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Long-term Inflation Expectations and Central Bank Credibility

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Abstract

This paper proposes a new measure of central bank credibility. I develop an inflation expectations model that specifies inflation expectations' mean-reverting properties, which is assumed to indicate the level of credibility. Estimating the model with US data, I find that the new measure, in general, shows a similar feature of changes in central bank credibility to existing indicators. However, the index in this paper captures the more fundamental changes in credibility. According to the index, central bank credibility in the recent period is maintained at its lowest level since 2017.

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1 Introduction

Since many central banks introduced inflation targeting, it has been very important for central banks to manage agents' inflation expectations, so that they remain stable. This is because the inflation target indicates a central bank's intention on how to steer actual inflation towards the target, and inflation expectations are a crucial determinant of actual inflation. Hence, the anchoring of expected inflation to targeted inflation is directly associated with attaining the effectiveness of the monetary policy.

There has been a large volume of research on inflation targeting and central bank credibility. However, there is no widespread consensus on the definition of central bank credibility and how to measure it. The measures in the existing literature mostly use the distance between inflation expectations and the inflation targets to evaluate the credibility level. However, in this case, changes in inflation expectations due to measurement errors or temporary shocks can also be identified as changes in credibility. Furthermore, an explicit inflation target or a range of the target is not always available, as in the case of the US. Lastly, inflation expectations data could have a higher long-run trend compared to the inflation target. If so, measurement based on the inflation target could cause a bias in understanding central bank credibility. For these reasons, the development of an indicator to assess more fundamental changes in credibility without an explicit inflation target is necessary.

To address this issue, I employ a model that emphasizes the mean-reverting properties of inflation expectations. In this model, inflation expectations are assumed to hover around a certain long-run trend, which implies an implicit target. When the inflation expectations deviate from the trend, the persistence of the inflation expectations declines so that they return to the target level faster. Moreover, the more inflation expectations deviate from the target, the faster they revert to the target. In this model, central bank credibility is defined as how fast inflation expectations return to the target level. The degree of central bank credibility is also assumed to be time varying. To this end, it is assumed that the degree of credibility varies depending on the credibility regime, in line with the changes in the speed of mean reversion.

With this model, I estimate the credibility level on US data. The estimation results reveal several interesting findings. First, long-term inflation expectations evolve with different degrees of mean-reverting properties under different regimes. Second, central bank credibility is currently at its lowest level, which is similar to 2008 on the verge of the global financial crisis. Third, the higher persistence of inflation expectations in the recent period is primarily due to undermined credibility. Last, the identified credibility index in this study reveals generally similar features to existing indicators, such as the de-anchoring index of inflation expectations and simple measures with a distance between expectations

and the target. However, the comparison demonstrates that the credibility index in this paper captures more fundamental changes in the credibility.

The remainder of the paper is organized as follows. Section 2 introduces existing measures of central bank credibility in the literature. Section 3 describes the model of central bank credibility by focusing on the mean-reverting properties of inflation expectations. Section 4 presents the estimation results. Section 5 provides comparisons of the estimated credibility index with other indicators. Section 6 concludes.

2 Model

2.1 Formation of Inflation Expectations

Agents are assumed to form their long-term inflation expectations by combining an inflation target and a cyclical component as follows:

$$\pi^e_{t|t+h} = \bar{\pi}_t + u_t, \tag{1}$$

where $\pi^e_{t|t+h}$ and $\bar{\pi}_t$ denote h-period ahead inflation expectations and their long-run trend, respectively. In this paper, the long-run trend is assumed to represent the inflation target. u_t is the cyclical component following AR(p) process with a mean of zero. Under these assumptions, inflation expectations hover around a certain level and should not deviate far away from it. A further assumption of the cyclical component is that the persistence of u_t is time-varying. Therefore, the law of motion for u_t is expressed by

$$u_t = \rho_t \sum_{i=1}^{p} \alpha_i u_{t-i} + \varepsilon_t, \tag{2}$$

where $\varepsilon_t \sim iidN(0, \sigma^2_\varepsilon)$ and α_i denotes the lag-order-specific coefficient. As proposed by Nobay, Paya, and Peel (2010) and Strohsal and Winkelmann (2015), if long-term inflation expectations are well anchored on the target level, the degree of mean reversion becomes stronger, as they deviate more from the target level. Following this spirit, the coefficient ρ_t is assumed to take the exponential smooth transition autoregressive (ESTAR) process:

$$\rho_t = G(\pi^e_{t-1|t+h-1}; \gamma; \bar{\pi}) = \exp\left[-\gamma(\pi^e_{t-1|t+h-1} - \bar{\pi})^2 \right], \tag{3}$$

where the parameter $\gamma \in \mathbb{R}_+$ determines the strength of mean-reverting properties.[1] If the parameter γ is higher, inflation expectations tend to revert to the inflation target more rapidly. In the sense that the more strongly agents' beliefs about the inflation target are formed, the more firmly inflation expectations are anchored on the target level, the size

[1] This non-linear specification of ρ_t is supported by non-linearity tests provided in Appendix D.

of γ is considered to be a proxy of central bank credibility. Hence, in this paper, central bank credibility is defined as an agent's belief that inflation will eventually fall in the inflation target range set by the central bank. Accordingly, the credibility is measured by the speed of inflation expectations' mean reversion.

2.2 Time-varying Credibility Index

Based on the definition of central bank credibility in this study, the degree of central bank credibility is further assumed to be time varying. Sometimes, agents firmly believe that the central bank will keep its commitment to the inflation target at any cost. In some cases, however, they might think that the central bank will allow a deviation of inflation from its target to some extent. It could depend on the objectives of monetary policy or the type of shocks that affect inflation. When central banks face a variety of objectives of monetary policy, such as full employment or financial stability, in addition to price stability, agents can be skeptical about central banks adhering to price stability. In addition, agents might think that the central bank will not respond to a supply shock as actively as to a demand shock.

In order to specify the time-varying degree of anchoring, a regime-switching model is considered.[2] In this model, the parameter γ switches between different values depending on the credibility regime. By combining (1)–(3), agents' inflation expectations are expressed by

$$\pi^e_{t|t+h} = \bar{\pi}_t + \left[\sum_{j=1}^{N} G(\pi^e_{t-1|t+h-1}; \gamma_j; \bar{\pi}_t) D_{jt}\right] \left[\sum_{i=1}^{p} \alpha_i (\pi^e_{t-i|t+h-i} - \bar{\pi}_t)\right] + \varepsilon_t, \tag{4}$$

where j denotes the credibility regime S_t, and D_{jt} represents the dummy variable. $D_{jt} = 1$ if $S_t = j$ and $D_{jt} = 0$ otherwise. N is the number of credibility regimes. $\varepsilon_t \sim iidN(0, \sigma^2_{\varepsilon,s})$, where $\sigma^2_{\varepsilon,s} = \sum_{j=1}^{N} \sigma^2_{\varepsilon,j} D_{jt}$. The credibility regime S_t is assumed to follow the 1st-order Markov process. In regard to the α_i coefficient, it is restricted by $\sum_{i=1}^{p} \alpha_i = 1$ to guarantee the stability of the law of motion. As Strohsal and Winkelmann (2015) assume, news shocks can be included in explanatory variables; however, the case is ruled out because long-term inflation expectations are not supposed to be affected by temporary news shocks.[3] Regarding the transition probability of S_t, a direct transition to another

[2]Ideally, one might consider a time-varying γ_t, which forms a state-space model identified by the extended Kalman filter, suggested by Harvey (1989), or the particle filter. However, due to the high degree of nonlinearity of $G(\cdot)$, in this paper, the state-space model cannot delicately approximate the movement of the state parameter γ_t. Lundbergh, Teräsvirta, and Dijk (2003) also consider a time-varying STAR model, which assumes a logistic transition between two regimes. In this case, however, a higher-order of regimes cannot be considered.

[3]One can find that news shocks do not significantly affect long-term inflation expectations in Strohsal and Winkelmann (2015).

regime without staying in the neighboring regime is not allowed, as Hwu, Kim, and Piger (2019) suggest:

$$\Pr[S_t = j|S_{t-1} = i] = \begin{cases} p_{ij} & \text{if } |i-j| \leq 1 \\ 0 & \text{if } |i-j| > 1 \end{cases}, \tag{5}$$

where $i, j \in \{1, \cdots, N\}$ and $\sum_{j=1}^{N} p_{ij} = 1$.[4]

After credibility regimes are identified, each regime is endowed with a different score. Then the credibility index is calculated by the weighted average of the scores as follows:

$$C_t = \sum_{j=1}^{N} w_{jt} Sc_j, \qquad Sc_1 > Sc_2 > \cdots > Sc_N, \tag{6}$$

where the weight w_{jt} denotes the identified state probability, $w_{jt} = \Pr[S_t = j|\psi_t]$.

3 Estimation

3.1 Data

For the estimation, monthly 5-year inflation expectations from the Michigan Survey of Consumers (MSC) are used at the aggregate level. Although there are various proxies of inflation expectations captured by financial variables such as the yield curve or an inflation-linked bond, I adhere to the survey expectations for the following reasons: first, the information derived from financial variables only represents the financial market participants' opinions. Second, survey data contains respondents' explicit opinions on future inflation, and thus, seems to better represent agents' expectations than the processed data for implied expectations. In addition, The inflation target is usually set in consideration of the monetary policy horizon, which is, generally longer than a year by the central bank. Hence, 5-year inflation expectations are more appropriate than 1-year inflation expectations to measure target credibility. For actual inflation and short-term inflation expectations in the auxiliary estimation in Section 3.2.2, the month-to-month increase rate of the consumer price index and 1-year inflation expectations from MSC are used.

The sample period for the analysis is from Jan. 1997 to Jun. 2019. This is because the implicit inflation target was stabilized in the US only after the mid-1990s, according

[4]This assumption is also helpful to reduce the number of parameters to be estimated. For example, if $N = 3$, the number of transition probability to be estimated is 6 without the restriction, but is 4 with the restriction.

to the estimates by Ireland (2007) and Coibion and Gorodnichenko (2011).[5] Leigh (2005) also suggests that the time-varying target approaches 2% only after the late-1990s.

3.2 Results

3.2.1 Estimation Results

Table 1 reports the estimation results for the inflation expectations model in (4). The model is estimated under three different categories by the number of credibility regimes. Model (1) is under the assumption without regime-switching. Model (2) and (3) are based on 2-state regime-switching. Lastly, Model (4) and (5) assume three states of the credibility level. For the estimation, I consider the case with the lag-order $p = 1$ to make the law of motion for expectations as simple as possible. Considering the agents' limited memory, it is likely that agents rely only on the last period.

First of all, in regard to transition probabilities, p_{ii} are all estimated to be close to unity in both cases of $N = 2$ and $N = 3$. This implies that one regime tends to be maintained for a substantial period of time. On the other hand, p_{21} amounts to 0.06 and 0.08 in Model (4) and (5), respectively, under $N = 3$. The probability p_{22} is lower than p_{11} or p_{33} in this case. This is because Regime 1 and Regime 3 can switch only to Regime 2, whereas Regime 2 can move to both Regime 1 and Regime 3. Hence, the probability that Regime 2 is maintained in the next period is accordingly lower than p_{11} or p_{33}.

In terms of the long-run trend of inflation expectations $\bar{\pi}$, which represents the agent's perceived target, it is estimated at approximately 2.8% in all cases. This figure is higher than the 2% of the implicit target level, commonly referred to in the literature. Under $N = 1$, $\bar{\pi}$ is slightly lower than the other models, but the difference seems negligible.

For the variance of the error term, all the estimates mostly lie between 0.1 and 0.15. $\sigma_{\varepsilon,1}$ in the high credibility regime is 0.1, which is lower than 0.13 in the low regime under $N = 2$. This indicates that high credibility accompanies more stable expectations. Furthermore, Model (5) demonstrates that $\sigma_{\varepsilon,1}$ and $\sigma_{\varepsilon,2}$ are close to each other, while $\sigma_{\varepsilon,3}$ is higher than other regimes. This result indicates that the volatility of inflation expectations becomes particularly large when central bank credibility is in the lowest regime.

Last but most importantly, the parameter of central bank credibility γ_s reveals substantial differences depending on the credibility regime. Under $N = 2$, γ_1 in the high credibility regime amounts to 99.2, which is significantly higher than the 2.17 of the model without regime-switching. In contrast, the parameter γ_2 is estimated at 1.4, which is much smaller than γ_1. This implies that there exists a substantial gap in the credibility level between the credibility regimes. Under $N = 3$, the credibility level γ_1 in the higher

[5] Since the inflation target is assumed to be time-constant in this paper, including the 1980s' and the 1990s' data can cause a bias in the estimation.

regime amounts to from 110 to 120, even higher than the case with $N = 2$. γ_2, in the middle regime, is approximately 5.0, which is significantly lower than the high regime. γ_3 for the low credibility regime remains approximately 1.1. These results strongly suggest that there exit substantial changes in the mean-reverting properties of inflation expectations over the sample period.

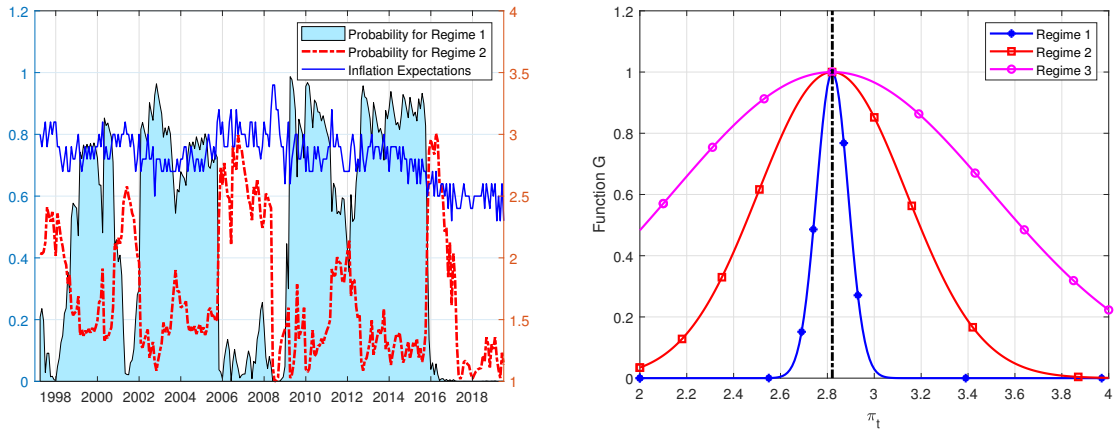
Table 1: Estimation of the Regime-Switching ESTAR Model

	$N=1$	$N=2$		$N=3$	
	(1)	(2)	(3)	(4)	(5)
p_{11}		0.971***	0.973***	0.961***	0.956***
		(0.016)	(0.015)	(0.025)	(0.032)
p_{21}				0.062	0.083
				(0.043)	(0.080)
p_{22}		0.975***	0.974***	0.896***	0.872***
		(0.016)	(0.016)	(0.065)	(0.105)
p_{33}				0.963***	0.971***
				(0.034)	(0.028)
$\bar{\pi}$	2.761***	2.819***	2.821***	2.821***	2.819***
	(0.029)	(0.011)	(0.010)	(0.012)	(0.011)
γ_1	2.168***	99.227**	96.668**	109.982*	120.434*
	(0.516)	(44.301)	(38.574)	(57.631)	(65.836)
γ_2		1.426***	1.422***	5.001**	5.461**
		(0.362)	(0.402)	(2.177)	(2.497)
γ_3				1.080***	1.204***
				(0.361)	(0.481)
$\sigma_{\varepsilon 1}$	0.135***	0.120***	0.106***	0.118***	0.106***
	(0.006)	(0.005)	(0.007)	(0.005)	(0.008)
$\sigma_{\varepsilon 2}$			0.134***		0.109***
			(0.009)		(0.025)
$\sigma_{\varepsilon 3}$					0.143***
					(0.013)
$\ln L$	156.39	175.48	178.63	176.07	179.79
AIC	-306.78	-338.95	-343.26	-334.15	-337.59
BIC	-296.01	-317.41	-318.13	-301.83	-298.09

Notes: Models are estimated using maximum likelihood estimation. *, **, and *** indicate significance at the 10%-, 5%-, and 1%-level, respectively. AIC $= -2\ln L + 2p$, BIC $= -2\ln L + p\ln n$. $\ln L$, p and n refer to the log-likelihood, number of parameters and number of observations respectively. The numbers in parentheses refer to standard errors.

The left panel of Figure 1 demonstrates the identified probability of each regime. As illustrated, the high credibility regime ranges from 1999–2006, and from 2009–2016. The mid-credibility regime intermittently appears in 2001, 2006–2007, and 2016–2017. Lastly, the low credibility regime appears in 2008 and 2017–2019. As indicated, the movement of recent inflation expectations is clearly differentiated from other periods. Long-term inflation expectations have declined since 2017 and have not recovered their original level. Agents might believe that the central bank will not attain the implicit inflation target at least within the expectation horizon. Furthermore, their beliefs seem to become stronger. The right panel of Figure 1 illustrates the persistence coefficient $G(\pi_{t-1};\gamma;\bar{\pi})$ under the

estimated γ_s. Comparing the persistence at $\pi_t^e = 2.5$, which is the average level of the recent period, the coefficient is close to zero under $\gamma_s = 110$ in the high regime. In contrast, it is 0.6 under $\gamma_s = 5$ in the mid-regime and 0.9 under $\gamma_s = 1$ in the low-credibility regime. This result indicates that, under low credibility, it takes a much longer time to return to the target level.



(a) State-probability

(b) $G(\pi_{t-1}; \gamma_s; \bar{\pi})$ under $N = 3$

Notes: In the left panel, the blue area denotes the identified state probability for the high credibility regime. The red dotted line represents Regime 2, and Regime 3 is not explicitly illustrated here. In the right panel, the black dotted line is the estimated implicit target level of inflation expectations.

Figure 1: Estimated State Probability and $G(\pi^e_{t-1|t+h-1}; \gamma; \bar{\pi})$

3.2.2 Changes in Credibility

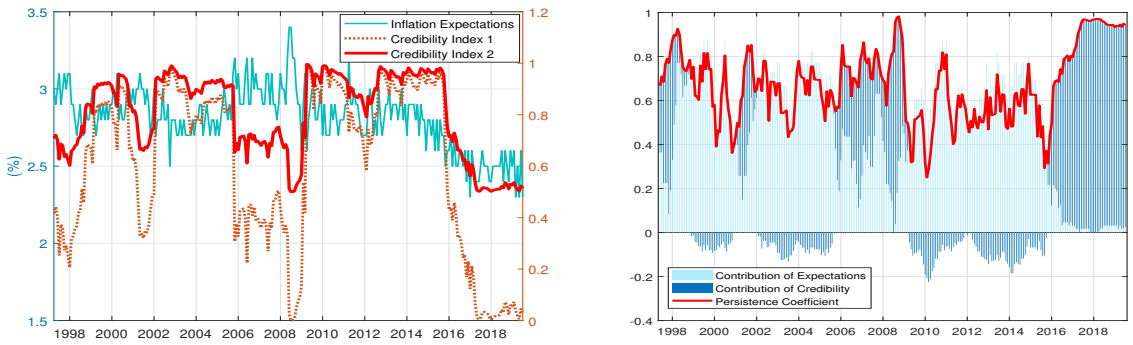
Now, I produce the credibility index by giving a score on each credibility regime identified in Section 3.2.1. Among the models estimated, I select Model (4) for the credibility index. Although Model (2) and (3) under $N = 2$ are slightly better at matching data in terms of information criteria, the model with $N = 3$ is used because it is required to assume more regimes to produce a smooth time-varying index.[6] Following (6), two cases are considered: $Sc_1 = 1.0$, $Sc_2 = 0.5$ and $Sc_3 = 0$ for the first case, and $Sc_1 = 1.0$, $Sc_2 = 0.75$ and $Sc_3 = 0.5$ for the second case.

The left panel of Figure 2 reports the credibility index over the sample period. As presented, central bank credibility begins at a low level in 1997–1998. It maintains a high level up to mid-2000, and then declines again from 2005–2008. The credibility, in particular, reaches the lowest level in 2008 before the financial crisis. It then fully recovers

[6]Appendix C provides the credibility index under $N = 2$. The result reveals that the index is relatively lower than that under $N = 3$, between 2006 and 2008, and 2016 and 2017. However, in general, the indexes show a similar feature.

and records the highest level between 2009 and 2015. However, it begins to decrease again in 2016. Since then, the credibility remains at its lowest level until mid-2019. The low credibility in the recent period is similar to 2008. However, there are two different points worth noting. First, in 2008, undermined credibility is accompanied by an upward deviation of inflation expectations, while it comes along with a downward deviation in the recent period. Second, the credibility level recovers soon after 2009 during the global financial crisis. On the contrary, the recent low credibility regime lasts for several years with inflation expectations remaining at the lowest level.

The right panel of Figure 2 illustrates the time-varying persistence coefficient from the estimated function $G(\pi_{t-1};\gamma;\bar{\pi})$. In line with the previous results, the persistence of inflation expectations substantially increases from 2016 and maintains its high level until 2019. In order to examine where the changes in the coefficient arise, contribution rates of expectations and credibility level for the persistent coefficient are calculated by $G(\pi_{t-1};\gamma_s;\bar{\pi})-G(\pi_{t-1};\bar{\gamma}_t;\bar{\pi})$, where $\bar{\gamma}_t = \sum_{j=1}^{3} \Pr[S_t = j|\psi_t]\gamma_j$. The resulting contribution rates suggest that the recent increase in persistence is primarily due to the undermined central bank credibility.



(a) Credibility Index

(b) Persistence Coefficient

Notes: In the left panel, Credibility Index 1 denotes the index with the scores 1.0, 0.5, and 0.0 for Regime 1, 2, and 3, respectively. Credibility Index 2 uses 1.0, 0.75, and 0.5, respectively.

Figure 2: Estimated Credibility Index and Persistence Coefficient

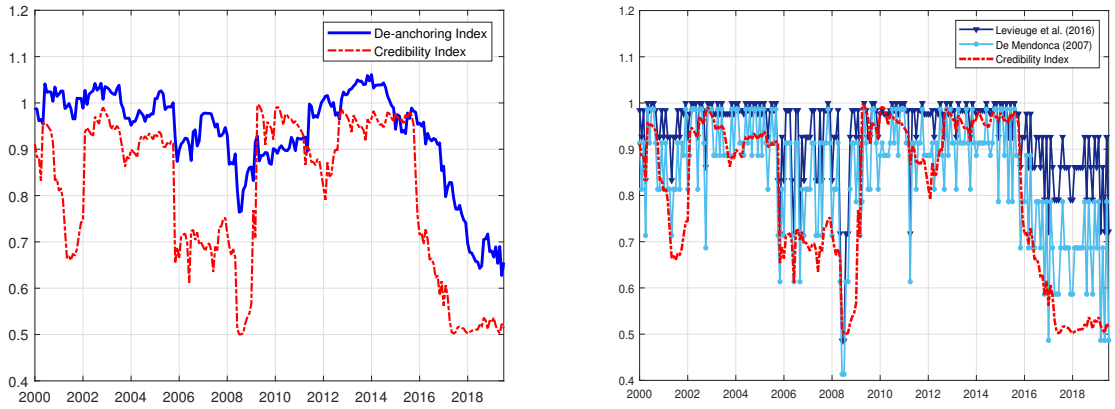
4 Comparison with Other Indicators

4.1 De-anchoring Index

First of all, I estimate the de-anchoring index of inflation expectations proposed by Strohsal, Melnick, and Nautz (2016) (see Appendix A). In this model, the long-term

inflation expectations are determined by an inflation target, current actual inflation, and the short-term inflation expectations. I estimate the time-varying coefficients on the actual inflation and short-term expectations, which denote the extent to which short-term inflation expectations and actual inflation affect determining long-term expectations.

The left panel of Figure 3 illustrates the identified de-anchoring index.[7] In general, the de-anchoring index is similar to the credibility index in terms of the direction. They are particularly close to each other in recent years, in that both significantly declines since 2016. However, they differ, in particular, between 2006–2008. The credibility index largely declines in 2008, whereas the de-anchoring index does not deviate from the average level as much as the recent period. Notably, as presented in Figure 4 in Appendix B, recent de-anchoring is primarily led by coefficient θ_{1t}, as long-term expectations and actual inflation are coupled. This differs from 2008, in which the de-anchoring is mostly caused by coefficient θ_2, short-term inflation expectations.



(a) De-anchoring Index (b) Distance between Expectations and Target

Notes: The credibility index is based on the scores 1.0, 0.5, and 0.0 for Regime 1, 2, and 3, respectively. In the right panel, the index by Levieuge, Lucotte, and Ringuedé (2016) is calculated with $\phi = 2.0$.

Figure 3: Comparison with Other Indicators

4.2 Distance from Inflation Target

As the most commonly used index to measure central bank credibility, the distance between inflation expectations and the target level is considered. Among a large volume of measures, I select De Mendonça (2007) and Levieuge, Lucotte, and Ringuedé (2016), who consider the downward deviation of expectations to be a deterioration of credibility.[8] The

[7] The estimation results and the identified θ_{1t} and θ_{2t} are provided in Appendix B.

[8] Some of the measures including Cecchetti and Krause (2002) consider the case with $\pi_t^e < \bar{\pi}$ to be within the range of full credibility. Under these measures, the credibility in the recent period remains its

difference is that the former treats the upward and downward deviations of expectations equally, whereas the latter treats them asymmetrically. For the first case, since the Fed in the US does not announce the explicit inflation target and the target range, I change the original form of the measure by assuming that the target range is 2%p. Hence, the index is calculated by $C_t = 1 - |\pi^e_{t|t+h} - \bar{\pi}|$. For the second case, (13) is used with $\phi = 2$.[9]

The right panel of Figure (3) presents the results. Three measures are generally close to each other. Specifically, all the indicators suggest the lowest level of credibility in 2008 and the recent period since 2017. However, since Levieuge, Lucotte, and Ringuedé (2016) assume an asymmetry in evaluating credibility, the credibility level does not decrease as much as the index of this paper in the face of the downward deviation of inflation expectations. For this reason, for the recent period, De Mendonça (2007) produces a more similar feature of the credibility to that in this paper. Nevertheless, the indicators measured by the distance from the target produce much noisier estimates of the credibility than does the index identified by the regime-switching ESTAR model. The index in this paper is better at capturing fundamental changes in central bank credibility.

5 Conclusion

This paper proposes a new measure for the central bank's credibility. To this end, central bank credibility is defined as the strength of the mean-reverting properties of long-term inflation expectations. I employ the regime-switching ESTAR model, which specifies mean reversion and regime-switching of the credibility.

The estimation results of the model with US data reveal several interesting findings. First, the degree of central bank credibility substantially changes over the sample period. Second, the credibility level recently shows a record low level, which is similar to 2008. Correspondingly, the persistence of inflation expectations increases, as it is primarily led by undermined credibility. Lastly, the identified credibility index appears similar to other indicators, such as the de-anchoring level of inflation expectations and the distance between expectations and the inflation target. Nonetheless, it seems that the index in this paper captures more fundamental changes in central bank credibility.

highest level, despite a huge downward deviation.

[9]The parameter ϕ determines the degree of asymmetry between the upward and downward deviations of expectations from the target. If the parameter ϕ is lower, the downward deviation of expectations is considered less serious than the upward deviation. Therefore, the credibility level would be somewhat higher for recent years if $\phi > 2$.

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Appendix

A Existing Measures for Central Bank Credibility

In this section, I summarize the related studies, which investigate central bank credibility by focusing on the role of the inflation target.[10] In general, the measures proposed in the literature can be divided into two major categories: a relative weight on the inflation target in agents' inflation expectations and a distance of inflation expectations from the target level.

Bomfin and Rudebusch (2000) suggest a measure for the central bank's target credibility as follows:

$$\pi^e_{t|t+h} = \lambda\bar{\pi}_t + (1-\lambda)\pi_{t-1}, \tag{7}$$

where $\pi^e_{t|t+h}$, $\bar{\pi}_t$, and π_{t-1} denote h-step ahead inflation expectations, the target level of inflation, and actual inflation in the previous period, respectively. λ represents a weight on the inflation target to form expectations. Therefore, the credibility index is defined by $C_t = \lambda$, and thus means the extent to which agents rely on the inflation targets published by central banks to form long-term inflation expectations.

In line with this concept of central bank credibility, Strohsal, Melnick, and Nautz (2016) suggest the time-varying degree of anchoring for inflation expectations as follows:

$$\begin{aligned} \pi^e_{t|t+l} &= \bar{\pi} + \theta_{1t}(\pi_{t-1} - \bar{\pi}) + \theta_{2t}(\pi^e_{t-1|t+s-1} - \bar{\pi}) + v_t \\ v_t &= \rho v_{t-1} + \varepsilon_t, \end{aligned} \tag{8}$$

where $\pi^e_{t|t+l}$ and $\pi^e_{t|t+s}$ denote long-term and short-term inflation expectations, respectively, and $\varepsilon_t \sim iidN(0, \sigma^2_\varepsilon)$. The coefficients θ_{1t} and θ_{1t} are further assumed as follows:

$$\theta_{1t} = \theta_{1t-1} + \epsilon_t, \tag{9}$$

$$\theta_{2t} = \theta_{2t-1} + \eta_t, \tag{10}$$

where $\epsilon_t \sim iidN(0, \sigma^2_\epsilon)$ and $\eta_t \sim iidN(0, \sigma^2_\eta)$. The coefficients denote relative weights on inflation and short-term inflation expectations; they imply the extent to which agents are affected by new shocks. Strongly anchored long-term expectations to the target level are not supposed to be significantly affected by temporary news shocks. In this respect, the

[10] Svensson (1993) firstly proposes the concept of *target credibility*, which measures the extent to which market participants believe future inflation to fall within the target.

degree of de-anchoring is measured by

$$C_t = 1 - \theta_{1t} - \theta_{2t}. \tag{11}$$

Cecchetti and Krause (2002) suggest the following simple measure:

$$C_t = \begin{cases} 1 & \text{if } \pi^e \leq \bar{\pi} \\ 1 - \dfrac{1}{20\% - \bar{\pi}}(\pi^e - \bar{\pi}) & \text{if } \bar{\pi} \leq \pi^e \leq 20\% \\ 0 & \text{if } \pi^e \geq 20\% \end{cases}, \tag{12}$$

where $\bar{\pi}$ denotes an inflation target. The credibility level varies in the range that inflation expectations are above the target and lower than 20%. Due to its simplicity, this type of credibility has been commonly used in the literature and, therefore, a lot of variants are proposed (see De Mendonça, 2007; De Mendonça and de Guimaraes e Souza, 2009).

Levieuge, Lucotte, and Ringuedé (2016) suggest an asymmetric measure for credibility as follows:

$$C_t = \frac{1}{\exp(\phi(\pi^e - \bar{\pi})) - \phi(\pi^e - \bar{\pi})}, \tag{13}$$

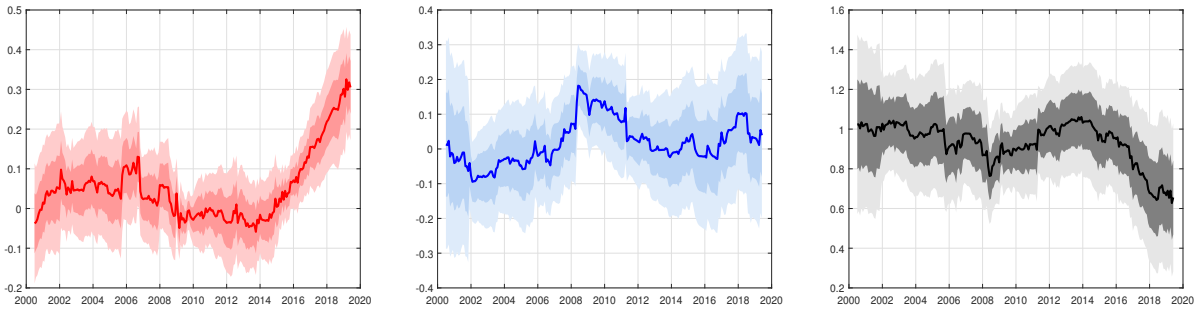
where ϕ denotes the degree of asymmetry. This assumption produces a skewed shape of the function that treats an upward deviation and a downward deviation of inflation expectations from the inflation target differently.

B Estimation of De-anchoring Index

Table 2: Estimation of Time-varying De-anchoring Index

c	ρ	σ_{e1}	σ_{e2}	σ_v
0.009	0.492^{***}	0.016^{***}	0.016^{**}	0.122^{***}
(0.011)	(0.083)	(0.005)	(0.008)	(0.006)

Notes: The model is estimated using maximum likelihood estimation. ** and *** indicate significance at the 5%- and 1%-level, respectively. The numbers in parentheses refer to standard errors.

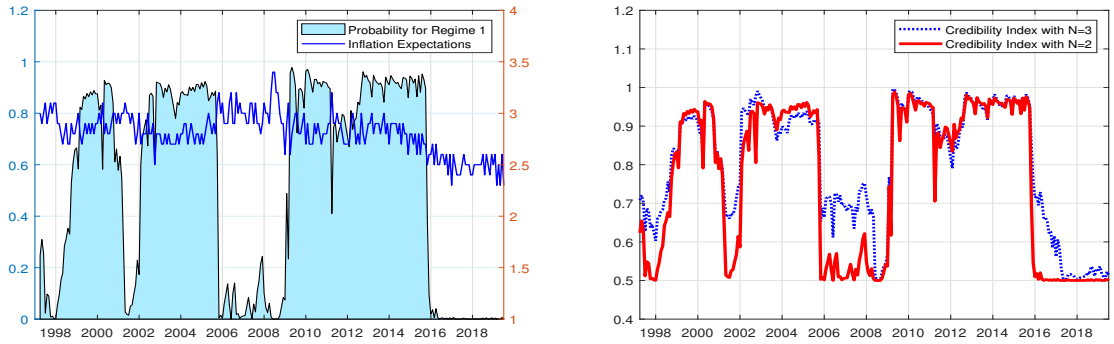


(a) Coefficient θ_{1t} (b) Coefficient θ_{2t} (c) $1–\theta_{1t}–\theta_{2t}$

Notes: The solid lines are the time-varying coefficients identified by Kalman smoother. The shaded areas denote 95% and 90% confidential intervals, respectively.

Figure 4: Estimated Time-varying Coefficients

C Credibility Index under $N = 2$



(a) State Probability (b) Credibility Index

Notes: In the left panel, the credibility index is produced with scores 1.0, 0.5 for Regime 1 and 2, respectively.

Figure 5: State Probability and Credibility Index With $N = 2$

D Non-linearity Test

Following the suggestion of Kapetanios, Shin, and Snell (2003), the t-test is conducted under the null hypothesis that inflation expectations follow a linear non-stationary autoregressive process (i.e. H_0: $\gamma = 0$). To this end, the inflation expectations model in (4)

is rewritten by

$$\Delta\widetilde{\pi}_{t|t+h} = \left[\exp(-\gamma\widetilde{\pi}^2_{t-1|t+h-1}) - 1\right]\widetilde{\pi}_{t-1|t+h-1} + \varepsilon_t \tag{14}$$

where $\varepsilon_t \sim iidN(0, \sigma^2_\varepsilon)$, $\Delta\widetilde{\pi}_{t|t+h} = \pi^e_{t|t+h} - \pi^e_{t-1|t+h-1}$, and $\widetilde{\pi}_{t|t+h} = \pi^e_{t|t+h} - \bar{\pi}$. The coefficient $\left[\exp(-\gamma\widetilde{\pi}^2_{t-1|t+h-1}) - 1\right]$ can be approximated by the 1-st order Taylor expansion around $\gamma = 0$ as follows:

$$\Delta\widetilde{\pi}_{t|t+h} = -\gamma\widetilde{\pi}^3_{t-1|t+h-1} + \varepsilon_t \tag{15}$$

If the t-test does not reject the null hypothesis $\gamma = 0$, the inflation expectations are likely to follow a linear process. Table 3 reports the test results. I test it with the whole sample period, and two sub-sample periods: the periods before and after the global financial crisis. In general, γ is significantly larger than zero. Particularly, the result suggests that non-linearity becomes even stronger in the post-crisis sample period. This result strongly supports a nonlinear inflation expectations model.

Table 3: Estimation results for Non-linearity Test

	All		Pre-crisis		Post-crisis	
$\bar{\pi}$	2.783^{***}	(0.035)	3.005^{***}	(0.044)	2.691^{***}	(0.018)
γ	1.485^{***}	(0.294)	2.594^{***}	(0.859)	3.900^{***}	(0.607)
σ_ε	0.136^{***}	(0.006)	0.127^{***}	(0.008)	0.129^{***}	(0.008)

Notes: Models are estimated using maximum likelihood estimation. Pre-crisis and Post-crisis include the sample periods from 1997–2008 and from 2009–2019, respectively. *** indicates significance at the 1% level. The numbers in parentheses refer to standard errors.