Rational Bias in Inflation Expectations

Robert G. Murphy*
Boston College

Adam Rohde
Charles River Associates

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Abstract

This paper argues that individuals may *rationally* weight price increases for food and energy products differently from their expenditure shares when forming expectations about price inflation. We develop a simple dynamic model of the economy with gradual price adjustment in the manufacturing (or "core") sector and flexible prices in the food and energy sectors. Serial correlation of supply shocks to the food and energy sectors allows individuals to gain an understanding about future shocks, possibly making it optimal for individuals to place more weight on the movement of prices in these sectors, as past movements of these prices may help predict future inflation. In particular, if food and energy price inflation exhibits a sufficient degree of persistence and wage adjustment is not too sluggish, we show that it is rational to put more weight on inflation in these sectors than their expenditure shares in the Consumer Price Index would warrant. We test the prediction of the model using data on expected inflation from the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters. Our results show that the weights implied by the model for constructing expectations of inflation differ from the expenditure shares of food and energy prices in the Consumer Price Index for the United States. We find that food price inflation is weighted more heavily and energy price inflation is weighted less heavily. But importantly, we cannot reject the hypothesis that these weights reflect rational behavior in forming expectations about inflation. Our analysis validates concerns sometimes raised by policymakers as to whether expectations might not be well anchored with respect to some commodity price shocks. As a consequence, policy may need to be calibrated carefully to prevent such shocks from becoming embedded in expected inflation.

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* Paper prepared for presentation at American Economic Association Meetings in Boston, MA January 3-5, 2015. Corresponding author: Robert G. Murphy, Department of Economics, Boston College, Chestnut Hill, MA 02467, murphyro@bc.edu. The views expressed herein are the views and opinions of the authors and do not reflect or represent the views of Boston College, Charles River Associates, or any of the organizations with which the authors are affiliated.

1. Introduction

Expectations about price inflation play a central role in modern macroeconomic analysis. They are important for understanding how households and firms make saving, spending, and investing decisions, and are a key input into negotiations for labor contracts and the pricing of financial instruments. Central banks track them for comparison with internal forecasts and targets for inflation. The ability of monetary authorities to achieve price stability depends on an accurate understanding of inflation expectations.

A concern sometimes raised by policymakers is whether inflation in highly visible products such as food and energy might overly influence the public's perception of inflation. For example, discussion at the Federal Open Market Committee meeting in June 2008 clearly illustrates this concern:

> *"Participants had become more concerned about upside risks to the inflation outlook--including the possibility that persistent advances in energy and food prices could spur increases in long-run inflation expectations."*
>
> *"Some noted that the increase was greatest for short-term survey measures of households' inflation expectations, which may be influenced disproportionately by consumers' perceptions of changes in the prices of food and gasoline…"*[1]

This concern is not a recent one, having featured prominently during policy discussions about supply shocks during the 1970s.[2]

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[1] Federal Open Market Committee, Minutes of the Meeting of June 24-25, 2008, pp. 6-7.
[2] See Van Duyne (1982) for several examples.

Our paper explores whether prices of items that individuals frequently purchase and that often are quite volatile, such as food and energy products, play a larger role in the formation of inflation expectations than their expenditure shares indicate. Similar to Van Duyne (1982), we show that it may be *optimal* for individuals to assign relative weights to price increases in the food and energy sectors that are larger than those sectors' shares in consumer expenditure. We develop a simple three-sector dynamic aggregate demand-aggregate supply model of the economy with gradual price adjustment in the manufacturing (or "core") sector and flexible prices in the food and energy sectors. Serial correlation of shocks to food and energy prices allows individuals to gain an understanding about future shocks, possibly making it optimal for individuals to place more weight on the movement of prices in these sectors, as past movements of these prices may help predict future inflation. We solve the model for a relationship determining expected inflation. Our framework extends Van Duyne (1982) by modeling aggregate demand as a function of the real interest rate and incorporating a Taylor-type policy rule for the nominal interest rate. We also test whether any observed bias in expectations about inflation is optimal, whereas Van Duyne tests only whether such bias is present but not whether it is optimal.

We estimate the model using survey data on expected inflation from the Federal Reserve Bank of Philadelphia.[3] Our results show that the weights implied by the model for constructing expectations of inflation differ from the expenditure shares of food and energy prices in the Consumer Price Index (CPI) for the United States. In particular, we

[3] As discussed in Section 3, we use data on expected CPI inflation from the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters (SPF) because it provides measures of expected inflation one-quarter and two-quarters ahead, which our methodology requires. Fuhrer (2012) and Mishkin (2007), among other authors, also use the SPF to capture the public's expectation of inflation at different horizons. See Croushore (1993) for an overview of the Survey of Professional Forecasters.

find that food price inflation is weighted more heavily and energy price inflation is weighted less heavily. But importantly, we cannot reject the hypothesis that these weights reflect rational behavior in forming expectations about inflation. Our analysis validates concerns sometimes raised by policymakers as to whether expectations might not be well anchored with respect to some commodity price shocks. As a consequence, policy may need to be calibrated carefully to prevent such shocks from becoming embedded in expected inflation.

Recent work by Trehan (2011) suggests that households are more sensitive to energy and food prices in forming inflation expectations than they are to core measures of inflation that exclude those items. He uses correlation analysis to show that survey measures of inflation expectations are more closely related to inflation in energy and food items than to core inflation. Experimental evidence presented by Georganas, Healy, and Li (2014) finds that perception of the economy-wide inflation rate is influenced by the frequency with which goods' prices are observed. A recent paper by Arora et al (2013) shows that expected inflation responds strongly to (what they term) "explosive deviations" of overall inflation from core inflation. All of these papers use non-structural methods in their analyses and none explicitly test whether the observed response reflects rational behavior.[4] By contrast, we develop a structural model of the economy and use it to test directly whether inflation expectations respond rationally to food and energy price movements.[5]

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[4] Other authors who have analyzed the relationship between expected inflation and commodity price movements using non-structural methods include Wong (2014) and Celasun et al (2012).

[5] Whereas we study how expected inflation responds to movements in commodity prices, a separate but related literature has explored the question of whether survey measures of expected inflation represent rational forecasts of future inflation. See, for example, the volume by Sinclair (2010) and articles by

The paper proceeds as follows. Section 2 develops a simple dynamic model of the economy to show how individuals may optimally overweight or underweight food and energy prices in forming expectations about overall inflation. Section 3 presents tests of the model's predictions using survey data on expected price inflation and provides support for rational bias in inflation expectations. Section 4 summarizes our findings and offers suggestions for further research.

2. The Model

Our model assumes prices are flexible in the food and energy sectors but adjust sluggishly in the core (non-food and non-energy) sector, where firms with market power set price as a markup over marginal cost. The model consists of a standard wage-price Phillips curve augmented to include supply shocks and a dynamic aggregate demand relationship incorporating a Taylor-type rule for monetary policy. Our approach builds on work by Van Duyne (1982), but differs from his by including a monetary policy rule for the nominal interest rate and expressing aggregate demand as a function of the real interest rate.[6]

2.1 Aggregate Supply[7]

The composite price of goods and services in the core sector is given as a constant markup (μ) over marginal cost, which we proxy by unit labor costs:

Capistran and Timmermann (2009), Mankiw et al (2004), Ehrbeck and Waldmann (1996), Noble and Fields (1982), and Mullineaux (1978).

[6] We also test in Section 3 whether any observed bias in expectations of inflation is optimal. Van Duyne only tests for bias itself, not whether it is optimal.

[7] See Whelan (1997) for a derivation of a wage-price Phillips curve similar to the one we develop here.

$$P_t^c = \mu \frac{w_t l_t}{y_t} \tag{1}$$

where w is the wage, l is employment, and y is output.[8] For simplicity, we assume a constant rate of labor productivity growth in the core sector so that equation (1) implies core inflation (π_t^c) equals wage inflation (ω_t) minus productivity growth (g):

$$\pi_t^c = \omega_t - g \ . \tag{2}$$

The equilibrium wage is assumed to rise at the rate of expected inflation plus productivity growth, adjusted for the degree of slack in labor markets:

$$\omega_t^* = E_{t-1}\pi_t + g - a_1 u_t \tag{3}$$

where $E_{t-1}\pi_t$ is the expectation in period t-1 of inflation for period t and u_t is the gap between the actual rate of unemployment and its natural (full-employment) level. Actual wage inflation adjusts to its equilibrium rate gradually, either because overlapping wage contracts make nominal wages sticky or costs of acquiring information lead to lags in updating otherwise flexible wages.[9] We approximate this gradual adjustment of wage inflation with a simple relationship:

$$\omega_t - \omega_{t-1} = a_2(\omega_t^* - \omega_{t-1}) \qquad 0 < a_2 \le 1 \tag{4}$$

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[8] Profit-maximizing monopolistically competitive firms will set price as a markup over marginal cost, where the markup may vary with demand conditions. For example, Mazumder (2014) finds that the markup in the U.S. manufacturing sector is countercyclical. For simplicity, and following Whelan (1997), we treat the markup as constant.

[9] The equilibrium wage can be interpreted as the wage that would prevail under full information. When information is costly to acquire, firms and workers will update information with some lag, implying a gradual adjustment of wage inflation toward its equilibrium rate. See Mankiw and Reis (2002) for implications of "sticky information" in a model of price setting behavior.

where parameter a_2 determines the speed with which wage inflation adjusts to its equilibrium value.

We ignore differences in sectoral productivity growth rates and assume that inflation rates in the food and energy sectors relative to the inflation rate in the core sector are driven by serially correlated supply shocks (ν_t and ε_t):

$$\begin{aligned} \pi_t^f &= \pi_t^c + \nu_t \qquad & \pi_t^e &= \pi_t^c + \varepsilon_t \\ \nu_t &= \sigma \nu_{t-1} + \xi_t \qquad & \varepsilon_t &= \delta \varepsilon_{t-1} + \eta_t \end{aligned} \tag{5}$$

where $|\sigma|, |\delta| < 1$, and ξ_t, η_t are mean-zero uncorrelated random shocks. In principle, the supply shocks could be either positively or negatively serially correlated and could be represented by more complicated time-series processes. As discussed in Section 3, we find that a first-order autoregressive process fits the data well and provides for a parsimonious representation of these shocks.

The overall rate of inflation for the economy is measured using a weighted average of price inflation in the food, energy, and core sectors of the economy:

$$\pi_t = A\pi_t^f + B\pi_t^e + (1 - A - B)\pi_t^c \tag{6}$$

where A and B are expenditure shares for food and energy items used to construct the price index for consumer expenditures.[10]

[10] Equation (6) holds for Laspeyres fixed-weight indexes. The official CPI for the United States uses a Laspeyres formulation at its upper level for aggregate items such as food and energy. See Bureau of Labor Statistics (2007) for details.

Using equations (2), (3), (4), (5), and (6), we can solve for a Phillips curve relating overall inflation to expected inflation and lagged values of inflation for the core, food, and energy sectors:

$$\pi_t = a_2 E_{t-1}\pi_t - a_1 a_2 u_t + (1-a_2)\pi_{t-1}^c + \sigma A(\pi_{t-1}^f - \pi_{t-1}^c) + \delta B(\pi_{t-1}^e - \pi_{t-1}^c) \tag{7}$$

where the last two terms are written as deviations of food and energy inflation from core inflation and can be interpreted as supply shocks. Equation (7) is similar to the expectations-augmented Phillips curve of Friedman (1968) as generalized by Gordon (1982) to incorporate supply shocks and inertia through lagged core inflation.[11]

2.2 Aggregate Demand

To complete the model, we specify an *IS*-type demand equation that relates the unemployment gap to the real interest rate:

$$u_t = a_3(i_t - E_t\pi_{t+1} - \rho) - \upsilon_t \tag{8}$$

where i_t is the nominal interest rate, $E_t\pi_{t+1}$ is the expectation of overall inflation in period t+1 as of period t, ρ is the natural or long-run value of the real interest rate at which the unemployment gap is zero, and υ_t is a mean-zero uncorrelated shock to

[11] See also Gordon (1982, 1990), Fuhrer (1995), and Murphy (2000) who provide empirical support for standard Phillips curve models of inflation. Bernanke (2008) provides an overview of several important issues for Phillips curve analyses of inflation. Ball and Mazumder (2011) incorporate anchored expectations into an otherwise standard Phillips curve as a possible reason for why the United States did not experience deflation during and immediately after the Great Recession. Murphy (2014) finds that a Phillips curve modified to account for uncertainty about regional economic conditions can explain the behavior of inflation following the Great Recession.

demand.[12] The monetary authority is assumed to target the nominal interest rate so as to raise (lower) the *real* interest rate when inflation exceeds (falls short of) its target or when unemployment is less than (greater than) its natural rate:[13]

$$i_t = \pi_t + \rho + \theta_1(\pi_t - \pi^*) - \theta_2 u_t \qquad 0 < \theta_1, \theta_2 . \tag{9}$$

Substituting this Taylor-type rule into equation (8) yields the following dynamic aggregate demand relationship:

$$u_t = \frac{a_3(1+\theta_1)}{1+a_3\theta_2}\pi_t - \frac{a_3}{1+a_3\theta_2}E_t\pi_{t+1} - \frac{a_3\theta_1}{1+a_3\theta_2}\pi^* - \frac{1}{1+a_3\theta_2}\upsilon_t . \tag{10}$$

Equation (10) shows that when inflation increases, the unemployment gap also increases as the monetary authority raises the real interest rate to reduce aggregate demand and contain inflation. The unemployment gap will respond more to inflation when the monetary authority places a larger weight, θ_1, on deviations from the inflation target and it will respond less to inflation when the monetary authority places a larger weight, θ_2, on stabilizing unemployment at its natural rate. An increase in expected inflation, given current and target inflation, lowers the real interest rate, raises demand and lowers the unemployment gap. Note that when inflation is constant and equal to its target level (and

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[12] Romer (2012), Chapter 6, derives a New Keynesian *IS* curve relationship similar to equation (8) from the maximizing behavior of households.

[13] See Taylor (1993) and Bryant, Hooper, and Mann (1993) for a discussion of central bank interest-rate policy that appears to be well approximated by such rules. We assume that θ_1 is greater than zero so that the central bank responds to an increase in inflation by raising the real interest rate—a condition commonly known as the Taylor Principle.

the demand shock is zero), equation (10) implies the unemployment gap is zero so that unemployment is equal to its natural rate.

2.3 Equilibrium

We can solve for the equilibrium value of inflation by using equation (10) to substitute for the unemployment gap in equation (7) and rearrange to obtain:

$$\pi_t = \frac{(1+a_3\theta_2)a_2}{X}E_{t-1}\pi_t + \frac{a_1a_2a_3}{X}E_t\pi_{t+1} + \frac{a_1a_2a_3\theta_1}{X}\pi^* + \frac{(1+a_3\theta_2)(1-a_2-\sigma A-\delta B)}{X}\pi^c_{t-1} + \frac{(1+a_3\theta_2)\sigma A}{X}\pi^f_{t-1} + \frac{(1+a_3\theta_2)\delta B}{X}\pi^e_{t-1} + \frac{a_1a_2}{X}\upsilon_t \qquad (11)$$

where $X = 1 + a_3\theta_2 + a_1a_2a_3(1+\theta_1)$. Equation (11) shows how inflation in period t depends on inflation expected for period t and inflation expected for period t+1. An increase in expected inflation for period t as of period t-1 leads to higher wage inflation, which in turn is partly passed through into higher core inflation and, hence, overall inflation. An increase in expected inflation for period t+1 as of period t lowers the real interest rate and raises aggregate demand (i.e., reduces the unemployment gap), thereby increasing inflation. The equation exhibits a neutrality property: if expected inflation rates, target inflation, and lagged sectoral inflation rates all increase by the same proportion (and the demand shock is zero), then overall inflation also will increase by the same proportion, and from equation (10) the unemployment gap will be unaffected.

To obtain a relationship describing equilibrium expected inflation, we take expectations of both sides of equation (11) as of time t-1, and rearrange to yield:

$$E_{t-1}\pi_t = \frac{a_1a_2a_3}{Z}E_{t-1}\pi_{t+1} + \frac{a_1a_2a_3\theta_1}{Z}\pi^* + \zeta[\alpha^*\pi^f_{t-1} + \beta^*\pi^e_{t-1} + (1-\alpha^*-\beta^*)\pi^c_{t-1}] \quad (12)$$

where:

$$\alpha^* = \frac{\sigma A}{1-a_2}, \quad \beta^* = \frac{\delta B}{1-a_2}$$
$$\zeta = \frac{(1-a_2)(1+a_3\theta_2)}{Z}$$
$$Z = (1-a_2)(1+a_3\theta_2) + [a_1a_2a_3(1+\theta_1)].$$

Note that the relative weights on lagged food, energy, and core inflation sum to one but in general are not equal to the expenditure shares used to compute the overall rate of inflation. In particular, the relative weights on food and energy inflation ($\alpha^*$and β^*) will exceed their respective expenditure shares (*A* and *B*) when $\sigma + a_2 > 1$ and $\delta + a_2 > 1$. These conditions are more likely to hold when the speed of wage adjustment is not too sluggish (so that a_2 is large) and the rate of inflation in the food and energy sectors is persistent (supply shocks to these sectors exhibit sufficient serial correlation so that σ and δ are large). Conversely, the relative weights will fall short of their respective expenditure shares when $\sigma + a_2 < 1$ and $\delta + a_2 < 1$.

Equation (12) imposes restrictions on the relative weights individuals should optimally place on inflation in the food and energy sectors when forming expectations about overall inflation: $\alpha^* = \frac{\sigma A}{1-a_2}$ and $\beta^* = \frac{\delta B}{1-a_2}$. In the next section, we describe how these restrictions can be tested using survey data on inflation expectations to estimate the parameters of our model.

3. Estimation Results

We estimate relationships of the following form that match equation (12):

$$ {}_{t-1}\pi_t^E = \gamma_0 + \gamma_1 \, {}_{t-1}\pi_{t+1}^E + \gamma_2 \pi_{t-1}^f + \gamma_3 \pi_{t-1}^e + \gamma_4 \pi_{t-1}^c \tag{13} $$

where ${}_{t-1}\pi_{t+i}^E$ is a measure of expected CPI inflation for period t+i as of period t-1 and π^f, π^e, and π^c are CPI inflation rates for food, energy and core sectors. Because the monetary authority's target for inflation is assumed fixed, we include a constant term in the equation. To estimate equation (13), we need data for inflation expected one and two periods in the future. The Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters (SPF) provides quarterly measures of CPI inflation in the United States expected for multiple time periods in the future, allowing direct estimation of equation (13).[14] Although the University of Michigan's Survey of Consumers is more representative of the population at large than the SPF, the Michigan survey reports monthly measures of expected inflation only over the next year and the next 5 to 10 years, not for one and two periods in the future.[15] In addition, the Michigan survey asks only about generic inflation, whereas the SPF asks about specific measures including the CPI. Because the SPF matches the timing of the expected inflation variables in our model and asks specifically about the CPI, we use those data in our analysis.[16]

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[14] The Survey of Professional Forecasters provides median inflation expected one, two, three, and four quarters into the future, along with an estimate for the next ten years. See Federal Reserve Bank of Philadelphia (2014) for details. The Philadelphia Fed also oversees the Livingston survey of forecasters, but that survey is conducted only every six months and provides forecasts for inflation over the next 6 and 12 months. See Murphy (1986) for an analysis of the term structure of inflation forecasts using the Livingston expected inflation data.
[15] See Curtin (1996) for details about the Michigan expected inflation series.
[16] See Fuhrer (2012) and Mishkin (2007) who also use the SPF median to measure the public's inflation expectations at various horizons.

The parameters α^* and β^* in equation (12) are related to the estimated coefficients of equation (13) by the following expressions:

$$\alpha^* \equiv \frac{\gamma_2}{\gamma_2 + \gamma_3 + \gamma_4}$$
$$\beta^* \equiv \frac{\gamma_3}{\gamma_2 + \gamma_3 + \gamma_4} \tag{14}$$

and represent the relative weights placed on food and energy prices in forming expectations about inflation. Under the null hypothesis that individuals form expectations about future inflation using our simple model, equations (12) and (14) imply the following restrictions:

$$\frac{\gamma_2(1-a_2)}{(\gamma_2+\gamma_3+\gamma_4)\sigma} = A$$
$$\frac{\gamma_3(1-a_2)}{(\gamma_2+\gamma_3+\gamma_4)\delta} = B \tag{15}$$

where we interpret *A* and *B* as the expenditure shares for food and energy used to compute the CPI. To test these restrictions, we need estimates of a_2, σ, and δ in addition to the parameters of equation (13). This requires estimation of equation (13) in combination with the wage adjustment equation and the autoregressive relationships for the supply shocks. To recover the wage adjustment parameter, a_2, we estimate a Phillips curve for wage inflation derived by substituting equation (3) into equation (4) and rearranging:

$$\omega_t = \phi_0 - \phi_1 u_t + \phi_2\, {}_{t-1}\pi_t^E + (1-\phi_2)\omega_{t-1} \tag{16}$$

where $\phi_2 \equiv a_2$. We impose the constraint that the sum of the coefficients on expected inflation and lagged wage inflation sum to one when estimating equation (16). To obtain estimates of the autoregressive parameters, σ and δ, we use equations (5) to derive the following relationships:

$$\pi_t^f - \pi_t^c = \vartheta_1(\pi_{t-1}^f - \pi_{t-1}^c) \qquad \pi_t^e - \pi_t^c = \vartheta_2(\pi_{t-1}^e - \pi_{t-1}^c) \tag{17}$$

where $\vartheta_1 \equiv \sigma$ and $\vartheta_1 \equiv \delta$. Using equations (16) and (17), the restrictions given by equation (15) can be written in terms of the estimated parameters:

$$\begin{gathered} \frac{\gamma_2(1-\phi_2)}{(\gamma_2+\gamma_3+\gamma_4)\vartheta_1} = A \\ \frac{\gamma_3(1-\phi_2)}{(\gamma_2+\gamma_3+\gamma_4)\vartheta_2} = B \end{gathered} \tag{18}$$

where, again, *A* and *B* are the expenditure shares of food and energy in the CPI.

We employ generalized method of moments (GMM) to jointly estimate equations (13), (16), and (17) using quarterly data for the United States.[17] For the inflation variables, we use the quarterly percent change expressed at an annual rate for the food, energy, and core components of the CPI for All Urban Consumers (CPI-U). We measure the unemployment gap using the difference between the quarterly civilian unemployment rate and the quarterly value of the natural rate estimated by the Congressional Budget Office (2014). For wage inflation, we use the quarterly percent change in average hourly

[17] The GMM estimation procedure allows for a generalized variance-covariance structure of regression error terms for these equations, which we use in our hypothesis tests. All data, except as noted, are from the U.S. Bureau of Labor Statistics.

earnings expressed at an annual rate. And as discussed earlier, we measure expected inflation using the SPF, which provides data for median expected inflation at an annual rate one and two quarters into the future. We start our sample period in 1982, the first full year that the SPF provides consistent data for multi-horizon expectations of inflation. In our estimation, we use as instruments four lags each of overall inflation, wage inflation, the unemployment gap, and inflation expected two quarters ahead.[18]

To test the hypotheses given by equation (18), we use the average relative importance for food and energy in the CPI-U as reported by the Bureau of Labor Statistics for our values of *A* and *B*. Figure 1 plots the relative importance of food and energy components over our sample period. Except for an initial decline from 1982 through 1986, both shares are reasonably stable, fluctuating in a band of only a couple of percentage points around their average values. The food share gradually trends down after 1986 while the energy share moves up slightly during recent years.

We report in Table 1 estimates for the coefficients of equations (13), (16), and (17) along with their standard errors.[19] For the period 1982 to 2013, all coefficients are of the correct positive sign and nearly all are statistically different from zero at very high levels of confidence. Only the coefficient on the unemployment gap in equation (16) is not significantly different from zero, possibly reflecting downward nominal wage rigidity during the prolonged episode of high unemployment associated with the recent Great

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[18] Our instrument set uses lagged values of only two-quarter-ahead expected inflation, since the one-quarter-ahead and two-quarter-ahead series are highly correlated. Estimates when both series are included in the instrument set and when only the one-period ahead series is included give results similar to those reported in the text.

[19] Estimates of the constant terms in equations (13) and (16) (not reported) were small in magnitude and generally not statistically significant.

Recession.[20] Hansen's J-statistic shows that we cannot reject at standard levels of confidence the set of overidentifying restrictions on the instruments. Our point estimate of the persistence of inflation in the food sector (ϑ_1) is higher than for the energy sector (ϑ_2), consistent the view that underlying shocks to raw energy prices feed through more rapidly into final-stage products and thus dissipate more quickly than do shocks to raw food prices.[21] Wage inflation adjusts to its equilibrium value at a rate that eliminates roughly 14 percent of the gap in one quarter, as captured by the point estimate of ϕ_2.

Table 1 also presents test results for the hypothesis that individuals form expectations rationally so that the parameters jointly satisfy the two restrictions given by equation (18).[22] The p-value of 0.53 indicates that we cannot reject the hypothesis that individuals form expectations rationally in accord with these restrictions. We can, however, reject the hypothesis that the estimated relative weights, as given by equation (14) and reported in Table 1 (also shown in Figure 1), are equal to the actual expenditure weights, as seen by the p-value of 0.00 for the test of relative weights. The estimated relative weight for food (0.249) is larger than its actual value (0.155) but the estimated relative weight for energy (0.041) is smaller than its actual value (0.083). This suggests rational overweighting for food but rational underweighting for energy in forming expectations about inflation. The underweighting of energy inflation is consistent with evidence that monetary policy was tightened sharply in response to energy-related supply

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[20] Gali (2011) also obtains an insignificant coefficient on unemployment in wage Phillips curves and argues that the estimate is overly influenced by downward nominal wage rigidity during the period of prolonged high unemployment accompanying the Great Recession.

[21] See Pedersen (2011) for analysis of the relative speed with which food and energy price shocks dissipate.

[22] The reported test statistic is distributed as χ^2 and is computed using the method described in Green (2012), p. 528, for both linear and nonlinear hypotheses. We use this method when calculating test statistics for all hypothesis tests reported in our paper.

shocks during the 1970s and early 1980s so as to dampen inflation, leading expectations to become better anchored and less responsive to these shocks in subsequent decades.[23]

As shown in Figure 1, the relative weights of food and energy in the CPI were higher in the early 1980s before falling sharply and becoming more stable after 1985. To assess whether our findings are robust to excluding the early 1980s, Table 1 also provides results for the period from 1986 to 2013. The estimates and test results are similar to those for the full sample period. Once again, we cannot reject the hypothesis of rational bias in expectations formation.

We also consider a version of the model in which food and energy sectors are combined. Here we use data on prices in the food and energy sectors along with relative expenditure shares to compute a price index for the combined sectors.[24] We estimate a model of the same structure as before except that now only one non-core inflation rate enters the model:

$$ {}_{t-1}\pi_t^E = \gamma_0 + \gamma_1\, {}_{t-1}\pi_{t+1}^E + \gamma_2 \pi_{t-1}^{ef} + \gamma_3 \pi_{t-1}^c \tag{13a} $$

$$ \omega_t = \phi_0 - \phi_1 u_t + \phi_2\, {}_{t-1}\pi_t^E + (1-\phi_2)\omega_{t-1} \tag{16a} $$

$$ \pi_t^{ef} - \pi_t^c = \vartheta_1(\pi_{t-1}^{ef} - \pi_{t-1}^c) \tag{17a} $$

where π_t^{ef} is the composite rate of price inflation in the food and energy sectors. We use generalized method of moments to jointly estimate equations (13a), (16a), and (17a) and,

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[23] Hooker (2002) finds that monetary policy has responded less forcefully to energy price shocks since around 1980 because expectations of inflation may have become less sensitive to such shocks. The underweighting of energy inflation in expectations formation is consistent with evidence discussed in Bernanke (2007) that inflation expectations have become better anchored with respect to energy price shocks in recent decades.

[24] See Bureau of Labor Statistics (2007), Chapter 17, pp. 34-38, for details on how to construct composite price indexes using relative expenditure shares and price indexes for sectors.

as before, employ as instruments four lags each of overall inflation, wage inflation, the unemployment gap, and inflation expected two quarters ahead. The restriction in equation (18) now takes the form:

$$\frac{\gamma_2(1-\phi_2)}{(\gamma_2+\gamma_3)\vartheta_1}=C \tag{18a}$$

where C is the combined expenditure share of food and energy in the CPI.

Table 2 provides results for the composite version of our model. All coefficients are of the correct positive sign and all are statistically significant at the 10-percent or better level. For the period 1982 to 2013, we cannot reject the hypothesis that expectations are formed rationally according to the structure of our model, as indicated by the probability value of 0.90 for the test of the restriction given in equation (18a). We can, however, reject the hypothesis that the estimated relative weight for the food-energy composite sector is equal to its actual value, as shown by the p-value of 0.00. The estimated relative weight of 0.103 is smaller than its actual value of 0.238, indicating rational underweighting of composite food-energy inflation in the formation of expectations. Given the results of Table 1 showing underweighting of energy inflation and overweighting of food inflation, this underweighting of composite food-energy inflation suggests that the influence of energy price inflation dominates the influence of food price inflation in forming expectations of overall inflation. As discussed above, this underweighting may reflect better anchoring of inflation expectations with respect to energy price shocks since the early 1980s. We again provide a robustness check on our results by estimating the composite model over the period 1986 to 2013. The second column of Table 2 shows that estimates over this shorter sample period are similar to those for the full sample.

4. Summary

This paper has argued that individuals may *rationally* weight price increases in the food and energy sectors differently from the expenditure shares of these sectors in the CPI when forming expectations about overall price inflation. We developed a simple dynamic model of the economy to illustrate this finding. Serial correlation of shocks to food and energy prices allows individuals to gain an understanding about future shocks, possibly making it optimal for individuals to place more weight on the movement of prices in these sectors, as past movements of these prices may help predict future inflation. In particular, if the degree of persistence for shocks to food and energy inflation is high enough and the speed of wage adjustment is not too sluggish, the model predicts individuals will overweight price movements for food and energy compared with their expenditure shares in the CPI.

Using data on expected inflation from the Federal Reserve Bank of Philadelphia's Survey of Professional Forecasters, we show that the weights implied by the model for constructing expectations of inflation differ from the expenditure shares of food and energy in the CPI. Specifically, we find that food price inflation is weighted more heavily and energy price inflation is weighted less heavily. But we cannot reject the hypothesis that these weights reflect rational formation of expectations about inflation. These results indicate that expectations might not be well anchored with respect to some commodity price shocks. It follows that policy makers may need to tailor responses to such shocks to account for the disparity between expenditure shares and the weights individuals place on sectoral inflation in forming expectations. This may mean more forceful policy is necessary in response to some shocks to prevent them from becoming embedded in expected inflation.

Our goal in this paper was to develop a simple dynamic model of the macroeconomy to illustrate the possibility of rational bias in expectations formation and to provide some preliminary results using survey data on inflation expectations. The analysis showed how this bias depends on persistence in commodity price inflation and the degree of inertia in wage adjustment. Future research should extend our work by exploring the links between rational bias and models of rational inattentiveness, where differences in the cost of acquiring information across sectors (or differences in willingness to pay attention to news across sectors) could lead to over or underweighting of inflation across sectors.[25] Our approach could also be applied to countries other than the United States to ascertain similarities and differences in the response of inflation expectations to movements in food and energy prices. Finally, our simple model could be modified to incorporate a greater degree of forward-looking behavior similar to New Keynesian sticky-price models.

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[25] See, for example, Mankiw and Reis (2003) and Carroll (2003) for models where information is updated only periodically.

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Table 1: Estimation Results for Food and Energy Model

$$_{t-1}\pi_t^E = \gamma_0 + \gamma_1\,{}_{t-1}\pi_{t+1}^E + \gamma_2\pi_{t-1}^f + \gamma_3\pi_{t-1}^e + \gamma_4\pi_{t-1}^c$$
$$\omega_t = \phi_0 - \phi_1 u_t + \phi_2\,{}_{t-1}\pi_t^E + (1-\phi_2)\omega_{t-1}$$
$$\pi_t^f - \pi_t^c = \vartheta_1(\pi_{t-1}^f - \pi_{t-1}^c)$$
$$\pi_t^e - \pi_t^c = \vartheta_2(\pi_{t-1}^e - \pi_{t-1}^c)$$

Sample Period	1982:1-2013:4	1986:1-2013:4
γ_1	0.765** (0.063)	0.847** (0.094)
γ_2	0. 057** (0.011)	0.055** (0.015)
γ_3	0.009** (0.002)	0.010** (0.002)
γ_4	0.164** (0.060)	0.104 (0.086)
ϕ_1	0.043 (0.029)	0.044 (0.028)
ϕ_2	0.138** (0.042)	0.150** (0.045)
ϑ_1	0.838** (0.073)	0. 867** (0.095)
ϑ_2	0. 340** (0.040)	0.361** (0.043)
Number of Observations	126	112
J-Statistic: $\chi^2(58)$ p-value	71.15 (0.12)	66.56 (0.21)
Rationality:[a] $\chi^2(2)$ p-value	1.28 (0.53)	0.94 (0.63)
Relative Weights:[b] $\chi^2(2)$ p-value	41.38 (0.00)	6.90 (0.03)
Relative Weights Food Energy	Estimated Actual 0.249 0.155 0.041 0.083	Estimated Actual 0.325 0.151 0.061 0.077

Note: $_{t-1}\pi_{t+i}^E$ is CPI inflation expected for period $t+i$ as of period t-1, π^f, π^e, and π^c are, respectively, CPI inflation in the food, energy, and core (non-food, non-energy) sectors, ω is wage inflation measured by average hourly earnings, and u is the unemployment gap computed using the CBO's estimate of the natural rate. Data are quarterly and inflation rates are measured as quarterly percent change at an annual rate. Estimation technique is GMM using as instruments a constant term and 4 lags each of overall CPI inflation, wage inflation, the unemployment gap, and inflation expected two quarters ahead. Robust standard errors are presented in parentheses under the coefficient estimates with * and ** indicating coefficient is statistically different from zero at 10-percent and 1-percent levels, respectively.

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[a] Test of null hypothesis that estimated relative weights satisfy restrictions given by equation (18).
[b] Test of null hypothesis that estimated relative weights equal actual relative weights.

Table 2: Estimation Results for Food-Energy Composite Model

$$ {}_{t-1}\pi_t^E = \gamma_0 + \gamma_1\, {}_{t-1}\pi_{t+1}^E + \gamma_2 \pi_{t-1}^{ef} + \gamma_3 \pi_{t-1}^c $$
$$ \omega_t = \phi_0 - \phi_1 u_t + \phi_2\, {}_{t-1}\pi_t^E + (1-\phi_2)\omega_{t-1} $$
$$ \pi_t^{ef} - \pi_t^c = \vartheta_1(\pi_{t-1}^{ef} - \pi_{t-1}^c) $$

Sample Period		1982:1-2013:4		1986:1-2013:4	
γ_1		0.585** (0.103)		0.671** (0.111)	
γ_2		0.038** (0.008)		0.047** (0.006)	
γ_3		0.336** (0.090)		0.283** (0.097)	
ϕ_1		0.059* (0.034)		0.075* (0.030)	
ϕ_2		0.164** (0.046)		0.189** (0.051)	
ϑ_1		0.345** (0.079)		0.345** (0.082)	
Number of Observations		126		112	
J-Statistic:	$\chi^2(43)$ p-value	56.14 (0.09)		48.25 (0.27)	
Rationality:[a]	$\chi^2(1)$ p-value	0.02 (0.90)		0.76 (0.38)	
Relative Weights:[b]	$\chi^2(1)$ p-value	15.20 (0.00)		3.95 (0.05)	
Relative Weights Food-Energy		Estimated 0.103	Actual 0.238	Estimated 0.144	Actual 0.228

Note: ${}_{t-1}\pi_{t+i}^E$ is CPI inflation expected for period *t+i* as of period *t*-1, π^{ef} is CPI inflation in the composite food and energy sector, π^c is CPI inflation in the core (non-food, non-energy) sector, ω is wage inflation measured by average hourly earnings, and *u* is the unemployment gap computed using the CBO's estimate of the natural rate. Data are quarterly and inflation rates are measured as quarterly percent change at an annual rate. Estimation technique is GMM using as instruments a constant term and 4 lags each of overall CPI inflation, wage inflation, the unemployment gap, and inflation expected two quarters ahead. Robust standard errors are presented in parentheses under the coefficient estimates with * and ** indicating coefficient is statistically different from zero at 10-percent and 1-percent levels, respectively.

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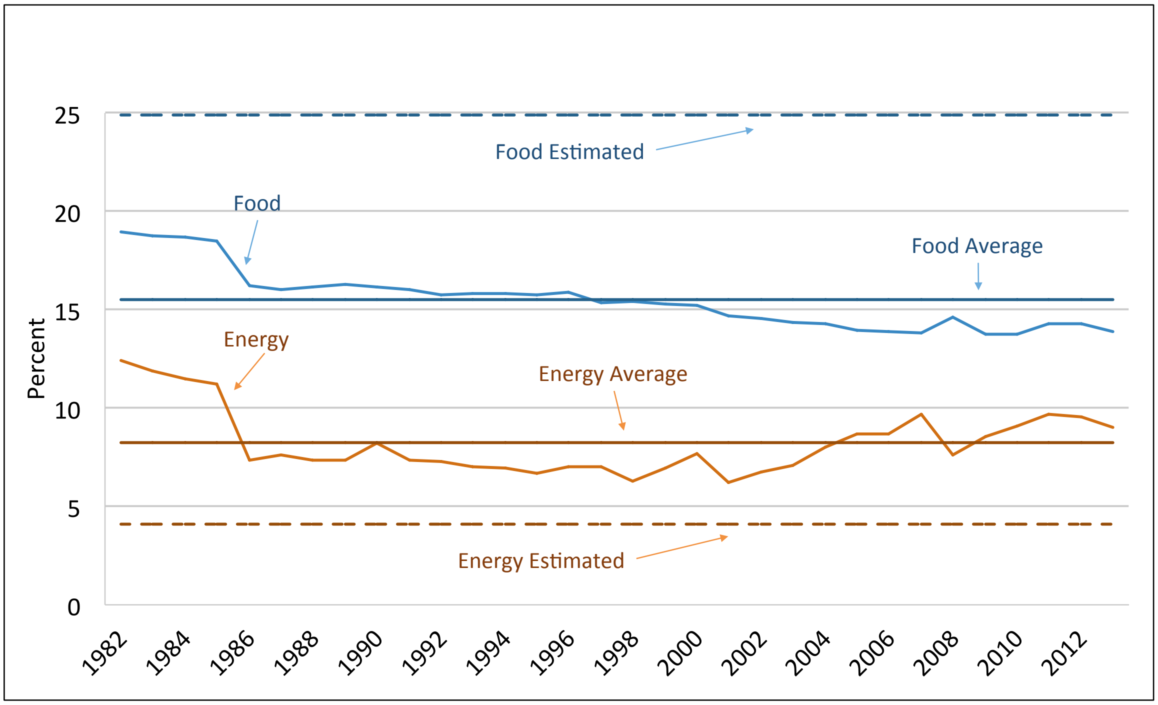
[a] Test of null hypothesis that estimated relative weights satisfy restrictions given by equation (18a).
[b] Test of null hypothesis that estimated relative weights equal actual relative weights.

Figure 1: Relative Importance of CPI Components, 1982 to 2013



Source: Bureau of Labor Statistics and authors' calculations.