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Expectations as a source of macroeconomic persistence: Evidence from survey expectations in a dynamic macro model ☆

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ABSTRACT

Embedding survey expectations in a standard DSGE model helps to identify key slope parameters in standard relationships; dramatically reduces the need for lagged dependent variables, often motivated by price-indexation and habit formation; and obviates the need for autocorrelated structural shocks in the key equations. Formal statistical tests demonstrate that much of the persistence in aggregate data is better accounted for by slow-moving expectations, rather than by habits, indexation and autocorrelated structural shocks.

1. Introduction

Macroeconomic models have followed two long-standing traditions. The first, typified by vector autoregressions (VARs), aims to achieve empirical fit while imposing minimal theoretical restrictions. The second is the DSGE tradition, which derives micro-founded models, imposing tight theoretical restrictions, while still hoping to obtain reasonable empirical success. In between these two strands are models like the Federal Reserve Board staff's FRB/US model, which embodies theory-based structural relationships, but also employs numerous empirically-motivated additions to the theory-model core. Curiously, most DSGE models, while beginning from sound theoretical foundations, have also added a number of empirically-motivated add-ons, to address significant counterfactual implications of the earlier versions of these models (see for example Estrella and Fuhrer, 2002; Rudd and Whelan, 2007). The additions of habit formation, price indexation (for which there is scant microeconomic evidence), adjustment costs, and serially correlated shocks all fall into this category.

This paper follows a different, hopefully fruitful route. The paper begins with a micro-founded model, but rather than adding terms such as habits and indexation, we instead replace expected variables with their survey counterparts, thus

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taking survey expectations to be the realized expectations in the model.[1] Of course, such a departure from rationality comes at a cost. The beauty of the rational expectations paradigm is that once one specifies the model, one simultaneously has specified the expectations that are consistent with the model. That beauty is lost with the introduction of survey expectations, as one can no longer "solve out" expectations in the simple way that has become standard in the DSGE literature.

To fully embed survey expectations in the model, this paper uses several theory-based approximations and empirically-motivated compromises, which will be described in more detail below.[2] The model comprises the core of most extant DSGE models: Output depends on expected output and the real rate of interest; inflation depends on expected inflation and real output or marginal cost; and short-term interest rates are set by a monetary authority according to a forward-looking policy rule that depends on expected inflation and output relative to their targets.

Three basic mechanisms are then employed to endogenize survey expectations. First, short-term expectations appear as data in the Euler equations for inflation and unemployment (which proxies for output). Second, expectations, while not rational, will be assumed consistent with the underlying logic of the relevant Euler equations, in the sense that the current expectation for inflation (unemployment) solves out to equal an infinite sequence of short-term expectations of unemployment (real rates). This sequence of expected unemployment rates (real rates) will be proxied by long-term survey expectations for inflation (unemployment), which are assumed to embody the relevant sequence of expectations for unemployment (real rates). Third, the actual short-run expectations may display intrinsic persistence, in the sense that they will gradually error-correct towards the expectations path implied by the long-run expectations. It is in this way that expectations can add intrinsic persistence to the other mechanisms in the model. However, the paper does not assume any specific degree of intrinsic expectations persistence, but rather allows the data to determine how much of this type of persistence best explains macroeconomic fluctuations.

The data used here comes from the Survey of Professional Forecasters, but in principle any direct measures of expectations could be employed. As noted above, one important criterion in using such measures is the availability of longer-term forecasts, as these are used to approximate the expected sums of future variables that figure prominently in key macroeconomic relationships.[3]

Using this approach, the paper develops evidence that the systematic use of survey expectations offers a number of advantages over many standard models with rational expectations. The identification of key parameters is improved, and the need for macroeconomic "epicycles" such as correlated shocks and pseudo-structural features that add lagged endogenous variables to the model is much reduced. Because expectations are fully endogenous, the model can be used to provide structural interpretations for shocks and impulse responses. The result is a compact model of inflation and unemployment that might compete with the Clarida-Galí-Gertler (1999) or Rudebusch-Svensson (1999) models. Recognizing the tradeoffs involved in the approach taken here, the paper concludes that the move to employing survey-based measures of expectations represents a viable and potentially useful direction for macroeconomic modeling.

Section 2 develops a DSGE model that employs an array of survey expectations measures, is consistent with the core of extant theory, and addresses some of the theoretical difficulties inherent in departing from rational expectations. Section 3 presents some single-equation evidence that suggests that a variety of survey expectations measures demonstrate empirical relevance in key elements of the standard models. Section 4 presents an array of empirical results from system estimation of the model developed in Section 2, along with a variety of tests to assess the relative contributions to aggregate dynamics from intrinsic persistence in the expectations process, versus persistence arising from habits, indexation and autocorrelated shocks. Section 5 concludes.

2. A Structural DSGE model with ubiquitous survey expectations

We develop a semi-structural model that is inspired by familiar micro-founded DSGE models. That is, while the model is not completely micro-founded, its form derives from well-known models that are. The model thus comprises a New Keynesian-style Phillips curve that links inflation, inflation expectations and unemployment; an "IS" curve linking

[1] To be sure, a large literature explores alternative expectations schema, in some cases employing survey data to help identify expectations mechanisms. An early example of such a strategy is Roberts (1997). Other examples are found in Fuster et al. (2012), Mankiw and Reis (2002), Carroll (2003) , Adam (2005), the many papers of Evans and Honkapohja and their 2001 book (Evans and Honkapohja, 2001), Milani (2007), Orphanides and Williams (2005), and Slobodyan and Wouters (2012), and Molnár and Ormeño (2015).

[2] The underlying assumptions that motivate the treatment of expectations in the paper draw in part on Adam and Padula (2011) and Branch and McGough (2009), and allow one to aggregate across heterogeneous agents, to ignore higher-order expectations, to pass expectations through linear operators, and importantly to allow surveys to conform to the law of iterated expectations. The aforementioned authors have shown that with these assumptions, one can derive models that embed survey expectations, and that are reasonably well-approximated by the underlying log-linearized relationships embodied in standard DSGE models. While the methods used in this paper may not apply to every macroeconomic model, they comprise elements that should be usable in many applications.

[3] Surveys now provide rather extensive data on the forecasts and expectations formed by agents in the economy. While the incentives to devote resources to expectation-formation are questionable in some surveys, for the respondents to the SPF employed in this paper, forecasting is a primary business line for the survey participants, so presumably the incentives are strong for devoting significant resources to forecasting. The paper will not test the extent to which survey expectations may be considered "rational" in the statistical senses of unbiased and efficient; many authors have done so in previous work (see Batchelor, 1986; Bryan and Gavin, 1986; Mehra, 2002; and Adam and Padula, 2011). Instead, this paper will take the survey expectations as given, despite the possibility that such expectations may be characterized by irrationality.

unemployment, unemployment expectations and a short-term real rate of interest; and a policy rule that makes the short-term policy rate a function of near-term forecasts of inflation and unemployment deviations from their targets, allowing for interest rate smoothing. The details of the specification follow.

2.1. Price-setting

Our measure of inflation is the overall or "headline" CPI, which we choose because the longest-available long-dated (10-year) survey expectations measure from the SPF reports forecasts for the overall CPI. Because transient shocks from changes in the relative prices of food and energy consistently buffet the headline CPI measure, and because our proxy for marginal cost (the unemployment gap) can only indirectly incorporate such shocks, we allow for the independent effects of food and energy prices on the CPI as "supply shifters." We thus begin with a simple expectations-augmented Phillips curve that is motivated by the NKPC, as follows,[4]

$$\pi_t = \beta\pi^S_{t+1,t} - \pi^u(U_t - U^*_t) + w^e dp^e_t + w^f dp^f_t. \tag{1}$$

To endogenize inflation expectations, we could iterate Eq. (1) forward one period, and then solve forward, which would imply that expected inflation depends on an infinite sequence of expected unemployment gaps. Here, we approximate this long sequence of expected unemployment gaps with the SPF measure of the 10-year average expected inflation rate, as this measure should embody—according to the model's underlying logic—the appropriate sequence of short-term expectations, in a sense performing the forward iteration for us. As noted above, we will also allow for the possibility that short-run expectations adjust gradually towards this long-run sequence of expectations. Together, these assumptions imply an error-correction equation for short-run expectations

$$\pi^S_{t+1,t} = \mu^\pi\left[A^{\pi e}\Pi^S_{LR,t} - \pi^u\left(U^S_{t+1,t} - U^*_{t+1}\right)\right] + (1-\mu^\pi)\left(\pi^S_{t,t-1}\right), \tag{2}$$

where the parameter $(1-\mu^\pi)$ indexes the speed of adjustment. Note that this partial adjustment formulation implicitly introduces lagged inflation expectations into the determination of inflation and inflation expectations. Equivalently, it builds some "intrinsic persistence" into the inflation *expectations* process without introducing lags of *realized* inflation. We will examine the importance of this partial adjustment mechanism in Sections 3 and 4, specifically by testing the data's ability to distinguish between the influence of lagged expected versus lagged actual inflation. Of course, to completely close the model, we will need to solve for the survey expectations for unemployment in subsequent periods. We will tackle this issue when we discuss the IS curve below.

Energy and food prices, which enter Eq. (1), are assumed to follow simple AR processes in log changes:

$$dp^e_t = a^e dp^e_{t-1} + \eta^e_t;\, dp^f_t = a^f dp^f_{t-1} + \eta^f_t \tag{3}$$

Long-run inflation expectations are taken as a proxy for the central bank's current inflation goal, which varies over time. In this model, the current inflation goal (and long-run inflation expectations) is assumed ultimately to converge to the fixed long-run central bank inflation target π^*. The inflation goal can deviate from its long-run target with some persistence, which we model via a partial adjustment equation with parameter ω

$$\Pi^S_{LR,t} = \omega\Pi^S_{LR,t-1} + (1-\omega)\pi^*. \tag{4}$$

OLS estimates of Eq. (4) imply that ω has a value of 0.95, and this value is used throughout the remainder of the paper. Note that we choose this slow-moving autoregressive process for the long-run inflation rate because it is a simple way of endogenizing a time-varying inflation goal. In the long run, expectations converge to the model's steady state. The AR(1) captures the timeseries pattern of long-run inflation expectations, but does not impute deeper behavioral reasons for movements in the central bank's target; neither does Eq. (4) impose any significant restrictions on the rest of the model.

2.2. IS curve

Underlying the IS curves in most DSGE models is the simple life-cycle model of consumption, which under rational expectations and reasonable assumptions about preferences implies a linear approximation to the first-order conditions that links consumption to the real interest rate. While we do not provide a true micro-founded derivation here, we assume that in the absence of capital investment, with fixed government spending, and with some common assumptions about the

[4] Note that the persistence of the headline inflation measure is actually *lower* than that of the core measure that excludes food and energy. That is, the relative price shifts that are captured in the food and energy measures are entirely transitory noise that *subtracts* from the underlying inflation measure's persistence. In no sense does inclusion of the relative price measures absorb persistence in the headline series; instead, these series soak up transitory noise in inflation that allows us better to identify the correlations among inflation, expectations, and unemployment. The estimated coefficients a^e and a^f in Eq. (3) below are both about 0.2, implying very little persistence of these shocks, and hence very little contribution to expectations of future inflation. As a consequence, these variables play very little role in the model other than absorbing contemporaneous and transitory relative price shifts in total CPI inflation.

underlying production function, one can write the IS curve in terms of unemployment and the real rate:[5]

$$U_t - U_t^* = u^{ue}\left(U_{t+1,t}^S - U_{t+1}^*\right) + u^{\rho}(\rho_t - \overline{\rho}). \tag{5}$$

where ρ_t and $\overline{\rho}$ are a real rate of interest and the long-run equilibrium value of that rate, respectively.[6] The real interest rate here is defined as the difference between the nominal interest rate and the inflation expectation from the SPF. Unemployment expectations are assumed to equal the survey expectations.

This equation is complete given observations on the one-period ahead survey expectations for unemployment, which are collected in the SPF. In order to close the model, we need to posit a process for the unemployment expectation. In parallel fashion to the price equation, we link the one-period-ahead inflation expectation to a long-term (e.g. ten-year average) unemployment expectation, which is meant to implicitly capture a sequence of short-run expectations of real interest rates:

$$U_{t+1,t}^S - U_{t+1}^* = \mu^U\left[u^{ue}\left(U_{LR,t}^S - U_t^*\right) + u^{\rho}(\rho_t - \overline{\rho})\right] + (1-\mu^U)\left(U_{t,t-1}^S - U_{t-1}^*\right). \tag{6}$$

While the SPF does not collect forecasts of the equilibrium unemployment rate on a consistent basis over a long sample, the Blue Chip forecast survey has done so since 1984. Eq. (6) also specifies the intrinsic persistence of short-run expectations, via partial adjustment of the short-run unemployment expectations to the longer-run expectations. As in the specification for inflation expectations, the parameter $(1-\mu^U)$ indexes the speed of adjustment.[7]

Because the steady state for the unemployment gap should be zero in this simple model, we close the model by assuming that long-run unemployment expectations deviate temporarily from zero, in a manner parallel to long-run inflation expectations as defined in Eq. (4). That is,

$$U_{LR,t}^S - U_t^* = \gamma^U\left(U_{LR,t-1}^S - U_{t-1}^*\right). \tag{7}$$

This approach guarantees that the long-run survey expectations will converge to the appropriate steady state for the unemployment gap (zero) in the long run. OLS estimates of Eq. (7) imply that γ^U has a value of 0.94, and this value is imposed throughout the remainder of the paper.

2.3. Interest rates

In most DSGE models, the appropriate real rate of interest for the IS curve is the one-period risk-free real rate of interest. This formulation implies that, with rational expectations, real activity will implicitly depend on the long-term real interest rate (achieved by iterating forward the Euler equation into the infinite future). The standard definition of the one-period real interest rate ρ_t^1 is just the difference between the current short-term policy rate and the one-period-ahead expected inflation rate,

$$\rho_t^1 \equiv i_t - \pi_{t+1,t}^S. \tag{8}$$

We specify a policy rule that defines the short-term policy rate i_t. We assume a forward-looking policy rule that employs survey expectations of inflation, long-term inflation, and unemployment. First, define the deviation of the federal funds rate, $\tilde{i}_t$ from its long-run equilibrium as

$$\tilde{i}_t \equiv i_t - \left(\Pi_{L,t}^S + \overline{\rho}\right). \tag{9}$$

We can then write a forward-looking policy rule in the policy rate deviation, allowing for interest-rate smoothing

$$\tilde{i}_t = a\tilde{i}_{t-1} + (1-a)\left[i^{\pi}\left(\pi_{t+1,t}^S - \Pi_{L,t}^S\right) - i^u\left(U_{t+1,t}^S - U_{t+1}^*\right)\right]. \tag{10}$$

For reasons discussed below, we replace Eq. (8) with a slightly longer-term real interest rate in the IS block, defined as the difference between the SPF expectations for the one-year-ahead Treasury bill rate and the one-year-ahead inflation rate, or[8]

$$\rho_t \equiv i_{1Y,t}^S - \pi_{1Y,t}^S \tag{11}$$

This compromise retains the spirit of the one-period trade-off implied by the consumption Euler equation and yields considerably better empirical performance, as will be shown below.[9] Of course, the one-year-ahead SPF forecast for the three-month Treasury bill, $i_{1Y,t}^S$ requires an internally-consistent definition to close the model. We assume that the forecasts implied by the policy rule for the federal funds rate will provide a reasonable approximation to the SPF's forecasts of the

[5] As discussed in Blanchard and Galí (2010), in simple models in which there is no difference between the intensive and the extensive margin of labor, and in which capital input is fixed or absent, output and employment are proportional.

[6] Because it is more difficult to construct a measure of equilibrium output that is consistent with the SPF forecasts of GDP through the years, and given the changes in methodology and base years, we choose this form of the IS curve, which is expressed in terms of the unemployment gap.

[7] As with inflation, the difference between the autocorrelations of the raw unemployment data and the unemployment gap is modest: the first autocorrelation coefficient for the raw data is 0.94; the corresponding AR coefficient for the gap is 0.93.

[8] Note the notational difference: ρ_t^1 denotes the one-period real interest rate, while ρ_t denotes the one-year real interest rate, which is the variable that enters the IS curve and its associated expectation equation, captured in Eqs. (5) and (6).

[9] In a much earlier paper, Fuhrer and Moore (1995) showed that a reduced-form IS curve that depends explicitly on a longer-term real interest rate achieves some empirical success. See also Fuhrer and Rudebusch (2004) for a discussion of identification of the IS curve.

three-month Treasury bill rate over the next year. Thus the model's forecast of the average short rate over the next four quarters is the rational expectation implied by the policy rule (and the rest of the model),

$$i^S_{1Y,t} = 0.25E_t(i_{t+1} + i_{t+2} + i_{t+3} + i_{t+4}) \quad (12)$$

In sum, the model comprises equations for the Phillips curve, short-run inflation expectations, the long-run evolution of inflation expectations (imposing convergence to the central bank's inflation target), the IS curve, short-run unemployment expectations, the long-run evolution of unemployment expectations (again imposing convergence to the natural steady-state of zero for the unemployment gap), two equations defining the monetary policy rule, and a term structure equation that defines the one-year rate as the expectation of the four quarterly short-term (policy) rates. The equations in question are found in (1), (2), (4)–(7), (9)–(12). As constituted, the model is a general equilibrium model of prices, output and interest rates, and thus may be suitable for counterfactual policy exercises, forecasting, and economic "story-telling," subject to the usual caveats.

Note that this is the only case in the model in which we allow rational expectations to play a role. Because rational in this context means "model-consistent," these expectations will of course take into account the role that survey expectations play in the determination of the key variables (unemployment and inflation) that enter the policy rule. This assumption thus implies that the rational expectations for the policy rate in this model will differ from those in a standard DSGE models in which all expectations are rational.

3. Single-equation evidence on the usefulness of survey expectations

We present a number of single-equation results linking survey expectations measures with key macroeconomic aggregates, using multivariate relationships that are similar to those that appear in standard macroeconomic models. The point is not to claim structural identification, but to demonstrate the strong correlations between survey variables and key macro variables in somewhat restricted regression equations that evoke standard macroeconomic relationships. We focus on the key building blocks of the simplified DSGE model laid out in Section 2: A price-setting Euler equation, an "IS" curve that is motivated by a consumption Euler equation, and a monetary policy rule that is explicitly forward-looking.

3.1. Price-setting

We first estimate Eq. (1), the expectations-augmented Phillips curve. The survey expectation is the four-quarter change in total CPI inflation from the Survey of Professional Forecasters. Actual inflation is measured as 400 times the log change in the total CPI, the measure to which the survey expectations refer. The estimation sample is 1982:Q4 to 2012:Q4, restricted by the availability of some of the survey data. We employ ordinary least squares (OLS) estimation, as the survey expectations are recorded in the middle of quarter t, and thus contain price and output information only for quarter $t-1$ and earlier.

The regression results and summary statistics are reported in panel 1.1 of Table 1 below. Fig. 1 displays the fitted values. Both the unemployment gap, measured as the difference between the civilian unemployment rate and the CBO's estimate of the NAIRU, and the two relative price variables for the log change in energy and food prices (dp^e and dp^f) enter contemporaneously and with two lags.[10,11] Restricting inflation expectations to enter with a coefficient of one is a step toward a more structural equation; moreover, the p-value for the F-test of this restriction is 0.76, so it is clearly not rejected by the data. The results suggest a prominent role for survey expectations in the inflation equation. These results are similar to those reported in Fuhrer (2012) and Fuhrer et al. (2012).

An empirical fact that has dogged researchers for decades is the dependence of macro variables on their own lagged values, after accounting for the normal structural influences. This empirical regularity has given rise to the inclusion of rule-of-thumb pricing or indexation (Galí and Gertler, 1999; Christiano et al., 2005) for price-setting, and to habit formation (Fuhrer, 2000; Carroll and Overland, 2000) for consumption models. Table 1 shows the diminished dependence of the Phillips and IS curves on lagged dependent variables once the survey expectations are taken into account. For the estimated Phillips curve, the coefficients on the two lags of inflation are small (summing to –0.021), and are estimated imprecisely. The inclusion of additional lags further weakens statistical significance. The autocorrelation of the residuals of Eq. (1), shown in the rightmost panel of Table 1, suggests no significant autocorrelation. While still a somewhat reduced-form equation, these results suggest little need for indexation or serially correlated markup shocks, once the survey expectations are included.

We estimate the inflation expectation Eq. (2) (abstracting from the error-correction term); the results are displayed in panel 1.2 of Table 1. As the table indicates, the one-year inflation expectations exhibit very strong correlation with the

[10] Lag lengths are chosen using standard criteria, specifically by minimizing the AIC and Schwartz–Bayes criteria, which suggest a lag length of one or two quarters.

[11] Most of the data in this paper are real-time data—the SPF forecasts are not revised, and neither is the CPI inflation measure, the federal funds rate, or the 10-year Treasury yield. The unemployment rate has small and mostly seasonal adjustment-related revisions. The CBO's estimate of the NAIRU is not a real-time estimate. The CBO publishes quasi real-time estimates of the NAIRU back to 1991. However, from 1991 to 2009 these were updated each year only in January. Thus no real-time data are available prior to 1991, and the yearly updates create some undesirable discontinuities in the series.

Table 1
Regression results, simple single-equation models 1982:Q4–2012:Q4.

1. **Inflation**				
$\pi_t = \beta\pi^S_{t+1,t} - \pi^u(U_t - U^*_t) + w^e dp^e_t + w^f dp^f_t$				
Variable	**Coefficient**	***p*-value**	**Residual autocorrelations**	
			Lag	**Value**
Expected inflation (β)	1	(imposed)		
Unemployment gap (π^u)	-0.12	0.018	1	0.19
Change in food prices (sum) (w^e)	0.085	0.0035	2	0.088
Change in energy prices (sum) (w^f)	0.10	0.00	3	0.077
Lagged inflation	$\mathbf{-0.021}$	**0.81**		
R^2: 0.86				
2. **Inflation expectations**				
$\pi^S_{t+1,t} = A^{\pi e}\Pi^S_{LR,t} - \pi^u\left(U^S_{t+1,t} - U^*_{t+1}\right)$				
Long-run inflation expectation ($A^{\pi e}$)	0.75	0.00	1	0.74[a]
One-quarter-ahead unemployment expectation (π^u)	-0.19	0.00	2	0.64[a]
R^2: 0.90			3	0.54[a]
3. **Unemployment gap (using long real rate)**				
$U_t - U^*_t = u^{ue}\left(U^S_{t+1,t} - U^*_{t+1}\right) + u^\rho(\rho_t - \bar{\rho}) + u^L(U_{t-1} - U^*_{t-1})$				
			Residual autocorrelations	
One-quarter-ahead unemployment expectation (u^{ue})	1.01	0.00	1	0.27[a]
Long-term real interest rate (u^ρ)	0.024	0.027	2	0.085
Lagged unemployment gap (u^L)	**0.22**	**0.00**	3	0.031
R^2: 0.99				
4. **Unemployment expectations (1984:Q4–2012:Q4)**				
$U^S_{t+1,t} - U^*_{t+1} = u^{ue}\left(U^S_{LR,t} - U^*_t\right) + u^\rho(\rho_t - \bar{\rho})$				
Long-run unemployment expectation (u^{ue})	1	(imposed)	1	0.97*
Short-term real interest rate, *or*	-0.11	0.032	2	0.91[a]
Ten-year real interest rate (u^ρ)	0.071	0.033	3	0.85[a]
R^2: 0.24, 0.24				
5. **Policy rule (Funds rate deviation) 1982:Q4–2007:Q3**				
$\tilde{i}_t = a\tilde{i}_{t-1} + i^\pi\left(\pi^S_{t+1,t} - \Pi^S_{L,t}\right) - i^u\left(U^S_{t+1,t} - U^*_{t+1}\right)$				
Lagged funds rate (a)	0.80	0.00	1	0.69[a]
SPF 4-quarter inflation expec. (i^π)	0.41	0.017	2	0.55[a]
SPF 1-quarter unemployment expec. (i^u)	-0.43	0.000	3	0.41
R^2: 0.95				

All regressions are estimated via ordinary least squares, with the independent variables as indicated in the left-hand column. In panels 1.1 and 1.4, the leading coefficient is constrained to equal one.

[a] indicates that the autocorrelation is more than two times the standard error.

longer-run unemployment gap expectation and with the one-quarter forecast. The top-right panel of Fig. 1 shows that this simple specification captures many—but not all—of the important fluctuations in this variable over its history (note the significant residual autocorrelations for panel 1.2 in Table 1). The persistent errors in the simple specification suggest sluggish adjustment of short-run expectations to longer-run fundamentals, a topic to which we will return in Section 4.

Taken together, these two equations suggest the beginnings of a relatively coherent model for inflation. Inflation adheres to the generic form now prevalent in the literature, depending with a coefficient of one on near-term inflation expectations, and driven by a real variable whose effect is estimated with reasonable precision. Expectations in turn depend on further-out expectations of the real variable, and are anchored to the long-run inflation expectation. Thus the single-equation results point toward a structural model that can close much of the expectations loop in a way that reasonably balances theory and empirics.

3.2. IS curve (unemployment)

As in many studies, we find that identification of the IS curve is not straightforward. A long-term interest rate, defined as the difference between the 10-year Treasury yield and the maturity-matched inflation expectation, enters significantly in the

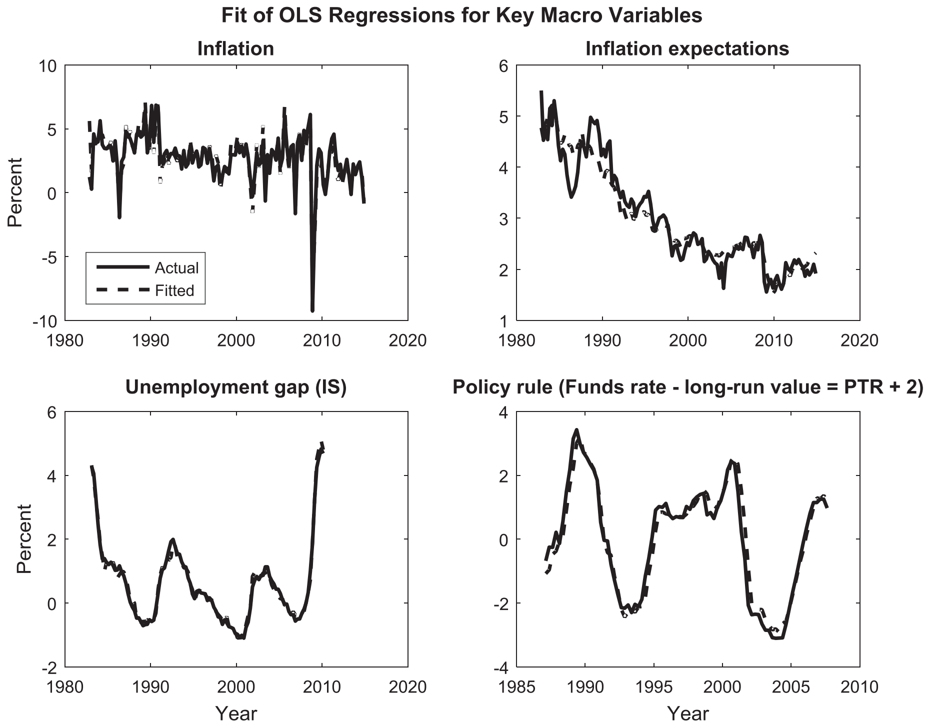

Fig. 1. The figure displays the actual and fitted values from the regression estimates displayed in Table 1.
Source: Author's calculations.

IS equation. However, it is difficult to develop a theoretical motivation for such a relationship. The equation with the one-period short-term rate performs poorly—the estimated coefficients often have the wrong sign and quite large standard errors.

In Table 1, panel 1.3 displays the OLS estimation results for Eq. (5), using a long-term real interest rate. The coefficient on the SPF unemployment gap expectation is precisely estimated at very near one, and the real interest rate is estimated with the correct sign and fairly high significance.[12] The relatively small coefficients of 0.02–0.03 on both the longer real rate and the short-term real rate are not unusual for estimated IS curves.[13]

The R^2 for the regression is 0.99; the residual autocorrelations in the rightmost panel of Table 1 suggest no serial correlation. The fitted values for the regression, shown in the bottom left panel of Fig. 1, suggest a very tight fit for the regression. A version of the model that includes a lagged unemployment gap, shown in the bottom row of panel of table 1.3, develops a small (but significant) coefficient. Thus while the role for lagged unemployment now is much diminished compared to the standard specifications with habit formation (the OLS estimate of 0.19 contrasts with that of 0.7–0.9 in many published estimates of the habit parameter), the reduced-form equation rejects the hypothesis that the lagged dependent variable has no influence.

Panel 1.4 of Table 1 reports results from OLS estimates of the short-run unemployment expectation as in Eq. (6), using the same two measures of the real interest rate. The sample begins in 1984, as the long-run survey expectations for unemployment begin at that time. As the table indicates, the results are not always as expected—the short-term real rate variable enters with the wrong sign. Section 4 will explore system estimates of this equation, which fare much better.

3.3. Policy rule

The results from the OLS estimation of Eq. (10) are shown in Table 1, panel 1.5. The sample ends in 2007:Q3 so as to avoid the zero lower bound period.[14] All the coefficients are estimated with correct signs and high statistical significance. Note that the long-run response coefficients for expected inflation and unemployment equal the estimated values reported in

[12] Once again, the lag length for the real interest rate is chosen using a combination of AIC and Schwartz–Bayes criteria, which agree in this case.

[13] For many models, a 1 percentage point change in the federal funds rate is roughly equivalent to a 0.25 to 0.33 percentage point rise in the 10-year rate, so the expected ratio of these coefficients is three or four to one. See, for example, Fuhrer and Olivei (2011) for a discussion of these multipliers in a discussion of the effects of the Federal Reserve's Large-Scale Asset Purchase programs.

[14] Estimates of the other equations in Table 1 using a sample that ends in 2007:Q3 produce nearly identical results to those reported in the table.

Table 1 premultiplied by $\frac{1}{1-a}$, which yields 2.41 and –2.25 for the responses to inflation and unemployment, respectively. The fit of the equation, displayed in the bottom-right panel of Fig. 1, is quite respectable. The estimated residuals for the equation exhibit modest serial correlation, which is not surprising given the inclusion of the lagged dependent variable. While one might wish for a policy rule that does not require interest-rate smoothing, sorting out the sources of apparent interest-rate smoothing is a job for another paper.

3.4. Cointegration

One simple explanation for the high correlation between rational expectations and realizations of survey expectations is that the two series are integrated of order one, and thus these regressions are simply uncovering a natural cointegration between a forecast and the realizations of the variable being forecasted. In this case, the exact lead-lag timing of the regression would not matter much: The exercise would be less likely to uncover an interesting dynamic macro link and more likely to reveal the general tendency for such paired series to move together at the low frequencies.

However, conventional unit root tests suggest it is extremely unlikely that the correlation between forecasts and realizations arises from a common unit root over the sample period in question, which in this case is 1982 to the present. This is largely because most of the conventional tests reject the presence of unit roots in these data with high confidence. Thus we can rule out an explanation that relies on cointegration.[15]

4. System estimates and identification

The preceding section provided suggestive quasi-structural evidence that survey expectations may serve as very useful proxies for expectations in dynamic macro models. But there are two reasons why these regressions cannot claim to provide true identification. First, the simultaneous causation among interest rates, output, and inflation that is latent in the data will be difficult to disentangle without estimating the policy rule (which implies causation from output and inflation to interest rates), the IS curve (which implies causation from interest rates to output), and the Phillips curve (which implies causation from output to inflation). The goal of this section is to estimate the model of Section 2, simultaneously estimating these key equations, with the aim of more confidently identifying the causal linkages among the key variables.

Second, the single equations do not explicitly solve the problem of how to close the model—that is, how to solve for future values of survey expectations, as highlighted in Section 1. In this section, we implement the compromises for closing the model with survey expectations as discussed in Section 2.

As suggested in Section 3, initial estimates suggest that whereas short-run expectations generally track movements in the long-run inflation expectation (the central bank's inflation goal or long-run unemployment expectations for inflation and unemployment, respectively), the initial estimates of Eqs. (2) and (6) show that the one-quarter expectations persistently deviate from the fundamentals specified in the respective equations.

Table 2 displays prior distributions and Bayesian (and, for comparison, OLS where available) estimates of all the parameters in the model, along with summary statistics for the simulated posterior distribution. The sample is 1984:Q2, the beginning date of the Blue Chip natural rate estimates, through 2007:Q3, prior to the beginning of the Great Recession, the period in which the funds rate was pinned at the zero lower bound, and prior to the widely-noted flattening of the Phillips curve. Fig. 2 plots the associated parameter distributions, along with prior distributions, for each of the parameters. The system estimates generally do not differ too dramatically from the OLS estimates presented in Table 1. But some differences are worth noting. The key elasticities in the Phillips and IS curves, π^u and u^ρ, both increase in magnitude relative to the single-equation OLS estimates. The difference is particularly striking for the Phillips curve, which is about four times the size of the OLS estimate. Still, in both cases the standard deviation of the posterior distribution is large enough to admit either OLS or Bayesian estimates.

Critically, the estimates of intrinsic expectations persistence—the partial adjustment coefficients implied by the estimates of $(1-\mu^\pi)$ and $(1-\mu^U)$ in Eqs. (2) and (6)—are large and statistically significant, at 0.87 and 0.89 respectively, with standard errors of 0.15 and 0.11. We can use the estimated model to assess the economic significance of the partial-adjustment. The top four panels of Fig. 3 display the in-sample fit of the model at the estimated values of $[\mu^\pi, \mu^U]$ and at values that drastically reduce the importance of partial-adjustment. It is at once obvious from this figure that the fit for inflation expectations, unemployment realizations, and unemployment expectations deteriorate quite dramatically in the absence of partial adjustment.[16] The fit of the Phillips curve is improved, but less significantly. Thus in this model, the intrinsic persistence in expectations is crucial for explaining fluctuations in unemployment, inflation and their expectations.

The estimated policy rule tracks the actual funds rate quite well (not shown). The estimated autocorrelations of the structural disturbances (not shown) are quite similar to those developed in the single-equation estimates of Section 3,

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[15] The results for the augmented Dickey-Fuller test are very strong for the inflation and unemployment gap series, rejecting the presence of a unit root with p-values of 1 percent or smaller. ADF tests are weaker for the presence of unit roots for inflation and unemployment gap expectations. However, the results for the Elliott-Rothenberg-Stock and Ng-Perron tests are extremely strong for these series.

[16] The fit is computed via a static simulation of the model over the sample indicated, taking relative food and energy prices and the long-run inflation expectation as exogenous.

Table 2
Estimates of DSGE model with survey expectations.

Parameter	Prior distribs. [{Support}, mean, standard deviation]	OLS	Posterior distribution summary statistics				
			Mode	Median	Std. Dev.	5th percentile	95th percentile
π^u	Gamma [{0.001,1.2},0.5,0.2]	0.069	0.34	0.44	0.27	0.083	0.98
μ^π	Beta [{0.001,0.99},0.3,0.1]	–	0.13	0.19	0.15	0.031	0.53
$A^{\pi e}$	Beta [{0.001,1},0.7,0.15]	0.75	0.75	0.64	0.24	0.17	0.95
u^{ue}	Gamma [{0.2,1.3},0.9, 0.2]	1.03	1.1	1	0.15	0.76	1.3
u^ρ	Gamma [{0.001,0.5},0.05,0.02]	0.028	0.067	0.087	0.061	0.013	0.21
$\bar{\rho}$	Gamma [{0.001,6},2.5,0.8]	–	2.6	2.7	0.72	1.6	4
μ^U	Beta [{0.001,0.99},0.3,0.1]	–	0.11	0.15	0.11	0.02	0.38
a	Beta [{0.2,0.99},0.7,0.15]	0.81	0.86	0.81	0.13	0.56	0.97
i^π	Gamma [{0.001,2.5},1.4,0.25]	2.4	0.52	1.2	1	0.16	3.3
i^u	Gamma [{0.001,2},0.5,0.2]	2.3	0.4	0.94	0.93	0.14	3.2

Sample: 1984:Q2–2007:Q3.
The estimation uses four blocks of 250,000 replications each; the first 50,000 are dropped for burn-in. Results for a larger burn-in allowance are virtually identical. The model is described in Section 2, and comprises Eqs. (1), (2), (4)–(7), (9)–(12).

although they are generally a bit smaller and even less significant. For a model that excludes lagged dependent variables and autocorrelated shock processes, the fit, while not an explicit estimation criterion, is quite good.

To be sure, identification is not completely trouble-free in this model. While the data clearly shift and generally sharpen the posterior distributions relative to the priors for most key parameters, including all IS curve parameters and the parameters associated with expectations in both IS and Phillips curves, this is not the case for the Phillips curve slope parameter, or for the slope parameters in the policy rule. The estimate of the Phillips curve slope, π_u , while larger than many estimates in the literature, is still estimated fairly imprecisely, with a [5%, 95%] confidence interval that spans [0.083, 0.98].

4.1. Tests for the importance of habits and indexation

We begin with a simple single-equation omitted variable test for the exclusion of the lagged dependent variables that proxy for habits or indexation in the IS and Phillips curves. The test takes the form

$$\varepsilon_t^i = \lambda y_{t-1}^i + \beta_i X_t^i + e_t, \tag{13}$$

where ε_t^i is the estimated structural disturbance for the inflation or unemployment gap equation, y_{t-1}^i is the lagged value of one of these variables, and the term $\beta_i X_t^i$ represents the other variables that enter the equation. The null hypothesis is that $\hat{\lambda} = 0$, suggesting no additional role for the lagged variable. The top panel of Table 3 presents the results for estimating this equation on the estimated shocks for the Phillips and IS curves. As the table indicates, consistent with the results in Section 3, the coefficient on lagged inflation in the Phillips curve is estimated to be quite small and insignificantly different from zero. The coefficient on the lagged unemployment gap in the IS curve is modest and significantly different from zero, suggesting a possibly statistically important degree of habit formation.

A systems-based testing method allows joint estimation of the effect of lagged inflation and lagged unemployment in the key equations, along with the partial-adjustment mechanism for unemployment expectations represented in Eq. (6). This entails modifying the Phillips curve and IS equations as follows:

$$\begin{aligned} \pi_t &= \pi^L \pi_{t-1} + (1-\pi^L)\pi_{t+1,t}^S - \pi^u (U_t - U_t^*) + w^e dp_t^e + w^f dp_t^f \\ U_t - U_t^* &= u^L (U_{t-1} - U_{t-1}^*) + (1-u^L)(U_{t+1,t}^S - U_{t+1}^*) + u^\rho (\rho_t - \bar{\rho}), \end{aligned} \tag{14}$$

and estimating the parameters π^L, u^L to assess the importance of lagged dependent variables in the augmented model. This test explicitly pits the lagged variables against the persistence that may be induced by the inclusion of survey expectations.

The posterior modes of the Bayesian estimates of π^L, u^L in Eq. (14) are displayed in the middle panel of Table 3, along with simulated standard errors from the posterior distribution. These estimated parameter distributions suggest no role for lagged inflation but a modest role for lagged unemployment in the model. Importantly, note that the estimated partial adjustment coefficients for both inflation and unemployment expectations remain high at about 0.8, with standard errors of 0.15–0.17.

While statistically significant, how economically important is the lagged unemployment gap in explaining model dynamics? The bottom panel of Fig. 3 displays its economic significance by simulating the model at the parameter values estimated in the top panel of Table 2 (the dashed black line) and alternatively by setting u^L to 0.01 (the dotted black line). As the figure indicates, the difference in the simulated values is virtually nil. As compared to the striking impact of the partial

Table 3
Tests of lagged variables in key macroeconomic relationships Single-equation test (Eq. (13)) $\varepsilon_t^i = \lambda y_{t-1}^i + \beta_i X_t^i + e_t$.

Equation	Lag Coefficient	*p*-value
Phillips	0.054	0.21
IS	0.21	0.00

System test for importance of lagged variables (Eq. (14))

$$\pi_t = \pi^L \pi_{t-1} + (1-\pi^L)\pi^S_{t+1,t} - \pi^u (U_t - U_t^*) + w^e dp_t^e + w^f dp_t^f$$
$$U_t - U_t^* = u^L (U_{t-1} - U_{t-1}^*) + (1-u^L)\left(U^S_{t+1,t} - U^*_{t+1}\right) + u^\rho(\rho_t - \overline{\rho})$$

Coefficient	Posterior mode	Standard deviation
π^L	0.10	0.16
u^L	0.57	0.24
$(1-\mu^\pi)$	0.79	0.17
$(1-\mu^U)$	0.79	0.15

RE "horse race" test (Eq. (15))

$$\pi_t - \lambda \Pi^S_{LR,t} = \lambda\left(E_t \pi_{t+1} - \Pi^S_{LR,t}\right) + \pi^L \pi_{t-1} + (1-\lambda-\pi^L)\pi^S_{t+1,t} - \pi^u (U_t - U_t^*) + w^e dp_t^e + w^f dp_t^f$$
$$U_t - U_t^* = \lambda E_t (U_{t+1} - U^*_{t+1}) + u^L (U_{t-1} - U^*_{t-1}) + (1-\lambda-u^L)\left(U^S_{t+1,t} - U^*_{t+1}\right) + u^\rho(\rho_t - \overline{\rho})$$

Parameter	Estimate	Standard error
λ	0.14	0.20
π^L	0.082	0.13
u^L	0.43	0.26
$(1-\mu^\pi)$	0.74	0.17
$(1-\mu^U)$	0.78	0.15

The details of the tests are provided in the text.

adjustment in unemployment expectations displayed in the top panels of Fig. 3, the test and the simulation together suggest there is no economically significant role for lagged actual data in the model with survey expectations.

Overall, these findings are striking. The simple OLS tests for omitted variables suggest at best a small role for lagged unemployment in the IS curve. The system tests also suggest an economically insignificant role for lagged dependent variables in the model. But the role of sluggishly-adjusting expectations in explaining current expectations appears critical to the model's success in explaining both expectations *and* realized data dynamics. What had appeared to be a strong dependence on lagged endogenous variables in DSGE models is better represented as the presence of inertia in expectations.

4.2. A rational expectations "Horse Race"

The paper now examines a head-to-head comparison of DSGE models based on rational expectations with those based on survey expectations, similar to the exercises in Del Negro and Eusepi (2010) and Nunes (2010). A simple way to perform such a comparison is to augment the model Eqs. (1) and (5) so that rational expectations enter with weight λ, and lagged dependent variables and survey expectations enter with weights as in Eq. (14), all of which sum to one as follows:

$$\begin{aligned} &\pi_t - \lambda \Pi^S_{LR,t} = \lambda\left(E_t \pi_{t+1} - \Pi^S_{LR,t}\right) + \pi^L \pi_{t-1} + (1-\lambda-\pi^L)\pi^S_{t+1,t} - \pi^u (U_t - U_t^*) + w^e dp_t^e + w^f dp_t^f \\ &U_t - U_t^* = \lambda E_t (U_{t+1} - U^*_{t+1}) + u^L (U_{t-1} - U^*_{t-1}) + (1-\lambda-u^L)\left(U^S_{t+1,t} - U^*_{t+1}\right) + u^\rho(\rho_t - \overline{\rho}). \end{aligned} \tag{15}$$

Under the null hypothesis that $\lambda = 0$, the rational expectations are unimportant in the determination of the model's key variables. As λ goes to 1 and π^L and u^L go to 0, only the rational expectations matter, and the survey expectations (and equations that determine their evolution) are irrelevant. Note that in this case, the equation is structured so that long-run expectation $\Pi^S_{LR,t}$ enters the Phillips curve with a coefficient of minus one as in Cogley and Sbordone (2008).[17] As $\lambda + \pi^L$ goes to 0, the weight on the survey expectations goes to 1, and similarly for the IS curve. It is critical to note that in this parameterization, the data can choose any combination of λ, π^L and u^L, so that outcomes can include rational expectations with no lags or surveys, rational expectations with lags due to habits and indexation, survey expectations with no lags, and so on. Thus this test puts rational expectations on a completely equal footing with survey expectations.

[17] The precise role that trend inflation should play in a rational expectations Phillips curve remains somewhat controversial. A version of the test that excludes Π^S_{Lt} from the Phillips curve in the test equations delivers the same results: λ is estimated to be 0.11 with an equal-sized standard error, and the other parameters attain approximately the same values.

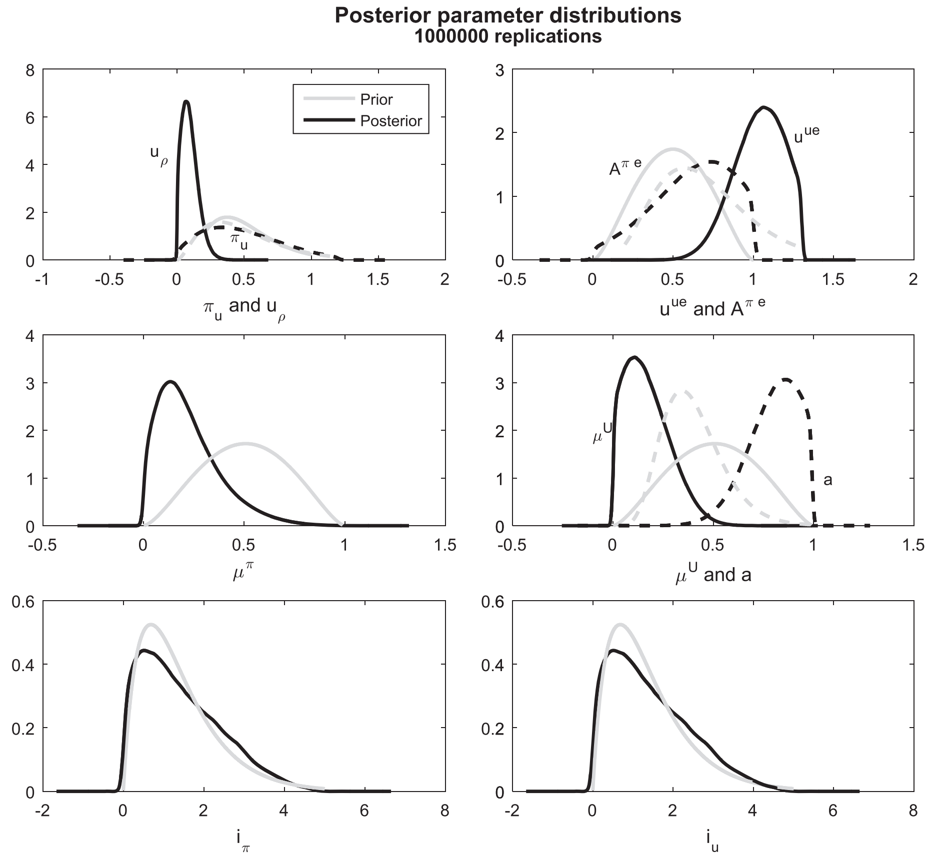

Fig. 2. The figure displays the prior (gray lines) and simulated posterior (black lines) distributions of the parameters in the baseline model of Eqs. (1), (2), (4)–(7), (9)–(12) as described in Section 2. Details of the prior distributions and the estimation method are provided in the text and in Table 2.
Source: Author's calculations.

As shown in the bottom panel of Table 3, estimating this model over the sample period 1984:Q1–2007:Q3, we obtain an estimate for λ of 0.14, although with a standard error of 0.20 the estimate is insignificantly different from zero.[18] The estimated impacts of lagged inflation and unemployment are 0.082 and 0.43; their standard errors are 0.13 and 0.26 respectively. The influence of lagged unemployment is diminished somewhat relative to the estimates in Table 3. But the observation about the economic insignificance of lagged unemployment as displayed in Fig. 3 still applies. Overall, these estimates suggest at best a very small role for rational expectations and lagged dependent variables in this model, once the information in survey expectations is taken into account.

Finally, to summarize the contributions of each of these model components to aggregate dynamics, we examine the implications for the vector autocorrelation function (ACF) that arise from omitting lagged dependent variables or sluggish adjustment of survey expectations, or increasing the weight on RE. Fig. 4 displays the ACF for the baseline parameters (very little weight on rational expectations, as estimated in Table 3, the solid line), setting the influence of lagged dependent variables to 0 (the solid dashed line), setting partial adjustment of survey expectations to zero (the light dotted line), and increasing the influence of rational expectations to 0.95 (the asterisks). As the figure indicates, eliminating partial adjustment in survey expectations or imposing rational expectations causes significant deterioration in the ACF relative to the estimated baseline. Including lags (or not) makes little difference to the ACF. Thus the ACF provides another way to assess the key sources of dynamics in the model. Consistent with the other results, the sluggish adjustment of survey expectations is far more important than the inclusion of lagged dependent variables.

4.3. Model forecasting performance

We briefly compare the forecasting performance of three versions of the model: (1) The baseline version, with parameters as estimated in Table 2; (2) a version with "pure" rational expectations (no habits or indexation, no survey

[18] The parameters and standard errors are taken from the posterior density computed as described at the beginning of this section. The priors for λ, π^L, u^L are normal with mean 0.5 and standard deviation 0.2, which allows a small portion of the mass of the prior and posterior distributions to lie below zero.

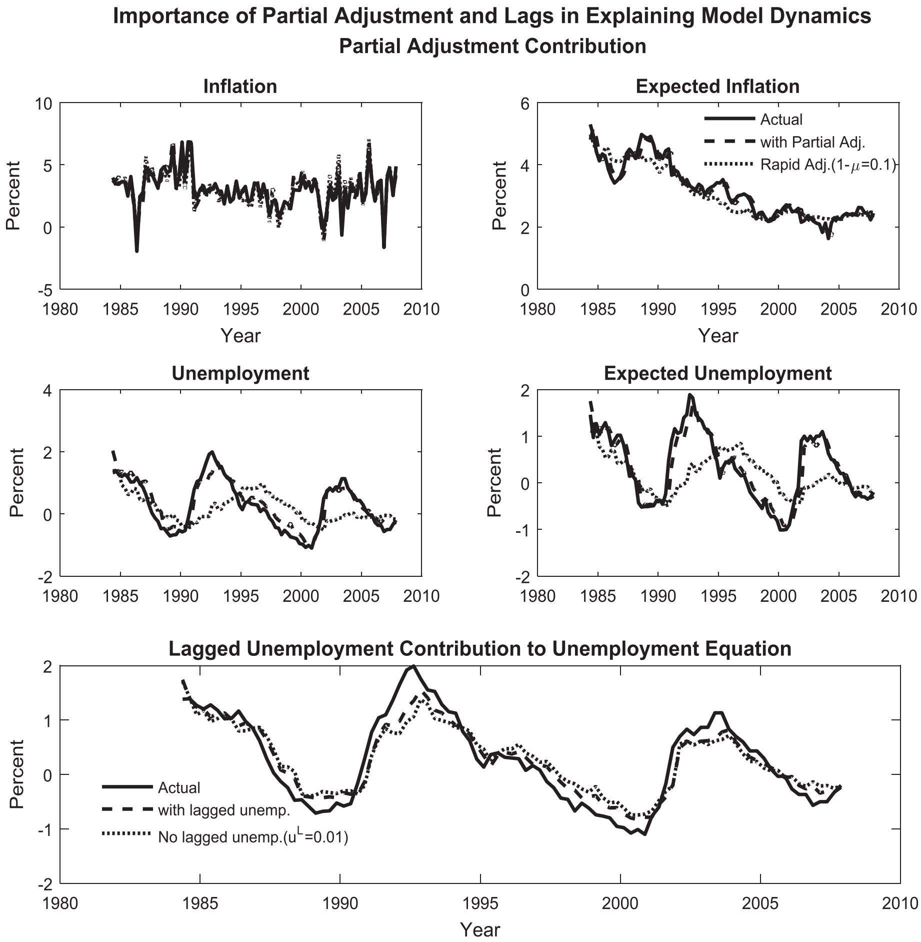

Fig. 3. The top four panels of the figure display the data (the solid black lines), along with the results of static simulations of the baseline model over the sample indicated, varying the amount of partial adjustment in expectations between the baseline estimates (the dashed black lines) and very rapid adjustment (the dotted black lines). The bottom panel displays the contribution of lagged unemployment to the fit of the unemployment equation.
Source: Author's calculations.

expectations); and (3) a version with rational expectations, imposing a weight of one-half on the lags that represent habit formation and price indexation.[19]

Table 4 displays the root-mean-squared errors for simulations of the model, both in-sample and out-of-sample, taking the prices of food and energy and the inflation goal as exogenous over the periods. The starting points for the first four rows of the table are near the troughs of each of the past four recessions, and these simulations extend for 16 quarters. The last line of the table presents results for the full sample. The baseline model dominates the other models for inflation forecast performance in every case. The performance for the unemployment gap is almost always dominant: the pure RE model outperforms the other two for one forecast horizon (starting in 2001:Q4). Generally, these results favor the survey expectations model.

5. Conclusions

The use of survey expectations in a standard DSGE model can mitigate difficulties with parameter identification, with strong dependence on lagged dependent variables, and with an excessive reliance on highly correlated structural shocks. The findings suggests that the improvements afforded by using surveys as the model's expectations are substantial. First,

[19] As estimated, the model's steady-state deviates from the theoretical norm because the parameter $A^{\pi e}$ is allowed to deviate from one. In order to simulate the model with reasonable steady-state properties, we set $A^{\pi e}$ equal to one and re-estimate the remaining model parameters, so that the steady-state for the key variables is as expected. Note that this parameter restriction falls outside the 95th percentile of the simulated posterior distribution for $A^{\pi e}$. A Wald test of this restriction rejects it convincingly. The steady-state values for the other variables are as expected—the unemployment gap is zero, the inflation rate attains the central bank's target, the real interest rate equals the equilibrium real interest rate, the Fisher equation holds in the long run, and so on.

these expectations serve well as expectations proxies in the standard linearized first-order conditions that make up DSGE models. Second, the results in Section 4 suggests that most all of the inertia imparted by lagged variables in previous DSGE models is better represented by inertia in expectations, both for inflation and for output. Third and related, using survey expectations obviates the need to incorporate complex error processes into models in order to match the dynamic properties of macro data. Fourth, survey expectations perform well in a system context, allowing one to identify key parameters well, although it would be overly optimistic to suggest that all identification issues are solved. Fifth, in a head-to-head empirical test of survey expectations versus rational expectations in a DSGE model, rational expectations receive a weight that is insignificantly different from zero, while survey expectations receive a weight that differs insignificantly from one.

Better understanding why survey expectations respond sluggishly to fundamentals and determining whether these expectations properties are stable across policy regimes is the subject of future work. Fuhrer (2015) examines the individual responses to the SPF, the European SPF, and the Michigan surveys and finds that individual expectations are strongly anchored to the lagged central tendency of expectations, a finding that is consistent with the partial adjustment of expectations that is found in the aggregate data in this study. That work suggests that at least in an empirical sense, sluggish expectation adjustment may be "micro-founded."

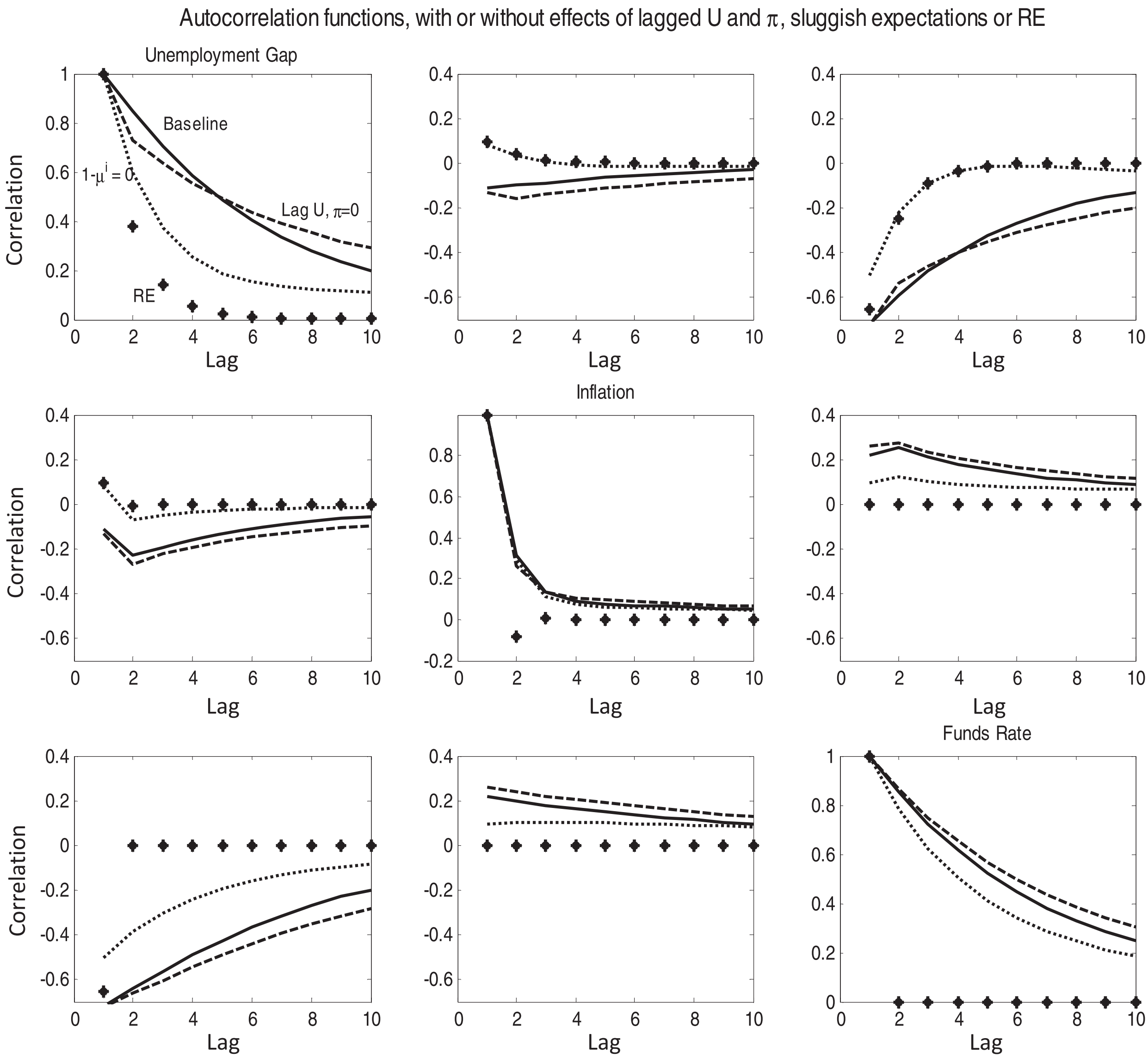

Fig. 4. The figure displays the vector autocorrelation function (ACF) for the unemployment gap, inflation, and the funds rate that is implied by the model for different parameter settings. The ACF at the baseline estimated parameters from Table 2 is displayed in the solid black line. The model with rational expectations rather than survey expectations is displayed in the black crosses. The model with no inertia in the survey expectations is indicated by the dotted line, and the model with no contribution from lagged inflation or unemployment is shown in the dashed line.
Source: Author's calculations.

Table 4
Root-mean-squared forecast errors, various specifications and samples. 16-quarter forecasts with start date as indicated.

Start date of 16-quarter forecast	Inflation			Unemployment		
	Survey	Pure RE	RE plus habits and indexation	Survey	Pure RE	RE plus habits and indexation
1984:Q2	0.95	3.9	3.8	0.41	1	1.3
1991:Q1	0.78	3.4	3	1.2	1.3	1.6
2001:Q4	1.1	2	1.7	0.8	0.69	0.98
Out of (estimation) sample						
2009:Q2	0.79	1.8	1.6	3	4	4.2
1984-2012*	0.87	3	2.9	1.6	1.6	1.8

*Full-sample (and largely in-sample) forecast.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.jmoneco.2016.12.003.

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