Macroeconomic Dynamics, **19**, 2015, 791–815. Printed in the United States of America.
doi:10.1017/S1365100513000618

HOW WELL DOES "CORE" INFLATION CAPTURE PERMANENT PRICE CHANGES?

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Does excluding food and energy prices from the Consumer Price Index (CPI) produce a measure that better captures permanent price changes? To examine this question, we decompose CPI inflation and "core" inflation into their permanent and transitory components, using a correlated unobserved-components model. The stationarity of inflation may be time-varying, so we examine the performance of the core measure of inflation separately for periods in which inflation is $I(1)$ and $I(0)$. For a period in which inflation appears to be $I(1)$, we find that core inflation and the permanent component of overall inflation are closely related, but there are some caveats. For a period in which inflation appears to be $I(0)$, we decompose the core and overall price levels and find that the permanent component of the core CPI is much more volatile than the actual core series and that the core excludes volatile permanent shocks to the overall price level.

Keywords: Consumer Price Index, Inflation, Unobserved Components, Food and Energy Prices

Sinclair gratefully acknowledges the generous support of the Institute for International Economic Policy (IIEP) at the Elliott School of International Affairs. Jansen thanks the Private Enterprise Research Center at Texas A&M University for research support. The authors thank Gabriel Lade, Sasha Frankel, Amy Guisinger, and Kavita Patel for excellent research assistance and Fred Joutz and Jun Ma for helpful comments on previous drafts. We also thank John Greenlees and Peter Zadrozny of the Bureau of Labor Statistics for discussions on the construction of the Consumer Price Index. Finally, the authors thank participants in the Western Economic Association Meetings, the Society for Nonlinear Dynamics and Econometrics Annual Meetings, the Workshop on Challenges to Inflation in an Era of Relative Price Shocks at Westfälische Wilhelms University, and the NBER-NSF Time Series Conference and seminar participants at the Federal Reserve Bank of Kansas City, the University of Kansas, Texas A&M, William & Mary, Loyola University Maryland, the University of Regensburg, the University of Pennsylvania, the University of Hawaii, the Bank of Canada, the Bureau of Economic Analysis, the University of Alabama, the University of Melbourne, Victoria University Wellington and the Reserve Bank of New Zealand, Australia National University, the University of New South Wales, Monash University, the University of Queensland, the Reserve Bank of Australia, and the University of Washington Conference in Honor of Charles Nelson for comments on earlier drafts. Address correspondence to: Tara M. Sinclair, Department of Economics, Elliott School of International Affairs, George Washington University, Washington, DC 20052, USA; e-mail: tsinc@gwu.edu.

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https://doi.org/10.1017/S1365100513000618 Published online by Cambridge University Press

1. INTRODUCTION

Economic agents, both in the private sector and in the public policy arena, make important economic decisions in an uncertain macroeconomic environment. Two important variables characterizing that environment are the price level and the inflation rate, both of which agents take into account when making a host of economic decisions. Moreover, agents' decision making is improved if they can decompose observed price movements into their permanent and temporary components. This can be true for either changes in the price level or changes in the inflation rate, depending upon the economic environment.[1]

Currently observable overall or "headline" inflation provides a noisy signal about actual price level movements. One widely used approach to decomposing headline inflation, both for policy makers and for private sector agents, is identification of the "core" inflation rate.[2] Core inflation is constructed to identify and eliminate volatile movements from the overall measure of inflation, most commonly by excluding food and energy prices. It is important to recognize, however, that volatility and impermanence are not necessarily the same thing. It is perfectly possible for permanent movements to be volatile. This possibility has often been assumed away in empirical research. For example, the classic "trend–cycle" decomposition was based solely on the assumption that the underlying (linear) trend was smooth and the cyclical deviations were temporary. It is clear that persistence is no guarantee of low volatility, and transitory components are not needed for high volatility, as is evident even in a simple random walk, a series with no temporary component. Moreover, extensive empirical research demonstrates that permanent movements in a variable can be volatile [see, e.g., Beveridge and Nelson (1981); Nelson and Plosser (1982); Morley et al. (2003); Sinclair (2009); Mitra and Sinclair (2012)]. Such results raise the possibility that core inflation might be smooth for reasons other than the exclusion of the presumed volatile and temporary price series. It also means that the ability of core inflation to capture permanent inflation depends upon its ability to exclude temporary volatile components while not excluding or masking permanent volatile components. It is this empirical question that we address in our paper.

A key issue in evaluating how well core inflation measures permanent price changes is the nature of the stochastic process for headline inflation. If inflation is $I(1)$, then agents face making economic decisions in an environment in which inflation experiences permanent changes. In this environment, agents will likely focus on identifying the permanent component of inflation. However, if inflation is $I(0)$, then the long-run inflation rate is a constant and agents likely shift their focus from identifying the permanent component of inflation to identifying the permanent component of the price level. Agents can be confident that changes in the inflation rate will dissipate, but need to know if changes in the price level are permanent or temporary.

Unfortunately, the evidence on the stationarity of inflation is quite mixed and there is no consensus as to whether it is $I(0)$ or $I(1)$. The results of stationarity

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testing depend upon the time period examined and the test performed. Our own examination of the stationarity of inflation provides mixed results. Over our entire sample, the preponderance of evidence suggests that inflation has a unit root, but the evidence is not unanimous. In contrast, for significant subperiods, particularly during the latter part of our sample, the evidence suggests that inflation is stationary, although again with some mixed results.

For this reason, we examine the performance of the core measure of inflation for periods during which it appears that inflation is $I(1)$ and for periods during which it appears that inflation is $I(0)$. We investigate the features of core and headline inflation, paying particular attention to the permanent and transitory components of the inflation rates constructed from these series. We decompose each inflation series into permanent and transitory components, using a multivariate extension of the correlated unobserved-components model developed by Morley et al. (2003). This model allows the permanent and transitory components to be correlated both within and across the series. One of the key aspects of the correlated unobserved-components model is that it is possible that shocks to the permanent component may be more variable than shocks to the series itself, because of offsetting transitory shocks correlated with the permanent shocks. For a period in which inflation appears to be $I(1)$, we find that core inflation and the permanent component of headline inflation are closely related, although we do find that the permanent component of core inflation is more volatile than core inflation itself. In addition, core inflation does have some drawbacks as a measure of permanent inflation. For example, the evidence suggests that it may overstate the permanent component of headline inflation during periods of relatively high inflation, and understate the permanent component of headline inflation during periods of relatively low inflation.

In contrast, for a period in which inflation appears to be $I(0)$, we find results that raise serious concerns about the performance of the core CPI. We find that the permanent component of core is much more volatile than the actual core series. We also find that actual core CPI is smooth because it excludes the volatile *permanent* shocks to the headline price level, not because it excludes volatile temporary movements. Actual core is also smooth because its own permanent shocks are correlated with offsetting transitory shocks.

In the next section of the paper we present the unobserved-components model and discuss its structure. This is followed by the data, the estimation results, and the interpretation of those results.

2. A MULTIVARIATE UNOBSERVED-COMPONENTS MODEL

As mentioned in the preceding, we investigate the characteristics of core inflation to see how well it serves as a measure of permanent inflation. We do this by comparing the properties of core inflation with the properties of the permanent component of headline inflation. One factor that makes such an investigation a challenge is the fact that the permanent component of inflation is not observable. The observed

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inflation rate includes both permanent movements and transitory movements. A mechanism for identifying these unobserved components is required.

We use an unobserved-components model to investigate movements in both core and headline inflation. An unobserved-components model starts by dividing an observable variable (x_{it}) into its unobservable permanent (τ_{it}) and transitory components (c_{it}). A bivariate version of the model is presented in the following, where x_{1t} and x_{2t} represent two different time series. For example, during our entire sample period when inflation is $I(1)$, x_{1t} represents the core inflation rate and x_{2t} represents the headline inflation rate.[3] The structure of the model is illustrated with the observation equation

$$\begin{bmatrix} x_{1t} \\ x_{2t} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \tau_{1t} \\ \tau_{2t} \\ c_{1t} \\ c_{2t} \\ c_{1t-1} \\ c_{2t-1} \end{bmatrix}. \tag{1}$$

The stochastic trend component, τ_{it}, is a random walk with drift, and the transitory component is modeled as a stationary AR(2) process.[4] The specification of these components is contained in the state equation

$$\begin{bmatrix} \tau_{1t} \\ \tau_{2t} \\ c_{1t} \\ c_{2t} \\ c_{1t-1} \\ c_{2t-1} \end{bmatrix} = \begin{bmatrix} \mu_1 \\ \mu_2 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & \phi_{11} & 0 & \phi_{21} & 0 \\ 0 & 0 & 0 & \phi_{12} & 0 & \phi_{22} \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \tau_{1t-1} \\ \tau_{2t-1} \\ c_{1t-1} \\ c_{2t-1} \\ c_{1t-2} \\ c_{2t-2} \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \eta_{1t} \\ \eta_{2t} \\ \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}. \tag{2}$$

Finally, the model not only permits estimation of the permanent and transitory portions of each variable but also permits correlation between the innovations in the two components, following Sinclair's (2009) multivariate extension of Morley et al. (2003). The variance–covariance matrix is thus

$$E\left(\begin{bmatrix} \eta_{1t} \\ \eta_{2t} \\ \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix} \begin{bmatrix} \eta_{1t} & \eta_{2t} & \varepsilon_{1t} & \varepsilon_{2t} \end{bmatrix} \right) = \begin{bmatrix} \sigma^2_{\eta_1} & \sigma_{\eta_1\eta_2} & \sigma_{\eta_1\varepsilon_1} & \sigma_{\eta_1\varepsilon_2} \\ \sigma_{\eta_1\eta_2} & \sigma^2_{\eta_2} & \sigma_{\eta_2\varepsilon_1} & \sigma_{\eta_2\varepsilon_2} \\ \sigma_{\eta_1\varepsilon_1} & \sigma_{\eta_2\varepsilon_1} & \sigma^2_{\varepsilon_1} & \sigma_{\varepsilon_1\varepsilon_2} \\ \sigma_{\eta_1\varepsilon_2} & \sigma_{\eta_2\varepsilon_2} & \sigma_{\varepsilon_1\varepsilon_2} & \sigma^2_{\varepsilon_2} \end{bmatrix}. \tag{3}$$

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Estimation of the model includes estimation of correlations among the permanent and transitory innovations in both variables, where we assume the innovations are jointly normally distributed. We apply the Kalman filter in maximum likelihood estimation of the parameters using prediction error decomposition and in estimation of the permanent and transitory components.

3. THE DATA

We estimate the unobserved-components model for monthly U.S. CPI data (consumer price index for all urban consumers). We estimate a series of bivariate models involving three different series (all seasonally adjusted): (1) Headline CPI, (2) All Items Less Food and Energy (or Core) CPI, and (3) Combined Food and Energy CPI. The sample starts in January of 1983 and ends in December of 2012. Our data begin in 1983 for two reasons. First, we avoid the definitional change regarding shelter in the CPI. Before 1983, mortgage interest rates were included in the CPI as a part of homeowner's costs, whereas since 1983, a rental equivalence measure has been used [see Smith (2005)]. Second, the 1983 start date also allows us to avoid issues of different monetary policy regimes as discussed in Murray et al. (2008).[5] Finally, because we calculate inflation as the year-over-year change in the price index, the actual estimation period begins in 1984.

Figure 1 presents the inflation rates for the core and headline series (measured as the log differences of the year-over-year values for the index).[6] This plot of the inflation rates immediately reveals the appeal of core inflation as a measure of "long-run" inflation. Core inflation is much smoother than headline inflation because it excludes the variation that is present in food and energy inflation. However, this simple comparison potentially overstates the case for the use of core inflation, because it fails to focus on the true permanent or "long-run" component of inflation.

4. TESTING FOR STATIONARITY AND COINTEGRATION OF INFLATION RATES

Before going further, it is important to determine whether the model should be estimated for the inflation rates or the (log) price levels. The unobserved-components model specifies a random walk for the permanent component, so it is not appropriate for a stationary series. If the inflation processes are $I(1)$, then it is appropriate to construct an unobserved-components model for inflation rates.[7] On the other hand, if the inflation processes are $I(0)$, then the unobserved-components model should be constructed for price levels, which themselves are $I(1)$.

Moreover, if the inflation processes are $I(1)$, then a determination must be made of whether or not the included inflation rates are cointegrated [Kiley (2008)]. If they are, then a common trend unobserved-components model could result in more efficient estimation of the model parameters and the common trend. If they are not cointegrated, then an unrestricted unobserved-components model that allows for

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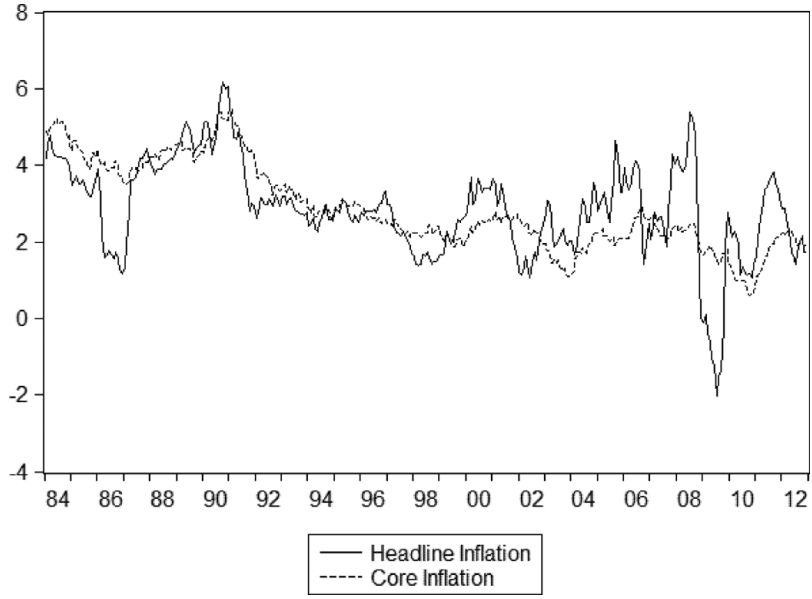


FIGURE 1. CPI inflation series: headline and core.

different long-run trends in the included inflation rates should be used. Because of the importance of this specification choice for determining results, we carefully consider the various possibilities.

There is debate about whether or not U.S. inflation is stationary. For example, Pivetta and Reis (2007) find that data from 1965 to 2001 do not reject a unit root in inflation and argue that inflation persistence has remained high and relatively unchanged over their sample. Similarly, Stock and Watson (2007) find a unit root in inflation for both 1970–1983 and 1984–2004. On the other hand, Leybourne et al. (2003) and Murray et al. (2008) find that inflation is stationary starting in the early 1980s. Kang et al. (2009) find that U.S. inflation experienced a sudden decrease in persistence in the early 1980s after experiencing an increase in persistence at the beginning of the 1970s.[8]

We follow this literature by testing for stationarity. We employ a battery of stationarity tests including the KPSS test, the augmented Dickey–Fuller test, the Phillips–Peron test, and the MPS test put forward by Morley et al. (2012).[9]

The results are presented in Table 1. We find mixed evidence on the stationarity of inflation. For the period 1984–2012, the KPSS tests indicates that both core inflation and headline inflation are stationary, as in neither case does the test statistic indicate a rejection of the null hypothesis of stationarity. The more powerful MPS test statistics, in contrast, indicate rejection of stationarity for both series. Finally, both the ADF and Phillips–Peron tests indicate that headline inflation is stationary, whereas core inflation is nonstationary. The evidence is fairly strong for a unit root for core inflation. Although the results for headline inflation are mixed, the results

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TABLE 1. Stationarity and cointegration test results

Stationarity tests: Year-on-year changes				
Inflation series	KPSS test statistic	MPS test statistic	ADF test statistic	PP test statistic
		Sample 1984–2012		
CPI	0.07	1.61	−3.39	−4.01
	($p = 0.60$)	($p = 0.06$)	($p = 0.05$)	($p = 0.01$)
	Supports $I(0)$	Supports $I(1)$	Supports $I(0)$	Supports $I(0)$
Core	0.20	34.73	−1.94	−2.55
	($p = 0.38$)	($p < 0.01$)	($p = 0.63$)	($p = 0.31$)
	Supports $I(0)$	Supports $I(1)$	Supports $I(1)$	Supports $I(1)$
FE	0.041	0.79	−4.74	−4.39
	($p = 0.94$)	($p = 0.07$)	($p < 0.01$)	($p < 0.01$)
	Supports $I(0)$	Supports $I(1)$	Supports $I(0)$	Supports $I(0)$
		Sample 1993–2012		
CPI	0.06	0.64	−2.54	−3.80
	($p = 0.80$)	($p = 0.12$)	($p = 0.31$)	($p = 0.02$)
	Supports $I(0)$	Supports $I(0)$	Supports $I(1)$	Supports $I(0)$
Core	0.08	2.43	−2.60	−2.71
	($p = 0.91$)	($p = 0.26$)	($p = 0.28$)	($p = 0.24$)
	Supports $I(0)$	Supports $I(0)$	Supports $I(1)$	Supports $I(1)$
FE	0.05	0.62	−3.50	−3.96
	($p = 0.84$)	($p = 0.10$)	($p = 0.04$)	($p = 0.01$)
	Supports $I(0)$	Supports $I(0)$	Supports $I(0)$	Supports $I(0)$

Johansen cointegration tests, core inflation, and CPI inflation		
Hypothesized number of cointegrating vectors	Trace test statistic	Conclusion
	Sample 1984–2012	
0	23.17	One cointegrating vector, <1,−1.34>
	($p < 0.01$)	$1.00\ \pi_{\text{core}} - 1.34\ \pi_{CPI} \sim I(0)$
1	1.92	
	($p = 0.17$)	
	Sample 1993–2012	
0	35.83	Two cointegrating vectors; supports
	($p < 0.01$)	conclusion that series are stationary
1	5.36	
	($p = 0.02$)	

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for core inflation and the relationship between core inflation and headline inflation imply that headline inflation is also $I(1)$. In sum, the results justify modeling both core and headline inflation as $I(1)$ over the full sample. We also look at these inflation rates over a more recent period, 1993–2012. This period was chosen because structural break tests on core CPI indicate a drift break in 1993.03.[10] In this more recent period, the KPSS and MPS tests support the inference that both headline and core inflation are stationary. The ADF and Phillips–Peron tests produce more mixed evidence, with the ADF indicating that both inflation series are nonstationary and the Phillips–Peron test indicating that headline inflation is stationary and core inflation is not.

These results lead us to investigate two approaches to modeling inflation with our correlated unobserved-components model. We model inflation for the full period, when the tests indicate it is $I(1)$. We model (log) price levels for the important subperiod for which tests suggest that it may be appropriate to also consider the case where inflation is $I(0)$. Note that the $I(1)$ model was considered over this sample as part of the full sample analysis.

For the period in which both headline inflation and core inflation appear to be $I(1)$, we test if the two series are cointegrated. The Johansen test indicates that they have one cointegrating vector. This raises the possibility that we could estimate a restricted unobserved-components model in which we impose a single long-run component on the two inflation measures. However, because of the importance of such a restriction to the interpretation of the results, we estimate the unobserved-components model for inflation in two ways. First, we estimate an unrestricted unobserved-components model to see if the results support a common long-run component between headline and core inflation. If the two series truly are cointegrated, then an unrestricted model should produce a similar long-run component for both series. Second, we estimate a restricted unobserved-components model with the assumption of a common long-run component in place.

5. MODEL ESTIMATION

As explained in the preceding section, we estimate three unobserved-components models, two for inflation rates and one for the level of prices. We take this approach to provide a broad set of results on the performance of core inflation as a measure of permanent price-level changes. By taking these different approaches, we are ensuring that our results and conclusions are not limited by the results of empirical tests of stationarity and cointegration, which are known to provide conflicting evidence.

5.1. Univariate Analysis

One straightforward method of beginning the examination of permanent inflation is to estimate univariate unobserved-components models for the inflation series. These univariate models are likely misspecified because they do not allow for

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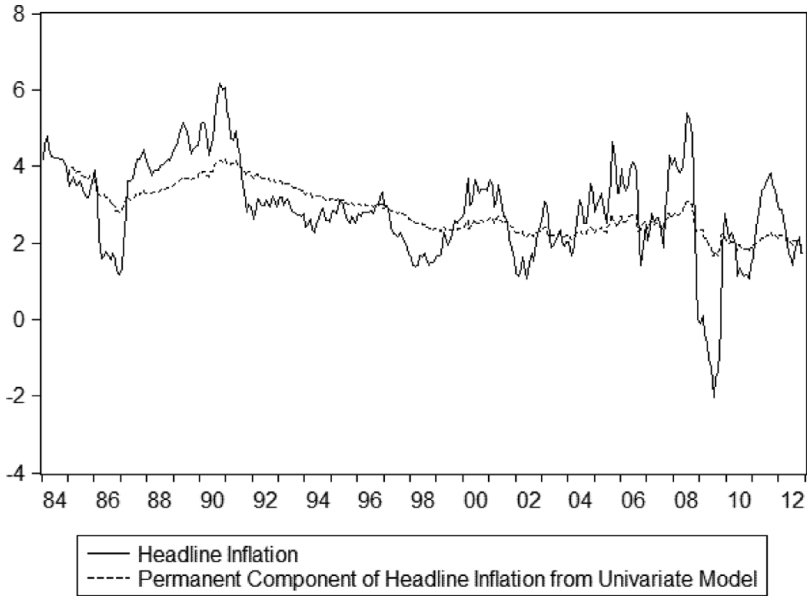


FIGURE 2. Headline inflation and the permanent component of headline inflation from a univariate model.

possible cross-series correlations, but they do provide a useful preliminary method for investigating the permanent behavior of inflation.

For example, Figure 2 presents the univariate permanent component of headline inflation along with the actual series. This shows that the permanent component of headline inflation is much smoother than the actual series and indicates that a closer look at the relationship between core inflation and permanent inflation is required. This point is reinforced by Figure 3, which compares core inflation with the estimated permanent component of headline inflation. This figure shows that core inflation is materially more variable than the permanent component of headline inflation in the univariate model, calling into question the utility of core inflation as a measure of the permanent component or long-run trend in headline inflation. Stated differently, although core inflation may appear smooth relative to overall headline inflation, it does not appear smooth relative to the permanent part of headline inflation. As a result, estimation of appropriate empirical models is needed to make a determination about how well core inflation captures permanent price changes.

5.2. An Unrestricted Unobserved-Components Model for Core and Headline Inflation

The first bivariate model we estimate is the unrestricted unobserved-components model for core inflation and headline inflation. This model allows the two inflation

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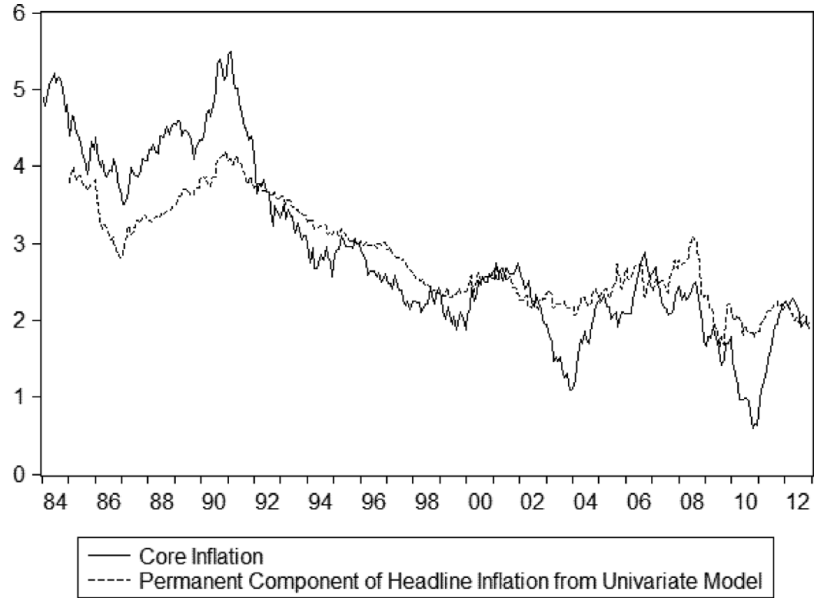


FIGURE 3. Core inflation and the permanent component of headline inflation from a univariate model.

series to have different long-run properties, including different drifts and different sequences of permanent shocks. The resulting parameter estimates are presented in Table 2 and the estimated permanent components are presented in Figure 4. A key finding is that short-run shocks to core inflation are negatively correlated with its long-run shocks, with a high degree of correlation, as the estimated correlation coefficient is –0.936. This allows core inflation to be smoother than its permanent component, as permanent shocks are offset by temporary shocks in the other direction. At the same time, the standard deviation of permanent shocks to core inflation is higher than the standard deviation of permanent shocks to headline (CPI) inflation, 0.167 versus 0.105. Finally, both core and headline inflation rates have negative, but statistically insignificant, drift terms over the period of estimation.

In Figure 4, the estimated permanent component of headline inflation is shown to be considerably smoother than CPI inflation. This occurs despite the estimated negative correlation between the permanent and transitory shocks to CPI inflation because the sizes of the offsetting shocks are not sufficient to cause the actual inflation rate to be smoother than its permanent component. Thus even though the negative correlation allows for the possibility of volatility in permanent shocks, it is possible to have a relatively smooth permanent component with a negative correlation between permanent and transitory shocks. The graph of core inflation and the permanent component of core inflation suggests that core inflation may be a good proxy for the permanent component of core inflation when inflation is

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TABLE 2. Unrestricted bivariate model core inflation and headline inflation

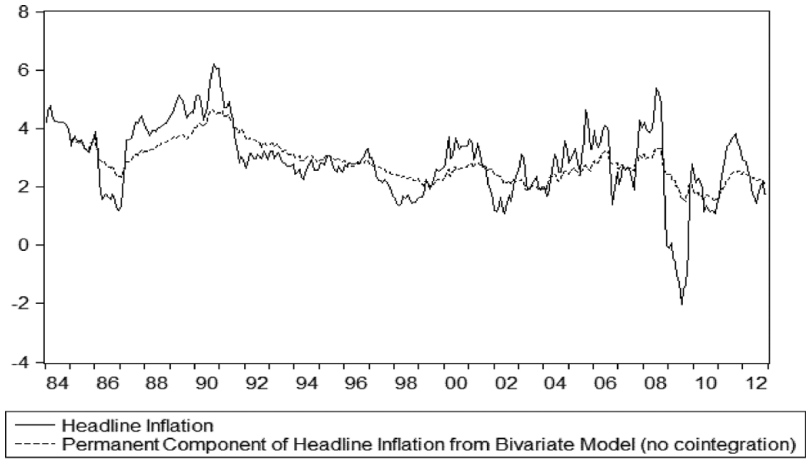
Parameter estimates (1 = core inflation, 2 = headline inflation)		
Parameter	Value	Std. dev.
σ_{η_1}	0.167	0.009
σ_{η_2}	0.105	0.029
σ_{ε_1}	0.047	0.016
σ_{ε_2}	0.416	0.040
μ_1	−0.008	0.009
μ_2	−0.004	0.006
ϕ_{11}	1.553	0.038
ϕ_{21}	−0.719	0.031
ϕ_{12}	1.281	0.055
ϕ_{22}	−0.393	0.055
Log likelihood value	114.718	
Correlations among the permanent and transitory shocks		
	Correlation	Std. dev.
$\rho_{\eta_1\eta_2}$	0.601	0.342
$\rho_{\eta_1\varepsilon_1}$	−0.936	0.036
$\rho_{\eta_1\varepsilon_2}$	−0.019	0.051
$\rho_{\eta_2\varepsilon_1}$	−0.834	0.236
$\rho_{\eta_2\varepsilon_2}$	−0.810	0.225
$\rho_{\varepsilon_1\varepsilon_2}$	0.356	0.110

I(1). This is also suggested by the estimates of the standard deviation of shocks to the temporary part of core inflation, which is 0.047 as compared with the standard deviation of shocks to the permanent part of core inflation, which is 0.167. Shocks to the temporary part of core inflation are an order of magnitude smaller than shocks to the permanent component.

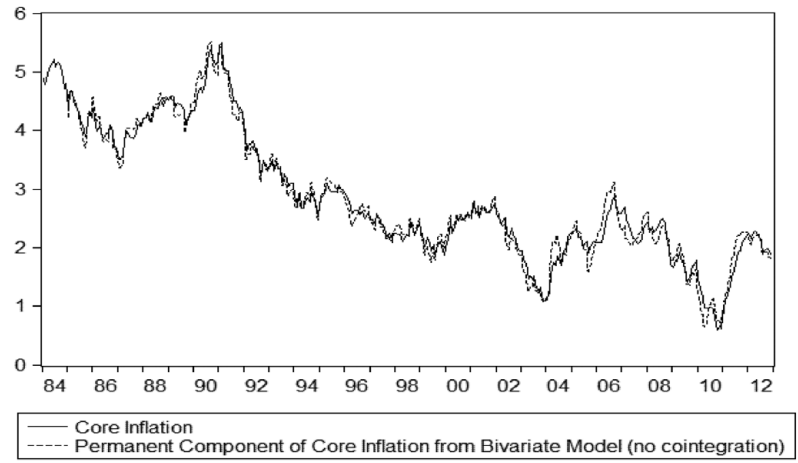
Figure 5 presents the two permanent components together. The two series appear to share a fair amount of comovement in their permanent components, which lends support to the idea of using core inflation as a measure of permanent inflation. However, the permanent core inflation series appears to be more volatile than the permanent component of headline inflation, which reduces its utility. The permanent component of core inflation also may be biased relative to the permanent component of headline inflation. The apparent bias arises from the fact that permanent core inflation is persistently above permanent headline inflation during periods in which the average inflation rate is relatively high and is persistently below permanent headline inflation during period in which inflation is relatively low.

We can gain additional insight into the dynamics of core inflation by examining the short-run component. We first note that both core inflation and headline inflation exhibit a high degree of persistence in their transitory components. The sum of

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Graph of headline inflation: Actual series and permanent component



Graph of core inflation: Actual series and permanent component

FIGURE 4. Permanent components from the unrestricted bivariate model (no cointegration).

the AR coefficients for the short-run core inflation model is 0.834 and the sum of the coefficients for the short-run headline inflation model is 0.888. A good way to investigate the short-run component is to calculate how core inflation would react to a one-standard-deviation permanent shock. Given the large negative correlation between permanent and transitory shocks to core inflation, a positive permanent shock is likely to be accompanied by a largely offsetting negative transitory shock, resulting in little initial increase in actual core inflation at the time of the shock. In subsequent periods, the short-run autoregressive model causes the actual core

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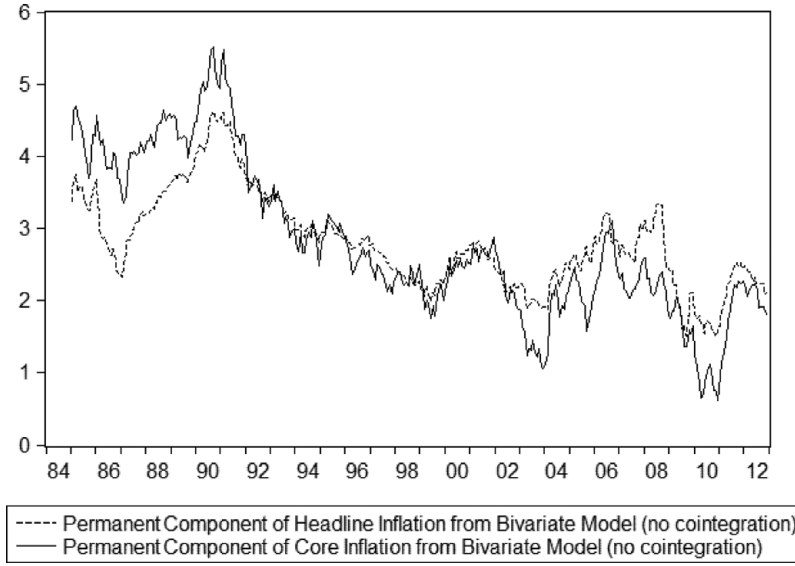


FIGURE 5. Unrestricted bivariate model (no cointegration): permanent components of headline inflation and core inflation.

index to temporarily move in the "wrong" direction before it begins to approach its permanent value. The short-run model, illustrated in Figure 6, indicates that it takes seven to eight months before actual core inflation approaches its long-run value. This is entirely consistent with the slow price adjustment or "inflation stickiness" associated with many items in the core index.[11]

5.3. A Restricted Unobserved-Components Model for Core and Headline Inflation

The unrestricted model identifies the permanent and transitory components of both core inflation and headline inflation for the case in which they are not cointegrated. If they are cointegrated, a restricted unobserved-components model is appropriate [Morley (2007)]. Given the mixed evidence on unit roots and cointegration, we also estimate this restricted unobserved-components model. This model restricts the two inflation series, headline and core, to sharing a single long-run component. The observation equation thus includes only a single stochastic trend for both inflation rates. The model does allow for a scaling parameter, γ, between the two long-run components:

$$\begin{bmatrix} \pi_{1t} \\ \pi_{2t} \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 \\ \gamma & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \tau_t \\ c_{1t} \\ c_{2t} \\ c_{1t-1} \\ c_{2t-1} \end{bmatrix}. \tag{4}$$

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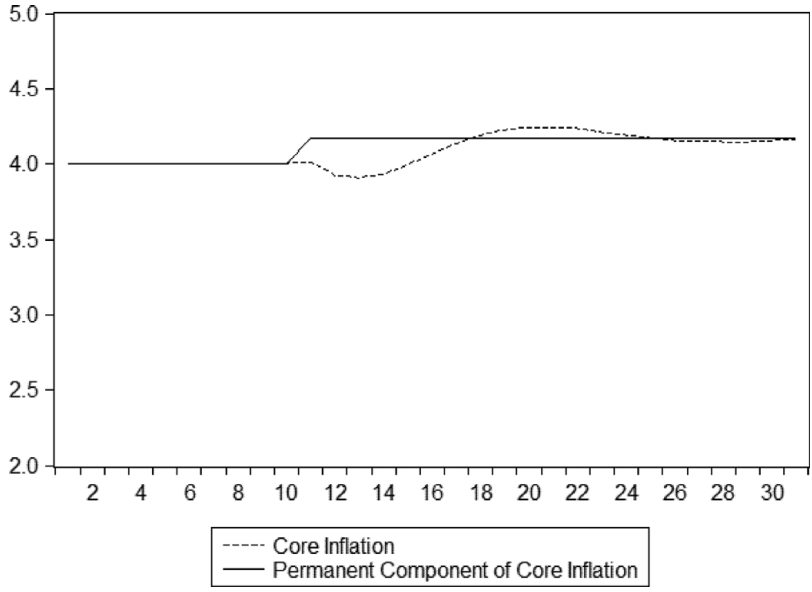


FIGURE 6. Simulated impact of a shock to the permanent component of core inflation on core inflation in the unrestricted bivariate model (no cointegration).

With only one stochastic trend, there is just one long-run shock in the state equation:

$$\begin{bmatrix} \tau_t \\ c_{1t} \\ c_{2t} \\ c_{1t-1} \\ c_{2t-1} \end{bmatrix} = \begin{bmatrix} \mu \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & \phi_{11} & 0 & \phi_{21} & 0 \\ 0 & 0 & \phi_{12} & 0 & \phi_{22} \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \tau_{t-1} \\ c_{1t-1} \\ c_{2t-1} \\ c_{1t-2} \\ c_{2t-2} \end{bmatrix} + \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \eta_t \\ \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix}. \tag{5}$$

The elimination of a second long-run shock also simplifies the variance–covariance matrix:

$$E\left(\begin{bmatrix} \eta_{1t} \\ \varepsilon_{1t} \\ \varepsilon_{2t} \end{bmatrix} [\, \eta_{1t} \quad \varepsilon_{1t} \quad \varepsilon_{2t} \,] \right) = \begin{bmatrix} \sigma_\eta^2 & \sigma_{\eta\varepsilon_1} & \sigma_{\eta\varepsilon_2} \\ \sigma_{\eta\varepsilon_1} & \sigma_{\varepsilon_1}^2 & \sigma_{\varepsilon_1\varepsilon_2} \\ \sigma_{\eta\varepsilon_2} & \sigma_{\varepsilon_1\varepsilon_2} & \sigma_{\varepsilon_2}^2 \end{bmatrix}. \tag{6}$$

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TABLE 3. Restricted bivariate model core inflation and headline inflation

Parameter estimates (1 = core inflation, 2 = headline inflation)		
Parameter	Value	Std. dev.
σ_η^2	0.141	0.014
σ_{ε_1}	0.131	0.032
σ_{ε_2}	0.281	0.020
ϕ_{11}	0.425	0.209
ϕ_{21}	−0.003	0.076
ϕ_{12}	1.431	0.062
ϕ_{22}	−0.520	0.060
γ	0.978	.054
Log likelihood value	100.367	
Correlations among the permanent and transitory shocks		
	Correlation	Std. dev.
$\rho_{\eta\varepsilon_1}$	−0.720	0.144
$\rho_{\eta\varepsilon_2}$	0.309	0.114
$\rho_{\varepsilon_1\varepsilon_2}$	−0.095	0.181

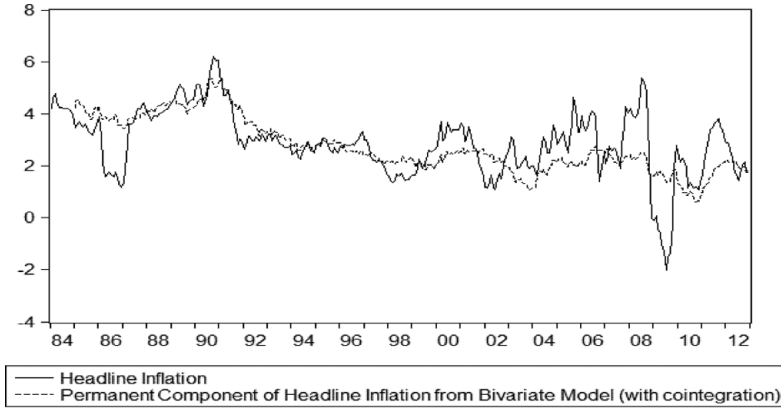
Note: We found that $\mu = 0$, so it is excluded from the final estimates.

The estimated parameters for this restricted model are presented in Table 3 and the permanent components of the model are presented in Figure 7. If core inflation and headline inflation are cointegrated, a single permanent component represents the long-run behavior in both. In this sense, the permanent component of core is also the (possibly scaled) permanent component of headline inflation. Moreover, the actual core inflation rate appears to closely align with the common permanent component of inflation. These results are favorable to the use of core inflation as a measure of long-run inflation.

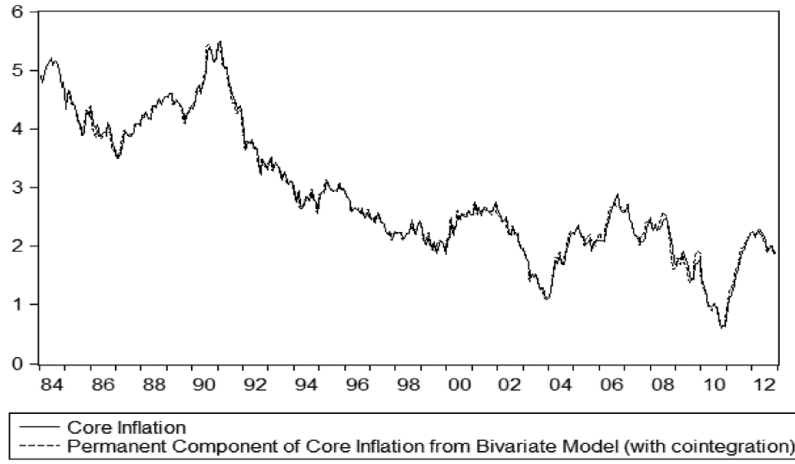
However, even in this case, *actual* core inflation may have drawbacks as a measure of permanent inflation. Table 3 shows that in the restricted model there is again a large negative correlation between permanent and transitory shocks to core inflation, -0.720, suggesting that core inflation may be too smooth a measure of permanent inflation. In contrast, transitory shocks to headline inflation are positively correlated with permanent shocks to inflation and the transitory shocks are slightly negatively correlated across the two series.

This difference is illustrated in Figure 8, which presents the responses in both core inflation and headline inflation to a permanent shock to inflation. The initial response in core inflation is muted, as the negative temporary shock initially offsets the permanent shock. It then takes five months for the actual core inflation rate to adjust to the permanent change. In contrast, headline inflation responds immediately to the long-run shock and, in fact, overshoots the long-run value.

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Graph of headline inflation and permanent component



Graph of core inflation and permanent component

FIGURE 7. Permanent components from the restricted bivariate model (with cointegration).

5.4. An Unrestricted Unobserved-Components Model for Price Levels

The last set of models we estimate are for price levels, not inflation rates. This model is appropriate if inflation is $I(0)$, which we find for the subperiod 1993–2012 as well as other subperiods in the latter part of the sample.[12] When inflation is $I(0)$, permanent inflation is a constant and economic agents will likely focus on identifying permanent price level movements. We thus apply the unobserved-components model to core and headline price levels.

The first model we estimate is similar to the unrestricted bivariate model in inflation rates with the exception that we are modeling the (log) levels of the

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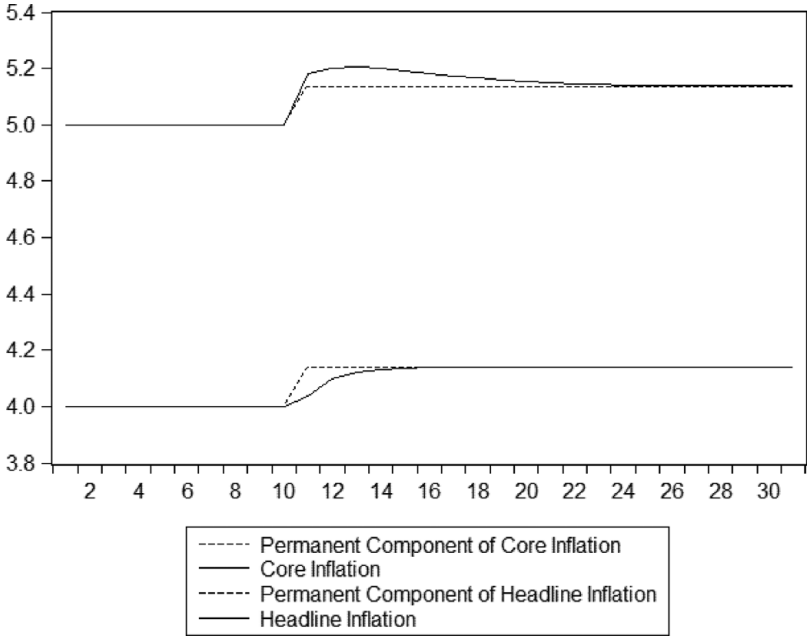


FIGURE 8. Simulated impact of a shock to the permanent component of core inflation on core inflation (bottom) and headline inflation (top) in the restricted bivariate model (with cointegration).

headline CPI and the core CPI. The results of estimating this model are given in Table 4. Similar to the bivariate model for inflation rates, we find that short-run shocks to both series are negatively correlated with their long-run shocks. We also find that the standard deviations of permanent and temporary shocks to core inflation are about the same size, but the standard deviation of permanent shocks to headline CPI is three times the size of the standard deviation of its transitory shocks.

This difference is reflected in the graphs of the permanent and temporary components of both series. Figure 9 presents the permanent component of the core CPI along with its actual value. It shows that the permanent component of core CPI is much more variable than the actual series. The relative smoothness of the actual series reflects the negative correlation between the permanent and transitory shocks along with the fact that the transitory shocks are sizable. That is, transitory shocks not only tend to offset permanent shocks but also are sufficiently large to smooth the actual series.

This is not the case for headline CPI, as shown in Figure 10. Although the permanent and transitory shocks are negatively correlated, the sizes of the offsetting temporary shocks are too small to cause the headline CPI to be smoother than its permanent component. These latter results suggest that the portion of the CPI

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TABLE 4. Unrestricted bivariate model in core and CPI prices

Parameter estimates (1 = core prices, 2 = CPI prices) Sample period 1993–2012		
Parameter	Value	Std. dev.
σ_{η_1}	0.307	0.029
σ_{η_2}	0.350	0.023
σ_{ε_1}	0.319	0.024
σ_{ε_2}	0.104	0.014
μ_1	0.165	0.021
μ_2	0.200	0.023
ϕ_{11}	0.942	0.018
ϕ_{21}	0.023	0.017
ϕ_{12}	−0.262	0.042
ϕ_{22}	−0.275	0.048
Log likelihood value	250.085	
Correlations among the permanent and transitory shocks		
	Correlation	Std. dev.
$\rho_{\eta_1\eta_2}$	0.871	0.053
$\rho_{\eta_1\varepsilon_1}$	−0.971	0.005
$\rho_{\eta_1\varepsilon_2}$	−0.849	0.058
$\rho_{\eta_2\varepsilon_1}$	−0.795	0.039
$\rho_{\eta_2\varepsilon_2}$	−0.987	0.027
$\rho_{\varepsilon_1\varepsilon_2}$	0.806	0.053

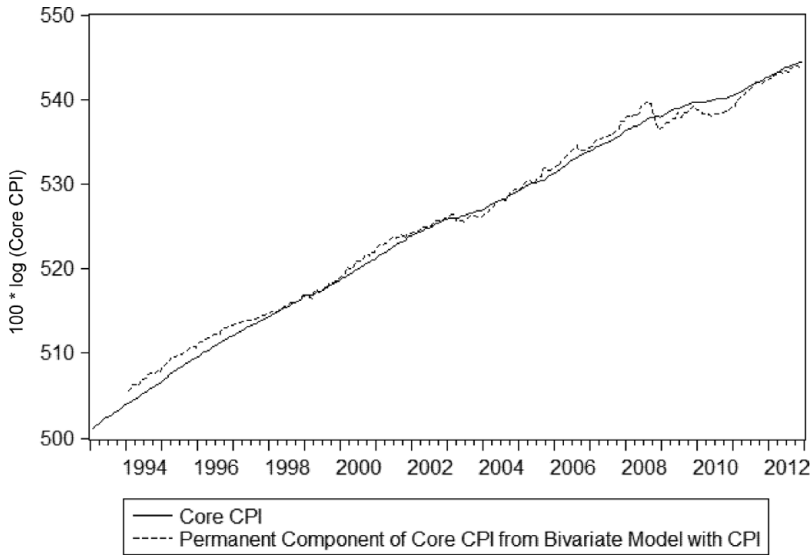


FIGURE 9. Core CPI and the permanent component of core CPI from a bivariate model in core CPI and headline CPI.

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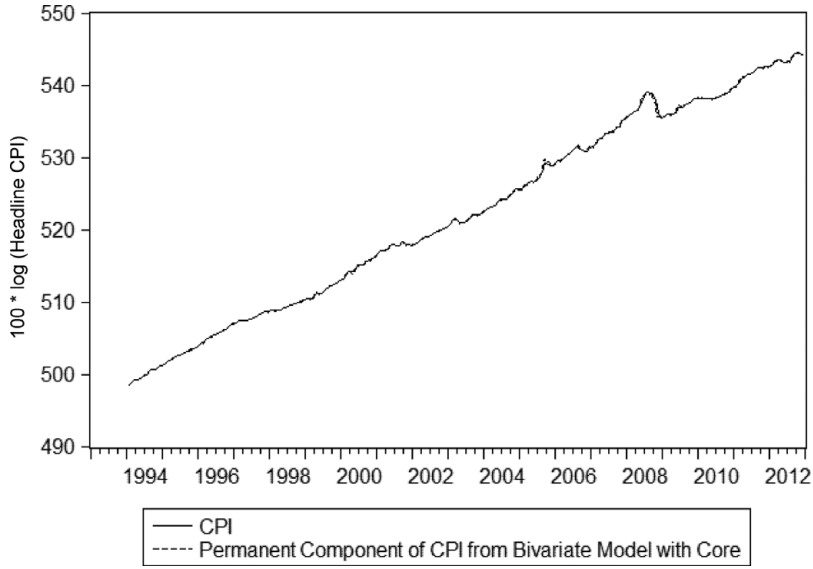


FIGURE 10. Headline CPI and the permanent component of headline CPI from a bivariate model in core CPI and headline CPI.

that is not included in the core CPI—food and energy prices—has a substantial permanent component.

This leads us to investigate an alternative bivariate model, for the core CPI and a food and energy CPI.[13] We estimate an unrestricted model that allows the two price series to have different long-run properties, including both different trends and different sequences of permanent shocks. The estimated parameters for this unrestricted price level model are presented in Table 5 and the permanent component for food and energy prices is presented in Figure 11. Key findings from this model are that, as in the previous bivariate model, the core CPI series is not correctly characterized as having only permanent movements, and that the food and energy series is not correctly characterized as having just temporary movements.

Our estimates allow us to say something about the standard deviation of the shock to the permanent component of each series, and we find that the core CPI series has a much lower standard deviation than the food and energy series. Thus, we find that the permanent component of the food and energy CPI series experiences much more volatile shocks—has a much higher standard error of shocks to the permanent component—than the permanent component of the core CPI.

In terms of the transitory components, the food and energy series has negative AR parameters, indicating that its dynamics follow a damped sinusoidal pattern, reflecting overshooting and undershooting. The core series has positive AR parameters. Also, the core series demonstrates a high degree of persistence in its transitory components, with the sum of the AR coefficients being 0.96.

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TABLE 5. Unrestricted bivariate model in core and food and energy prices

Parameter estimates (1 = core prices, 2 = food and energy prices)
Sample period 1993–2012

Parameter	Value	Std. dev.
σ_{η_1}	0.344	0.199
σ_{η_2}	1.368	0.144
σ_{ε_1}	0.365	0.270
σ_{ε_2}	0.437	0.044
μ_1	0.166	0.023
μ_2	0.267	0.095
ϕ_{11}	0.931	0.074
ϕ_{21}	0.034	0.058
ϕ_{12}	−0.267	0.124
ϕ_{22}	−0.316	0.102
Log likelihood value	−66.806	

Correlations among the permanent and transitory shocks

	Correlation	Std. dev.
$\rho_{\eta_1\eta_2}$	0.582	0.235
$\rho_{\eta_1\varepsilon_1}$	−0.980	0.041
$\rho_{\eta_1\varepsilon_2}$	−0.386	0.057
$\rho_{\eta_2\varepsilon_1}$	−0.547	0.155
$\rho_{\eta_2\varepsilon_2}$	−0.972	0.074
$\rho_{\varepsilon_1\varepsilon_2}$	0.365	0.040

Our results show that there is an important permanent component to the food and energy series, contradicting the assumption that food and energy price movements are wholly or largely transitory. This can be seen by examining Figure 11, which shows that the permanent component is the main determinant of the actual series.

Another way to look at this issue is to compare the movement in the estimated permanent components with the movement in the actual index for the core and food and energy indices. This can be done by comparing Figures 9 and 11, which show that the permanent component is very important for both series, as shown in Table 6. In fact, close inspection of the figures shows that the permanent component appears to be less important for the core series. Such a conclusion is further supported by comparing the ratio of the variance of the permanent component to the variance of the transitory component for both series. This comparison shows that the relative size of the variance of the permanent shocks is smaller for the core series. This stands in contradiction to the assumption that the core series contains permanent price movements whereas the two excluded series contain mostly temporary price movements.[14]

Important information is also contained in the contemporaneous correlation of the shocks. First, the correlations between the permanent and transitory shocks

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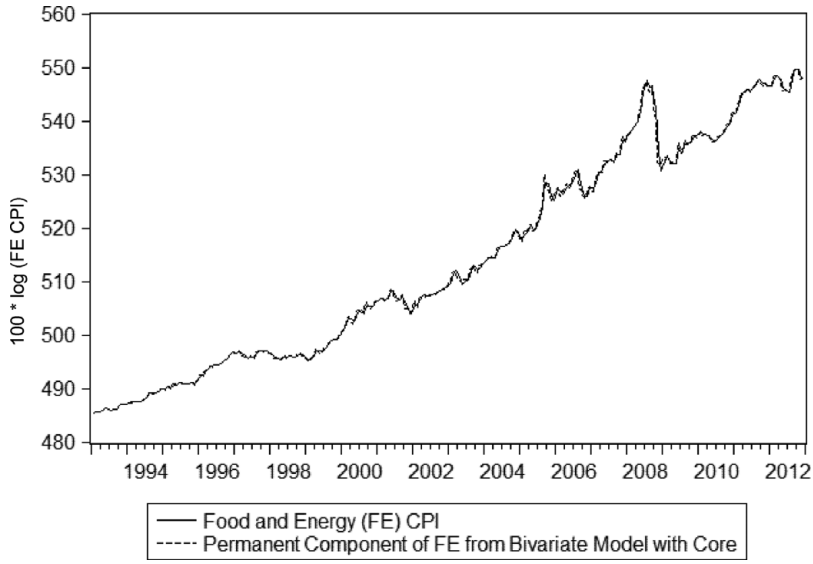


FIGURE 11. Food and energy CPI and the permanent component of food and energy CPI from a bivariate model in core CPI and food and energy CPI.

TABLE 6. Ratio of the standard error of the permanent shocks to the standard error of the transitory shocks

Series	Ratio
Core	0.919
Food and energy	3.114

for an individual series provide insight into the pattern of arrival of shocks to the series. For both core and food and energy, permanent and transitory within-series shocks are highly negatively correlated, implying that the full effects of permanent shocks are partially mitigated in the short run. If the adjustment to a permanent shock is somewhat gradual, the actual value in the period of incidence will be below the permanent value, giving rise to a temporary negative shock in the opposite direction. This is consistent with a macroeconomic model including sticky prices.

Cross-series correlations also yield interesting information about the relationship among the shocks to the three series. First, permanent shocks to the core series are correlated with permanent shocks to the food and energy series. We interpret this as suggesting that there may be underlying structural shocks to the food and energy series with permanent components that are related to the permanent movement in the core series.

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In sum, when inflation is $I(0)$, permanent inflation is a constant, but the price level appears to experience volatile permanent shocks. These permanent movements in the overall price level are not well captured by core CPI for two reasons: (1) permanent shocks to core are volatile but offset by temporary shocks, so that the core series appears more smooth than its permanent component, and (2) food and energy prices experience permanent movements not captured in the core price series.

6. CONCLUSION

We examine the utility of core inflation as a measure of permanent inflation through the estimation of a series of unobserved-components models. Although we find some evidence supporting the use of core inflation, we also find some important concerns about its use. This leads us to the following conclusions.

First, the utility of core inflation critically depends upon the existence of a cointegrating relationship between headline inflation and core inflation. However, the results from estimating models of this relationship are mixed and change depending upon the model used and time period studied.

Moreover, the evidence for even the nonstationarity of inflation is mixed. This result suggests that it is important to consider both inflation models and price-level models, and we estimate both types.

Second, we estimate both unrestricted and common-trend unobserved-components models for core inflation and headline inflation. From the unrestricted model, we find permanent shocks to core inflation have a larger variance than the permanent shocks to headline inflation, particularly for more recent years. This undermines the utility of core inflation as a measure of permanent price changes. We also find that actual core inflation is smoother than permanent core inflation. This is because there is a strong negative correlation between transitory and permanent shocks to core inflation. This is consistent with short-run sticky prices for the items included in core inflation. In addition, we find that actual core inflation is more variable than the permanent component of headline inflation and we find some evidence that suggests that core inflation may overstate (during periods of relatively high inflation) or understate (during periods of relatively low inflation) the true permanent component of inflation. Thus it could provide a misleading signal to policy makers. Finally, we find that the short-run dynamics of core inflation indicates that it is slow to adjust to permanent shocks. This could lead policy makers using core inflation as a measure of permanent inflation to react too slowly to permanent shocks.

Third, the restricted unobserved-components model provides evidence more favorable to the use of core inflation as a measure of permanent price changes because, by construction, the permanent part of core and the permanent part of headline inflation are specified to be the same. Nevertheless, we find that actual core inflation is smoother than its permanent component because of a negative correlation between permanent core inflation shocks and temporary core shocks

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and because of a slow adjustment in core inflation to permanent shocks. This reduces the usefulness of actual core inflation as a measure of permanent inflation.

Fourth, because we find evidence that inflation may be stationary over the last 20 years, we estimate an unobserved-components model in price levels for that recent subperiod. We find that the core CPI series is not characterized as having only permanent movements, and the food and energy series is not correctly characterized as having just temporary movements. Furthermore, the temporary movements in core CPI regularly offset permanent movements, so shocks to the permanent component of core CPI are actually more volatile than the shocks to the observed series. These results also raise concerns about the use of core CPI as the basis for measuring permanent price changes.

NOTES

1. For example, central banks may target the price level or the inflation rate.

2. Evidence for the importance of a core price measure in private-sector decision making is given by its persistent and widespread discussion in the popular and business press and economics blogs. For examples, see Coy (2008), CBC News (2009), and Picerno (2005). Discussions of the use of core inflation by monetary authorities are provided by Mishkin (2007), Bodenstein et al. (2008), and Bullard (2011).

3. When we consider a subsample when inflation is $I(0)$, x_{1t} will represent core CPI and x_{2t} will represent headline CPI.

4. At least AR(2) dynamics is necessary for identification [see discussion in Morley et al. (2003) and Sinclair (2009)]. Additional lags did not change the key results; therefore we selected the most parsimonious model. An additional benefit of the AR(2) specification is that it makes it much easier to ensure the global maximum using the constraint described in Morley (1999).

5. This difference was also discussed in much earlier work by Bradley and Jansen (1986), among others.

6. To ensure that the results are not an artifact of our method of calculating inflation, we also investigated using annualized monthly inflation rates. That method of calculating inflation produced similar results.

7. Alternatively, we could estimate a model for the price levels in which the drift term is modeled as a random walk so that the price levels are $I(2)$. Oh and Zivot (2006) and Oh et al. (2008) show that a correlated version of this "double-drift" model is not identified without additional restrictions. We therefore focus on directly modeling inflation with an unobserved-components model in the case where prices are $I(2)$.

8. Piger and Rasche (2008) also find that "the size of permanent shocks to the inflation rate has varied substantially over the sample period." They find for the end of their sample, from 1994 to 2005, that the permanent shocks to inflation are "quite small from a historical perspective" (p. 101).

9. The MPS tests the null hypothesis of stationarity, similar to the KPSS test, but with better properties when dealing with data-generating processes of the kind relevant to correlated unobserved-component models.

10. This break date was determined by a Quandt–Andrews test.

11. Inflation stickiness is discussed, for example, by Roberts (1997). See also Levin and Piger (2003). Kim et al. (2011) and Morley et al. (2011) discuss implications of trend inflation for the New Keynesian Phillips Curve.

12. Stationarity tests for core, headline, and food and energy price levels all reject stationarity, implying that the price series are $I(1)$ for this subperiod.

13. The Bureau of Labor Statistics (BLS) does not publish a Food & Energy index (FE), but it does publish separate monthly indices for Food (F), Energy (E), and Core (C). It also provides the weights

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on these indices for aggregating to the overall CPI. We obtained monthly data on F, E, C, and CPI from the BLS, as well as the annual weights for food, energy, and core that apply to 1987–2012. We applied the 1987 weights to 1983–1986. At every point in time, $w_F F + w_E E + w_C C = \text{CPI}$, so we construct FE as $\frac{w_F}{(1-w_C)} F + \frac{w_E}{(1-w_C)} E = FE$. Note that $(1 - w_C) FE + w_C C = \text{CPI}$, as required.

14. This finding is in stark contrast to the finding in McElroy and Trimbur (2012), who find a high signal-to-noise ratio for core, but whose model, like most others, assumes zero correlation between permanent and temporary shocks.

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