP, and relative import price inflation is measured as the year-on-year change in the ratio of local currency import price deflator to the GDP price deflator. The CPI and the import price and GDP price deflators are obtained from Statistics Iceland, while the data on inflation expectations and the output gap are from the Central Bank of Iceland.

We start by estimating a simple linear version of the Phillips curve, treating π_t^{uc} as a constant and without imposing the dynamic homogeneity restriction in Eq. (2). The results are reported in the first column of Table 1 (Model 1). The table also reports the sup$F$ test for a structural break at an unknown date, which strongly suggests a structural break in the Phillips curve relation in early 2012 – either in π_t^{uc} or in the parameters on inflation and inflation expectations. The latter two are found to sum to close to unity and the dynamic homogeneity restriction is not rejected by the data (p-value = 0.24). The second column of Table 1 (Model 2) therefore imposes the dynamic homogeneity restriction but continues to treat π_t^{uc} as a constant. Again, the sup$F$ test indicates a structural break in either π_t^{uc} or in the β parameter in early 2012. Model 3 therefore estimates Eq. (2), allowing π_t^{uc} to change in 2012Q2 as suggested by the sup$F$ test, using a shift dummy D_t that equals 1 from 2012Q2 but 0 prior to that:

$$(3) \qquad \pi_t^{uc} = \pi^{uc} + \delta D_t$$

The shift dummy is found to be negative and highly significant. The point estimates suggest that the unobserved component declined from the statistically significant $\pi_1^{uc} = \pi^{uc}$ $= 2.1$ percentage points (p-value $= 0.00$) before 2012 to the non-significant $\pi_2^{uc} = \pi^{uc} + \delta =$ 0.2 percentage points (p-value $= 0.42$) from 2012Q2. The sup$F$ test does not rule out further parameter instability in β but adding an additional shift dummy variable to capture a structural break in β in 2012Q1 turns out to be non-significant once the shift in π_t^{uc} is accounted for (not shown). The same applies when testing for additional parameter instability in ϕ or λ.

Table 1. Linear specifications of the Phillips curve

	Model 1		Model 2		Model 3	
Parameter	Estimate	Std. error	Estimate	Std. error	Estimate	Std. error
π^{uc}	-0.284	1.018	1.406	0.255[a]	2.081	0.311[a]
δ	–	–	–	–	-1.886	0.424[a]
β	0.529	0.111[a]	0.483	0.100[a]	0.431	0.089[a]
γ	0.724	0.186[a]	–	–	–	–
$1-\beta$	–	–	0.517	0.100[a]	0.569	0.089[a]
ϕ	0.425	0.084[a]	0.412	0.085[a]	0.453	0.077[a]
λ	0.094	0.025[a]	0.110	0.022[a]	0.104	0.019[a]
R^2	0.940		0.938		0.953	
σ_ϵ	0.948		0.957		0.845	
$\log L$	-73.860		-74.944		-67.431	
sup$F$ test	p-value	Date	p-value	Date		
π^{uc}	0.000	12Q2	0.002	12Q2		
β	0.004	12Q2	0.001	12Q1		
γ	0.000	12Q2	–	–		
ϕ	0.214	09Q1	0.126	09Q1		
λ	0.095	13Q4	0.108	13Q4		

Note: The table reports the regression results for three versions of the Phillips curve for the sample period of 2003Q1-2016Q4 ($T = 56$). The standard errors are robust (Hubert-White) errors. a, b, and c denotes point estimates significant at the 1%, 5%, and 10% critical level, respectively. Model 1 is the unrestricted linear Phillips curve with π_t^{uc} treated as a constant: $\pi_t = \beta\pi_{t-1} + \gamma(\pi^{uc} + \pi_t^b) + \phi y_{t-1} + \lambda r_{t-1} + \epsilon_t$. Model 2 is the Phillips curve specification in Eq. (2), again treating π_t^{uc} as a constant, while Model 3 assumes that π_t^{uc} is determined by the shift dummy given in Eq. (3). The sup$F$ test is the Andrews (1993) test for a structural break of an unknown date. The p-values reported are obtained using Hansen's (1997) method.

Source: Author's calculations.

Once taking the time-variation in π_t^{uc} into account, the Phillips curve specification in Eqs. (2)-(3) seems sufficient to capture inflation dynamics in Iceland over the inflation-targeting period, in particular the post-crisis disinflation towards the end of the sample period.[8] However, the way that the change in π_t^{uc} is captured is not completely satisfactory: the shift dummy implicitly implies a sudden shift in expectations formation in early 2012, which economic agents identify as a new regime with a probability of one. This seems implausible when thinking about the general population gradually learning and updating their views on the commitment and credibility of the monetary policy authority as new information on inflation and policy responses becomes available (cf. Backus and Driffill, 1985, and Barro, 1986). In the next section, we explore this issue further and model the change in π_t^{uc} in a more plausible way that should lend itself to a more meaningful interpretation.

3.3. A Phillips curve with π_t^{uc} modelled as an unobserved random variable

3.3.1. Markov switching model

Rather than assuming that π_t^{uc} is a deterministic process driven by a simple shift dummy variable, a more plausible specification assumes that it is driven by a latent, random state variable. Economic agents are therefore assumed to observe which inflation regime they are in only indirectly and therefore need to assign a probability of being in a particular regime at any given time, based on the observed outcomes of inflation and monetary policy actions.

In particular, we assume that $\pi_t^{uc} = \pi(s_t)$ is a state-dependent variable that can switch between two states determined by the unobservable random variable s_t, which follows an ergodic first order Markov chain. The Markov switching (MS) specification of the Phillips curve is therefore:

$$\pi_t = \beta\pi_{t-1} + (1-\beta)(\pi(s_t) + \pi_t^b) + \phi y_{t-1} + \lambda r_{t-1} + \epsilon_t \tag{4}$$

where $\pi(s_t)$ can switch between two inflation regimes, equalling $\pi(s_t = 1) = \pi_1^{uc}$ in the high inflation regime and $\pi(s_t = 2) = \pi_2^{uc}$ in the low inflation regime, with transition probabilities:

$$\Pr(s_t = 1|s_{t-1} = 1) = p; \qquad \Pr(s_t = 2|s_{t-1} = 2) = q \tag{5}$$

As the unobserved state variable s_t can only take a finite number of discrete values (two in our case), the error term in the stochastic process that drives the state variable is not normally distributed and the standard Kalman filter for estimating models with time-varying unobserved variables cannot be applied. However, Hamilton (1989) has proposed a non-linear procedure for estimating these types of models.[9] Together with the parameters of the Phillips curve in Eq. (4) and the transition probabilities in Eq. (5), this procedure generates estimates of the probability of being in each regime at any given time. Two types of estimated probabilities can be obtained: the filtered probability of being in regime j ($j = 1, 2$), $\Pr(s_{t|t} = j)$, which conditions on all the information available at time t, and the

[8] The residuals appear to be normally distributed but there is some evidence of serial correlation and heteroscedasticity in the unrestricted version of the Phillips curve that disappears once the dynamic homogeneity restriction is imposed.

[9] For an earlier application of the MS model to Icelandic data, see Pétursson's (2000) modelling of business cycle dynamics.

smoothed probability, which conditions on the full sample information, $\Pr(s_{t|T} = j)$. The former is typically used to evaluate the strength of the contemporaneous regime signal while the latter is more useful for historical dating of different regimes. In the context of our study, these probabilities can be interpreted as a measure of the credibility of the inflation-targeting regime (cf. Ruge-Murcia, 1995), with the filtered probability measuring the credibility of the regime as perceived by economic agents in each given period, while the smoothed probability gives a historical measure of the regime's credibility.

Table 2. MS specification of the Phillips curve

Parameter	Estimate	Std. error
π_1^{uc}	2.034	0.302[a]
π_2^{uc}	0.230	0.279
β	0.432	0.090[a]
$1-\beta$	0.568	0.090[a]
ϕ	0.454	0.079[a]
λ	0.105	0.021[a]
σ_ϵ	0.818	0.100[a]
$\log L$	-71.603	
p	0.979	0.031[a]
q	0.967	0.023[a]
$\Pr(s_t = 1)$	0.610	0.251[b]
$\Pr(s_t = 2)$	0.390	0.251
d_1	47.5	1.473[a]
d_2	30.4	0.708[a]

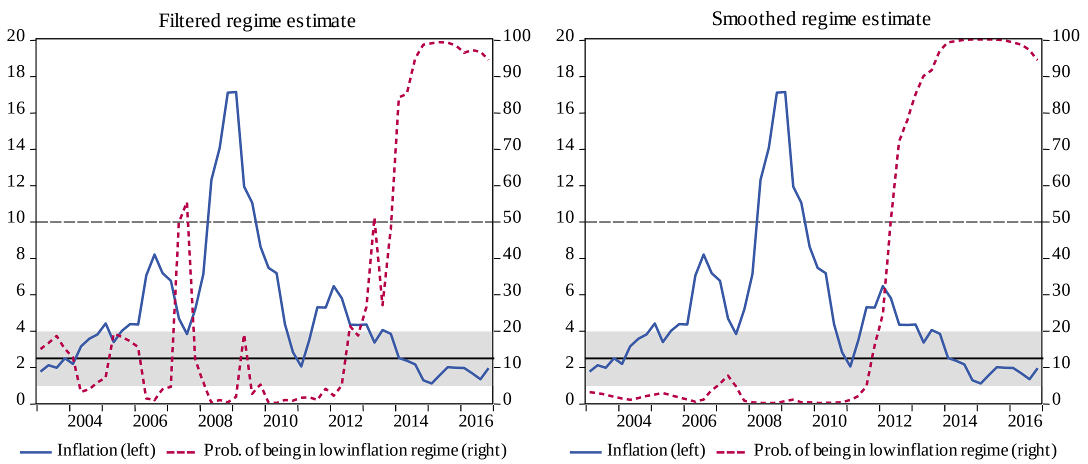
Note: The table reports estimation results for the MS specification of the Phillips curve in Eqs. (4)-(5). The sample period of 2003Q1-2016Q4 (T = 56). The standard errors are robust (Hubert-White) errors. *a*, *b*, and *c* denotes point estimates significant at the 1%, 5%, and 10% critical level, respectively. $\Pr(s_t = 1) = (1-q)/(2-p-q)$ and $\Pr(s_t = 2) = 1 - \Pr(s_t = 1)$ are the unconditional probabilities of being in regimes 1 and 2, respectively, and $d_1 = 1/(1-p)$ and $d_2 = 1/(1-q)$ are the expected durations of the regimes (in quarters).

Source: Author's calculations.

The estimation results for the MS model are reported in Table 2. The parameter estimates are practically identical to what was obtained using the simple linear specification with the shift dummy in Table 1. The estimates of $\pi(s_t)$ in the two inflation regimes is given as 2.0 and 0.2 percentage points, respectively; identical to the estimates obtained in Table 1. The lower panel of Table 2 shows that these two regimes are very persistent: the probability of remaining in a given regime (either the low- or high-inflation regime) is higher than 95% and the duration of each regime is high, or close to eight years for the low-inflation regime and almost twelve years for the high-inflation regime. The table also reports unconditional probabilities of each regime, which shows that the probability of being in the high-inflation regime is higher than being in the low-inflation regime – reflecting the fact that the economy has been more frequently in the high-inflation regime over the sample period analysed here.[10]

The filtered and smoothed probabilities are very similar as shown in Figure 3. They suggest that the probability of being in the low-inflation regime is extremely low for a large part of the sample period. The filtered probability rises slightly above 50% (a threshold typically used to identify different regimes) in mid-2007 as inflation falls to just under 4% from a peak of more than 8% in mid-2006, but this proves short-lived and the probability falls back soon after as inflation starts picking up again. The filtered probability starts rising again in 2012 and moves above 50% in 2013 and above 90% in mid-2014, where it has remained since. Based on contemporaneous information, economic agents therefore seem to identify a regime shift towards the low-inflation regime occurring late in 2013 but using the full information set from the smoothed estimate suggests that the regime shift occurred more than a year earlier, or in early 2012 – which coincides with the dating from the sup$F$ test in the previous section. The smoothed probability therefore suggests that the inflation-targeting regime did not become credible until the start of the second disinflation episode in 2012.

Figure 3. Estimated probability of being in low inflation regime



Note: Inflation and the probability of being in the low-inflation regime (both in %). The solid horizontal line gives the 2.5% inflation target (left axis) and the shaded area the 1-4% inflation-target deviation band (left axis). The broken horizontal line gives the 50% probability threshold (right axis).

Source: Author's calculations.

[10] Allowing σ_ϵ^2 to switch between regimes yields practically identical results to those reported here. Furthermore, the null hypotheses that β, ϕ, λ and σ_ϵ^2 are identical across the two regimes cannot be rejected at the 1% critical level when all the parameters of the Phillips curve are allowed to switch between regimes. Allowing the transition probabilities in Eq. (5) to be a function of past trend inflation or inflation volatility does not change the results in any way either. As these more general specifications do not add any new insights to the analysis and are quite demanding on the relatively short sample period used here, the more simple specification of the MS model where only π_t^{uc} is allowed to switch and where the transition probabilities are constant is preferred.

3.3.2. Time-varying parameter model

Instead of treating π_t^{uc} as a discrete random variable that shifts downwards as the inflation target became more credible, one can treat it as a continuous random variable. The Phillips curve now becomes:

$$(6) \qquad \pi_t = \beta\pi_{t-1} + (1-\beta)(\pi_t^{uc} + \pi_t^b) + \phi y_{t-1} + \lambda r_{t-1} + \epsilon_t$$

where π_t^{uc} is now specified as:

$$(7) \qquad \pi_t^{uc} = \pi_{t-1}^{uc} + v_t$$

and ϵ_t and v_t are white noise errors with variances σ_ϵ^2 and σ_v^2, respectively. Here π_t^{uc} is assumed to follow a random walk, but it could easily be assumed that it follows a stationary autoregressive process (the estimated autoregressive coefficient is very close to unity). Here, the Kalman filter can be applied to estimate this unobserved random walk process simultaneously with other parameters of the Phillips curve.

Table 3. TVP specification of the Phillips curve

	Unrestricted TVP model		Restricted TVP model	
Parameter	Estimate	Std. error	Estimate	Std. error
π_T^{uc}	0.153	0.792	0.181	0.582
β	0.232	0.128[c]	0.358	0.100[a]
$1-\beta$	0.768	0.128[a]	0.642	0.100[a]
ϕ	0.535	0.110[a]	0.477	0.090[a]
λ	0.111	0.022[a]	0.110	0.020[a]
σ_ϵ	0.565	0.139[a]	0.788	0.076[a]
σ_v	0.580	0.166[a]	0.249	–
$\log L$	-75.478		-78.472	

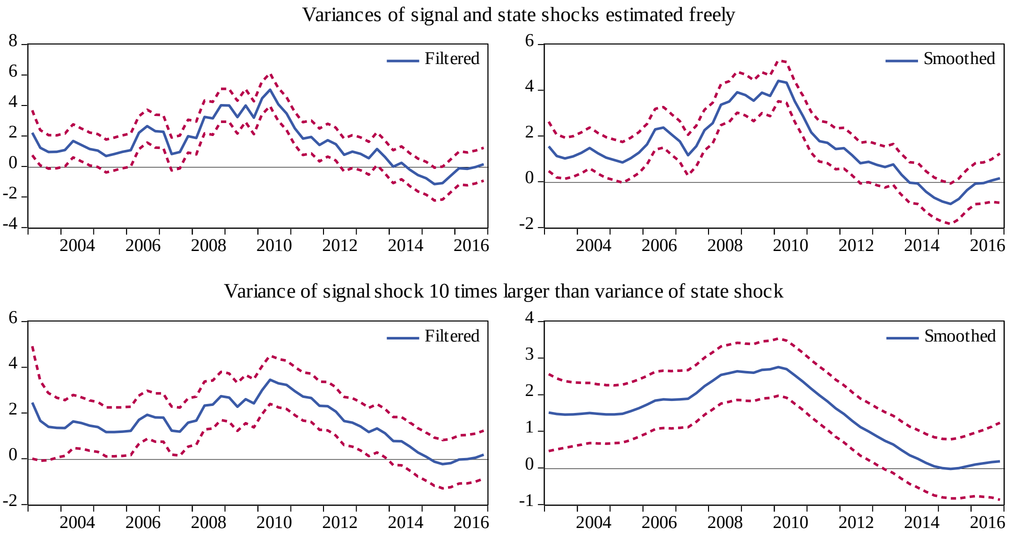
Note: The table reports estimation results for the TVP specification of the Phillips curve in Eqs. (6)-(7). The sample period of 2003Q1-2016Q4 ($T = 56$). The standard errors are robust (Hubert-White) errors. a, b, and c denotes point estimates significant at the 1%, 5%, and 10% critical level, respectively. π_T^{uc} gives the final state estimate of π_t^{uc} (its time path is shown in Figure 4). The unrestricted TVP model estimates σ_v^2 and σ_ϵ^2 freely, while the restricted TVP model imposes the restriction that $\sigma_v^2 = \sigma_\epsilon^2/10$.

Source: Author's calculations.

The first column of Table 3 gives the parameter estimates of this time-varying parameter (TVP) model. It reports the point estimates of the parameters of Eq. (6) that are assumed to be constant and the end-of-sample estimate of π_t^{uc} in Eq. (7). The time-invariant parameters are very similar to the estimates reported in the other specifications, although the weight on lagged inflation (β) is lower.

The upper panel of Figure 4 gives the time path of π_t^{uc}, with 2-standard-error bands. Two versions are reported: the filtered estimate gives an estimate of π_t^{uc} using only data up to period t ($\pi_{t|t}^{uc}$), while the smoothed estimate gives the full sample estimate of π_t^{uc} ($\pi_{t|T}^{uc}$). The figures show a clear downward trend in π_t^{uc} from mid-2010 when it starts declining from a peak of roughly 4 percentage points towards zero; and becoming statistically insignificant from zero by mid-2012.

Figure 4. Time-varying estimates of the unobserved expectations component



Note: Filtered and smoothed Kalman estimates of π_t^{uc} (in percentage points). The upper panel gives the estimates when σ_ϵ^2 and σ_v^2 are estimated freely while the lower panel gives the estimates when $\sigma_v^2 = \sigma_\epsilon^2/10$. Broken lines show 2-standard-error bands.

Source: Author's calculations.

In addition to the clear downward trend, the figures also exhibit some short-term variation in π_t^{uc}. In fact, the estimated variation in ϵ_t and v_t is quite similar as shown in Table 3. However, it may be more plausible to assume that π_t^{uc} does not vary greatly from quarter to quarter but is a more slow-moving process. Table 3 therefore also presents a specification of the TVP model assuming that the variance of v_t is one-tenth of the variance of ϵ_t (the restricted variance estimates lie within their unrestricted 95% confidence intervals). The other parameters of the Phillips curve are more or less unchanged, although the size of β increases to just under 0.4 – which is closer to the linear regression estimates obtained given in Table 1 and the MS model in Table 2. The estimated time path of π_t^{uc} after imposing this additional smoothness is given in the lower panel of Figure 4. Similarly to the unrestricted estimate, it rises steadily from 1.5 percentage points at the start of the sample to just under 3 percentage points in mid-2010 (averaging 2.2 percentage points from 2003-2011) before gradually easing to zero (and becoming statistically insignificant from zero in mid-2013).[11]

[11] Although our previous analysis suggests that other parameters in the Phillips curve can be treated as constant, one could also estimate a TVP model where all the parameters are allowed to vary over time. The marked decline in π_t^{uc} continues to come out clearly but no clear pattern or trend can be found in the other parameters, although there is some short-term variation, especially around the financial crisis. However, given their standard deviations, they can be treated as constant throughout the sample period.

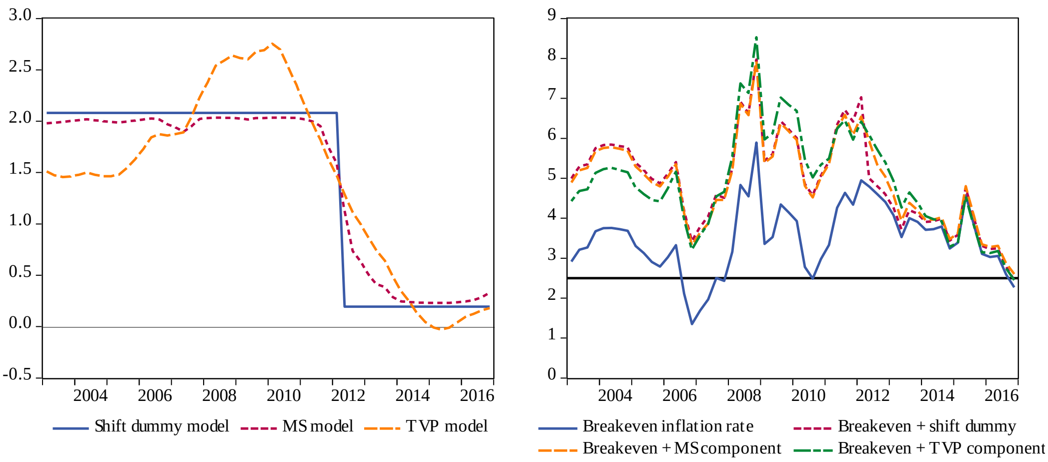
4. Key findings

4.1. Model parameters and interpretation

4.1.1. Interpretation of π_t^{uc}

The empirical results reported above suggest that a declining unobserved component in long-term inflation expectations has been an important feature of the post-crisis inflation dynamics in Iceland. This unobserved component is interpreted as capturing the legacy of poor inflation control over a long period in Iceland and the inherent stickiness in the expectations formation of non-financial economic agents that led to a much slower adjustment of their expectations than among financial markets participants as inflation performance gradually improved. This therefore implies that long-term inflation expectations of wage and price setters ($\pi_t^e = \pi_t^{uc} + \pi_t^b$) were both higher and more persistent than suggested by bond market expectations. However, households and firms have gradually updated their view of the inflation regime as inflation performance has improved, eventually leading to a convergence in their long-term inflation expectations towards those of financial markets – as both have gravitated towards the inflation target.

Figure 5. Long-term inflation expectations adjusted
for unobserved expectations component



Note: The left panel gives estimates of π_t^{uc} in different Phillips curve specifications (in percentage points): the linear shift dummy model in Table 1, the MS model in Table 2, and the restricted TVP model with extra smoothing in Table 3. The smoothed estimates of π_t^{uc} are used in the latter two models. The right panel adds π_t^{uc} to the 10-year breakeven inflation rate (in %) to give a measure of long-term inflation expectations of wage and price setters ($\pi_t^e = \pi_t^{uc} + \pi_t^b$). The solid horizontal line gives the 2.5% inflation target.

Source: Author's calculations.

As the left panel of Figure 5 shows, different specifications of π_t^{uc} give very similar results: all three suggest that it has fallen from roughly 2 percentage points to zero in the last five years. Long-term inflation expectations of wage and price setters have therefore gradually declined from roughly 6% in 2011 to the 2.5% target at the end of the sample period (Figure 5, right panel).

The shift dummy variable suggests a regime shift occurring in early 2012, while the more plausible estimates from the MS and TVP models suggest a more gradual regime change occurring in the period 2012-2013. But what could explain this regime change? In Central Bank of Iceland (2017), it is argued that this critically relates to the rate hiking cycle that started in August 2011. Up till then the Bank had been lowering rates continuously since early 2009, but in the spring of 2011 a centralised wage bargaining round resulted in a sizeable increase in wage inflation which had a marked effect on both short- and long-term inflation expectations (see Figures 1 and 2). The Central Bank responded by raising rates in August that year and signalled further rate hikes, eventually ending by raising rates by 175 basis points in just over a year until November 2012 when long-term inflation expectations had started to decline again. The negative reaction to the rate-hike cycle from politicians and the population at large was enormous, but the empirical estimates above suggest that this may have finally convinced economic agents of the firm intentions of the Bank to anchor inflation at the 2.5% inflation target. A further bout of wage inflation came in the spring of 2015, pushing long-term inflation expectations above 4% again. The Bank responded by hiking rates (again to strong popular opposition), perhaps further cementing its inflation-fighting credentials before easing rates back once inflation expectations declined towards the target in late 2016.

The unobserved component is obviously open to alternative interpretations to the one proposed here. Two come to mind but neither seem plausible. First, as previously mentioned, long-term bond market inflation expectations are not directly observed from the breakeven inflation rate as it can also contain a (possibly) time-varying risk premium to compensate investors for inflation and liquidity risks. Thus, if π_t^m are the true inflation expectations of financial market participants, then $\pi_t^b = \pi_t^m + \rho_t$, where ρ_t is the risk premium. At first sight it therefore seems possible that the observed variation in π_t^{uc} is simply reflecting a time-varying risk premium rather than changes in long-term inflation expectations. The problem with this interpretation is that the observed decline in π_t^{uc} would require the risk premium to have been rising in recent years, which seems implausible given the declining level and volatility of inflation and inflation expectations over the same period.[12] To see this, assume that the true difference between long-term inflation expectations of wage and price setters on one hand and bond market participants on the other hand is given as $\kappa_t = \pi_t^e - \pi_t^m$. This would imply that $\pi_t^{uc} = \pi_t^e - \pi_t^b = \kappa_t - \rho_t$, thus requiring ρ_t to be rising to be able to explain a declining π_t^{uc}. A more plausible explanation is therefore that the decline in π_t^{uc} is actually capturing the falling κ_t.

The unobserved component can also be interpreted as capturing measurement errors in the output gap used here. The problem with this interpretation is that the positive π_t^{uc} implies that the slack that emerged after the financial crisis was in fact much smaller than the official output gap estimate used suggests. More specifically, while the output gap would

[12] For example, Central Bank of Iceland (2017) reports a decline in the volatility of various measures of inflation and inflation expectations in the last five years, together with declining dispersion of survey responses in different survey measures of inflation expectations.

largely correspond to the official estimate from 2013 onwards, the output gap would have turned negative by just over 1% of potential output in early 2010 (compared to the 4% suggested by the official data) and close again in mid-2011 (compared to early 2015 in the official data). This seems an implausibly small and short-lived contraction given the enormity of the twin currency and banking crisis that hit Iceland and its impact on the financial system, private sector balance sheets, and the real economy (cf. Einarsson et al., 2015).

4.1.2. Other parameters of the Phillips curve

Other parameters of the Phillips curve are tightly estimated and of plausible size. Their estimates are also found to be robust to different specifications of the Phillips curve. The coefficient on lagged inflation is close to 0.4 – giving a weight of 0.6 on long-term inflation expectations, which is close to the post-1990s median estimate for advanced economies reported by Blanchard et al. (2015) and IMF (2016). The point estimate of β is also close to the predicted value of ½ from the theoretical models of Fuhrer and Moore (1995) and Christiano et al. (2005); see also Boivin and Giannoni (2006).

The slope of the Phillips curve is estimated to be just under 0.5, which is in the higher end of the range of international estimates (for example, Ball and Mazumder, 2011). This could reflect the fact that Phillips curves tend to be steeper in countries with a history of high and volatile inflation (cf. Ball et al, 1988, Ball and Mazumder, 2011, IMF, 2013). Finally, the impact effect of shocks to relative import prices is found to be close to 0.1, which implies a complete exchange rate pass-through effect of roughly 0.2. This is similar to the median estimate found by Gagnon and Ihrig (2004) for 20 OECD countries and for 42 high-income countries in Pétursson (2008).[13]

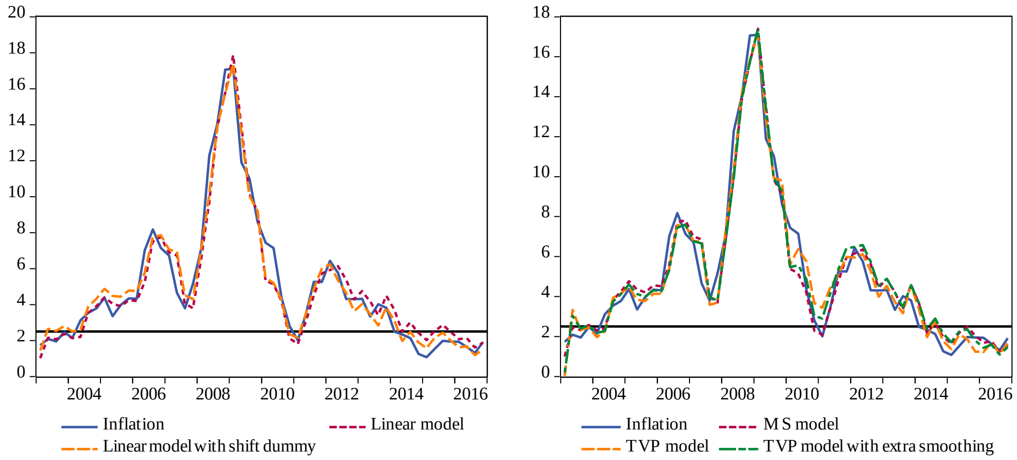
4.2. Model fit and out-of-sample forecasting performance

All the Phillips curve specifications fit the data well (Figure 6). They capture the gradually rising inflation in the years before the financial crisis and its sharp increase following the currency crisis. They also capture the decline in inflation in 2009 and 2010, although the models predict a faster decline in early 2010 than actually occurred. The temporary increase in inflation in 2011 and early 2012, following large wage increases in the spring of 2011, are also captured; as is the sustained disinflation since early 2012. None of the models fully captures the sharp decline in inflation in late 2014 and in 2015 following the large global oil price shock, however. Thus, it appears that the oil price shock had a larger impact on inflation in Iceland than is captured by the historical link between inflation and relative import prices. Finally, note how a failure of accounting for changes in π_t^{uc} leads to persistent over-predictions of inflation in the most recent period.

[13] The coefficient on lagged inflation lies between the estimates reported in Hunt (2006) and Daníelsson et al. (2015) using Icelandic data. The slope of the Phillips curve is somewhat higher than those studies report, however. The estimated pass-through is lower than studies using longer estimation periods typically find (cf. Hunt, 2006, Pétursson, 2008) but is close to what Daníelsson et al. (2015) and Forbes et al. (2017) find using more recent data. This could reflect the improved anchoring of inflation expectations, which tends to reduce the second-round effects of exchange rate shocks on inflation (see, for example, Gagnon and Ihrig, 2004, on the link between exchange rate pass-through and monetary policy credibility).

The measure of fit reported in Figure 6 essentially represents in-sample one-quarter-ahead forecasts of inflation. However, a more challenging and informative test of these models are out-of-sample dynamic forecasts, i.e. forecasts that use simulations beyond the estimation period treating past inflation as endogenous. For this exercise, the models are therefore re-estimated through 2011Q4 and dynamic out-of-sample forecasts are generated for the five-year period 2012Q1-2016Q4 (using observed values of the explanatory variables).

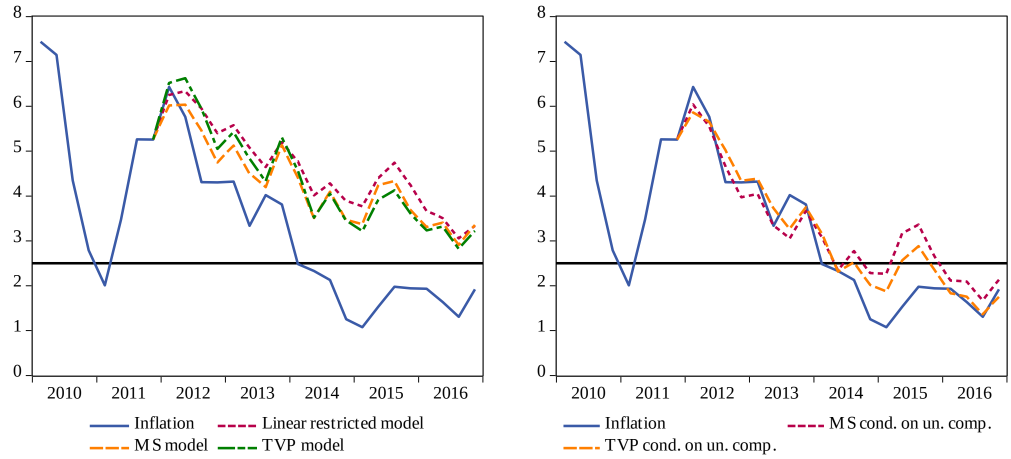
Figure 6. Inflation and fit of different Phillips curve specifications



Note: Actual and fitted inflation (in %). The solid horizontal line gives the 2.5% inflation target.

Source: Author's calculations.

Figure 7. Out-of-sample dynamic forecasts for different Phillips curve specifications



Note: Actual and forecasted inflation (in %). The left panel shows out-of-sample dynamic forecasts for the period 2012Q1-2016Q4 for the models reported in Tables 1 and 2 re-estimated through 2011Q4. The right panel shows the same out-of-sample dynamic forecasts for the MS and TVP models treating π_t^{uc} as an observed variable (using the full-sample smoothed estimates). The solid horizontal line gives the 2.5% inflation target.

Source: Author's calculations.

The results are shown in Figure 7. The left panel shows that all of the specifications of the Phillips curve capture a sizable part of the recent disinflation but fail to capture the full extent of it. The MS and TVP specifications are very similar and tend to do better than the linear specification. This can also be seen in Table 4, which reports the average bias and root mean square errors (RMSE) for each specification (adding the unrestricted linear specification for comparison). All show a sizable positive bias, reflecting the persistent over-prediction over the whole period, while the MS and TVP specifications have markedly smaller RMSEs than the linear specifications. Note also how imposing the dynamic homogeneity restriction on lagged and expected inflation significantly improves the out-of-sample properties of the linear specification.

Table 4. Out-of-sample forecast errors

Different Phillips curve specifications	Bias	RMSE
Unrestricted linear model	2.422	2.558
Restricted linear model	1.716	1.883
MS model	1.375	1.586
TVP model	1.464	1.586
MS model conditional on full-sample estimate of π_t^{uc}	0.323	0.715
TVP model conditional on full-sample estimate of π_t^{uc}	0.230	0.526

Note: The table reports the average bias and RMSE for out-of-sample dynamic forecasts for the period 2012Q1-2016Q4 for the models reported in Tables 1 and 2 re-estimated through 2011Q4 (in percentage points). The table also reports out-of-sample dynamic forecasts for the MS and TVP models treating π_t^{uc} as an observed variable (using the full-sample smoothed estimates).

Source: Author's calculations.

To what extent does this over-prediction reflect the failure of the Phillips curve specifications to take into account the improved anchoring of inflation expectations as captured by the decline in π_t^{uc} reported above? To answer this, the out-of-sample forecasting exercise is repeated but treating π_t^{uc} as an observed variable (using the full-sample smoothed estimates from the MS and TVP models). The right panel of Figure 7 clearly shows that the over-prediction of inflation disappears to a large extent once the decline in π_t^{uc} is taken into account: the disinflation up to mid-2014 is fully captured and dynamic forecasts for 2016 are almost spot on. What the models continue to miss are the effects of the large oil price decline in late 2014 and 2015 discussed above. The improvement in the forecasting ability of the models once the decline in π_t^{uc} is taken into account can also be seen in the sharp decline in average bias and RMSE in the lower part of Table 4. Thus, it seems that an important part of the apparent over-prediction of inflation in Iceland in recent years can be explained by the failure to take the gradual improvement in monetary policy credibility since 2012 into account. In the next section, we attempt to take a closer look at this issue and quantify to what extent this improved anchoring of inflation expectations can explain the declining inflation in Iceland since 2012.

4.3. The role of improved anchoring of inflation expectations in the recent disinflation episode

Recent years have seen exceptionally low inflation in all advanced economies, with inflation even starting to decline further from 2011 despite a sustained and synchronised recovery of global demand and historically low unemployment rates in many countries. In fact, inflation rates are typically lower now than they were following the Global Financial Crisis (GFC) and are currently below target in most advanced economies. The fact that this phenomena is so widespread suggests that this "missing inflation" is to an important extent driven by common factors, such as the persistent output slack in most advanced economies, large positive supply shocks (e.g. the large decline in oil, commodity and telecommunication prices), and a sizable overcapacity in the manufacturing sector in a number of large exporting countries (IMF, 2016). IMF (2016) also suggests that available estimates of inflation expectations may underestimate their true decline and that the output slack may actually be larger in many advanced economies than is currently estimated using standard methods (see also Constancio, 2015).[14] This raises the question to what extent the disinflation in Iceland from 2012 and the low recent inflation, despite a strong cyclical recovery, is due to these global factors (and therefore "good luck") and to what extent it is driven by improved credibility of monetary policy as suggested by the decline in long-term inflation expectations.

To answer this, we attempt to decompose the inflation dynamics to quantify the contribution of individual factors (inflation expectations, the output gap, and relative import prices) to the development of inflation in recent years. For this exercise, we use the full-sample estimates of the MS and TVP specifications of the Phillips curve to generate dynamic simulations from 2011Q1. The deviations of the simulated inflation paths from the 2.5% inflation target are then decomposed into contributions from each explanatory variable which are constructed from counterfactual simulations where each factor is set to zero (the output gap, relative import prices, and π_t^{uc}) or equal to the inflation target (bond market inflation expectations).[15]

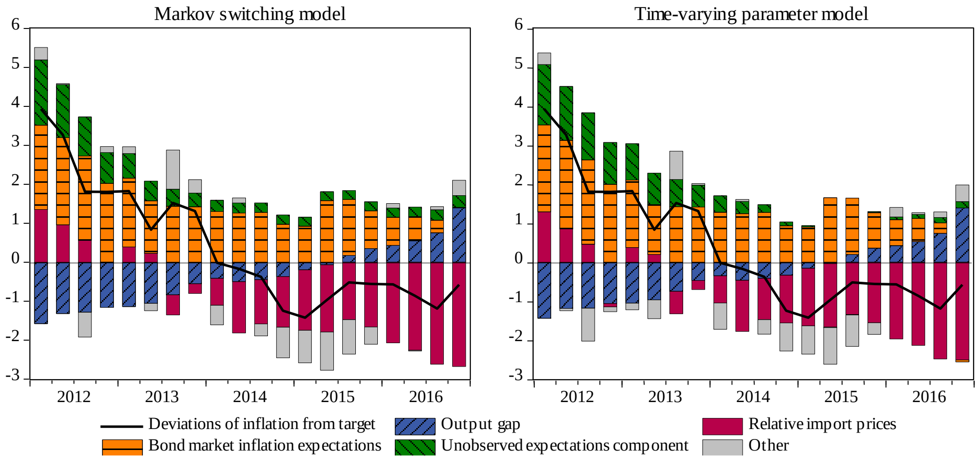
Figure 8 presents the results. As the figure shows, inflation was significantly above target in the early part of the period, which can mainly be explained by long-term inflation expectations well above target and the lagged effects of past exchange rate depreciation, which overwhelm the negative contribution from the sizeable slack in the economy following

[14] Inflation was also remarkably stable during the Great Recession in 2008-2010, with most conventional models suggesting that the sharp output contraction and significant increase in unemployment following the GFC would lead to a much larger decline in inflation, or even deflation, than was actually observed. This "missing disinflation" puzzle has attracted a great deal of attention in policy circles and in academic research. A number of explanations have been put forward, including improved credibility of monetary policy and the flattening of the Phillips curve (IMF, 2013, Blanchard et al., 2015). The same explanations have also been put forward in a US context (cf. Ball and Mazumder, 2011), but among additional suggestions are the rise in household inflation expectations (reflecting increases in oil prices from 2009 to 2011) offsetting the impact of cyclical unemployment (Coibion and Gorodnichenko, 2015), and the decline in short-term unemployment relative to overall unemployment (Gordon, 2013).

[15] See Yellen (2015) and IMF (2016) for similar exercises. Note that since the simulations are dynamic, each factor also affects inflation through the lagged inflation term. Note, however, that the counterfactual simulations hold other factors constant, thus ignoring the possible effects of the factors on each other.

the financial crisis. The contribution from the poorly anchored inflation expectations is large: high long-term bond market expectations add 2.1 percentage points on average to inflation in 2012, with a further 1.2 percentage point contribution from π_t^{uc}. In total, the deviations of long-term inflation expectations from target therefore add more than 3 percentage points to inflation in 2012. The effect starts to wane as inflation expectations ease towards target: 2 percentage points are added to inflation in 2013, but the contribution falls to 1 percentage point by the end of 2015, and to zero in 2016. The improved anchoring of long-term inflation expectations therefore appears to have played a key role in the gradual decline in inflation to target.

Figure 8. Contributions to deviations of inflation from target



Note: The columns give the contribution of each explanatory variable in the Phillips curve to the deviations of inflation from target in 2012Q1-2016Q4 for the MS model in Table 2 and the restricted TVP model with extra smoothing in Table 3, respectively (in percentage points). The contributions are obtained by comparing a dynamic simulation of inflation starting in 2011Q1 to a counterfactual simulation of each model setting the value of the explanatory variable to zero (the output gap, relative import prices, and π_t^{uc}) or equal to the inflation target (bond market long-term inflation expectations). "Other" is a residual capturing the part of deviations from target not explained by the model.

Source: Author's calculations.

From mid-2013, import prices start to add further downward pressures on inflation, adding to the impact from the slack in the economy and the declining positive contribution from above-target inflation expectations. These downward pressures from import prices gather strength from 2014, gradually pushing inflation below target. Inflation falls further below target as the combined effect of falling global commodity prices and currency appreciation gathers strength. Partially offsetting this is the gradual disappearance of spare capacity in early 2015 and the consequent emergence of a positive output gap.

Finally, the model residuals ("other" in Figure 8) seem to play a relatively minor role in explaining the deviation of inflation from target in recent years. The exception is in late 2014 and in 2015 when the models fail to explain the full extent of the decline in inflation, reflecting the large oil price shock discussed above. But other than that, the Phillips curve specifications used here seem to perform well in explaining the downward trend in inflation over the last five years and the persistent undershooting of the target since 2014. In that respect, there does not appear to be any puzzle concerning the developments of inflation in the post-GFC period in Iceland.

4.4. The cost of disinflation and improved monetary policy credibility

The slope of the Phillips curve gives an estimate of how inflation is affected by changes in cyclical output given expected inflation and relative import price inflation. Equivalently, it also determines the sacrifice ratio, i.e. the output cost of a sustained disinflation (holding other factors constant). With a typical estimate of the slope of the Phillips curve of just under 0.5, the implied average sacrifice ratio over this sample period is given as 1.3 – that is, the cost of reducing inflation permanently by 1 percentage point requires a sustained 1.3% fall in output.[16] This is slightly higher than the 0.9 ratio obtained by Andersen and Gudmundsson (1998) for the second phase of the large disinflation episode in Iceland in the late 1980s and early 1990s. It is also similar to what Coffinet et al. (2007) and Durand et al. (2008) find for the euro area but about half as large as the median estimate for industrial countries in Ball (1994a).[17]

The direct estimate of the sacrifice ratio from the Phillips curve above implicitly assumes that the cost is the same for all disinflation episodes and holds everything else constant, in particular inflation expectations. In reality, disinflation episodes can be different in terms of their associated output cost. For example, one can easily think of a scenario where inflation expectations fall permanently by 1 percentage point, which leads to a corresponding permanent decline in inflation without any loss of output. The sacrifice ratio is therefore zero in this case, i.e. the disinflation is costless in terms of lost output.[18]

This seems particularly relevant for the post-crisis disinflation episode in Iceland. The first phase from early 2009 to early 2011 saw inflation decline from close to 20% to the 2.5% target, which coincided with a very deep recession following the financial crisis. The second phase, from early 2012 to early 2015 when inflation declined from more than 6% to 1%, coincided with a strong boom in the economy, however: output growth averaged 3% during the disinflation period and reached more than 4% in 2015 (and an eye-popping 7.4% in 2016). This reflects the combination of positive external shocks and an appreciating currency, which boosted domestic incomes and demand while also lowering import prices and reducing inflation. The analysis above suggests, however, that without improved monetary policy credibility, as captured by the decline in bond market inflation expectations and the falling π_t^{uc}, inflation would have been more persistent. Alternatively, to achieve the disinflation actually observed a greater contraction in output would have been required.

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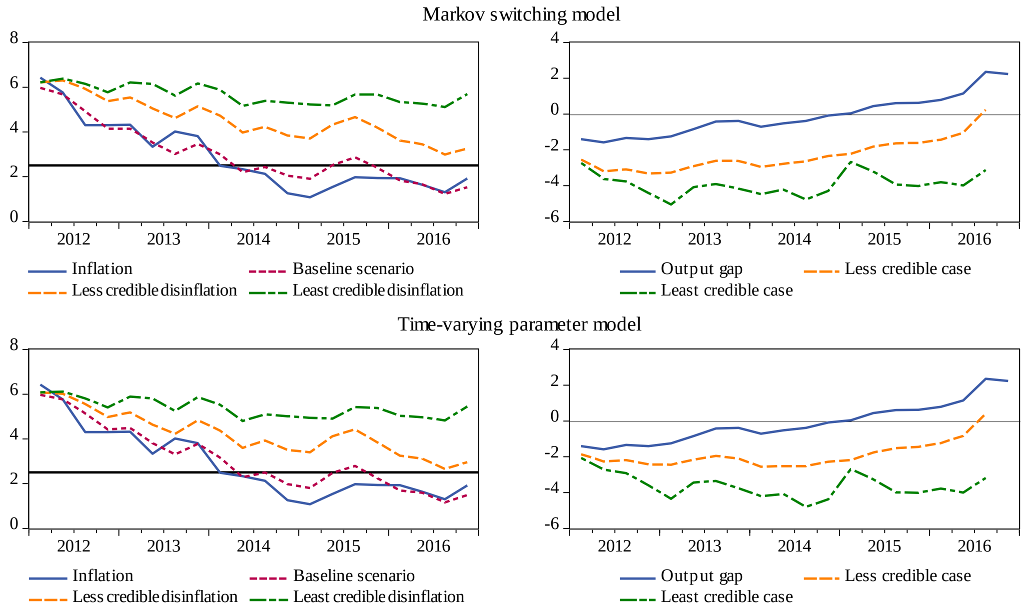
[16] The sacrifice ratio is typically defined as the cumulative decline in output divided by the cumulative decline in inflation over the same period. This can be obtained directly from the Phillips curve as $(1-\beta)/\phi$.

[17] The lower sacrifice ratio in Iceland compared to other advanced economies could be related to a more flexible labour market (cf. Ball, 1994a), in particular, the high flexibility of real wages (cf. Andersen and Gudmundsson, 1998).

[18] See, for example, Ball (1994b, 1995) and Sargent (1983) on the role of monetary policy credibility in explaining different costs of disinflation episodes.

To illustrate this, Figure 9 shows alternative inflation paths assuming different degree of credibility of the disinflation episode. The left panel of the figure compares the actual decline in inflation from 2012 to three dynamic simulations starting in 2012Q1. The baseline scenario assumes that inflation expectations decline in line with the observed decline in π_t^b and π_t^{uc} (using the smoothed estimates). Thus, agents gradually come to recognise that the economy has entered a new inflation regime and therefore update their inference on future inflation and its anchoring at the 2.5% inflation target as the low-inflation regime signal strengthens. The two other paths assume that the disinflation episode is less credible than in the baseline scenario and therefore that inflation expectations remain more persistent. The first ("less credible") path assumes that π_t^b declines as observed but that π_t^{uc} does not fall as estimated, while the second ("least credible") path assumes that neither π_t^b nor π_t^{uc} decline. The baseline scenario follows the observed disinflation quite closely, while the two less credible paths are much slower.

Figure 9. Inflation and output for different degree of disinflation credibility



Note: The left panel compares actual inflation to three alternative dynamic simulations (all in %). The baseline scenario uses the observed π_t^b and the smoothed estimates of π_t^{uc}. The second ("less credible") path assumes that π_t^b develops as observed while π_t^{uc} is given by the high-inflation regime value, π_1^{uc}, throughout the simulation period in the MS model and by its 2011Q4 estimate in the TVP model. The third ("least credible") path assumes that π_t^{uc} is given as in the "less credible" case and in addition that π_t^b remains constant at its 2011Q4 level. The right panel compares the actual output gap to counterfactual output paths that are required to replicate the baseline inflation path, assuming that π_t^{uc} and π_t^b evolve as in the two less credible cases (all as % of potential output). The solid horizontal line gives the 2.5% inflation target.

Source: Author's calculations.

The right panel of the figure backs out the output paths in the two low-credibility cases that are required to replicate the baseline inflation path, assuming that π_t^{uc} and π_t^b evolve as in the less credible cases (i.e. the output gap path needed to replicate the baseline inflation path without the decline in π_t^{uc} and π_t^b). What the figure shows is that without the gradually improving credibility of monetary policy, the recessions would have needed to be much more prolonged and deeper to generate the disinflation observed. The counterfactual output path is more than 5% lower than the actual output path in the least credible case (when neither π_t^b nor π_t^{uc} decline) and roughly 2% lower when π_t^b declines but π_t^{uc} remains constant. In the former, the output gap remains significantly negative at the end of the sample period but just about closes at the end of the sample in the latter – almost two years later than it actually does.

The sacrifice ratio is therefore much larger in these two less credible disinflation scenarios. For the decline in inflation from the start of 2012 to early 2015, the sacrifice ratio is estimated to be negative in the baseline scenario, but without the decline in π_t^{uc} it rises to roughly 1.0. The sacrifice ratio rises much further (to roughly 4.0) if, in addition, π_t^b is assumed to remain constant throughout the disinflation episode.[19] This simple exercise therefore shows how big a role the decline in inflation expectations and improved monetary policy credibility played in the recent disinflation episode in Iceland.

5. Conclusions

Inflation in Iceland has declined substantially from its high level immediately after the Global Financial Crisis and has remained low and stable for a longer period than seen for a long time, despite a strong recovery in domestic activity and a sharp fall in unemployment in recent years. The first disinflation phase, which saw inflation decline from almost 20% in early 2009 to the 2.5% inflation target in early 2011, was mainly driven by the deep recession following the financial crisis, which overwhelmed the lingering effects of the currency collapse in 2008. However, inflation started to rise again in 2011 and reached more than 6% in early 2012. It averaged around 4% from mid-2012 until end-2013 before easing to the inflation target in early 2014. Since then it has mostly remained between 1.5-2%, despite output growth averaging around 4% since 2011, rising further to more than 7% in 2016, and unemployment falling below 3% from early 2015.

What explains this? One obvious factor is the low global inflation in recent years that, together with the appreciation of the domestic currency, has resulted in a large fall in import prices. However, the analysis presented in this paper suggests that there is more to this than just good luck. A key factor has been the large decline in long-term inflation expectations, which had remained stubbornly well above the inflation target, reflecting the legacy of poor inflation control in Iceland for most of the inflation-targeting period. This improvement in the credibility of the inflation target can be seen in the gradual decline in bond market long-term inflation expectations from around 5% in 2011 to the target in late 2016, but our analysis suggests that this is only part of the story. Estimating a forward-looking, open-economy Phillips curve suggests a structural shift in the average relation between inflation and its key drivers occurring around 2012. It is argued that this reflects the convergence of long-term inflation expectations of households and firms towards the

[19] The sacrifice ratio is calculated as the cumulative output gap over the disinflation period, assuming that output is at potential at the start of the disinflation episode (cf. Ball, 1994a).

downward trending bond market expectations as non-financial economic agents have become more convinced that a change towards a low-inflation regime has occurred. The long-term inflation expectations of households and firms are not observed, but using a Markov switching model and a time-varying parameter model suggests that this unobserved component of long-term inflation expectations has declined from an average of about 2 percentage points in 2003-2011 towards zero at the end of the sample period.

Thus, the decline in long-term inflation expectations has been much steeper than is captured by bond market expectations and it turns out that the failure to take this into account goes a long way in explaining the persistent over-prediction of inflation in Iceland by most forecasters in recent years. Furthermore, the overall decline in long-term inflation expectations, together with the large imported deflation, play a key role in explaining the post-2012 disinflation and why it did not coincide with any loss of output. The analysis shows that without the improved credibility of monetary policy, a large output contraction would have been needed to generate the observed disinflation. The paper therefore highlights the importance of monetary policy credibility and a firm anchor for long-term inflation expectations for a successful disinflation and for maintaining low and stable inflation over a sustained period.

References

Andersen, P. S. and M. Gudmundsson (1998). Inflation and disinflation in Iceland. Central Bank of Iceland *Working Papers* no. 1.

Andrews, D. W. K. (1993). Tests for parameter instability and structural change with unknown change point. *Econometrica*, 61, 821-856.

Backus, D. and J. Driffill (1985). Rational expectations and policy credibility following a change in regime. *Review of Economic Studies*, 52, 211-221.

Ball, L. (1994a). What determines the sacrifice ratio? In *Monetary Policy* (G. N. Mankiw, ed.). Chicago: University of Chicago Press.

Ball, L. (1994b). Credible disinflation with staggered price setting. *American Economic Review*, 84, 282-289.

Ball, L. (1995). Disinflation with imperfect credibility. *Journal of Monetary Economics*, 35, 5-23.

Ball, L. (2000). Near-rationality and inflation in two monetary regimes. *NBER Working Paper Series* no. 7988. National Bureau of Economic Research.

Ball, L., N. G. Mankiw and D. Romer (1988). The New Keynesian Economics and the output-inflation trade-off. *Brooking Papers on Economic Activity*, 1, 1-65.

Ball, L. and S. Mazumder (2011). Inflation dynamics and the Great Recession. *Brooking Papers on Economic Activity*, Spring, 337-381.

Barro, R. J. (1986). Reputation in a model of monetary policy with incomplete information. *Journal of Monetary Economics*, 17, 3-20.

Blanchard, O. (2016). The US Phillips curve: Back to the 60s? Peterson Institute for International Economics, *Policy Brief*, PB16-1.

Blanchard, O., E. Cerutti, L. Summers (2015). Inflation and activity: Two explorations and their monetary policy implications. In *Inflation and Unemployment in Europe: Conference Proceedings*. ECB Forum on Central Banking. European Central Bank.

Boivin, J. and M. P. Giannoni (2006). Has monetary policy become more effective? *Review of Economics and Statistics*, 88, 445-462.

Borio, C. and A. Fillardo (2007). Globalisation and inflation: New cross-country evidence on the global determinants of domestic inflation. *BIS Working Papers* no. 227. Bank of International Settlement.

Calvo, G. A. (1983). Staggered prices in a utility-maximizing framework. *Journal of Monetary Economics*, 12, 383-398.

Carroll, C. D. (2003). Macroeconomic expectations of households and professional forecasters. *Quarterly Journal of Economics*, 118, 269-298.

Central Bank of Iceland (2017). Monetary policy based on inflation targeting: Iceland's experience since 2001 and post-crisis changes. Central Bank of Iceland *Special Publication* no. 11.

Christiano, L. J., M. Eichenbaum and C. L. Evans (2005). Nominal rigidities and the dynamic effects of a shock to monetary policy. *Journal of Political Economy*, 113, 1-45.

Coffinet, J., J. Matheron and C. Poilly (2007). Estimating the sacrifice ratio for the Euro area. Banque de France *Bulletin Digest*, no. 160.

Coibion, O. and Y. Gorodnichenko (2015). Is the Phillips Curve alive and well after all? Inflation expectations and the missing disinflation. *American Economic Journal: Macroeconomics*, 7, 197-232.

Constancio, V. (2015). Understanding inflation dynamics and monetary policy. Speech at the Jackson Hole Economic Policy Symposium, 29 August 2015.

Daníelsson, Á., B. G. Einarsson, M. F. Gudmundsson, S. J. Haraldsdóttir, T. G. Pétursson, S. Sigmundsdóttir, J. Sigurdsson and R. Sveinsdóttir (2015). QMM: A quarterly macroeconomic model of the Icelandic economy. Central Bank of Iceland *Working Papers* no. 71.

Durand, J.-J., M. Huchet-Bourdon and J. Licheron (2008). Sacrifice ratio dispersion within the Euro zone: What can be learned about implementing a single monetary policy? *International Review of Applied Economics*, 22, 601-621.

Einarsson, B. G., K. Gunnlaugsson, T. T. Ólafsson and T. G. Pétursson (2015). The long history of financial boom-bust cycles in Iceland – Part I: Financial crises. Central Bank of Iceland *Working Papers* no. 68.

Forbes, K., I. Hjortsoe and T. Nenova (2017). Shocks versus structure: Explaining differences in exchange rate pass-through across countries and time. External MPC Unit, *Discussion Paper* no. 50.

Friedman, M. (1968). The role of monetary policy. *American Economic Review*, 58, 1-17.

Fuhrer, J. C. and G. Moore (1995). Inflation persistence. *Quarterly Journal of Economics*, 110, 127-159.

Gagnon, J. E. and J. Ihrig (2004). Monetary policy and exchange rate pass-through. *International Journal of Finance and Economics*, 9, 315-338.

Gali, J. and M. Gertler (1999). Inflation dynamics: A structural econometric analysis. *Journal of Monetary Economics*, 44, 195-222.

Gordon, R. J. (2013). The Phillips Curve is alive and well: Inflation and the NAIRU during the slow recovery. *NBER Working Paper Series* no. 19390. National Bureau of Economic Research.

Gudmundsson, G. (1990). Statistical analysis of inflation in Iceland 1962-1989. *Fjarmalatidindi*, 37, 43-53. (In Icelandic).

Gudmundsson, G. (1998). A model of inflation with variable time lags. Central Bank of Iceland *Working Papers* no. 2.

Gudmundsson, G. (2002). The relation between inflation, wages and import prices. *Fjarmalatidindi*, 49, 23-34. (In Icelandic).

Gudmundsson, B. R. and G. Zoega (1997). Unemployment in Iceland: In search for an equilibrium. *Fjarmalatidindi*, 44, 18-39. (In Icelandic).

Hamilton, J. D. (1989). A new approach to the economic analysis of non-stationary time series and the business cycle. *Econometrica*, 57, 357-384.

Hansen. B. E. (1997). Approximate asymptotic p-values for structural change tests. *Journal of Business and Economic Statistics*, 15, 60-67.

Hunt, B. (2006). Simple efficient policy rules and inflation control in Iceland. Central Bank of Iceland *Working Papers* no. 30.

IMF (2013). The dog that didn't bark: Has inflation been muzzled or was it just sleeping? *World Economic Outlook*, Chapter 3, April 2013. International Monetary Fund.

IMF (2016). Global disinflation in an era of constrained monetary policy. *World Economic Outlook*, Chapter 3, October 2016. International Monetary Fund.

Ihrig, J., S. B. Kamin, D. Lindner and J. Marquez (2010). Some simple tests of the globalization and inflation hypothesis. *International Finance*, 13, 343-375.

Kumar, S., O. Coibon, H. Afrouzi and Y. Gorodnichenko (2015). Inflation targeting does not anchor inflation expectations: Evidence from firms in New Zealand. *Brooking Papers on Economic Activity*, Fall 2015, 151-208.

Mankiw, N. G. and R. Reis (2002). Sticky information versus sticky prices: A proposal to replace the New Keynesian Phillips curve. *Quarterly Journal of Economics*, 117, 1295-1328.

Mankiw, N. G., R. Reis and J. Wolfers (2003). Disagreement about inflation expectations. *NBER Working Paper Series* no. 9796. National Bureau of Economic Research.

Mikolajun, I. and D. Lodge (2016). Advanced economy inflation: The role of global factors. *ECB Working Paper Series* no. 1948. European Central Bank.

Pétursson, T. G. (1996). Are prices forward-looking? Evidence from Iceland. University of Iceland, *Iceland Economic Papers* no. 37.

Pétursson, T. G. (1998). Price determination and rational expectations. *International Journal of Finance and Economics*, 3, 162-176.

Pétursson, T. G. (2000). Business cycle forecasting and regime switching. Central Bank of Iceland *Working Papers* no. 7.

Pétursson, T. G. (2002). Wage and price formation in a small open economy: Evidence from Iceland. Central Bank of Iceland *Working Papers* no. 16.

Pétursson, T. G. (2008). How hard can it be? Inflation control around the world. Central Bank of Iceland *Working Papers* no. 40.

Pétursson, T. G. (2010). Inflation control around the world. Why are some countries more successful than others? In *Inflation Targeting Twenty Years On: Past Lessons and Future Prospects* (D. Cobham, O. Eitrheim, S. Gerlach and J. F. Qvigstad, eds.). Cambridge: Cambridge University Press.

Phelps, E. S. (1968). Money-wage dynamics and labour-market equilibrium. *Journal of Political Economy*, 76, 678-711.

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

Ruge-Murcia, F. (1995). Credibility and changes in policy regime. *Journal of Political Economy*, 103, 176-207.

Sargent, T. (1983). Stopping moderate inflations: The methods of Poincaré and Thatcher. In *Inflation, Debt, and Indexation* (R. Dornbusch and M. Simone, eds.), 54-96. Cambridge, MA: MIT Press.

Sims, C. A. (2011). Rational inattention and monetary economics. In *Handbook of Monetary Economics*, Vol. 3A (B. M. Friedman and M. Woodford, eds.), 155-181. Amsterdam: Elsevier North-Holland.

Zoega, G. (2002). Inflation and unemployment in Iceland in the light of Natural-Rate theory. Central Bank of Iceland *Working Papers* no. 17.

Yellen, J. L. (2015). Inflation dynamics and monetary policy. The Philip Gamble Memorial Lecture, University of Massachusetts, Amherst, September 24.