How Much Do Official Price Indexes Tell Us About Inflation?

Jessie Handbury
University of Pennsylvania

Tsutomu Watanabe
University of Tokyo

David Weinstein
Columbia University and NBER

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Outline

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Introduction

- The BOJ uses the Japanese Consumer Price Index (CPI) as an indicator of inflation.
- The CPI is an imperfect measure of cost-of-living inflation:
  - Formula Errors: Formulas used are not theoretically motivated
  - Sampling Errors: Samples may not be representative
- If these errors move around, the CPI is also a "noisy" indicator.
  - Svensson and Woodford [2003, 2004], Aoki [2003]
- Key Question:

What is the relationship between the CPI and true inflation?

This Paper

- We use sales price and quantity data from over 200 Japanese grocery stores to measure cost-of-living inflation from 1988 to 2010 using a superlative Törnqvist index.

- What is the difference between this index and the grocery component of the Japanese CPI?
  - A CPI inflation rate of 1.6 percent corresponds to a true inflation rate of 0, implying that 2 percent inflation target is approximately price stability.
  - CPI errors varied dramatically between 1988 and 2010 with a standard deviation of 0.96 percent.

- What does this noise mean for inflation inference based on the CPI?
  - **The CPI is a good predictor of true inflation when in high inflation regimes but poor when CPI inflation is below 2.4 percent**
    - When the CPI inflation rate is below 2.4 percent, a 1 percentage point increase in the CPI corresponds to a 0.5 percent increase in true inflation

Signal-to-Noise Ratio

- The conditional expectation depends on the signal-to-noise ratio in the CPI.
    - If the signal-to-noise ratio is high, most CPI movements are due to actual inflation changes and one should expect true inflation to move close to one-to-one with the CPI.
    - If the signal-to-noise ratio is low, most CPI movements will be due to noise, and one should not expect true inflation to move around much when the CPI changes.
- While much focus has been on eliminating CPI biases, our paper suggests that the second moment, *i.e.*, the variance of measurement error, also matters a lot for inflation inference.
    - See the surveys on CPI biases by Hausman [2003], Lebow and Rudd [2003], and Reinsdorf and Triplett [2009].

Intuition

- We find high inflation regimes tend to have high inflation volatility.
  - In our data, the variance of inflation increases by 470 percent as inflation rises above 2.4 percent.
  - Consistent with prior work, *e.g.*, Okun [1971], Friedman [1977], Taylor [1981], Ball et al [1988]
- We find CPI noise rises with inflation because lower-level substitution bias rises with inflation.
  - See, *e.g.*, Vining and Elwertowski [1976], Parks [1978], Fischer [1981], Stockton [1988], Cecchetti [1997], Shapiro and Wilcox [1996]
  - We show the variance of this noise does not rise much with inflation.
- **The rapid rise in inflation variance but not in noise means that signal-to-noise ratio is high in high inflation regimes but not in low ones, and the CPI becomes more reliable when inflation is high.**
  - Same intuition for why a bathroom scale for measuring a person's weight but not a mouse's weight.

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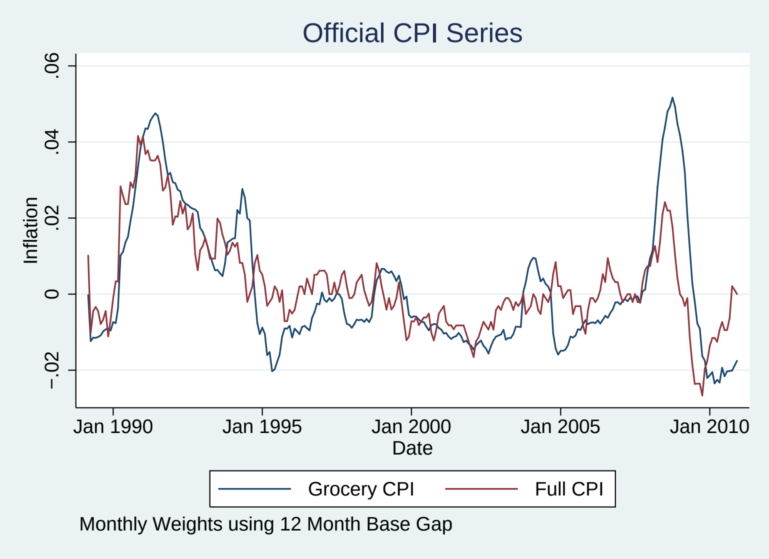
Japanese CPI

- Methodology
  - Japan's CPI conforms to the International Labor Organization (ILO) standard.
  - "Inflation" refers to the inflation rate in a given month relative to the same month in the previous year.
- Sample
  - We work with grocery items, accounting for 17 percent of the CPI.
  - These products have barcodes so price measurement is easy.
    - 30-day price change of a 300 mL can of Coca Cola sold in a certain store is much easier to determine than major expenditure items like imputed rent or recreational services.
    - Thus, our paper may understate the magnitude of the overall CPI error.

Grocery CPI is Quite Similar to Overall CPI



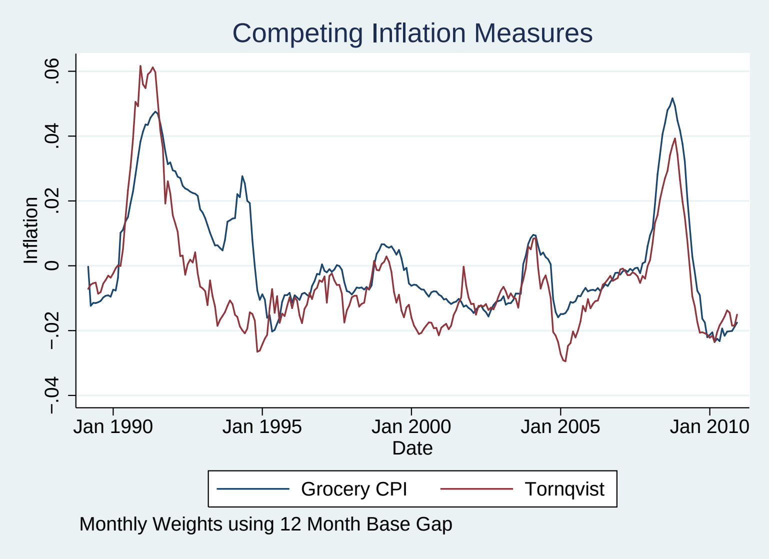
Nikkei Point of Sale Data

- Unit of observation is quantity of a barcoded good purchased in a store on a day, and the sales revenue for that barcode on that day.
- A typical month includes price *and* quantity observations of:
  - Nearly a quarter million different grocery items.
  - Sold at hundreds of grocery and convenience stores throughout Japan.
- Amazing time dimension: 1987–2010
- Grocery CPI is based on about 0.01 billion price observations and quantity observations (upper-level expenditure weights updated every 5 years).
  - Nikkei POS has 4.8 billion observations.

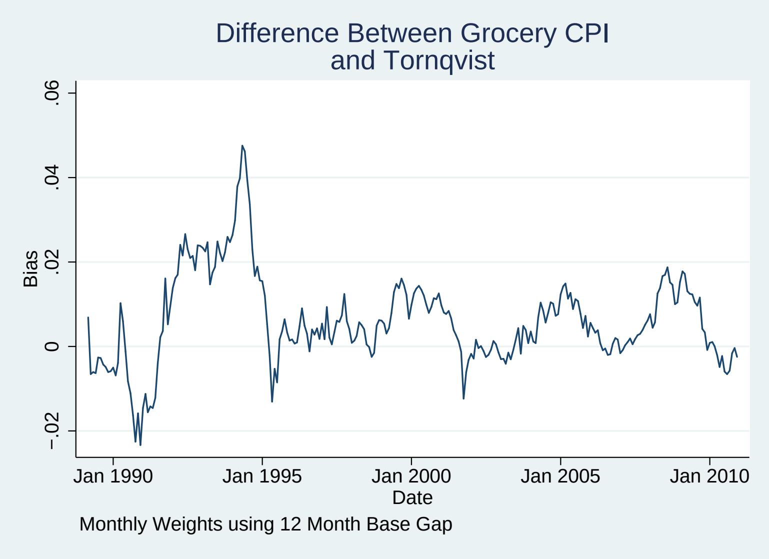
What is our Preferred Measure of Inflation?

- Follow standard price measurement theory and define "true" inflation by the Törnqvist index.
  - The Törnqvist is a second order approximation to *any* twice-differentiable homothetic expenditure function.
  - As close as we can come to computing an exact inflation index without actually specifying preferences.

Törnqvist vs. CPI



CPI error is not constant but flying around



Bias Statistics

Index Bias	$\pi^{\text{CPI}} - \pi^{T}$
Annualized Total Bias	0.625
Standard Deviation of Bias	0.961
Annualized Total Bias (Post-93)	0.762
Standard Deviation of Bias (Post-93)	0.763

- The mean bias is 0.62 percent, but the standard deviation of the bias is 0.96 percentage points.
- If the official inflation rate is one percent per year, the 95 percent confidence interval for the true inflation rate is between -1.68 and 2.28 percent. Thus, **a one percent measured inflation rate would not be sufficient information for a central bank to know if the economy is in inflation or deflation.** Similar result is reported by Broda and Weinstein [2010] for US.

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What has the price measurement literature focused on?

- The price measurement literature asks, "how well does the CPI measure the truth?"
  - If we denote CPI inflation by π_t^{CPI}, true inflation by π_t^T, and measurement error by ϕ_t, price measurement papers examine

$$\pi_t^{CPI} = \pi_t^T + \phi_t \tag{1}$$

  - Prior work on price measurement has focused on the link between true and measured inflation by estimating $\pi_t^{CPI} = \pi_t^T + \alpha + \epsilon_t$, where $E\left[\epsilon_t\right] = 0$, and $\phi_t = \alpha + \epsilon_t$.
- But many economists want to know what is the expectation of true inflation conditional on the CPI, i.e. $E\left[\pi_t^T \middle| \pi_t^{CPI}\right]$.

What is the relationship between the truth and the CPI?

- Under some conditions,

$$E\left(\pi_t^T | \pi_t^{CPI}\right) = E\left(\pi_t^T\right) + \frac{Cov\left(\pi_t^T, \pi_t^{CPI}\right)}{Var\left(\pi_t^{CPI}\right)}\left[\pi_t^{CPI} - E\left(\pi_t^{CPI}\right)\right] \tag{2}$$

- We can rewrite equation 2 in terms of a regression coefficient, β, obtained from regressing π_t^T on π_t^{CPI}:

$$\beta \equiv \frac{Cov\left(\pi_t^T, \pi_t^{CPI}\right)}{Var\left(\pi_t^{CPI}\right)} = \frac{Var\left(\pi_t^T\right) + Cov\left(\pi_t^T, \phi_t\right)}{Var\left(\pi_t^T\right) + Var\left(\phi_t\right) + 2Cov\left(\pi_t^T, \phi_t\right)} \tag{3}$$

- If no variance in measurement error, $\beta = 1$, but otherwise one cannot express true inflation as measured inflation plus a constant.

β is smaller than one, and depends on the SNR

- If $Cov\left(\pi_t^T, \phi_t\right) = 0$, $Cov\left(\pi_t^T, \pi_t^{CPI}\right) = Var\left(\pi_t^T\right)$, and

$$\beta = \frac{Var\left(\pi_t^T\right)}{Var\left(\pi_t^T\right) + Var\left(\phi_t\right)} = \frac{Var\left(\pi_t^T\right)/Var\left(\phi_t\right)}{Var\left(\pi_t^T\right)/Var\left(\phi_t\right) + 1} \leq 1 \tag{4}$$

- The $\frac{Var\left(\pi_t^T\right)}{Var\left(\phi_t\right)}$ is the signal-to-noise ratio.
- If the CPI Noise is classical β will vary with $Var\left(\pi_t^T\right)$.

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Introduction

Data and Index Comparison

Simple Inference Theory

Results
- Non-linear relationship between true inflation and the CPI
- Microstructure behind the non-linearity

Extensions
- Are the results due to dataset differences?
- Are other price index methodologies superior?

Conclusion

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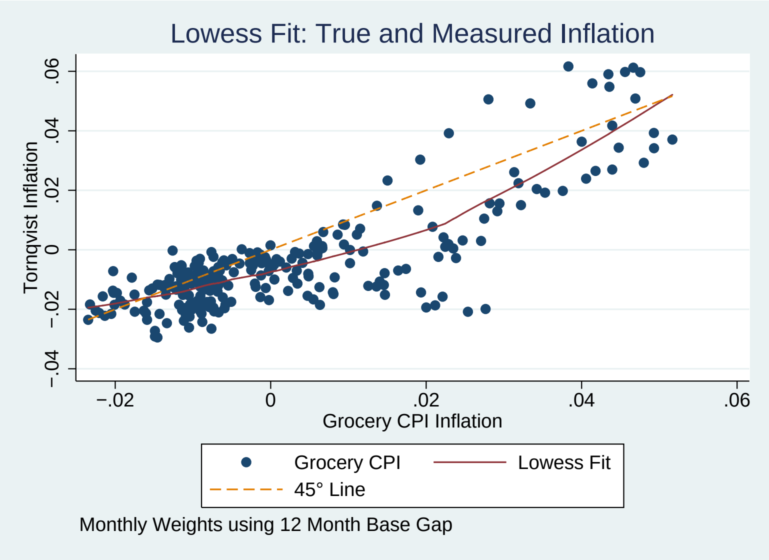
Plotting the Data: Törnqvist vs. CPI Inflation



Formally Testing the Non-Linearity

	Dependent Variable: Törnqvist			
Grocery CPI	0.832***	0.553***		
	(0.148)	(0.151)		
Grocery CPI^2		0.119**		
		(0.049)		
Knot			1%	2.385%
Grocery CPI ($\leq$Knot)			0.398**	0.505***
			(0.189)	(0.165)
Grocery CPI ($>$Knot)			1.257***	1.843***
			(0.241)	(0.446)
Constant	-0.584***	-0.908***	-0.894***	-0.775***
	(0.173)	(0.224)	(0.216)	(0.183)
Observations	262	262	262	262
Adjusted R^2	0.668	0.717	0.713	0.739

Lag-11 Newey West standard errors in parentheses; * (p<0.10), ** (p<0.05), *** (p<0.01)

Implications of Non-Linearity

- How should we interpret a move in Japanese inflation from -1% to 2%?
  - From the symmetric spline regression, we can infer that an inflation rate of -1% per year corresponds to a true inflation rate of -1.2%. Very small bias when inflation is moderately negative. But a rise to 2% increases the magnitude of the bias dramatically, up to 1.8 percentage points.
  - An increase in CPI from -1% to 2% corresponds an increase in true inflation from -1.2% to 0.2%
- However, further increases in CPI inflation imply much sharper rises in true inflation.
  - An increase in inflation from 2% to 5% would correspond to an increase in true inflation from 0.2% to 3.4%. Close to one-to-one relationship.
  - Central banks should pay much more attention to inflationary changes when inflation is high than when it is close to zero. **A central bank that deems a movement in CPI inflation from -1 to 2 percent as the same as a movement from 2 to 5 percent is liable to dramatically overreact to inflation when it is low and and underreact when it is high.**

What Have We Learned So Far?

- Non-linear relationship between true inflation and CPI.
- This relationship crucially depends on the variance of true inflation rising with inflation.
- Assuming CPI errors are uncorrelated with true inflation and/or constant does not change the result.
- Next step: Understand the micro structure of these results.

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Micro-Structure Behind Non-Linearity Result

- For:
  - $\pi_{it} = \mu_t + \nu_{it}$,
  - $\pi_t^T = \sum_{i=1}^n w_{it}\pi_{it}$, and
  - $\pi_t^{CPI} = \pi_t^T + \phi_t = \sum_{i=1}^n (w_{it} + \epsilon_{it})(\pi_{it} + \delta_{it})$
- We have that:

$$\begin{aligned}\beta &= \frac{Var\left(\pi_t^T\right)}{Var\left(\pi_t^T\right) + Var\left(\phi_t\right)} \\ &= \frac{\sigma_{\mu_t}^2 + \sigma_{\nu_t}^2 \sum_{i=1}^n s_{it-1}^2 + n\left[\sigma_{\nu_t^2}^2 \gamma^2/4\right]}{Var\left(\pi_t^T\right) + \underbrace{\sigma_{\delta_t}^2 \sum_{i=1}^n s_{it-1}^2 + n\left[\sigma_{\epsilon_t}^2\sigma_{\nu_t}^2 + \sigma_{\epsilon_t}^2\sigma_{\delta_t}^2 + \frac{\gamma^2}{4}\left(\sigma_{\delta_t}^2\sigma_{\nu_t}^2\right)\right]}_{\text{“CPI Noise”}>0}}\end{aligned}$$

Decomposing β into Micro-Components

	Full Sample	Ratio in High vs. Low Inflation Samples		
		1% Knot	2% Knot	2.4% Knot
$\beta(\pi^{\text{CPI}}, \pi^T)$	0.833	2.56	3.42	3.65
$\sigma^2_{\pi^T}$	3.18e-04	10.41	8.01	5.68
Var of idiosyncratic component: σ^2_ν	3.49	**2.46**	**2.55**	**2.34**
Var of aggregate component: σ^2_μ	0.79	**7.45**	**5.77**	**4.16**
Var of upper-level weighting errors: σ^2_ε	0.32	**1.14**	**1.19**	**1.35**
Var of lower-level measurement errors: σ^2_δ	2.83	**1.57**	**1.60**	**1.62**
Var of "CPI Noise"	0.20	2.36	2.49	2.56
γ_t	-0.68			

Entries for σ^2_ν, σ^2_μ , σ^2_ε, σ^2_δ, and the CPI Noise are divided by the entry for $\sigma^2_{\pi^T}$.

σ^2_ν, σ^2_ϵ, σ^2_δ reports the mean of these variances across items.

Lower vs. Upper-Level Errors

- How much of the variance in the CPI noise would fall if we eliminated upper-level errors by setting $\sigma^2_{\epsilon_t} = 0$?
  - Eliminating upper-level weighting errors would only reduce the variance in CPI noise by 22%.
  - Eliminating lower-level measurement errors, i.e. setting $\sigma^2_{\delta_t} = 0$, would reduce the variance in CPI noise by 88%.
- Major problem in the CPI is the existence of substantial formula biases and other measurement errors at the lower level.

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Extensions

- Do the errors arise because of differences between the Nikkei Data and the CPI Data?
  - No, if we replicate the CPI methodology using Nikkei Data we obtain the same pattern.
- Does the U.S. PCE Deflator Methodology Work Better?
  - Yes, similar knot but the bias is less.
- Is the problem sampling or formula errors?
  - If we replicate the U.S. CPI sampling procedures, but switch to a Törnqvist aggregation structure at the lower level, most of the bias and nonlinearity goes away.
    - Suggests the problem is the formula error at the lower level not the sampling error

Differences Between the CPI, PCE-D, and the Törnqvist

- Sampling
  - J-CPI uses purposive samples of prices and ignores sale prices.
  - PCE deflator (PCE-D) uses random sample of prices and includes sale prices.
- Formula
  - J-CPI: Dutot index nested in a Laspeyres index
  - PCE-D: Jevons index nested in a quasi Törnqvist Index
    - Dutot index is an arithmetic price average; Jevons is a geometric average.
- Weighting
  - Upper-level weights are historic (J-CPI) and based on long-time averages (J-CPI and PCE-D).
  - Neither index employs lower-level weighting.
  - Törnqvist weights change month to month and are correlated with price changes, while CPI and PCE-D lower-level weights are not.

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Replicating CPI Methodology Using Nikkei Data

	Dependent Variable: Törnqvist			
Replicated CPI	0.671***	0.608***		
	(0.095)	(0.061)		
Replicated CPI^2		0.119**		
		(0.049)		
Knot			1%	1.5%
Replicated CPI ($\leq$Knot)			0.434**	0.464***
			(0.097)	(0.090)
Replicated CPI ($>$Knot)			1.075***	1.181***
			(0.094)	(0.124)
Constant	-0.622***	-0.849***	-0.852***	-0.804***
	(0.150)	(0.189)	(0.176)	(0.164)
Observations	113	113	113	113
Adjusted R^2	0.748	0.794	0.810	0.812

Lag-11 Newey West standard errors in parentheses; * (p<0.10), ** (p<0.05), *** (p<0.01)

Note that this series covers 2000–2010

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Replicating US PCE-D Using Nikkei Data

	Dependent Variable: Törnqvist			
Replicated PCE	0.925***	0.789***		
	(0.079)	(0.048)		
Replicated PCE^2		0.064***		
		(0.012)		
Knot			1%	2.251%
Replicated PCE($\leq$Knot)			0.668***	0.725***
			(0.062)	(0.066)
Replicated PCE ($>$Knot)			1.202***	1.454***
			(0.096)	(0.081)
Constant	-0.433***	-0.645***	-0.657***	-0.591***
	(0.088)	(0.095)	(0.099)	(0.091)
Observations	240	240	240	240
Adjusted R^2	0.898	0.923	0.921	0.925

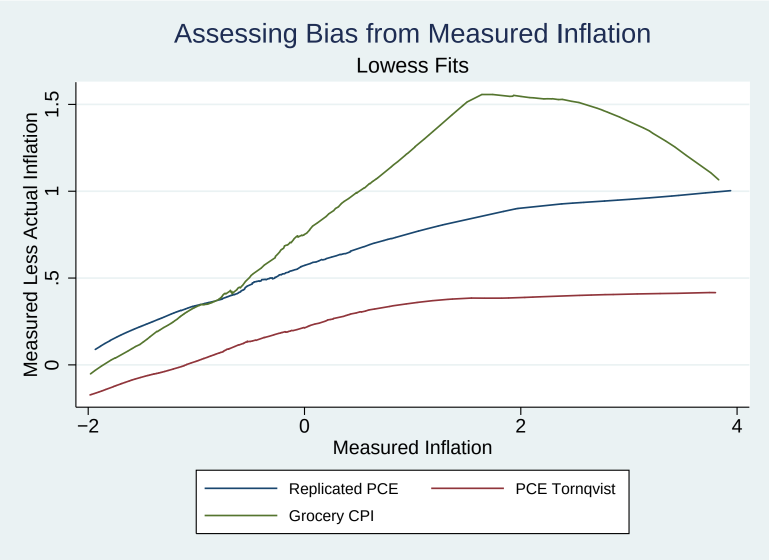
Lag-11 Newey West standard errors in parentheses; * (p<0.10), ** (p<0.05), *** (p<0.01).
This index starts in January 1991 because that is the first date by which we have 2 full calendar years' worth of data.

US PCE-D with Törnqvist Weighting at the Lower Level

	Dependent Variable: Törnqvist			
Törnqvist PCE	0.896***	0.818***		
	(0.047)	(0.021)		
Tornqvist PCE^2		0.042***		
		(0.004)		
Knot			1%	0.611%
Törnqvist PCE($\leq$Knot)			0.710***	0.695***
			(0.034)	(0.032)
Törnqvist PCE ($>$Knot)			1.120***	1.087***
			(0.031)	(0.031)
Constant	-0.061	-0.261***	-0.286***	-0.311***
	(0.061)	(0.050)	(0.056)	(0.053)
Observations	262	262	262	262
Adjusted R^2	0.957	0.975	0.974	0.974

Lag-11 Newey West standard errors in parentheses; * (p<0.10), ** (p<0.05), *** (p<0.01)

Alternative Methodologies Compared



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Conclusion

- We show the informativeness of the CPI rises with inflation.
  - When measured inflation is low (under 2.4 percent), a one percentage point increase in the CPI is only associated with at 0.5 percent increase in true inflation.
  - Outside this range, a one percentage point increase in the CPI is associated with a 2 percent increase in inflation.
- The Japanese CPI bias is not constant but depends on the level of inflation.
  - When CPI inflation is 0, the upward bias is 0.8, but when CPI inflation is 2 percent the bias rises to 1.8 percent!
  - So, a 2 percent CPI inflation target is close to a price stability target when using annual data.
- PCE-D is superior to Japanese CPI but even this methodology is problematic in low inflation regimes.