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A Dynamic Factor Model for Icelandic Core Inflation*

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Abstract

Using monthly data on 230 subcomponents of the consumer price index, a new measure of core inflation in Iceland is proposed based on a dynamic factor model. The measure is then compared along several dimensions to the set of core inflation measures currently monitored by the Central Bank of Iceland (including both exclusion and statistical measures). This comparison indicates that the dynamic factor measure outperforms other core inflation measures for the period March 1997 to July 2014 in terms of matching the mean of CPI inflation while having lower volatility. When examining subsamples determined by the availability of other measures of core inflation, the results are less clear-cut: the measures that match the mean of CPI inflation provide little or no reduction in volatility, while the dynamic factor measure does not match the mean of inflation perfectly but has the advantage of lower volatility. An evaluation of whether the core inflation measures are unbiased predictors of future inflation indicates that, of all the measures examined, only the dynamic factor measure and one exclusion measure (core index 1) are unbiased predictors, both of them weakly exogenous. A potential drawback of the dynamic factor model approach is that its core inflation estimate may be subject to large revisions when new data become available. However, the results indicate that the dynamic factor measure is quite robust to the addition of new data. Thus the results of the paper indicate that the dynamic factor measure of core inflation may be a valuable complement to the set of measures of core inflation currently monitored by the Central Bank of Iceland.

Keywords: Core inflation, Iceland, Dynamic factor model.
JEL Classification: C32, E31, E32, E52

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1 Introduction

Core inflation has seen widespread use in discussions of monetary policy. For an inflation targeting central bank such as the Central Bank of Iceland (CBI), it is important to have a good measure of underlying inflationary pressures that helps predict future inflation developments. While the CBI's inflation target is formalised as a numerical target for inflation as measured by changes in the consumer price index (CPI), in practice, monetary policy needs to look beyond just this headline measure, as CPI inflation consists of persistent or general inflation developments as well as short-lived effects on inflation such as changes in relative prices, changes in indirect taxes, or other transitory price changes that do not have a lasting effect on inflation and can thus usually be ignored in the formulation of monetary policy.

Despite the need to measure core inflation, there is no consensus on either its exact definition or its measurement. Hence various measures of core inflation exist.[1] Those currently published in Iceland can broadly be categorised as exclusionary and statistical. The exclusionary measures aim to remove short-lived idiosyncratic effects by removing various subindices of the CPI, usually the most volatile ones or those thought to reflect supply shocks, such as petrol prices, which the monetary authorities should treat differently from demand shocks, or government-regulated prices. The statistical measures also work by removing volatile subcomponents of the CPI but limit themselves to removing the most volatile components only within a given period, usually a month. Statistics Iceland publishes four different exclusionary measures of core inflation: core index 1, which excludes prices of agricultural products and petrol; core index 2, which excludes prices of public services as well; core index 3, which adds the cost of real mortgage interest to the list of exclusions; and finally, core index 4, which also excludes the market price of housing. In addition, the CBI calculates several statistical measures of core inflation: various trimmed-mean measures of core inflation, which exclude a certain percentage of components with the largest monthly price changes, and a weighted median measure based on the price change of the weighted median of the CPI components. See Pétursson (2002) for an evaluation of the first two exclusionary measures published by Statistics Iceland.

A different measure of core inflation is suggested by the growing factor model literature. Using disaggregated CPI data, an underlying component is extracted that is common to all the subindices representing general inflation developments. This method has been employed by various central banks and academics. For the UK, Kapetanios (2002) uses a dynamic factor model to estimate a common component representing core inflation, and Cristadoro et al. (2005) do the same for the euro area, using both euro area and national level data. Using data on New Zealand, Giannone & Matheson (2007) and Kirker (2010) estimate a measure of core inflation, with the latter employing an identification scheme separating it into its tradable and non-tradable components. Furthermore, Tekatli (2010)

[1] For a more comprehensive review of the various approaches to measure core inflation, see Wynne (2008).

estimates core inflation for Turkey, and Reis & Watson (2010) estimate "pure inflation" in the US. Using a factor model, Khan et al. (2013) estimate the common component of the CPI in Canada. The dynamic factor approach is further extended to include daily data to assess underlying inflation in Amstad & Potter (2009), Amstad, Potter & Rich (2014), and Amstad, Huan & Ma (2014).

The contribution of the present paper is twofold. First, a new measure of core inflation in Iceland is proposed, using a dynamic factor model. Second, an assessment is provided of the quality of the range of core inflation measures currently published by Statistics Iceland and the Central Bank of Iceland, and the one proposed by the paper.

The remainder of the paper is structured as follows. Section 2 discusses the data used. Section 3 presents the dynamic factor model and the estimation strategy. Section 4 presents the estimation results and Section 5 an evaluation of the quality of the measures. Section 6 concludes.

2 Data

The consumer price index and its subindices are published monthly by Statistics Iceland. After removing series that have been discontinued or have missing values, a total of 230 subindices remain, spanning the period from March 1997 to July 2014. Including headline CPI inflation in the panel allows for the computation of core inflation. The model is thus estimated using a panel of 231 series. The data are first differenced in log levels of the series, and then each series is standardised by subtracting its mean and dividing by its standard deviation prior to estimation of the model.

3 The dynamic factor model

Let us assume that CPI inflation, π_t, can be decomposed into two orthogonal components, a core inflation component, π_t^c, and a non-core inflation component, π_t^{nc}. That is:

$$\pi_t \equiv \pi_t^c + \pi_t^{nc} \tag{1}$$

where π_t^c captures underlying inflationary pressures as presented by persistent or general inflation developments and π_t^{nc} captures short-lived effects on inflation. Thinking of π_t^c as the part of inflation that is common among all categories of goods and π_t^{nc} as the part that is idiosyncratic among categories such as relative price changes and transitory effects gives rise to the use of a factor model.

A factor model is a statistical method that describes the variability in a set of variables as the sum of one or more factors that represent the co-movement among the variables and an idiosyncratic error term capturing what is unexplained by the co-movement in the set of variables. A dynamic factor model results from assuming that the panel is a distributed lag of the common factors and positing time series properties for both the factors and the idiosyncratic term. Thus, for a panel of inflation series, π_{it}, the dynamic factor model takes the form:

$$\pi_{it} = B_i F_t + e_{it} \tag{2}$$

where F_t is the common factor and B_i the factor loading of inflation series i. The common factor, F_t, is assumed to follow the AR(2) process:

$$F_t = c + \rho_1 F_{t-1} + \rho_2 F_{t-2} + v_t, \quad V(v_t) = Q. \tag{3}$$

Allowing for the possibility of serial correlation in the idiosyncratic error term, it is assumed that e_{it} follows the AR(1) process:

$$e_{it} = \alpha_i e_{it-1} + \varepsilon_{it}, \quad V(\varepsilon_{it}) = R_i. \tag{4}$$

For convenience, we arrange the panel of inflation series such that headline inflation is the first series (i.e. $i = 1$). Comparing the equation for headline inflation given by equation 1 and equation 2 gives an expression for core inflation as the multiple of the factor loading for headline inflation and the common factor; that is, $\pi_t^c = B_1 F_t$, leaving the transitory component as the idiosyncratic error term e_{1t}. Note that because a dynamic factor model requires the data to be standardised prior to estimation, the final measure of core inflation is obtained by rescaling with the mean and standard deviation of headline inflation.

The dynamic factor model is estimated using the Gibbs sampling algorithm described in Appendix A, assuming a single common factor. The algorithm is used to create 5,000 draws, with the first 4,500 discarded as the burn-in sample. Core inflation is calculated during each iteration of the algorithm. The point estimate of core inflation is found as the median value of the distribution in each month.

4 Estimation results

Figure 1 presents the estimated dynamic factor core inflation measure along with CPI inflation. It is apparent that estimated core inflation tracks CPI inflation fairly closely. The largest discrepancy is at the onset of the financial crisis in the latter half of 2008, when it amounts to roughly 4.9 percentage points. Interestingly, there is minimal difference between core inflation and CPI inflation after the depreciation of the Icelandic króna in 2001, while this is not the case after the depreciation episodes in 2006 and 2008-2009. Additionally, the disinflation of the last two years is somewhat slower according to the dynamic factor model, with estimated core inflation roughly a percentage point higher than headline inflation at the end of the sample.

Figure 2 replicates a figure routinely published in the Central Bank's *Monetary Bulletin*, with the dynamic factor core inflation measure added. The dynamic factor core inflation seems to lie at the upper range of core inflation measures monitored by the Central Bank, and it also appears to be among the smoothest. Interestingly, both core inflation according

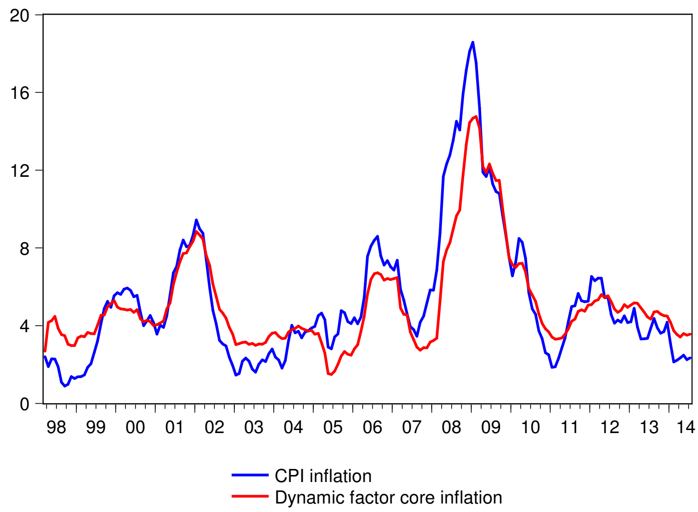

Figure 1: Dynamic factor measure of core inflation
Sources: Statistics Iceland, author's calculations.

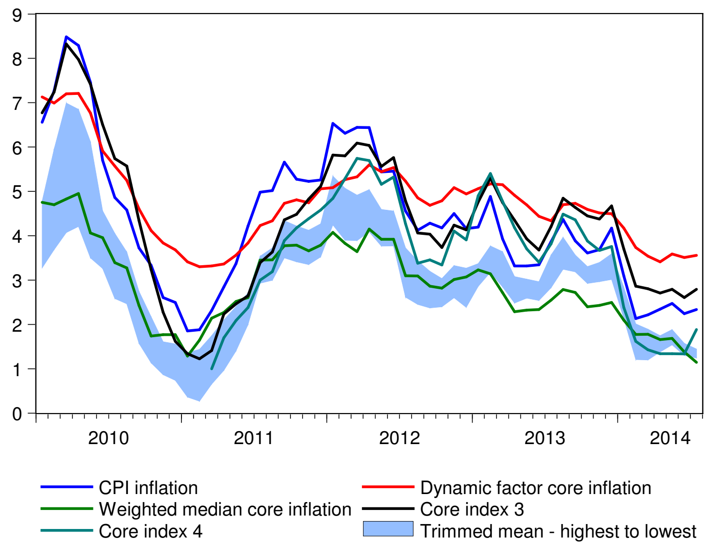

Figure 2: Various measures of core inflation
Sources: Central Bank of Iceland, Statistics Iceland, author's calculations.

to the weighted median and the area formed by the range of trimmed mean measures always lie beneath CPI inflation.

5 Evaluation of the core inflation measure

The dynamic factor measure of core inflation is evaluated along four dimensions. First, a good measure of core inflation should be unbiased relative to CPI inflation in terms of mean inflation. Second, it should be less volatile than CPI inflation, as it is supposed to capture the underlying trend in inflation. Third, because it should capture underlying inflationary pressures, it should be a predictor of future inflation developments. Fourth, from a policy perspective, the core inflation measure should be available in a timely manner and should not be subject to substantive revisions. The available core indices and the dynamic factor measure are evaluated based on these criteria in the remainder of this section.

5.1 Unbiasedness and volatility

Table 1 presents the mean and standard deviation of CPI inflation and various core inflation measures. Because not all measures are available for the full sample period, the table is divided into sections, with each section beginning when a new core inflation measure becomes available. This is done to ensure comparability of the sample moments.

When considering the full sample, for which only the dynamic factor measure and core indices 1 and 2 are available, we see that the mean of all the core inflation measures is on a par with the mean of CPI inflation. The dynamic factor measure, however, has a substantially lower standard deviation than the other measures. The standard deviation of core index 2 is actually slightly greater than that of CPI inflation. Moving on to the sample beginning in 2005M1, when core index 3 becomes available, we see that all of the core indices capture the mean of CPI inflation fairly well, while the mean of the dynamic factor measure falls short by about 0.7 percentage points. On the other hand, the dynamic factor measure provides the greatest reduction in standard deviation, with the standard deviation of the core indices roughly on a par with that of CPI inflation.

The trimmed mean and weighted median measures are calculated from 2007M1. As Figure 2 implied, the mean of those measures is significantly lower than that of CPI inflation; however, those measures do provide the greatest reduction in volatility. Again, the core indices capture the mean of CPI inflation somewhat better than the dynamic factor measure but have standard deviations roughly on a par with that of CPI inflation, whereas the standard deviation of the dynamic factor measure is a full percentage point lower.

The final section of the table examines the sample beginning in 2011M3, for which core index 4 is available. Again, the means of the trimmed mean and weighted median measures fall more than a percentage point short of the mean of CPI inflation, but their volatility is somewhat lower than that of CPI inflation for the 25% trimmed mean and

Table 1: Descriptive statistics of core inflation measures

1998M3	CPI	DF	CI 1	CI 2	CI 3	CI 4	TM5%	TM25%	WM
Mean	5.3	5.2	5.3	5.3					
St.dev.	3.5	2.6	3.3	3.6					
2005M1									
Mean	6.3	5.6	6.1	6.2	6.3				
St.dev.	3.8	3.0	3.6	4.0	3.6				
2007M1									
Mean	6.6	6.1	6.4	6.4	6.5		5.2	4.3	4.7
St.dev.	4.2	3.1	4.0	4.4	4.0		3.9	2.6	2.8
2011M3									
Mean	4.1	4.5	3.9	3.7	4.1	3.6	2.9	2.8	2.8
St.dev.	1.3	0.7	1.0	1.0	1.1	1.4	1.2	0.8	0.8
Correlation with CPI inflation									
	-	0.92	0.98	0.98	0.97	0.84	0.99	0.97	0.97
Highest correlation with lagged output gap									
	0.59	0.53	0.63	0.66	0.70	0.17	0.78	0.84	0.82
At lag	3	4	3	3	4	1	2	2	2

Notes: CPI refers to CPI inflation, DF is the dynamic factor measure of core inflation, CI 1 through 4 are the exclusionary core indices, TM5% and TM25% are the trimmed mean measures at 5% and 25% cut offs, and WM is the weighted median measure. The sections of the table correspond to different lengths of time series on core inflation. All sections end in 2014M7. Correlations are calculated over the longest available sample for each measure.

the weighted median. The core indices capture the mean of CPI inflation fairly well; however, they provide little or no reduction in volatility compared to CPI inflation. The mean of the dynamic factor measure is 0.4 percentage points higher than the mean of CPI inflation, although of all the core inflation measures, it does provide the greatest reduction in volatility.

Table 1 also presents two correlation measures, the contemporaneous correlation of the core inflation measures with CPI inflation and the highest correlation with lagged output gap. The contemporaneous correlation with CPI inflation is quite high for all core inflation measures, ranging from 0.84 to 0.99.[2] This indicates that while there may be some difference in level between the core inflation measures and CPI inflation, the various measures all move in tandem with CPI inflation. The second correlation measure is the highest correlation with lagged output gap, which is often thought of as an indicator of underlying inflationary pressures. If a core inflation measure captures underlying inflationary pressures better than CPI inflation, then one would expect it to be more correlated with the output gap than CPI inflation and thus a better indicator of future inflationary pressures. This is case for all of the core inflation measures except the dynamic factor measure and core index 4. Interestingly, of all the core inflation measures, the trimmed mean and weighted median measures have the highest correlation with the output gap.

5.2 Predictive ability

One of the desirable features of a core inflation measure is that it is a predictor of future inflation developments. One test of this characteristic is proposed by Cogley (2002). The method consists of running two regressions:

$$\pi_{t+h} - \pi_t = \alpha + \beta \left(\pi_t^c - \pi_t\right) \tag{5}$$

$$\pi_{t+h}^c - \pi_t^c = \gamma + \delta \left(\pi_t - \pi_t^c\right) \tag{6}$$

where π_t is CPI inflation and π_t^c is some core inflation measure. Equation 5 provides the test of whether the core inflation measure is a predictor of future inflation in the sense of whether the deviation of headline inflation from core inflation predicts how headline inflation will change over some horizon h; that is, β should be positive and statistically significant. Furthermore, if α is zero and β is equal to unity, the core inflation measure is an unbiased predictor of headline inflation at horizon h. Equation 6 examines whether the deviation of the core inflation measure from headline inflation explains future changes in the core inflation measure over some horizon h. Thus a test of weak exogeneity of the core inflation measure can be performed by testing whether γ and δ are equal to zero.

Table 2 presents the estimation results of Equations 5 and 6 for a range of core inflation measures for horizons of 12, 18, and 24 months. Looking first across the top half, containing

[2]The correlation is also quite high if only using data for the more stable period beginning in 2011, ranging between 0.83 and 0.96, indicating that the high correlation is not simply due to the large spike in all inflation measures following the onset of the financial crisis in 2008.

the estimated coefficients from equation 5, we see that for the dynamic factor measure, α is never statistically significant from zero, and furthermore, that β is always greater than zero and statistically significant from zero at the 1% level at horizons of 18 and 24 months, while only at the 8% level at the 12 month horizon. The same results apply to core index 1, with the exception that the estimates of β are always statistically significant at the 1% level. For core indices 2 and 3, none of the estimates of α and β are statistically significant at any horizon. For core index 4, both the α and β estimates are significant at the 10% level but have a negative sign. For both trimmed mean measures and the weighted median measure, both parameters are significant at the 1% level at all horizons.[3] However, their size is much greater than would be expected, indicating that these measures are severely biased indicators of future inflation.

Moving to the bottom half of Table 2, an assessment of whether the core measures are weakly exogenous can be made. For the dynamic factor measure and core indices 1 through 3, the estimate of γ is insignificant from zero at all horizons. The estimates for δ are insignificant for the dynamic factor measure at horizons of 18 and 24 months, for core index 1 at 12 and 24 months, and for core index 3 at 18 and 24 months. For core index 4, the trimmed mean measures, and the weighted median, both coefficients are significant at the 1% level at all horizons.

The two candidate measures that could be weakly exogenous unbiased predictors for inflation are thus the dynamic factor measure and core index 1. Tests of whether the estimates of β are statistically significant from unity cannot reject the null hypothesis at standard significance levels at horizons of 18 and 24 months for the dynamic factor measure or at horizons of 12 and 24 months for core index 1, which indicates that the measures are an unbiased predictor for inflation at those horizons.

[3] The equations were also estimated for the 10%, 15%, and 20% trimmed mean measures, yielding qualitatively the same results. Those results are not presented in Table 2 but are available upon request.

Table 2: Coefficient estimates

	DF		CI 1		CI 2		CI 3		CI 4		TM5%		TM25%		WM	
Horizon	α	β	α	β	α	β	α	β	α	β	α	β	α	β	α	β
12	0.17	0.37	0.19	1.54	0.09	−0.23	−0.12	−0.12	−1.15	−0.7	9.01	6.69	5.73	2.41	5.24	2.75
	(0.32)	(0.21)	(0.31)	(0.48)	(0.32)	(0.43)	(0.50)	(0.50)	(0.38)	(0.37)	(1.21)	(0.80)	(0.66)	(0.31)	(0.56)	(0.22)
18	0.34	0.81	0.29	2.14	0.14	−0.01	−0.21	0.23	−1.98	−0.73	11.31	8.34	7.27	3.09	6.2	3.37
	(0.35)	(0.23)	(0.35)	(0.52)	(0.36)	(0.48)	(0.60)	(0.58)	(0.45)	(0.40)	(1.51)	(0.97)	(0.66)	(0.21)	(0.56)	(0.21)
24	0.44	1.23	0.2	1.59	0.11	−0.29	−0.4	0.78	−3.12	−1.19	8.02	6.92	6.21	2.99	4.97	3.18
	(0.36)	(0.23)	(0.38)	(0.56)	(0.38)	(0.51)	(0.64)	(0.60)	(0.84)	(0.68)	(1.65)	(1.07)	(0.61)	(0.19)	(0.56)	(0.20)

Horizon	γ	δ	γ	δ	γ	δ	γ	δ	γ	δ	γ	δ	γ	δ	γ	δ
12	−0.05	0.43	0.13	−0.33	0.09	1.24	−0.23	1.48	−1.15	1.89	7.34	−5.51	3.35	−1.46	2.96	−1.67
	(0.26)	(0.17)	(0.30)	(0.46)	(0.32)	(0.43)	(0.46)	(0.45)	(0.34)	(0.33)	(1.23)	(0.81)	(0.37)	(0.12)	(0.35)	(0.13)
18	0.04	0.10	0.24	−1.26	0.13	0.97	−0.35	1.0	−2.54	2.15	9.45	−7.07	4.1	−1.83	3.26	−1.99
	(0.30)	(0.19)	(0.34)	(0.51)	(0.37)	(0.49)	(0.59)	(0.57)	(0.39)	(0.35)	(1.49)	(0.96)	(0.37)	(0.12)	(0.36)	(0.13)
24	0.14	−0.25	0.17	−0.69	0.12	1.38	−0.53	0.46	−3.96	2.79	6.29	−5.72	3.33	−1.73	2.25	−1.82
	(0.30)	(0.19)	(0.37)	(0.56)	(0.40)	(0.54)	(0.66)	(0.62)	(1.08)	(0.88)	(1.65)	(1.07)	(0.43)	(0.13)	(0.41)	(0.15)

Notes: DF refers to the dynamic factor measure of core inflation, CI 1 through 4 are the exclusionary core indices, TM5% and TM25% are the trimmed mean measures at 5% and 25% cut offs, and WM is the weighted median measure. Standard errors are in parentheses.

Table 3: Mean absolute revision of core inflation

	T	$T-1$	$T-2$	$T-3$	$T-4$
Subsample mean and variance	0.15	0.14	0.14	0.14	0.14
Full sample mean and variance	0.09	0.09	0.10	0.10	0.10

Notes: Mean absolute revision of core inflation in the last five months of each subsample. Percentage points. Subsample and full sample indicate the sample used to calculate the mean and variance used to rescale the estimated core inflation.

5.3 Real-time stability

A possible drawback to the dynamic factor approach is that it is estimated using a smoothing filter, whereas the exclusionary and other statistical measures currently published in Iceland do not. As such, the core inflation measure proposed in the present paper is subject to revisions as new data become available. In other words, because the Kalman filter is employed in the estimation process, the estimated core inflation may suffer from the well-known end-point problems.[4]

To examine the magnitude of the revision to real-time estimates, the following exercise was performed. The sample was shortened to May 2010, the model estimated and the results stored. Then the sample was lengthened by one month of data, the model re-estimated and the results stored. This was repeated until the end of the full sample, for a total of 50 revisions. Revision is then calculated for the last five months of each subsample; i.e., π^c_{T-i} for $i = 0, 1, ..., 4$, where T is the end-point of each shortened sample, as the difference between the estimate of core inflation for the shortened sample and the estimate for the full sample.

Table 3 presents the mean of the absolute revisions to the estimate of core inflation. The first line shows that the estimate of core inflation for the last period of a sample is revised, on average, by 0.15 percentage points in absolute value, and the estimate for the four preceding periods by an average of 0.14 percentage points in absolute value. Part of this revision comes from the fact that the estimate of core inflation is constructed using the mean and standard deviation of headline inflation, which change between subsamples. It is therefore informative to perform the same exercise but to always use the mean and standard deviation of headline inflation calculated using the full sample. The second line of Table 3 shows the resulting mean absolute revision to core inflation. When only the mean and standard deviation of the full sample are used, the mean absolute revision to estimated core inflation for the last period of the sample drops to 0.09 percentage points. The penultimate period's mean absolute revision also drops to 0.09 percentage points, and for the three preceding periods it drops to 0.1 percentage points. This suggests that the estimate of core inflation is relatively robust to adding new data and that the model is not overly plagued by end-point problems.

[4] Another possible drawback of using a smoothing filter is the possibility of too much smoothing. This could lead to core inflation being overestimated in times of low inflation and underestimated in times of high inflation. This possibility is, however, not examined in the present paper.

6 Conclusion

The measure of core inflation proposed in the present paper by use of a dynamic factor model seems to hold some promise. A dynamic factor model lends itself naturally to estimating a common component among the subindices of the CPI. Evaluation of this measure of core inflation along with the measures currently monitored by the Central Bank shows that, for the full sample, the dynamic factor measure of core inflation outperforms other measures available for the same period, core indices 1 and 2. While all measures capture the mean of CPI inflation well, only the dynamic factor measure provides any substantial gain in terms of reduced volatility. When examining subsamples, determined by the availability of other core inflation measures, the dynamic factor captures the mean of CPI inflation less well but remains the measure that generally reduces volatility the most, while the core indices provide virtually no reduction of volatility. The trimmed mean and weighted median measures, while providing reduced volatility, capture the mean of CPI inflation the worst; however, of all the core inflation measures, they have the highest correlation with lagged output gap.

An evaluation of whether the core inflation measures are unbiased predictors of future inflation follows from Cogley (2002). The results indicate that, of all the measures, only the dynamic factor measure and core index 1 are unbiased predictors, the dynamic factor measure at 18 and 24 months ahead and core index 1 at 12 and 24 months ahead. Additionally, both are weakly exogenous.

A potential drawback of the dynamic factor model approach is that the core inflation estimate may be subject to revisions. However, the results indicate that the dynamic factor measure is quite robust to the addition of new data, with the last four periods being revised on average by about 0.14 percentage points in absolute value.

For a small open economy like Iceland, which is heavily dependent on imports of consumer goods and has a history of large exchange rate fluctuations, further research along the lines of Kirker (2010), separating core inflation into a tradable and a non-tradable component, would be of interest.

The results of the paper indicate that the dynamic factor measure of core inflation could be a valuable complement to the set of measures of core inflation currently monitored by the Central Bank of Iceland.

Appendix

A The Gibbs Sampler

Restating the dynamic factor model for convenience, we have:

$$\pi_{it} = B_i F_t + e_{it} \tag{7}$$

where π_{it} is a panel of inflation series, and

$$F_t = c + \rho_1 F_{t-1} + \rho_2 F_{t-2} + v_t, V(v_t) = Q \tag{8}$$

$$e_{it} = \alpha_i e_{it-1} + \varepsilon_{it}, V(\varepsilon_{it}) = R_i \tag{9}$$

where F_t is the common factor.

Rewriting the model in state space form, the observation equation is

$$\underbrace{\begin{pmatrix} \tilde{\pi}_{1t} \\ \cdot \\ \cdot \\ \cdot \\ \tilde{\pi}_{Nt} \end{pmatrix}}_{Y_t} = \underbrace{\begin{pmatrix} B_1 & -B_1\alpha_1 \\ \cdot & \cdot \\ \cdot & \cdot \\ \cdot & \cdot \\ B_N & -B_N\alpha_N \end{pmatrix}}_{H} \underbrace{\begin{pmatrix} F_t \\ F_{t-1} \end{pmatrix}}_{\xi_t} + \underbrace{\begin{pmatrix} \varepsilon_{1t} \\ \cdot \\ \cdot \\ \cdot \\ \varepsilon_{Nt} \end{pmatrix}}_{\varepsilon_t} \tag{10}$$

where $\tilde{\pi}_{it} = \pi_{it} - \alpha_i \pi_{it-1}$. The transition equation is

$$\underbrace{\begin{pmatrix} F_t \\ F_{t-1} \end{pmatrix}}_{\xi_t} = \underbrace{\begin{pmatrix} c \\ 0 \end{pmatrix}}_{\mu} + \underbrace{\begin{pmatrix} \rho_1 & \rho_2 \\ 1 & 0 \end{pmatrix}}_{\Phi} \underbrace{\begin{pmatrix} F_{t-1} \\ F_{t-2} \end{pmatrix}}_{\xi_{t-1}} + \underbrace{\begin{pmatrix} v \\ 0 \end{pmatrix}}_{v} \tag{11}$$

The Gibbs sampling algorithm is as follows:

1. Obtain an initial estimate of the factor via principal component analysis. Set starting values for the state vector $\xi_{0|0}$ and its covariance matrix $P_{0|0}$. Set starting values for R, Q and α.

2. Sample the factor loadings conditional on F_t and R_i. The factor loadings are defined by the model in Equations 7 and 9. Rewrite the regression to remove serial correlation

$$\underbrace{\pi_{it} - \alpha_i \pi_{it-1}}_{Y^*} = B_i \underbrace{(F_t - \alpha_i F_{t-1})}_{X^*} + \underbrace{e_{it} - \alpha_i e_{it-1}}_{\varepsilon_{it}} \tag{12}$$

   The factor loadings are sampled from $B_i \sim N(\bar{B}_i, V)$, where $\bar{B}_i = (X^{*\prime} X^*)^{-1}(X^{*\prime} Y^*)$ and $V = R_i (X^{*\prime} X^*)^{-1}$.

3. Sample α_i using the regression model $e_{it} = \alpha_i e_{it-1} + \varepsilon_{it}, V(\varepsilon_{it}) = R_i$, where e_{it} is obtained from step 2. The sampling is done from $\alpha_i \sim N(\bar{\alpha}_i, \bar{V})$, where $\bar{\alpha}_i =$

$(e'_{it-1}e_{it-1})^{-1}(e'_{it-1}e_{it})$ and $\bar{V} = R_i(e'_{it-1}e_{it-1})^{-1}$.

4. Sample R_i from the Inverse Gamma distribution

$$R_i \sim IG(\varepsilon'_{it}\varepsilon_{it}, T) \tag{13}$$

5. Sample the coefficients of Equation 8 conditional on F_t. Note that Q is assumed to equal unity to identify the scale of the factor. The coefficients, $\Gamma = \{c, \rho_1, \rho_2\}$, are sampled from $\Gamma \sim N(\bar{\Gamma}, Z)$, where $\bar{\Gamma} = (X'X)^{-1}(X'Y)$ and $Z = (X'X)^{-1}$, where $Y = F_t$ and $X = [1\ F_{t-1}\ F_{t-2}]$.

6. Set up the matrices of the state space model in Equations 10 and 11, and sample the factor $\{F_t\}_1^T$ from their conditional distribution using the Carter-Kohn algorithm.

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