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Macroeconomic News in Asset Pricing and Reality

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ABSTRACT

Revisions in successive Greenbook forecasts of quarterly real GDP growth proxy for news of current and expected future economic growth. In the sample 1975 through 2015, news of future growth is slightly negatively related to contemporaneous changes in Treasury bond yields, while news of current growth is strongly positively related to changes in these yields. Both results are difficult to reconcile with a representative agent's bondholding first-order condition. A continuous-time dynamic model of output attributes almost all of the covariation with yields to martingale innovations in log output and a minimal amount to innovations in the conditional drift of log output.

MACROFINANCE RESEARCH EXPLORES THE JOINT dynamics of economic growth and a stochastic discount factor (SDF). Models typically characterize time-varying conditional expectations of both economic growth and the SDF. Since real yields are inverses of conditional expectations of the SDF, these models often have rich implications for the comovement of news about economic growth—both current and expected future growth—with innovations in real yields.

I estimate relations between growth news at various forecast horizons and contemporaneous innovations in real yields, putting no economic restrictions on the possible patterns. The methodology is designed to shed light on which mechanisms are plausibly important in linking economic growth with real yields. I use forecast-to-forecast revisions in Federal Reserve Greenbook/Tealbook predictions of real GDP growth as news about economic growth. Contemporaneous changes in nominal Treasury yields proxy for innovations

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in real yields, motivated by the evidence of Duffee (2018) that over short horizons such a quarter, news about expected inflation accounts for very little of the news in nominal yields. Changes in a one-year ex ante real yield (nominal yield less expected inflation) also proxy for real-yield innovations.

Regressions identify key properties of the data, but cannot be applied directly to macroeconomic models owing to the time-averaging inherent in measured output. I therefore also build and estimate a continuous-time dynamic model of aggregate real output with martingale innovations to log output and transitory innovations in the conditional mean of output growth. Model estimation explicitly accounts for time-averaging of measured output. The model imposes no restrictions on the sensitivities of yields to macroeconomic news, letting the data speak.

Data spanning the period 1975 through 2015 speak clearly, revealing two striking results. First, there is no positive relation between news about expected future output growth and contemporaneous innovations in real yields. Point estimates are negative and economically close to zero, with tight standard errors. Second, news about *current* output growth is closely tied to contemporaneous changes in real yields. A 1% positive innovation in the nowcast—a Greenbook prediction of current-quarter output growth that is 1 percentage point higher than the previous Greenbook's prediction of output growth in the same quarter—corresponds to increases in yields of around 20 basis points. The continuous-time dynamic model cleanly restates both of these regression results. Yields are almost entirely insensitive to innovations in the conditional mean of instantaneous output growth, and they load positively on martingale innovations to instantaneous log output.

Some economic structure helps interpret these results. In representative agent settings, two broad types of mechanisms link economic growth with real yields through the logic of the first-order condition

$$R_t = \frac{1}{E_t \left(\frac{MU_{t+1}}{MU_t} \right)}, \tag{1}$$

where R_t is the gross one-period real risk-free rate from t to $t+1$ and MU is the representative agent's marginal utility of consumption. I label them "first-order" and "correlation" mechanisms.

Growth affects conditional expectations of relative marginal utility through first-order effects of consumption on marginal utility. All else equal, higher expected consumption next period lowers expected relative marginal utility and thus raises real yields. This is the standard elasticity of intertemporal substitution (EIS) effect that appears in all consumption-based models with news about the future. This EIS effect creates positive comovement between news about future growth and innovations in real yields. Ignoring the difference between news about aggregate consumption growth and news about output growth, this positive EIS relation sharply contrasts with the small negative relation in the data.

Another first-order effect appears in models with habit formation such as Campbell and Cochrane (1999) and Smets and Wouters (2003). All else equal, an immediate change in consumption that is anticipated to be permanent (i.e., a martingale innovation) raises expected relative marginal utility because the representative agent anticipates a rising habit in the future, or equivalently a declining surplus. This lowers real yields. This habit effect creates negative comovement between news about current growth and innovations in real yields, again in sharp contrast to the strong positive relation in the data.

In addition, economic growth can be indirectly related to conditional expectations of relative marginal utility through correlations of economic growth with other determinants of these expectations. Two standard correlation channels work through precautionary savings and preference shocks.

Correlations with precautionary savings arise when news about current or expected future growth is correlated with the conditional volatility of marginal utility. Possible channels include countercyclical conditional volatility of surplus consumption as in Campbell and Cochrane (1999) or countercyclical macroeconomic uncertainty. With countercyclical conditional volatility, high growth accompanies higher real yields through a reduction in the precautionary savings motive.

Real yields can also vary simply because investors arbitrarily choose a different trade-off between consumption today and consumption in the future. These shocks to the representative agent's time rate of preference (akin to demand shocks in the New Keynesian literature) are plausibly correlated with news about current and expected future economic growth. Nonzero correlations arise naturally in New Keynesian models following Smets and Wouters (2003). In an endowment economy setting, Albuquerque et al. (2016) provide empirical evidence supporting nonzero correlations between economic growth rates and shocks to the time rate of preference.

Within the representative agent framework, the evidence here indicates that correlation mechanisms must play a central role driving comovement between economic growth and real yields. The signs implied by first-order mechanisms do not match the signs in the data. Nothing in these results contradicts the logic of first-order mechanisms. Instead, with a representative agent, the effects of correlation mechanisms must dominate those of first-order mechanisms.

However, matching the signs of both main results likely poses a considerable challenge even for representative agent models with correlation mechanisms. A mechanism's direction needs to switch sign with the horizon of the economic news. With countercyclical conditional volatility, good news about current output corresponds to lower precautionary savings and thus higher real yields. The resulting positive comovement between news of current output and changes in yields matches the sign in the data. But if this mechanism also operates at longer horizons, good news about expected output growth in the near future should similarly lead investors to anticipate lower precautionary savings demand in the near future. Again, bond yields should increase, creating positive comovement between news of expected future output and changes in yields. This positive comovement works in the same direction as the EIS effect. Their combined effect should generate positive comovement between news about expected future output growth and changes in yields, not weakly negative comovement as in the data.

Along the same lines, a positive shock to the representative agent's desire to consume rather than save raises real yields. In New Keynesian models with slow adjustment, this positive shock raises current output and expected future economic growth for the next few quarters (three to four quarters in Smets and Wouters (2003)). These preference shocks induce positive comovement between news of current growth and changes in yields, matching the sign in the data. They also induce positive comovement between news of expected future growth over the next few quarters and changes in yields, missing the sign in the data.

An alternative framework linking economic growth with real yields steps away from the representative agent setting, emphasizing limited participation in asset markets. I argue that the evidence here is not more easily interpreted through the lens of limited participation, raising the modeling challenge.

Hall (1988) introduces the standard approach to estimating a representative agent's EIS. Section I connects the empirical analysis contained here to the literature that descends from Hall. Section II describes the data, presents regression results, and conducts a variety of robustness checks. Section III describes the continuous-time model of output dynamics and asset sensitivities. Section IV presents and interprets estimates of the dynamic model. Section V concludes.

I. Motivating Theory

Standard asset-pricing logic links real bond yields to the dynamics of a representative agent's consumption. In discrete time, consider this agent's first-order condition at t for a bond that pays a unit of consumption at period $t+1$. An important special case is expected utility with constant relative risk aversion defined over aggregate consumption. Combined with the assumption that the conditional probability distributions of aggregate consumption are log-normal, these preferences imply

$$r_t = \beta_0^* + \frac{1}{EIS} E_t(\quad c_{t+1}) - \frac{CRRA^2}{2} \mathrm{var}_t(\quad c_{t+1}), \tag{2}$$

where β_0^* is a constant that depends on the time rate of preference, EIS denotes the elasticity of intertemporal substitution, CRRA is the coefficient of relative risk aversion, and c_t is the log of aggregate consumption. Attanasio and Weber (1989) show that with joint log-normality of consumption growth and asset returns, the linear relation in (2) between the real rate and expected consumption growth generalizes to the recursive utility preferences of Epstein and Zin (1989). The desire to smooth consumption over time connects expected consumption growth directly to the real rate.

A. Hall (1988)

Hall (1988) uses (2) to estimate the EIS. He assumes homoskedasticity, which allows him to combine the precautionary savings term in (2) with the constant. He then reverses the sides of (2), using instrumental variables (IVs) to estimate

$$c_{t+1} = \beta_0 + \beta_1 r_t + e_{t+1}, \tag{3}$$

where the IV estimate of β_1 is an estimate of the EIS. Real rates are proxied with nominal returns to Treasury bills less expected inflation.[1]

Other contemporaneous research explores similar approaches to estimating the EIS. Hansen and Singleton (1983) and Summers (1982) work with nonlinear versions of (2). They use maximum likelihood and nonlinear two-stage least squares, respectively, to estimate the EIS, or equivalently in an expected utility setting, the inverse of the CRRA. Using real returns to Treasury bills and instruments dated t and earlier, both conclude that the EIS is roughly one.

Hall argues that these estimates are incorrect because the econometric methodologies ignore the properties of time-averaged consumption. Although the properties are well-known from Working (1960), it is worth going into a little detail. Consider a jump in instantaneous consumption sometime during quarter t that conveys no information about expected future growth in instantaneous consumption—a martingale innovation. Through time-averaging, this jump will raise quarter $t+1$'s measured consumption more than it raises quarter t's measured consumption. If the innovation is instantaneously contemporaneously correlated with the real rate, then the real rate at the end of period t will predict the growth in measured consumption from quarter t to quarter $t+1$.

The concern of Hall is that the empirical relation between the real rate at t and future measured consumption growth from t to $t+1$ combines the true predictive relation underlying (2) and a contaminating contemporaneous relation at t. By using instruments dated only $t-1$ and earlier, Hall avoids this time-aggregation problem. He reports estimates of the EIS that are close to zero. Taken literally, the estimates indicate that the representative investor strongly values smooth consumption.

The post-Hall literature follows his lead, using twice-lagged instruments to infer the EIS.[2] This literature does not recognize a logical puzzle with the argument. Under the maintained joint hypothesis of (2) and homoskedasticity, there can be no contaminating contemporaneous relation because the model does not admit the possibility that the real rate covaries with anything other than expected future consumption growth. Therefore, there is no reason to avoid instruments known at t.

[1] Hall also considers versions of (3) where the expected real return to the stock market replaces the real return to Treasuries. The analysis here focuses only on his results for Treasuries.

[2] See, for example, Campbell and Mankiw (1989), Ogaki and Reinhart (1998), Basu and Kimball (2002), Yogo (2004), Dacy and Hasanov (2011), and Gomes and Paz (2013).

The large estimates of the EIS in Hansen and Singleton (1983) and Summers (1982) relative to those in Hall (1988) are not a consequence of an econometric error, but rather evidence that the model studied by these authors is misspecified. The estimates indirectly reveal a large positive contemporaneous relation between economic growth and real rates, a relation explicitly documented in the next section. This contemporaneous relation sharply contrasts with the tested model. Since the conclusion that the EIS is close to zero relies on the model, a more robust conclusion is that estimation of (3) cannot reveal the EIS without more economic structure.

B. A Reversed Regression

Even using twice-lagged instruments, estimation of (3) with IV produces inconsistent estimates of the EIS when real rates vary for other reasons. One source of variation is a stochastic precautionary savings motive. Bansal and Yaron (2004) discuss the errors-in-variables problem with (3) created by conditional heteroskedasticity. The same problem accompanies shocks to the agent's time rate of preference.

When the real rate varies independently of future economic growth, estimation of the reversed regression

$$r_t = \gamma_0 + \gamma_1 \quad c_{t+1} + e_{t+1} \tag{4}$$

with IV can produce consistent estimates of the inverse of the EIS. Independent variation in the real rate shows up in the residual of (4) but does not affect IV estimates of γ_1 unless this variation is correlated with the IV projection of consumption growth.

More generally, differences between EIS estimates from (3) and (4) point to misspecification. Campbell and Mankiw (1989) find such differences and argue that they are consistent with a heterogeneous agent model in which liquidity-constrained agents account for much of consumption. If so, both (3) and (4) are misspecified. Section II.C takes a close look at this limited-participation argument. More striking evidence of misspecification appears in Canzoneri, Cumby, and Diba (2007). To oversimplify their analysis, they use vector autoregression forecasts of consumption growth to instrument for expected consumption growth and find negative estimates of γ_1 rather than positive values implied by the desire to smooth consumption.

Unfortunately, as noted by Neely, Roy, and Whiteman (2001), instruments contain relatively little information about future consumption growth. Thus the point estimates and confidence bounds for (4) are unreliable. Canzoneri, Cumby, and Diba (2007) do not report standard errors, but in the text they mention the statistical insignificance of their results. Yogo (2004) explores this weak instruments problem in detail, arguing that robust estimation methods produce estimates of the relation between real rates and expected consumption growth that align closely with those of Hall.

In sum, this early literature concludes that estimates of (4) are poorly behaved, yet equating the regression coefficient in (3) with the EIS relies on a homoskedastic setting with uncomplicated preferences. My empirical approach resuscitates the estimation of equations such as (4) by treating Greenbook economic forecasts as direct measures of expected economic growth at various horizons.

C. Generalizing EIS Regressions

Rather than simply plugging Greenbook forecasts into (3) and (4), I work with generalized versions of these equations to better understand connections between real rates and economic growth. The model of Smets and Wouters (2003), with habit formation and shocks to the time rate of preference, helps motivate the approach. The real-rate equation of Smets and Wouters is (ignoring a constant term)

$$r_t = \frac{1}{1-h}\frac{1}{EIS}E_t\left(C_{t+1} - C_t\right) - \frac{h}{1-h}\frac{1}{EIS}\left(C_t - C_{t-1}\right) + (1-\rho)\sum_{i=0}^{\infty}\rho^i \eta_{t-i}, \quad (5)$$

where $0 \leq h < 1$ measures the degree of habit formation, the innovations are time rate of preference shocks, and ρ is the persistence of these shocks. New Keynesian models use demand shocks to generate exogenous fluctuations in the representative agent's desire to consume. Preference innovations are one type of demand shock, and I use the shorthand "demand shock" to refer to time rate of preference shocks.

Asset-pricing logic underpins (5). Holding constant current consumption growth (the second term on the right) and demand shocks, high expected future consumption growth corresponds to a higher real rate because the investor wants to borrow from the future to consume today. A high degree of habit formation h, like a low value of EIS, means that the real rate has to rise substantially for the representative agent's first-order condition to be satisfied without borrowing. In other words, high h and low EIS both raise the sensitivity of the real rate to expected consumption growth.

Holding constant expected future consumption growth and demand shocks, higher contemporaneous consumption growth corresponds to a lower real rate because the representative agent wants to save for times when their future habit is high. Finally, demand shocks in this model are equivalent to a lower desire to save for the future, thus they raise the real rate.

In the spirit of (5), we can augment (4) with contemporaneous consumption growth. The conditional expectation version is

$$r_t = \gamma_0 + \gamma_1 E_t \Delta c_{t+1} + \gamma_2 \Delta c_t + e_{t-1}. \quad (6)$$

In addition to its role in capturing habit formation, explicitly including contemporaneous consumption growth in (6) helps disentangle the time-averaging problem, avoiding the need for using twice-lagged instruments to form the conditional expectation of future consumption growth.

In the special case of (5) where demand shocks are orthogonal to current and expected future consumption, parameters of (6) pin down both the EIS and the degree of habit formation. But we need not take this special case seriously because it cannot match the sign of the coefficient on contemporaneous consumption growth. In (5), this coefficient is negative. The evidence in the next section, anticipated by the wedge in EIS estimates between Hall (1988) and those of Hansen and Singleton (1983) and Summers (1982), tells us that in the data the coefficient γ_2 in (6) is positive.

In principle, correlation effects can explain this discrepancy. Procyclical demand shocks and countercyclical precautionary savings bias upward both regression coefficients in (6). In Smets and Wouters (2003), positive recent demand shocks (higher desire to consume) produce higher interest rates along with higher current and expected future consumption growth. In their endowment economy with time rate of preference shocks, Albuquerque et al. (2016) estimate that positive shocks to the desire to save lower both real rates and consumption growth.

A large literature summarized by Bloom (2014) documents countercyclical macroeconomic uncertainty. Thus good news about economic growth—presumably either news about current growth or news about expected future growth—should be accompanied by a lower demand for precautionary saving, driving consumption and real rates in the same direction. Similarly, habit models along the lines of Campbell and Cochrane (1999) naturally generate a countercyclical precautionary savings motive. Good news about economic growth raises the representative agent's consumption further away from the habit boundary, lowering the conditional volatility of surplus. Wachter (2006) shows how to parameterize a habit model such that higher consumption corresponds to higher real yields.

In a nutshell, the first-order effects of consumption smoothing should produce a positive coefficient γ_1 (through the EIS) in (6) and either a zero or negative coefficient γ_2 (negative with habit formation). Correlation effects should produce positive coefficients on both γ_1 and γ_2. Simple regressions such as (6) cannot disentangle all of these effects.

Estimation of full-blown joint models of economic growth and interest rates such as Smets and Wouters (2003) and Schorfheide, Song, and Yaron (2018) can disentangle the effects if we assume the models are correct. However, as the discussion in this section makes clear, misspecification is more likely than not. Therefore, I take a different approach that summarizes atheoretically empirical connections between economic growth and interest rates.

My approach differs in three ways relative to (6). First, I use Greenbook forecasts of real output growth rather than real aggregate consumption growth. An extensive literature studies the properties of Greenbook's output forecasts rather than its consumption forecasts.[3] This choice prevents interpreting regression coefficients as measures of the EIS or habit. However, evidence of

[3] For example, Romer and Romer (2000), Sims (2002), Tulip (2009), and Reifschneider and Tulip (2019) all examine properties of Greenbook output growth forecasts.

misspecification is sufficiently strong that such interpretations are an overreach even when using aggregate consumption. I instead focus on signs and rough magnitudes.

Second, I examine comovement of economic growth with short-maturity and long-maturity yields rather than simply the one-period real rate. There might be important information in the comovement with long-maturity yields that we miss by studying exclusively short-maturity yields.

Third, I examine innovations rather than levels because I do not directly observe real yields. Instead, I have proxies for their innovations between two dates. Consider two days t_1 and t_2, $t_2 > t_1$, where t_2 is some time during calendar quarter τ. Since the data align with Greenbook forecasts, these two days are about six weeks apart. Denote the log of aggregate real output in quarter τ by y_τ. Denote the yield on an m-maturity real bond at the end of quarter τ by $r_{m,\tau}$. In the spirit of (6), the innovation version is

$$E_{t_2} - E_{t_1} \; r_{m,\tau} = \rho_1 \; E_{t_2} - E_{t_1} \quad y_{\tau+j} + \rho_2 \; E_{t_2} - E_{t_1} \quad y_\tau + e_{t_1,t_2}, \quad t_1 < t_2 < \tau. \tag{7}$$

Equation (7) links innovations in real yields to contemporaneous news about current and expected j-quarter-ahead economic growth.

Following Duffee (2002), assume that yields are close to martingales over short horizons, and replace the yield innovation on the left of (7) with the change in the yield from the earlier to the later date. I add a constant term so that identification of the important parameters comes from second moments rather than means. The result is

$$r_{m,t_2} - r_{m,t_1} = \rho_0 + \rho_1 \; E_{t_2} - E_{t_1} \quad y_{\tau+j} + \rho_2 \; E_{t_2} - E_{t_1} \quad y_\tau + e_{t_1,t_2}. \tag{8}$$

To help interpret the estimation results for (8), I estimate corresponding regressions for excess aggregate stock returns from t_1 to t_2,

$$xr_{t_1,t_2} = \psi_0 + \psi_1 \; E_{t_2} - E_{t_1} \quad y_{\tau+j} + \psi_2 \; E_{t_2} - E_{t_1} \quad y_\tau + e_{t_1,t_2}. \tag{9}$$

The general idea behind (8) and (9) is to identify different types of economic news exclusively from forecast innovations of output growth, then asks how this news relates to bond yields and stock returns. Thus this research is close in spirit to Cieslak and Pang (2021), who impose intuitive restrictions on the joint dynamics of stock returns and bond yields to identify "monetary" and "growth" shocks (as well as risk-premia shocks) from high-frequency asset data. They then ask how these shocks covary with lower-frequency innovations to output and inflation survey forecasts. In other words, they identify different types of economic shocks exclusively from stock returns and bond yields, then ask how these shocks relate to macroeconomic forecast innovations.

II. Regression Evidence

This section presents results of estimating (8), (9), and related regressions. The first two subsections describe the data and the final two subsections discuss the regression results.

A. News about Expected Growth

Federal Reserve Board staff produce economic forecasts prior to every meeting of the Federal Open Market Committee (FOMC). The forecasts, known as either Greenbook (prior to 2010) or Tealbook (since 2010) forecasts, are available with a five-year lag for all FOMC meetings since 1967. I use the term "Greenbook forecast" regardless of the date of the forecast. Real quarterly output growth (initially GNP, then GDP) is one of the five macroeconomic variables included in every Greenbook forecast. The maximum forecast horizon is only one or two quarters ahead for most of the 1960s. By mid-1974, the maximum horizon is routinely at least four quarters ahead. The empirical analysis in this paper uses Greenbook projections beginning with the final forecast of 1974 through 2015.

Index each Greenbook by $i = 0, \ldots, T$, and hence index forecast revisions by $1, \ldots, T$. The index corresponds to the order of the FOMC meetings rather than specific points in calendar time. Forecast $i = 0$ occurs on December 11, 1974 and forecast $i = T = 348$ occurs on December 9, 2015. Denote the quarter in which a forecast is made as q_i, an index from 0 (1974Q4) to 164 (2015Q4). The forecast horizon is indexed with j, from $j = -1$ (what was output growth last quarter?) to $j = 5$. Greenbook reports these as quarterly growth rates compounded to an annual horizon. I convert these forecasts to continually compounded growth rates expressed in annualized percent,

$$forecast_i^{(j)} = 100 \log E_i^G \left[\left(\frac{GDP_{q_i+j}}{GDP_{q_i+j-1}} \right)^4 \right],$$

where E^G refers to the raw Greenbook forecasts. The term "nowcast" refers to the forecast for $j = 0$.

This research relies heavily on the interpretation of Greenbook forecasts as close to rational forecasts (or, at least, investors' forecasts) of output growth. A standard tool to help evaluate forecast rationality uses the property that realized variables equal rational forecasts of these variables plus an unforecastable residual. A regression implementing this logic is

$$realized\,growth_{q_i+j} = b_0 + b_1 \left(forecast_i^{(j)} \right) + b_2(nowcast_i) + e_{q_i+j}. \tag{10}$$

In words, (10) regresses the outcome on the corresponding prediction made j quarters earlier. Some regression specifications also include the nowcast made j quarters earlier. If the forecasts are rational, then in population the coefficient on the lagged forecast is one and the coefficient on the lagged nowcast is zero. I estimate this regression for various forecast horizons. Realizations

Table I

Greenbook Forecast Accuracy

Greenbook i, produced in quarter q_i, forecasts j-quarter-ahead growth in real GDP. The table reports estimated coefficients from regressions of realized growth in quarter $q_i + j$ on the forecast at meeting i. These are labeled “Regression 1.” For $j > 0$, results are also reported when the lagged nowcast ($j = 0$) is included as an explanatory variable. These are labeled “Regression 2.” Realizations are from the NIPA real-time data set as of quarter $q_i + j + 2$. Newey-West standard errors are in parentheses, adjusted for $j + 1$ moving-average residuals. Asymptotic two-sided p-values for tests that the coefficient equals one (zero) are in brackets (braces). The regressions use 349 observations from December 1974 through December 2015. Two observations are missing for $j = 4$ and 45 are missing for $j = 5$.

	Regression 1		Regression 2		
Horizon of Realization (j)	j-Ahead Forecast	R^2	j-Ahead Forecast	Lagged Nowcast	R^2
0	0.934	0.61			
	(0.076)				
	[0.386]				
1	0.767	0.26	0.735	0.032	0.26
	(0.140)		(0.231)	(0.161)	
	[0.095]		[0.251]	{0.844}	
2	0.726	0.16	0.747	−0.027	0.16
	(0.186)		(0.204)	(0.145)	
	[0.140]		[0.215]	{0.852}	
3	0.559	0.08	0.556	0.005	0.08
	(0.258)		(0.244)	(0.088)	
	[0.087]		[0.068]	{0.955}	
4	0.642	0.08	0.727	−0.119	0.09
	(0.280)		(0.285)	(0.094)	
	[0.201]		[0.338]	{0.204}	
5	0.784	0.09	0.818	−0.058	0.09
	(0.226)		(0.231)	(0.094)	
	[0.339]		[0.430]	{0.534}	

on the left side of (10) are from the Philadelphia Federal Reserve’s real-time National Income and Product Accounts (NIPA) data set as of quarter $q_i + j + 2$.

The regression results do not allow us to reject the hypothesis of rational forecasts. Table I reveals that all of the point estimates on the lagged forecast are less than one, but none are statistically different from one at the 5% level. All of the estimated coefficients on the lagged nowcast are economically small. None are statistically different from zero at the 10% level.

Revisions from meeting $i - 1$ to meeting i in forecasts of j-ahead real quarter-to-quarter GDP growth are

$$ {}_{i}^{(j)} \equiv 100 \quad \log E_i^G \quad \frac{GDP_{q_i+j}}{GDP_{q_i+j-1}}^{4} - \log E_{i-1}^G \quad \frac{GDP_{q_i+j}}{GDP_{q_i+j-1}}^{4} , \; j = -1, \ldots, 4. \tag{11} $$

Note that the horizon j refers to the horizon as of forecast i rather than the horizon for forecast $i - 1$. For example, a Greenbook forecast of two-quarter-ahead growth made in 2012Q2 is forecasting growth from 2012Q3 to 2012Q4. If the previous Greenbook forecast was also made in 2012Q2, the corresponding forecast is also a two-quarter-ahead forecast. If the previous Greenbook forecast was made in 2012Q1, then the corresponding forecast is the three-quarter-ahead forecast.

Another check on the rationality of these forecasts asks whether these forecast revisions are predictable with revisions as of the previous Greenbook. The regressions have the form

$$ {}_{t}^{(j)} = b_0 + b_1 \, {}_{t-1}^{(0)} + b_2 \, {}_{t-1}^{(3)} + e_t^{(j)}, \qquad j = 0, \ldots, 4. $$

The two forecast revisions on the right roughly capture the term structure of lagged revisions. The Internet Appendix reports regression estimates.[4] The maximum R^2 among the five regressions is only 0.04, lending support to the view that the forecast revisions represent information revealed between the two Greenbook dates.

Table II reports sample covariances among the forecast revisions. (More precisely, the table contains mean outer products—sample means are not subtracted.) Asymptotic standard errors for these means treat each observation as an independent draw from an unknown distribution. Results are displayed separately for the 1975 through 1996 and 1997 through 2015 periods. The literature on stock-bond correlations mentioned in the introduction motivates the choice of break point. For brevity, refer to the periods as "early" and "late." The samples contain 196 and 152 Greenbook forecast dates, respectively.

The two periods exhibit qualitatively different macroeconomic dynamics. In the early period, near-contemporaneous innovations (the previous quarter and the nowcast) are negatively correlated with innovations beyond one quarter ahead. In the late period, forecast innovations are positively correlated for all pairs of horizons. In addition, early-period volatilities exceed late-period volatilities. The Internet Appendix uses forecast revisions from the Survey of Professional Forecasters (SPF) to verify that these properties are not just an artifact of Greenbook forecasts. The SPF data range from 1969 through 2019, although the sampling frequency is only half that of the Greenbook data.[5]

The unstable dynamic properties over the sample period tell us we need to be careful about drawing inferences based solely on full-sample results. Connections between asset prices and macroeconomic innovations plausibly depend on the dynamics of macroeconomic innovations. Thus, I report subsample results for many of the empirical exercises that follow.

B. Asset Data

I treat changes in nominal yields between successive Greenbook forecasts (approximately six-week changes) as proxies for innovations in real yields. Two

[4] The Internet Appendix may be found in the online version of this article.

[5] I exclude the pandemic sample because it is drawn from a different distribution from the other observations. The SPF nowcast revision for 2020Q2 is a 33-standard-deviation event.

Table II
Sample Covariances of Greenbook Forecast Revisions of Output Growth

The forecast revision of j-ahead output as of Greenbook i is the forecast in Greenbook i less the forecast for the same calendar quarter in Greenbook $i-1$. The table reports sample mean outer products of these revisions. Revisions are expressed in annualized percentage points. Asymptotic standard errors are in parentheses. Asterisks represent two-sided p-values at the 10%, 5%, and 1% significance levels.

Horizon	Horizon (Quarters Ahead)					
(Quarters Ahead)	−1	0	1	2	3	4
Panel A: 1975 through 1996, 196 Observations						
−1	1.14***					
	(0.18)					
0	0.14	1.58***				
	(0.10)	(0.24)				
1	−0.11	0.38***	0.62***			
	(0.08)	(0.11)	(0.09)			
2	−0.15*	−0.14*	0.18***	0.38***		
	(0.09)	(0.08)	(0.05)	(0.08)		
3	−0.12*	−0.22***	0.04	0.23***	0.28***	
	(0.07)	(0.07)	(0.05)	(0.07)	(0.06)	
4	−0.12***	−0.16***	−0.02	0.09***	0.15***	0.17***
	(0.04)	(0.05)	(0.03)	(0.04)	(0.04)	(0.03)
Panel B: 1997 through 2015, 152 Observations						
−1	0.80***					
	(0.09)					
0	0.02	0.66***				
	(0.07)	(0.13)				
1	0.05	0.31***	0.46***			
	(0.05)	(0.11)	(0.12)			
2	0.07	0.13**	0.23***	0.28***		
	(0.05)	(0.06)	(0.07)	(0.07)		
3	0.07*	0.09**	0.13***	0.18***	0.19***	
	(0.04)	(0.04)	(0.05)	(0.05)	(0.05)	
4	0.06**	0.05	0.06*	0.10***	0.10***	0.12***
	(0.03)	(0.03)	(0.04)	(0.03)	(0.03)	(0.02)

types of evidence discussed in Duffee (2018) motivate this interpretation. First, as earlier research documents, monthly and quarterly changes in yields are reasonable proxies for innovations. Random walk forecasts are often slightly more accurate than econometric forecasts. Over short horizons such as a quarter, differences between random walk and econometric forecasts are minimal.

Second, the inflation component of innovations in nominal yields is small. News about expected one-year inflation accounts for between 7% and 15% of the variance of quarterly changes in nominal one-year yields. Similarly, news about expected 10-year inflation accounts for between 10% and 14% of the variance of quarterly changes in nominal 10-year yields. Thus, either news about real rates or news about risk premia (minimal for a one-year bond) drive the bulk of variation in these yields.

I check this assumption by also using changes in a one-year ex ante real yield. The ex ante real yield is the nominal yield less expected inflation. Comparing results based on the one-year ex ante real yield with those based on the one-year nominal yield reveals the (lack of) importance of inflation. In addition, in Section II.C I examine directly the relation between news of expected inflation and news of expected output to evaluate whether inflation news can plausibly account for empirical relations between revisions in growth forecasts and revisions in nominal yields.

Contemporaneous changes in yields between successive Greenbook forecast dates are

$$n_{1y,i}, \Delta\ n_{10yr,i} : \text{change in nominal 1-year yield and 10-year yield from date of forecast}$$
$$i-1 \text{ to date of forecast } i$$
$$r_{1y,i} : \quad n_{1y,i} - (\text{expected 1-year inflation at date of forecast } i$$
$$- \text{ expected 1-year inflation at date of forecast } i-1).$$

Changes in nominal bond yields from forecast $i-1$ to forecast i use daily observations of Treasury zero-coupon 1-year and 10-year nominal yields from Gurkaynak, Sack, and Wright (2007). The contemporaneous change in the ex ante one-year real yield is the change in one-year nominal yield less the change in expected inflation over the next year. I construct one-year expected inflation with Greenbook forecasts of the GDP deflator. All of these data are expressed with continuously compounded annual rates. The Internet Appendix contains additional details about the data and their construction.

Some of the empirical results that follow use the excess stock market return from one Greenbook forecast date to the next. The notation is

$$xr_{i-1,i} : \text{excess log aggregate stock return from date of forecast } i-1$$
$$\text{to date of forecast } i.$$

Daily aggregate value-weighted stock returns from the Center for Research in Security Prices are cumulated to construct the log stock return between forecast dates. Excess returns are calculated assuming that the three-month Treasury bill yield as of the date of forecast $i-1$ is the risk-free rate for each day between the two forecasts. The daily three-month Treasury bill yield is from the Federal Reserve's H-15 release.

C. Projections of Growth News on Changes in Yields

Hall (1988) applies IVs to (3) to estimate the predictive power of real rates for future economic growth. The first set of regressions here capture and generalize the same idea by regressing Greenbook forecast revisions on contemporaneous changes in yields. Rather than considering only the one-quarter-ahead growth forecast, the horizons here range from the backcast through four quarters ahead. The regression using changes in a one-year nominal bond yield is

$$ {}_{i}^{(j)} = b_0 + b_1 \quad n_{1y,i} + e_i^{(j)}. \tag{12}$$

Other regressions replace the change in the one-year nominal yield with the change in the one-year ex ante real yield and the change in the nominal 10-year yield.

Table III reports estimates of (12). The table reports results for all forecast horizons from $j = -1$ through $j = 4$. Regression evidence for the full sample of 1975 through 2015 is in Panel A. Subsample results are in Panels B and C, motivated by the evidence in Section II.A that forecast revision dynamics changed substantially during the full sample.

The evidence leaves no room for ambiguity. There is a strong positive relation between changes in yields and news about contemporaneous output growth. At horizons $j - 1$ through $j + 1$, the estimated coefficients are all positive. The point estimates imply that a 10 basis point yield change corresponds to between a 6 and 10 basis point change in the nowcast. Estimated coefficients for the nowcast are all statistically different from zero at the 5% level; eight of the nine are statistically significant at the 1% level. Results for the one-quarter-ahead forecast and the one-quarter-lagged backcast are consistent with a purely contemporaneous relationship contaminated by time-averaging quarterly output.[6]

By contrast, the relation between changes in yields and news about expected future output growth ranges from strongly negative to zero. At horizons $j \geq 2$, all of the full-sample parameter estimates for all three yields are negative. Most are statistically different from zero at the 1% confidence level. The same summary for $j \geq 2$ applies to the early sample of 1975 through 1996. In the late sample of 1997 through 2015, none of the coefficients for $j \geq 2$ are statistically different from zero, and six of the nine are negative. As discussed in Section I.A, this combination of results could be predicted (but apparently were not) by the discrepancy between the results of Hall (1988) and those of Hansen and Singleton (1983) and Summers (1982).

These results for output growth cast doubt on a common interpretation of a near-zero EIS estimated with aggregate consumption data. As mentioned in Section I, Campbell and Mankiw (1989) view Hall's estimate of a low EIS with aggregate consumption data as an artifact of limited participation in debt markets. Limited participation drives a wedge between agents who hold bonds and agents who collectively account for much of aggregate consumption. Research beginning with Mankiw and Zeldes (1991) draws the same conclusion in different asset-pricing contexts. One indication that Hall's regressions do not

[6] The Internet Appendix explains why the time-averaging effect in these regressions is stronger one quarter ahead than one quarter behind.

Table III
Projections of Greenbook Forecast Revisions of Output Growth on Changes in Yields

Revisions in Greenbook forecasts of j-quarter-ahead real output growth are regressed on contemporaneous changes in bond yields. These are all bivariate regressions. Variables are expressed in annualized percentage points. The table reports parameter estimates. Asymptotic White standard errors are in parentheses. Regressions for $j = 4$ are missing 17 observations from 1975 through 1996. Regressions with the one-year ex ante real yield as the explanatory variable are missing four observations for $j < 4$ from 1975 through 1996. Asterisks denote statistical significance at two-sided p-values of 10%, 5%, and 1%.

Explanatory	Horizon (Quarters Ahead)					
Variable	−1	0	1	2	3	4
Panel A: 1975 through 2015, 348 Observations						
1-Yr Real Yield	0.213**	0.662***	0.203**	−0.052	−0.102*	−0.125***
	(0.094)	(0.106)	(0.092)	(0.070)	(0.053)	(0.041)
1-Yr Nominal Yield	0.170**	0.739***	0.247***	−0.114*	−0.160***	−0.160***
	(0.077)	(0.118)	(0.090)	(0.069)	(0.053)	(0.041)
10-Yr Nominal Yield	0.161	0.926***	0.223	−0.200***	−0.211***	−0.186***
	(0.111)	(0.170)	(0.152)	(0.074)	(0.063)	(0.060)
Panel B: 1975 through 1996, 196 Observations						
1-Yr Real Yield	0.228**	0.625***	0.147	−0.057	−0.107*	−0.132***
	(0.099)	(0.113)	(0.095)	(0.072)	(0.055)	(0.043)
1-Yr Nominal Yield	0.163**	0.682***	0.153*	−0.163**	−0.187***	−0.175***
	(0.082)	(0.123)	(0.085)	(0.069)	(0.052)	(0.044)
10-Yr Nominal Yield	0.107	1.006***	0.167	−0.283***	−0.262***	−0.243***
	(0.132)	(0.207)	(0.175)	(0.082)	(0.075)	(0.076)
Panel C: 1997 through 2015, 152 Observations						
1-Yr Real Yield	0.086	1.057***	0.844***	−0.012	−0.066	−0.066
	(0.285)	(0.328)	(0.286)	(0.260)	(0.218)	(0.147)
1-Yr Nominal Yield	0.257	1.333***	1.244***	0.396	0.122	−0.011
	(0.237)	(0.335)	(0.302)	(0.242)	(0.186)	(0.120)
10-Yr Nominal Yield	0.328*	0.690**	0.377	0.025	−0.077	−0.040
	(0.199)	(0.286)	(0.292)	(0.151)	(0.123)	(0.107)

correctly identify consumers' EIS is that household-level evidence supports higher values. Dynan (2000) and Gross and Souleles (2002) find that households alter their consumption paths as interest rates change. Vissing-Jørgensen (2002) examines the consumption of households that hold bonds and estimates an EIS somewhat below one.

A key feature of limited participation interpretations of Hall's evidence is that the average consumer is not the average investor. The first-order condition (1) is irrelevant to households at a corner solution. Guvenen (2006, 2009) makes a qualitatively similar argument on different grounds. He starts from the observation that dynamic production-based macroeconomic models require that the marginal investor in firms has an EIS close to one. He reconciles this requirement with Hall-type results by assuming that most investors are poor, hold only bonds, and have a near-zero EIS. Relatively few wealthy investors participate in the stock market, and thus own the capital stock. These investors have a high EIS.

These arguments suggest that changes in yields should be more closely linked to news about future aggregate output than to news about future aggregate consumption. Wealthy investors participate in stock and bond markets; they are at their first-order conditions. News about expected future aggregate output is news about *their* expected future consumption. Therefore, news of higher aggregate output growth should be accompanied by news of higher yields.

Table III provides zero support for this limited participation argument. More broadly, these results raise considerably the bar that a limited-participation model must clear. Some agents hold both stocks and bonds. These agents share in anticipated macroeconomic growth, yet do not appear to demand higher yields at times of higher anticipated output growth. Nonetheless, they do demand higher yields when current output is unexpectedly high.

D. Projections on Growth News

Equations (8) and (9) connect news about current and expected future economic growth to contemporaneous changes in yields and to contemporaneous stock returns. I implement these regressions using two Greenbook forecast revisions to capture news about current and future economic growth. The obvious choice for news about current growth is the nowcast revision. My proxy for news about future economic growth is the three-quarter-ahead forecast revision, which has 17 more valid observations than does the four-quarter-ahead forecast revision. The one-year nominal bond yield regression is

$$n_{1y,i} = b_0 + b_1 \;{}_{i}^{(0)} + b_2 \;{}_{i}^{(3)} + e_{1yr,i}. \tag{13}$$

I also estimate a version of (13) with the excess aggregate stock return on the left side.

Regression evidence for the full sample of 1975 through 2015 is in Panel A of Table IV. Subsample results are in Panels B and C. The least surprising result is nonetheless important. Good news about aggregate output is generally good news for the stock market. The relation is particularly strong for news about future output growth. The full-sample point estimate implies that a 1% innovation in three-quarter-ahead expected output corresponds to an increase in the stock market of 4%. The magnitude of the positive relation varies across two subsamples, 1975 through 1996 and 1997 through 2015, but the statistical strength of the relation is consistently strong. The relation between nowcast news and the stock market is weaker, both economically and statistically.

Table IV

Projections of Stock Returns and Changes in Yields on Forecast Revisions of Output Growth

Excess aggregate stock returns and changes in bond yields between FOMC forecast dates are regressed on contemporaneous revisions in Greenbook forecasts of current quarterly real output growth (the nowcast) and three-quarter-ahead real output growth. Stock returns are expressed as a percent. All variables are expressed in annualized percentage points. The table reports parameter estimates. Asymptotic White standard errors are in parentheses. Asterisks denote statistical significance at two-sided p-values of 10%, 5%, and 1%.

Dependent Variable	Nowcast	Three Quarters Ahead	R^2
Panel A: 1975 through 2015, 348 Observations			
Excess Stock Return	0.705**	4.400***	0.15
	(0.299)	(0.820)	
1-Yr Real Yield	0.209***	−0.081	0.15
	(0.051)	(0.080)	
1-Yr Nominal Yield	0.224***	−0.169**	0.19
	(0.052)	(0.069)	
10-Yr Nominal Yield	0.127***	−0.105**	0.14
	(0.027)	(0.042)	
Panel B: 1975 through 1996, 196 Observations			
Excess Stock Return	0.173	2.554***	0.06
	(0.281)	(0.774)	
1-Yr Real Yield	0.242***	−0.040	0.16
	(0.071)	(0.117)	
1-Yr Nominal Yield	0.232***	−0.230**	0.20
	(0.070)	(0.100)	
10-Yr Nominal Yield	0.127***	−0.111**	0.16
	(0.034)	(0.053)	
Panel C: 1997 through 2015, 152 Observations			
Excess Stock Return	1.286**	6.850***	0.34
	(0.614)	(1.434)	
1-Yr Real Yield	0.124***	−0.076	0.14
	(0.026)	(0.080)	
1-Yr Nominal Yield	0.155***	−0.017	0.20
	(0.033)	(0.066)	
10-Yr Nominal Yield	0.121***	−0.092	0.09
	(0.037)	(0.068)	

This evidence shows that the information leading the Fed to update its forecasts of expected future output growth is used by investors to price assets. However, bond yields load positively and strongly on the nowcast news, and only on the nowcast news. Asymptotic t-statistics reject at the 1% level the hypothesis that coefficients on nowcast revisions equal zero. The point estimates imply that a 1% nowcast innovation, which is slightly less than the full-sample standard deviation of nowcast revisions, corresponds to increases in annualized bond yields by between 13 and 23 basis points. By contrast, bond yield loadings on news of future output growth are negative with mixed statistical significance.

These conclusions are robust across time and across different sources of forecast data. The table shows that they hold for both of the subsamples 1975 through 1996 and 1997 through 2015. The Internet Appendix documents that the same results hold when using revisions in four-quarter-ahead output growth instead of revisions of three-quarter-ahead output growth. This Appendix also shows that the results hold when using forecast revisions of consensus output growth from the SPF over the sample 1969 through 2019. Finally, this Appendix shows that the results hold when using Greenbook forecast revisions of real personal consumption expenditures instead of real output.

The final set of robustness checks address whether news about expected inflation can account for these results. I present these checks before discussing what we learn from the results of Table IV.

E. Inflation

Nominal yields rise with innovations in the nowcast. Nominal yields decline modestly with innovations in the three-quarter-ahead forecast. How much of this variation is plausibly attributed to news about expected inflation?

One way to answer this question is to regress innovations in expected inflation on output forecast innovations. I construct innovations in Greenbook forecasts of expected inflation (GDP deflator) in the same way that I construct innovations of forecasts of output growth with (11). These innovations are expressed in percent per year, like the bond yields. The regressions are

$$ {}^{(j)}_{\pi,i} = b_{0,j} + b_{1,j}\;{}^{(0)}_{i} + b_{2,j}\;{}^{(3)}_{i} + e_{1yr,i}, $$

where the subscript on the left side refers to inflation. I estimate this equation for forecast horizons from $j = 1$ to $j = 5$ quarters ahead. The results are in Table V.

The table contains two main messages. First, nowcast innovations are associated with only small innovations in expected inflation—much smaller than the variations in nominal yields documented in Table IV. From one to five quarters ahead, a 100 basis point nowcast innovation raises expected inflation by an average of only 2.5 basis points (full sample), less than a basis point (early sample), or 2.9 basis points (late sample). These tiny numbers are why, in Table IV, the estimated nowcast coefficients for the ex ante one-year real yield are almost identical to those for the one-year nominal yield.

Second, innovations in three-quarter-ahead output forecasts are modestly related to innovations in expected inflation, with an unstable sign over time. In the early sample, a 100 basis point three-quarter-ahead output innovation

Table V

Projections of Forecast Revisions of Inflation on Forecast Revisions of Output Growth

Revisions in Greenbook forecasts of quarter-to-quarter inflation in the GDP price deflator are regressed on contemporaneous revisions in Greenbook forecasts of current quarterly real output growth (the nowcast) and three-quarter-ahead real output growth. All variables are expressed in annualized percentage points. The table reports parameter estimates. Asymptotic White standard errors are in parentheses. Asterisks denote statistical significance at two-sided p-values of 10%, 5%, and 1%.

Inflation Horizon (Quarters)	Obs	Nowcast	Three Quarters Ahead	R^2
Panel A: 1975 through 2015				
1	348	0.015	−0.035	0.00
		(0.027)	(0.067)	
2	348	0.018	−0.095**	0.03
		(0.022)	(0.045)	
3	348	0.018	−0.095***	0.05
		(0.016)	(0.067)	
4	331	0.039***	−0.010	0.05
		(0.013)	(0.028)	
5	283	0.036***	0.001	0.04
		(0.014)	(0.031)	
Panel B: 1975 through 1996				
1	196	−0.005	−0.142*	0.03
		(0.033)	(0.077)	
2	196	−0.013	−0.212***	0.08
		(0.028)	(0.067)	
3	196	0.004	−0.187***	0.12
		(0.019)	(0.048)	
4	179	0.030*	−0.055	0.05
		(0.018)	(0.036)	
5	133	0.019	−0.043	0.03
		(0.018)	(0.042)	
Panel C: 1997 through 2015				
1	152	0.012	0.138	0.03
		(0.040)	(0.108)	
2	152	0.043*	0.060	0.05
		(0.022)	(0.041)	
3	152	0.001	0.062	0.02
		(0.018)	(0.039)	
4	152	0.037**	0.053	0.11
		(0.018)	(0.035)	
5	150	0.053***	0.034	0.11
		(0.017)	(0.037)	

lowers expected inflation over quarters one through five by an average of about 13 basis points. In the late sample, the same innovation raises expected inflation by an average of around 7 basis points. Results for the full sample are an average of these subsample results.

The results of Tables IV and V combine to tell a simple story. Real yields are insensitive to both nowcast innovations and three-quarter-ahead forecast innovations. For the early sample (and, to a lesser extent, the full sample), the three-quarter-ahead forecast innovation is negatively associated with expected inflation. This inflation news creates a modest negative relation between three-quarter-ahead forecast innovations and nominal yields, as seen in Panels A and B of Table IV. In the late sample, there is not enough inflation news associated with output news to drive a wedge between the behavior of real yields and nominal yields.

The empirical approach of Table V is limited in two ways. First, the maximum forecast horizon for expected inflation innovations is short, only five quarters. Second, news about the inflation risk premium could drive a wedge between real and nominal bond yields even in the absence of news about expected inflation. The most direct way to determine whether the results for nominal yields are informative about real yields is to repeat the analysis in Tables III and IV for real yields.

Unfortunately, Treasury Inflation-Protected Securities (TIPS) yields are available only from 1999. The Internet Appendix contains the results of estimating versions of (12) and (13) for a 10-year zero-coupon TIPS yield. The sample is 1999 through 2015, excluding two Greenbook forecasts in the fourth quarter of 2008. As discussed in the Internet Appendix, the failure of Lehman Brothers in September 2008 created substantial distortions in the TIPS market that persisted through 2008. The results are in line with the results for the 10-year nominal yield: only the nowcast innovation matters, not the three-quarter-ahead forecast innovation.

F. Discussion

In sum, changes in yields are disconnected from variations in expected future economic growth, yet closely connected with variations in contemporaneous growth. Qualitatively, these results run counter to the first-order effects of consumption smoothing by a representative agent. Yields should rise in anticipation of good times ahead. Holding constant news of the future, news about current growth should either leave yields unaffected, as with Epstein-Zin preferences, or lower yields, because the representative agent knows she will become accustomed to her improved circumstances.

Mechanically, it is easy to construct a representative agent endowment economy model with correlation effects to explain these results. At each date, two types of news arrive. One is news about current economic growth and the other is news about expected future economic growth. The former type of news negatively comoves with either the conditional volatility of the SDF or with shocks to patience. The latter type of news is orthogonal to both the conditional volatility of the SDF and shocks to patience. Finally, the representative agent has an extremely high EIS. With this model, good news about current output corresponds to higher bond yields either through a reduction in the precautionary savings motive or through less patience. Good news about expected future output has a minimal effect on yields because the representative agent has an extremely high EIS.

Although mechanically successful, this description requires two highly implausible features. The first implausible feature is that correlation effects must be restricted to news about contemporaneous growth. Consider the correlation effect that works through precautionary savings. In this toy model, good news about today's growth lowers the conditional volatility of the one-quarter-ahead SDF. However, good news about expected growth in, say, two quarters must not lower the conditional volatility of the two-quarter-ahead or three-quarter-ahead SDF. If this good news about the future lowered these more distant conditional volatilities, then this news would correspond to higher one-year bond yields. In the data, no such positive relation exists.

Similarly, the correlation effect that works through shocks to patience must apply only to news about contemporaneous growth. A negative shock to patience (higher demand) corresponds to higher current economic activity, but this higher activity must be either a martingale shock or a mean-reverting shock. By contrast, slow adjustment to demand shocks is inherent in New Keynesian models because goods prices and/or wages do not respond instantly to innovations. As mentioned in Section I.C, positive demand shocks in the model of Smets and Wouters (2003) raise interest rates, current output and consumption, and expected output and consumption for the next few quarters.

The second implausible feature is that monetary policy is both nonexistent and extraordinarily powerful. Any variation in real yields owing to the intervention of the central bank corresponds to very large swings in expected economic growth. Because of her high EIS, the representative agent is happy to drain her savings to increase consumption whenever the central bank eases, or sharply reduce consumption when the central bank tightens. Since we do not observe such covariation between yields and expected economic growth, the central bank must not engage in a noticeable amount of easing or tightening. Naturally, the macroeconomic literature does not agree with this view of the central bank. Models designed to explain the effects of monetary policy such as Christiano, Eichenbaum, and Evans (2005), Smets and Wouters (2003, 2007), and Guvenen (2006, 2009) all use values of the EIS around one.

III. A Model of Output Dynamics and Asset Responses

Regression (13) projects changes in a yield on the nowcast revision and the three-quarter-ahead forecast revision. Qualitatively, we can think of the regression as decomposing output growth news into martingale changes in output and pure news about expected future output growth. The proxy for martingale changes is nowcast news, holding constant news about expected future growth. The proxy for pure news about future growth is the three-quarter-ahead revision, holding constant the nowcast.

This section describes and estimates a reduced-form model of output dynamics and asset responses that makes this interpretation exact. Martingale and growth rate innovations affect instantaneous output. Sensitivities of bond yields and the aggregate excess stock return to these innovations are free parameters rather than pinned down by an asset-pricing model.

A. Continuous-Time Output Dynamics

Time is continuous and measured in quarter-years. Quarters begin and end at integers. Denote by y_t the instantaneous flow of log output. Its dynamics are

$$dy_t = x_t dt + \sigma_y dB_{1t}, \tag{14}$$

$$dx_t = -\rho x_t dt + \sigma_x dB_{2t}, \tag{15}$$

$$\sigma_{xy} \equiv \mathrm{cor}(dB_{1t}, dB_{2t}), \tag{16}$$

$$\sigma_y \geq 0,\ \sigma_x \geq 0,\ \rho > 0,\ -1 < \sigma_{xy} < 1.$$

I refer to the Brownian increment in (14) as "martingale" or "immediate output" news and the Brownian increment in (15) as "growth rate" news. The correlation parameter (16) allows immediate output news to be either positively or negatively correlated with growth rate news. The unconditional drift of log output is irrelevant to the empirical work that follows, thus it is set to zero.

Expected future log output at fixed date τ conditioned on current output and the current growth rate is

$$E(y_\tau | y_t, x_t) \equiv f(\tau, y_t, x_t) = y_t + \frac{x_t}{\rho}\left(1 - e^{-(\tau - t)\rho}\right),$$

with martingale dynamics

$$df_t(\tau) = \sigma_y dB_{1t} + \frac{\sigma_x}{\rho}\left(1 - e^{-(\tau - t)\rho}\right) dB_{2t}. \tag{17}$$

Equation (17) describes how both immediate output news and growth rate news affect expected future log output. Innovations of expected future log output for different forecasting horizons τ are imperfectly correlated. Inspection of (17) reveals that both Brownians have permanent effects on log output (the limit as τ approaches infinity). However, the model can be reframed as one where log output is the sum of a martingale component and a component with a stochastic mean. Depending on the parameters, the latter component can be either stationary in first differences or stationary in levels.

The reframed model combines the dynamics of the conditional drift (15) with

$$y_t = y_{1,t} + y_{2,t}.$$

The dynamics of log output's two components are

$$dy_{1,t} = \sigma_{y1} dB_{*t}, \tag{18}$$

$$dy_{2,t} = x_t dt + \sigma_{y2} dB_{2t}, \tag{19}$$

$$dB_{*t} = \left(1 - \sigma_{xy}\right)^{-1/2} \left(dB_{1t} - \sigma_{xy} dB_{2t}\right), \tag{20}$$

$$\sigma_{y1} = \sigma_y \left(1 - \sigma_{xy}\right)^{1/2}, \quad \sigma_{y2} = \sigma_y \sigma_{xy}.$$

The Brownian in (20) that drives the martingale component of output (18) is orthogonal to the Brownian that drives the component (19) with a stochastic mean.

Define the conditional expectation of the second component at time τ by

$$g(\tau, y_{2t}, x_t) \equiv E(y_{2\tau} | y_{2t}, x_t).$$

Then the permanent effect of a Brownian increment to this second component is

$$\lim_{\tau \to \infty} dg_t(\tau) = \left(\sigma_{y2} + \frac{\sigma_x}{\rho}\right) dB_{2t}.$$

If the term in parentheses on the right is zero, then innovations to $y_{2,t}$ are completely transitory. In this case, the stochastic mean component is stationary in levels. Otherwise it is stationary in first differences. Research from Campbell (1986) through Chernov, Lochstoer, and Song (2021) argues that the sign of the sensitivity of bond yields to macroeconomic innovations depends on whether the innovations are transitory or permanent. This model allows for either possibility, but does not impose an a priori restriction on the sensitivity of bond yields to either Brownian.

B. Information Arrival, the Stock Market, and Bonds

The Greenbook dated October 26, 2005 predicted annualized output growth of 3.15% for 2005:Q3, the most recently ended quarter. Six weeks later, the Greenbook dated December 7 predicted annualized growth of 4.2% for the same past quarter. This example illustrates a common feature of Greenbook forecasts. Two Greenbooks prepared at different dates in the same quarter disagree about output growth in the previous quarter. Forecasts for quarters that have already ended can change over time only because forecasters do not observe the current state of the economy. I model this property by assuming that when forming forecasts of output growth, forecasters observe realizations of the macroeconomic Brownian increments with a lag $L \geq 0$. In line with the reduced-form nature of the model, there is no explicit mechanism that ties down the lag length.

Earlier evidence supports the view that the macroeconomic state is observed by agents with a lag. A high-frequency literature beginning with Schwert (1981) documents that prices respond to macroeconomic news about the past. Fleming and Remolona (1997) and Balduzzi, Elton, and Green (2001) list a variety of announcements that move Treasury bond prices, including nonfarm payrolls and durable goods orders. Such announcements also move aggregate stock prices, with sensitivities that depend on economic conditions. McQueen and Roley (1993) and Boyd, Hu, and Jagannathan (2005) show that stock prices respond to industrial production and unemployment announcements.

I do not attempt to couple these output dynamics with a pricing kernel. Instead, I ask in a purely reduced-form setting how sensitive stock prices and bond yields are to output news. Aggregate stock returns and bond yields covary with the same Brownian increments that drive output. The stock market and bond yields also have sources of variation independent of the Brownian processes that drive output.

For notational convenience, stack the immediate output and growth rate news Brownians into a vector of macroeconomic Brownians,

$$dB_{mt} = dB_{1t} \quad dB_{2t} \quad .$$

The instantaneous dynamics of the log of the value of aggregate stock market, the one-year ex ante real yield, the one-year nominal yield, and the 10-year nominal yield are

$$d\begin{pmatrix} s_t \\ r_{1yr,t} \\ n_{1yr,t} \\ n_{10yr,t} \end{pmatrix} = \underbrace{\Omega_a}_{4\times 2} dB_{m,t-L} + \underbrace{\Sigma_a}_{4\times 4} dB_{nm,t}. \tag{21}$$

The subscripts "a" on the right side refer to assets. The time subscript on the macroeconomic Brownian vector indicates that stocks and bonds are sensitive to these increments with a lag L, consistent with the lag in forecasters' observation of these same innovations. Nonmacro variation is created by $B_{nm,s}$, a length-four vector of Brownians. The subscript denotes nonmacroeconomic news. The vector is nothing more than a residual picking up all variation in the stock market and yields that is orthogonal to output innovations. To emphasize, the left and right sides of (21) are both observed at time t. Without loss of generality, Σ_a is the lower triangular Cholesky decomposition of the instantaneous covariance matrix of the nonmacro innovations in stock returns and bond yields.

Equation (21) ignores conditional means. The empirical analysis applies (21) to stock returns and changes in bond yields between two forecast dates. In practice, the contributions of conditional means to total variation between two forecast dates are small.

C. Forecast and Asset Innovations

The cumulated instantaneous log output from long-distant date zero to any date t is

$$Y_t \equiv \int_0^t dy_s ds.$$

Recall that quarters begin and end at integers. Log output during the quarter beginning at integer $\tau - 1$ and ending at integer τ is

$$Y_\tau^Q = Y_\tau - Y_{\tau-1}. \tag{22}$$

Quarters are indexed with the ending integer of the quarter, as the notation on the left of (22) implies. In taking this model to the data, I ignore the difference between the log of cumulative output in a quarter (i.e., the log of the sum of instantaneous output) and (22), which is the sum of the logs of instantaneous output.

Agents at arbitrary times t forecast first-differenced log quarterly output at various horizons. Keeping track of these forecasts is inherently cumbersome in the model because of the multiple dates that define the forecast. Denote the log-difference in quarterly output at integer horizon j from the perspective of time t as (using the floor function)

$$Y_{t(j)}^Q \equiv \begin{cases} Y_{t+j}^Q - Y_{t+j-1}^Q, & t = \lfloor t \rfloor; \\ Y_{\lfloor t \rfloor+j+1}^Q - Y_{\lfloor t \rfloor+j}^Q, & t > \lfloor t \rfloor. \end{cases} \tag{23}$$

To illustrate (23), fix the current time t as the date of Greenbook forecast t_i. Imagine this time is 3.2, which is during the calendar quarter indexed by 4. The calendar quarter begins at 3.0 and ends at 4.0. For $j = 1$, (23) is log output during the quarter ending at $t = 5$ less log output during the quarter ending at $t = 4$.

Consider forecasts of (23) at dates t_{i-1} and t_i. Think of these as dates of successive Greenbook forecasts. Denote the forecast innovation by

$$\eta_{t_i}^{(j)} \equiv \left(E_{t_i} - E_{t_{i-1}}\right) Y_{t_i(j)}^Q. \tag{24}$$

The notation on the left does not explicitly reference either the date of the previous forecast t_{i-1}, nor the forecast horizon at that date. The one-quarter-ahead forecast at t_i corresponds to the one-quarter-ahead (two-quarter-ahead) forecast at t_{i-1} if the forecast dates are in the same calendar quarter (successive calendar quarters).

Define the innovations in excess aggregate stock returns and bond yields between these two forecast dates as

$$ {}^{(xr)}_{t_i} = s_{t_i} - s_{t_{i-1}}, \epsilon \quad {}^{(r1)}_{t_i} = r_{1yr,t_i} - r_{1,t_{i-1}}, \epsilon \quad {}^{(nk)}_{t_i} = n_{(k)yr,t_i} - n_{(k)yr,t_{i-1}}, \ k = 1, 10. $$

Assume that at date t_i we have forecast innovations for log output at horizons j_{min} through j_{max}. In practice, these horizons are the first lagged quarter through four quarters ahead. Stack output forecast innovations and asset innovations in the vector

$$ {}_{t_i} \equiv \quad {}^{(j_{min})}_{t_i} \quad \ldots \quad {}^{(j_{max})}_{t_i} \quad {}^{(xr)}_{t_i} \quad {}^{(r1)}_{t_i} \quad {}^{(n1)}_{t_i} \quad {}^{(n10)}_{t_i} \quad . \tag{25} $$

The model described in Sections III.A and III.B implies that this innovation vector is multivariate normally distributed with an analytic covariance matrix

$$ C(t_i, j_{min}, j_{max}; \text{parameters}) \equiv E_{t_{i-1}} \quad {}_{t_i} \ {}_{t_i} \ . \tag{26} $$

As with (24), (26) does not explicitly reference the date of the previous forecast nor the forecast horizons at that date. The only relevant conditioning information for the conditional covariance are the dates of the two Greenbook meetings. The conditional covariance is larger when the dates are further apart. The conditional covariance is also affected by whether forecasters learn a quarter-end value during the time between the two dates. The Appendix contains additional details.

D. Estimation Mechanics

The data are described in Sections II.A and II.B. The Greenbook forecast i is at time t_i, given by mapping dates to a timeline measured in quarters. Stack the observed data for Greenbook i in the vector

$$ \hat{}_{i} = \quad \hat{}^{(j_{min})}_{i} \quad \ldots \quad \hat{}^{(j_{max})}_{i} \quad xr_{i-1,i} - \overline{xr} \quad r_{1y,i} \quad n_{1y,i} \quad n_{10yr,i} \quad . \tag{27} $$

The observed vector (27) is the empirical equivalent of the model's innovation vector (25), with two caveats. First, observed output forecast innovations are assumed to be contaminated by i.i.d. normally distributed measurement error

$$ \hat{}^{(j)}_{i} = {}^{(j)}_{i} + \omega^{(j)}_{i}, \qquad \text{var} \ \ \omega^{(j)}_{i} \ \ = \sigma^2_j . $$

Measurement error is a catch-all picking up missing components in the model, such as occasional news about more-distant output growth that is not captured by this parsimonious model of aggregate output. Measurement error variances depend on the forecast horizon.

Second, the model's covariances are scaled to match those of the data. Recall from (11) that the observed innovations of expected output growth are expressed at annualized rates. The model measures time in quarters. The relevant elements of the model's covariance matrices are scaled to match the use of annualized rates.

Stack the model parameters in a vector ψ,

$$\psi = \begin{pmatrix} \sigma_y & \sigma_x & \sigma_{xy} & \rho & L & \sigma_{err} & \mathrm{vec}(\Omega_a) & \mathrm{vech}(\Sigma_a) \end{pmatrix},$$

where σ_{err} is the vector of standard deviations of measurement error in observed innovations of expected output growth. The matrix Ω_a contains the sensitivities of the aggregate stock return and bond yields to the Brownians. The lower triangular matrix Σ_a contains the parameters that determine covariances among stock returns and bond yields owing to innovations orthogonal to innovations in forecasted output.

As mentioned before, the model's dynamics imply that discrete-horizon forecast errors and asset innovations are jointly normally distributed. Since the distribution of the forecast errors is known (conditional on parameters), maximum likelihood estimation is asymptotically efficient. Statistical inference is performed using the outer product estimate of the information matrix. The Appendix contains a few additional estimation details.

IV. Estimation Results and Interpretations

How do stock returns and bond yields covary with immediate output news? How do they covary with news about the growth rate of output? Answers to these questions plausibly depend on the nature of output dynamics. Recall that Section II.A documents sharp differences between dynamics in the 1975 through 1996 period and dynamics in the 1997 through 2015 period. This evidence motivates estimating the model separately for the two samples. The Internet Appendix contains full-sample estimates. Full-sample estimates are close to the estimates for the early sample because volatilities of forecast innovations are substantially larger in the early sample. Maximum likelihood emphasizes fitting these early data rather than the lower-volatility data in the late sample.

A. *Estimates of Macroeconomic Dynamics*

Tables VI and VII report parameter estimates for the early and late sample periods, respectively. Volatility parameters σ_y, σ_x, and σ_{err} are all expressed in percentage terms with time measured in quarters. In other words, reported values in the tables are 100 times their natural-unit values.

According to the point estimates, early-period output dynamics differ in three economically significant ways from late-period dynamics. First, news about immediate output is twice as volatile in the early period than in the late period, as measured by the diffusion component of (14). Second, growth rate news is three times as volatile in the early period, as measured by its permanent effect on log output (the limit as the horizon approaches infinity in

Table VI

Model Parameter Estimates, 1975 through 1996

The model and estimation method are described in Section III. Asymptotic standard errors are in parentheses. In Panel B, asterisks represent asymptotic two-sided p-values versus zero of 10%, 5%, and 1%.

Panel A: Output Growth Dynamics

					Std Dev of Measurement Error (Horizon)					
σ_y	σ_x	σ_{xy}	ρ	L	−1	0	1	2	3	4
0.63	0.17	−0.61	0.05	0.27	0.23	0.16	0.19	0.11	0.07	0.07
(0.06)	(0.03)	(0.07)	(0.05)	(0.04)	(0.01)	(0.03)	(0.01)	(0.01)	(0.01)	(0.01)

Panel B: Loadings of Stock Returns and Bond Yields on Macro Innovations

Innovation	Stock Return	1-Year Real Yield	1-Year Nominal Yield	10-Year Nominal Yield
Immediate	1.02	0.58***	0.54***	0.25***
Output	(1.15)	(0.18)	(0.16)	(0.08)
Growth	2.54**	0.13	−0.06	−0.05
Rate	(1.15)	(0.19)	(0.19)	(0.10)

Panel C: Cholesky Factorization of Non-Output Components of Stock Returns and Bond Yields

	Stock Return	1-Year Real Yield	1-Year Nominal Yield	10-Year Nominal Yield
Stock Return	7.66			
	(0.37)			
1-Year	−0.28	1.07		
Real Yield	(0.11)	(0.06)		
1-Year	−0.31	0.94	0.36	
Nominal Yield	(0.12)	(0.05)	(0.01)	
10-Year	−0.23	0.36	0.15	0.44
Nominal Yield	(0.05)	(0.04)	(0.04)	(0.03)

(17)). Third, these two types of news are strongly negatively correlated in the early period (−0.6) and minimally correlated in the late period (−0.05). It is worth noting in advance that Section IV.D documents another difference between the early and late periods. In the early (late) period, growth rate news is negatively (positively) correlated with innovations in expected future inflation. This is not surprising, given the evidence on expected inflation discussed in Section II.E.

Panels A and B of Figure 1 display model-implied conditional standard deviations of instantaneous log output at $t + s$ conditional on agents' information at t. Notwithstanding the relatively high volatilities of immediate output news and growth rate news in the early period, the early-period standard deviations are only modestly larger than late-period standard deviations (at least through

Table VII

Model Parameter Estimates, 1997 through 2015

The model and estimation method are described in Section III. Asymptotic standard errors are in parentheses. In Panel B, asterisks represent asymptotic two-sided p-values versus zero of 10%, 5%, and 1%.

Panel A: Output Growth Dynamics

					Std Dev of Measurement Error (Horizon)					
σ_y	σ_x	σ_{xy}	ρ	L	−1	0	1	2	3	4
0.30	0.23	−0.05	0.23		0.22	0.15	0.09	0.06	0.06	0.06
(0.03)	(0.04)	(0.23)	(0.06)	-	(0.02)	(0.01)	(0.01)	(0.01)	(0.01)	(0.01)

Panel B: Loadings of Stock Returns and Bond Yields on Macro Innovations

Innovation	Stock Return	1-Year Real Yield	1-Year Nominal Yield	10-Year Nominal Yield
Immediate	1.14	0.22***	0.25***	0.18***
Output	(0.99)	(0.05)	(0.04)	(0.07)
Growth	5.84***	0.01	0.09*	0.00
Rate	(0.75)	(0.05)	(0.05)	(0.05)

Panel C: Cholesky Factorization of Non-Output Components of Stock Returns and Bond Yields

	Stock Return	1-Year Real Yield	1-Year Nominal Yield	10-Year Nominal Yield
Stock Return	5.78			
	(0.39)			
1-Year	0.03	0.31		
Real Yield	(0.04)	(0.03)		
1-Year	0.05	0.23	0.17	
Nominal Yield	(0.03)	(0.03)	(0.02)	
10-Year	0.09	0.14	0.07	0.37
Nominal Yield	(0.05)	(0.05)	(0.04)	(0.02)

12 quarters ahead). The negative correlation in the early period between these two types of news largely offsets the higher volatilities. Two-standard-error confidence bounds are tight, widening more at the long end of the early period than at the long end of the late period.

Panels C and D of the same figure display model-implied innovations to expected log output conditioned on a positive unit increment to the Brownian that drives growth rate news. This unit increment produces an increase in instantaneous output growth of a little less than 0.2%/quarter in the early period and a little more than 0.2%/quarter in the late period. For this exercise, the realization of the Brownian that drives immediate output news is not fixed at zero, but instead given by its expectation conditioned on the Brownian

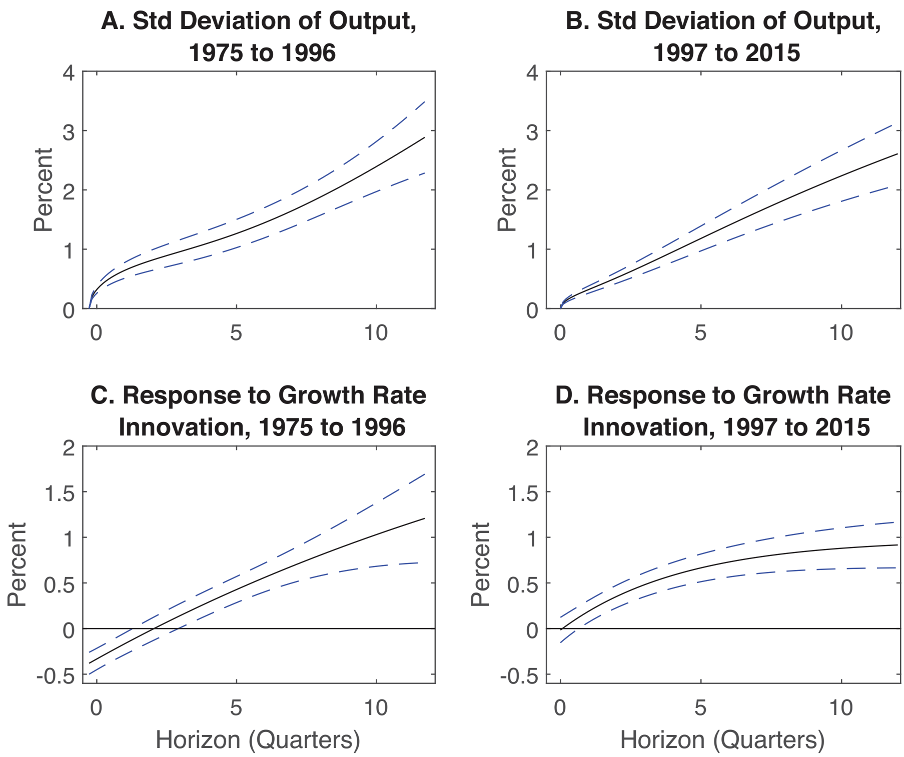

Figure 1. Properties of the estimated dynamic model of output. Section III describes the model, which is estimated separately over the 1975 to 1996 and 1997 to 2015 samples. Panels A and B plot model-implied standard deviations of s-ahead instantaneous log output. The horizon s can be negative in the early sample because the estimated early-sample model implies that output is observed with a lag. Panels C and D plot the expected path of instantaneous log output conditioned on one quarterly standard deviation innovation to the drift of instantaneous log output. The solid lines are point estimates and the dashed lines are plus/minus two standard errors. (Color figure can be viewed at wileyonlinelibrary.com)

increment to growth rate news. This expectation equals the instantaneous correlation between the two increments.

Since immediate output and growth rate news are negatively correlated in the early period, a positive unit increment to the drift corresponds to an immediate drop in early-sample output of about 0.4%. The drop appears in Panel C slightly to the left of the zero horizon because of the lag of 3.5 weeks in observed output. Forecasters see the lagged Brownian realization at time zero. These forecasters anticipate that the temporarily high output growth rate will eventually dominate the immediate drop in output. According to the point estimates, the long-run effect on expected log output is about 3% in the early period (beyond the horizon plotted in the figure) and 1% in the late period. Substantial statistical uncertainty accompanies point estimates of long-run effects.

Table VIII

Model-Implied Population Covariances of Greenbook Forecast Revisions of Output Growth

The forecast revision of j-ahead output as of Greenbook i is the forecast in Greenbook i less the forecast for the same calendar quarter in Greenbook $i-1$. The table reports model-implied covariances among these forecasts. Section III describes the model and Section IV estimates the model over two separate samples. Revisions are expressed in annualized percentage points. Asymptotic standard errors are in parentheses.

Horizon	Horizon (Quarters Ahead)					
(Quarters Ahead)	−1	0	1	2	3	4
Panel A: 1975 through 1996, 196 Observations						
−1	0.95					
	(0.08)					
0	0.16	1.72				
	(0.04)	(0.24)				
1	−0.04	0.03	0.79			
	(0.01)	(0.05)	(0.09)			
2	−0.04	−0.23	0.11	0.36		
	(0.01)	(0.05)	(0.02)	(0.03)		
3	−0.04	−0.22	0.10	0.17	0.24	
	(0.01)	(0.05)	(0.02)	(0.02)	(0.01)	
4	−0.04	−0.21	0.10	0.16	0.16	0.24
	(0.01)	(0.05)	(0.02)	(0.02)	(0.02)	(0.02)
Panel B: 1997 through 2015, 152 Observations						
−1	0.80					
	(0.11)					
0	0.01	0.75				
	(0.00)	(0.08)				
1	0.00	0.18	0.49			
	(0.00)	(0.06)	(0.06)			
2	0.00	0.06	0.21	0.26		
	(0.00)	(0.05)	(0.04)	(0.03)		
3	0.00	0.05	0.17	0.16	0.18	
	(0.00)	(0.04)	(0.03)	(0.02)	(0.02)	
4	0.00	0.04	0.13	0.12	0.10	0.14
	(0.00)	(0.03)	(0.02)	(0.02)	(0.01)	(0.02)

Table VIII reports the implications of the model for covariances among Greenbook forecast revisions. A glance back at Table II helps put Table VIII in context. Table II lists sample mean outer products of observed forecast innovations. The reported standard errors are proportional to the standard deviations of period-by-period products of realized innovations. Table VIII contains the mean across Greenbook forecasts of model-implied covariances in (26). Standard errors measure the uncertainty in these model-implied covariances owing to uncertainty in parameter estimates. Thus, the standard errors in the two tables measure different uncertainties.

The two estimated models reproduce the signs of the sample covariances between nowcast innovations and innovations in expected future output growth. In the early period, good nowcast news corresponds to bad news about expected future output growth because immediate output news and growth rate news are negatively correlated. In the late period, these two types of news are close to uncorrelated, allowing a weaker effect to determine the sign of these covariances. Growth rate news affects both the nowcast (since the quarter is not yet over) and forecasts of expected future growth. This common exposure to growth rate news produces small positive covariances between the nowcast and innovations in expected future output growth.

The model's parsimonious structure cannot reproduce the rich variety of empirical covariances in Table II. Covariances for the late period are particularly difficult to match. The first column of Panel B reports that empirical covariances between innovations in forecasts of lagged output growth and innovations in expected future output growth are all positive. Corresponding model-implied covariances in Panel B of Table VIII are all zero to two decimal places. The estimated information lag of zero is to blame. A positive information lag allows forecasters to observe growth rate news, recognize that the growth rate changed at some time in the past, and update both past output growth and expected future output growth accordingly.

However, a positive information lag lowers the covariance between innovations in the nowcast and the one-quarter-ahead forecast. The mechanical effect of time-averaging accounts for a substantial part of this covariance, as news about current instantaneous output affects both output growth in the current quarter and expected output growth next quarter. A positive information lag weakens the time-averaging component of this covariance. Even with an information lag of zero, the model cannot match the empirical covariance of $0.31(\%)^2$; the model-implied mean covariance is only $0.18(\%)^2$. The likelihood is maximized when the information lag is on the boundary of zero, giving up the ability to fit covariances between innovations in forecasts of lagged output growth and innovations in expected future output growth.

B. Asset Responses to Macroeconomic Innovations

Panel B of Tables VI and VII reports estimates of the matrix Ω_a in (21). The matrix contains sensitivities of excess stock returns and bond yields to immediate output news and growth rate news. The results are consistent with the regression evidence of Section II. Moreover, although output dynamics in the early period differ substantially from the dynamics in the late period, estimates of asset sensitivities tell similar stories.

First consider innovations to the immediate level of instantaneous output. In the early period, a unit increment to the martingale Brownian permanently raises log output by 0.6% (from Panel A) and raises annualized one-year yields about 55 basis points and the 10-year yield about 25 basis points. The standard errors are tight. In the late period, a unit increment to the martingale Brownian raises log output by half as much (0.3% in Panel A) and also raises annualized yields by about half as much. Differences between sensitivities of one-year real and nominal yields are tiny, indicating that news about expected inflation does not explain any of the sensitivity of the one-year nominal yield to output news. Stock prices also load positively on the martingale Brownian, but the standard errors are too large to draw any interesting conclusions.[7]

Next, consider innovations to the drift of log output. Estimated sensitivities of bond yields to growth rate news are insignificant, both economically and statistically. This conclusion holds for both sample periods. By contrast, news of a higher growth rate corresponds to a statistically significant increase in stock prices. A unit increment to the growth rate Brownian raises stock prices by 2.5% in the early period and 5.8% in the late period. As Panels C and D of Figure 1 show, the implications of these innovations for expected future output differ substantially between the two sample periods.

Differences between sensitivities of one-year real and nominal yields are economically small, although not as tiny as differences in sensitivities to immediate output news. In the early period, the loadings of nominal yields on growth rate news are slightly negative, and are slightly positive in the late period. Section IV.D explains these differences based on news about expected inflation.

C. Missing Pieces

The discussion in Section IV.A pointed out mismatches between empirical covariances among forecast innovations and corresponding covariances implied by the parsimonious model of macroeconomic dynamics. Table IX uses model-implied variance decompositions to measure the magnitude of these mismatches. According to the model, variances of innovations of Greenbook forecast i are sums of variances due to exposure to macroeconomic Brownians and variances due to "measurement error." Panel A of Table IX reports the means, across forecasts, of the fractions of total variance explained by the macroeconomic Brownians and the fractions explained by measurement error. The table labels the latter as "Unmodeled News."

The first line of Panel A shows that innovations in lagged output growth are either entirely (late period) or almost entirely (early period) explained by measurement error. For other horizons, the output news explains, on average, a little more than half of the variation in the early period and about 65% in the late period. These results tell us the model's structure is too limited. Perhaps in reality, immediate output innovations are observed as they occur, but growth rate innovations are observed with a lag because they do not immediately affect the level of output. Or perhaps there are multiple types of growth rate news with different degrees of persistence.

Perhaps the most embarrassing empirical property of this and other macro-finance models is the limited ability to explain aggregate stock returns and changes in bond yields. The problem is not with the models per se. More

[7] The corresponding coefficient for the full-sample results in the Internet Appendix is statistically significant at the 1% level.

Table IX

Model-Implied Variance Decompositions

The model and estimation method are described in Section III. News about current and expected future output growth explains part of the variation in innovations to forecasts of quarterly output growth, excess stock returns, changes in one-year ex ante real yields, and changes in one-year and 10-year nominal yields. Other, unmodeled news explains the remainder of this variation. Panel A reports fractions of model-implied total variance explained by the macroeconomic and unmodeled news. Panel B reports model-implied correlations between excess stock returns and bond yields implied by the model, as well as model-implied correlations created by the two types of news.

	Estimates for 1975 to 1996		Estimates for 1997 to 2015	
	Macro News	Unmodeled News	Macro News	Unmodeled News
Panel A: Expected Output Growth, by Forecast Horizon				
One Q Lag	0.11	0.89	0.00	1.00
Nowcast	0.77	0.23	0.49	0.51
One Q Ahead	0.30	0.70	0.76	0.24
Two Q Ahead	0.49	0.51	0.76	0.24
Three Q Ahead	0.69	0.31	0.70	0.30
Four Q Ahead	0.63	0.37	0.55	0.45
Panel B: Assets				
Excess Stock Return	0.07	0.93	0.51	0.49
1-Yr Real Yield	0.18	0.82	0.33	0.67
1-Yr Nom Yield	0.23	0.77	0.45	0.55
10-Yr Nom Yield	0.17	0.83	0.16	0.84

broadly, much of the variation in stock returns and bond yields cannot be connected to macroeconomic news. Results in Table IV, first discussed in Section II, illustrate the low explanatory power of macroeconomic news. Table IV reports R^2s of regressions of aggregate stock returns and changes in bond yields on output forecast revisions. For the full sample of 1975 through 2015, the R^2s of regressions on the nowcast innovation and the three-quarter-ahead forecast innovations are all less than 0.2. The R^2s for changes in bond yields are around 15% across the early and late samples. The R^2 for aggregate stock returns is only 6% in the early period, rising to 34% in the late period.

These regressions use only two forecast innovations as explanatory variables. Estimation of the macroeconomic model extracts information from the entire term structure of forecast innovations, compressing this information through the model's lens. Panel B of Table IX contains model-implied decompositions of total variance into components due to exposure to macroeconomic Brownians and variances due to nonmacroeconomic variation ("Unmodeled News"). These are the two components on the right side of (21). Relative to the regressions, the model attributes somewhat more of variation in aggregate stock returns and changes in bond yields to macroeconomic news. The implied R^2s for stock returns are 7% in the early period and 51% in the late period.

Implied R^2s for changes in bond yields are about 20% in the early period and about 30% in the late period.

The explanatory power of macro news for excess stock returns is puzzling because it varies so much across the two sample periods. The explanatory power for changes in yields is disappointing but not surprising. The term structure literature struggles to find macroeconomic variables that explain, at least statistically, changes in bond yields. Duffee (2013) provides a handbook discussion of the (lack of) evidence.

D. Other Properties of Macroeconomic Dynamics

The model in Section III focuses narrowly on output dynamics and sensitivities of stock prices and bond yields to output innovations. Here I extend the use of the model to confirm the evidence in Section II about expected inflation. I also use it to examine the persistence of bond yields.

D.1. Inferring Shocks

In the model, the covariance matrix of innovations to the state vector, combined with the loadings of stock returns and yield changes on innovations to the vector, determine the joint covariance matrix of observed variables. To somewhat oversimplify, estimation infers properties of the unobserved macroeconomic state vector from the sample covariance matrix of observed variables.

This discussion extends the estimation logic. Consider projecting discrete-time innovations in the macroeconomic Brownians on the observed forecast and asset innovations,

$$B_{1,t_i} - B_{1,t_{i-1}} = \chi_{1,i}\,\hat{\ }_{i} + e_{1,\tau_2}, \tag{28}$$

$$B_{2,t_i} - B_{2,t_{i-1}} = \chi_{2,i}\,\hat{\ }_{i} + e_{2,\tau_2}. \tag{29}$$

Although the left sides are unobserved, analytic expressions for the regression coefficients are functions of the model's parameters. The functions depend on the timing of the forecasts i and $i-1$, thus the coefficients are indexed by i. The functions are derived in the Internet Appendix.

Fitted values of the unobserved changes in the Brownians are readily calculated, denoted

$$IMMEDIATE\_OUTPUT_i = \chi_{1,i}\,\hat{\ }_{i}, \tag{30}$$

$$GROWTH\_RATE_i = \chi_{2,i}\,\hat{\ }_{i}. \tag{31}$$

Table X
Relation between Innovations in Inflation Forecasts and Output Forecasts

Revisions in Greenbook forecasts of inflation from zero (nowcast) to four quarters ahead are regressed on contemporaneous fitted news about immediate output and news about the growth rate of output. The news is inferred from a dynamic model of output that is estimated using revisions in Greenbook forecasts of real output growth, stock returns, and changes in real and nominal yields. The model is estimated separately over the samples 1975 through 1996 and 1997 through 2015. Asymptotic standard errors are adjusted for generalized heteroskedasticity. Asterisks represent asymptotic two-sided p-values versus zero of 10%, 5%, and 1%.

	1975 to 1996			1997 to 2015		
Horizon of Inflation Forecast	Immediate News	Growth News	R^2 [Obs]	Immediate News	Growth News	R^2 [Obs]
Nowcast (Zero Ahead)	-0.280^{**}	-0.377^{***}	0.098	0.069	-0.337^{***}	0.146
	(0.121)	(0.093)	[196]	(0.151)	(0.077)	[152]
One Quarter Ahead	-0.086	-0.218^{**}	0.065	0.043	0.134^{*}	0.054
	(0.092)	(0.093)	[196]	(0.059)	(0.074)	[152]
Two Quarters Ahead	-0.108	-0.302^{***}	0.158	0.029	0.086^{***}	0.073
	(0.076)	(0.082)	[196]	(0.025)	(0.029)	[152]
Three Quarters Ahead	-0.059	-0.255^{***}	0.205	0.010	0.058^{**}	0.042
	(0.050)	(0.057)	[196]	(0.014)	(0.029)	[152]
Four Quarters Ahead	0.046	-0.074	0.073	0.049^{***}	0.074^{***}	0.189
	(0.050)	(0.047)	[179]	(0.019)	(0.025)	[152]

The units of the fitted values are standard deviations per unit of time (a quarter). The standard deviations of the fitted values are around 0.6.[8]

The remainder of this section uses these fitted time series to answer two questions. First, what is the relation between revisions in inflation forecasts and these Brownian changes? Second, are the contemporaneous responses of yields to the Brownians reversed over the next few months?

D.2. Inflation Expectations

I construct innovations in Greenbook forecasts of expected inflation (GDP deflator) in the same way that I construct innovations of forecasts of output growth with (11). I use inflation forecast revisions at horizons ranging from the nowcast through four quarters ahead.

Table X reports estimates of regressions of inflation forecast revisions on the fitted innovations (30) and (31). The regressions are, for forecast horizons zero through four,

$$ {}^{(j)}_{\pi,i} = b_{j,0} + b_{j,1} IMMEDIATE\_OUTPUT_i + b_{j,2} GROWTH\_RATE_i + e^{(j)}_{\pi,i}. $$

[8] Greenbook forecasts occur every six weeks and quarters have 13 weeks. A perfect fit to regressions (28) and (29) would produced fitted values with standard deviations of $\overline{6/13}$, or about 0.67.

The coefficients are conceptually comparable to the sensitivities of bond yields to the Brownians reported in Panel B of Tables VI and VII. Standard errors are adjusted only for generalized heteroskedasticity, not for the generated regressor problem.

These results align closely with the regression results in Section II. For both the early and late samples, immediate output news is largely unrelated to innovations in inflation expectations. Only one of the 10 estimated coefficients (two samples, five forecast horizons) is statistically different from zero. In the early period, the mean coefficient is about negative five basis points and in the late period the mean is about three basis points. For comparison, sensitivities of nominal yields to immediate output and growth rate news are around 35 basis points in the early period and 20 basis points in the late period.

Again, as in Section II, Table X shows that growth rate news is related to innovations in expected inflation with an unstable sign. In the early period, growth rate news and expected inflation are negatively correlated. A one-unit positive realization of growth rate news lowers expected inflation over the next four quarters by about 21 basis points. In the late period, the same magnitude realization of growth rate news lowers expected inflation over the next four quarters by about 9 basis points. These values approximately equal differences in sensitivities of one-year real and nominal yields to growth rate news.

D.3. Persistence of Yields

Real and nominal yields covary with permanent innovations to output. How persistent are these changes? Are the changes in yields reversed quickly? I investigate this question by regressing changes in yields on current and lagged values of fitted immediate news. I exclude growth rate news because Tables VI and VII document that this news is only weakly related to bond yields. Using the notation of (27) for changes in yields, the regressions have the form (here, for the one-year real rate)

$$\begin{aligned} r_{1y,i} =& b_{r1,0} + b_{r1,1} IMMEDIATE\_OUTPUT_i \\ &+ b_{r1,2} \sum_{j=1}^{6} IMMEDIATE\_OUTPUT_{i-j} + e_{r1,i}. \end{aligned}$$

If changes in yields associated with contemporaneous immediate news about output are partially reversed through the next six Greenbook meetings (about three quarters), the coefficient on the sum of lagged permanent innovations will be negative. The coefficient will be zero if, on average, changes are not reversed within three months. Standard errors are adjusted only for generalized heteroskedasticity, not for the generated regressor problem.

Results are in Table XI, and are easy to summarize. There is no evidence that the yield changes are reversed during the next few months. In the early

Table XI

Persistence of Macro-Related Changes in Yields

Changes in bond yields from the date of one Greenbook forecast to the next are regressed on contemporaneous and lagged fitted news about immediate output and news about the growth rate of output. The news is inferred from a dynamic model of output that is estimated using revisions in Greenbook forecasts of real output growth, stock returns, and changes in real and nominal yields. The model is estimated separately over the samples 1975 through 1996 and 1997 through 2015. Asymptotic standard errors are adjusted for generalized heteroskedasticity. Asterisks represent asymptotic two-sided p-values versus zero of 10%, 5%, and 1%.

Explanatory Variables	1-Year Real Yield	1-Year Nominal Yield	10-Year Nominal Yield
Panel A: 1975 through 1996			
Contemporaneous	0.650***	0.705***	0.375***
Immediate News	(0.158)	(0.156)	(0.071)
Sum of Lags 1–6 of	−0.018	−0.016	0.013
Immediate News	(0.060)	(0.055)	(0.023)
R^2	0.222	0.264	0.210
Obs	186	190	190
Panel B: 1997 through 2015			
Contemporaneous	0.306***	0.352***	0.272***
Immediate News	(0.050)	(0.038)	(0.035)
Sum of Lags 1–6 of	0.021*	0.027**	−0.031*
Immediate News	(0.012)	(0.012)	(0.016)
R^2	0.474	0.598	0.254
Obs	146	146	146

period, the estimated lag coefficient is close to zero (economically and statistically) for all three bond yields. In the late period, the estimated coefficients are also economically small—on the order of 1/10 of the coefficients on contemporaneous news. From a statistical perspective, on balance the evidence points to continued changes in the same direction rather than reversals.

V. Conclusion

To better understand connections between economic growth and real yields, I examine empirically how changes in yields are associated with contemporaneous innovations in Greenbook forecasts of real output growth. In the data, changes in yields and news about expected future economic growth are unrelated, while changes in yields are strongly positively related to news about current economic growth.

Why do forward-looking investors who care about consumption smoothing not drive yields up when good news about the future arrives? Why do these same investors require higher yields when current output is unexpectedly high? It is mechanically possible to build a representative agent model to match these signs. The agent's demand for precautionary savings and/or their time rate of preference shocks needs to have some specific correlation properties with output news. However, the gap between possible and plausible appears large.

An off-the-shelf limited participation framework does not appear to fit these empirical patterns. Perhaps they are driven by dynamic limited participation, where agents cycle between an interior and a corner solution to the trade-off between consumption today and consumption tomorrow. More progress in this area requires better theory.

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Appendix: Additional Model Derivations

This appendix provides the intuition underlying the analytic expression for the covariance matrix of innovations (26). Additional details are in the Internet Appendix.

A. Discrete-Time Dynamics

Stack instantaneous log output, cumulative log output, and the instantaneous drift in the macroeconomic vector[9]

$$X_{m,t} \equiv \quad y_t \quad x_t \quad Y_t \quad . \tag{A1}$$

The state vector's dynamics are

$$dX_{m,t} = K_m X_{m,t} dt + \Omega_m dB_{m,t}, \tag{A2}$$

$$K_m = \begin{pmatrix} 0 & 1 & 0 \\ 0 & -\rho & 0 \\ 1 & 0 & 0 \end{pmatrix}, \qquad \Omega_m = \begin{pmatrix} \sigma_y & 0 \\ 0 & \sigma_x \\ 0 & 0 \end{pmatrix}. \tag{A3}$$

The subscripts "m" refer to macroeconomic values.

Augmenting these dynamics with asset dynamics requires keeping track of when information is observed by agents. The macroeconomic vector (A1) is not observed until $t + L$. Define an augmented state vector, with every component observed at $t + L$, as

$$X_t = \quad X_{m,t} \quad s_{t+L} \quad r_{1yr,t+L} \quad n_{1yr,t+L} \quad n_{10yr,t+L} \quad .$$

Using (A2) and (A3), the dynamics of the augmented state vector are

[9] Thanks to discussant Scott Joslin for proposing this framework, which considerably simplifies the math relative to an earlier version of the paper.

$$dX_t = KX_t dt + \Omega dB_{m,t} + \Sigma dB_{nm,t+L}, \tag{A4}$$

$$K \equiv \begin{pmatrix} K_m & 0_{3\times 4} \\ 0_{4\times 3} & 0_{4\times 4} \end{pmatrix}, \qquad \Omega = \begin{pmatrix} \Omega_m \\ \Omega_a \end{pmatrix}, \qquad \Sigma = \begin{pmatrix} 0_{4\times 4} \\ \Sigma_a \end{pmatrix}. \tag{A5}$$

Probability distributions of the state vector are multivariate normal. The discrete-time conditional expectation and covariance are the usual Ornstein-Uhlenbeck forms, which use matrix exponentials. The formulas are

$$E\left(X_{t+h}|X_t\right) = \exp(Kh)X_t, \tag{A6}$$

$$\mathrm{cov}\left(X_{t+h}|X_t\right) = \int_0^h \exp(Ku)\Omega Z\Omega' \exp(Ku)'\, du + h\Sigma\Sigma', \tag{A7}$$

with Z defined as the instantaneous correlation matrix of the Brownian increments,

$$Z = \begin{pmatrix} 1 & \sigma_{xy} \\ \sigma_{xy} & 1 \end{pmatrix}.$$

Both (A6) and (A7) have standard analytic solutions that depend on the dynamic form (A4) and its parameters (A5). See the Internet Appendix for more details.

B. Forecasts of Output Growth

The change in log output from quarter $\tau + j - 1$ to quarter $\tau + j$, where τ is an integer, is given by first-differencing (22):

$$Y^Q_{\tau+j} = Y_{\tau+j} - 2Y_{\tau+j-1} + Y_{\tau-j-2}. \tag{A8}$$

Agents at a noninteger date t in quarter τ forecast (A8). The time until the next quarter-end is, using the floor function,

$$d(t) = 1 + \lfloor t \rfloor - t.$$

For example, at $t = 3.2$, the quarter ends at $t + d(t) = 4$ and the time until the next quarter-end is $d(t) = 0.8$. Using this definition and the identity $\tau \equiv t + d(t)$, the forecast is

$$E_t\left(Y^Q_{t+d(t)+j}\right) = E_t\left(Y_{t+d(t)+j}\right) - 2E_t\left(Y_{t+d(t)+j-1}\right) + E_t\left(Y_{t+d(t)-j-2}\right). \tag{A9}$$

The notation in (A9) is technically correct but obscures some complexity. As of time t, one or more of the random variables that appear on the right may be realized (i.e., known to agents). In this case, the time-t expectation is simply the realization, observed at some time prior to t.

The analytic expression for (A9) consists of four cases. Each case corresponds to the number of random variables on the right side that are already realized at time t, between zero and three. The number of realized values depends on horizon j, the information lag length L, and the location in the quarter of t. When none are realized, the expression for (A9) depends only on the state vector observed as of date t. When one or two are realized, the expression also depends on the state vector(s) as of the dates the agents observe them. When all three are realized, the expression depends only on the state vectors on the three dates that agents observe them. The Internet Appendix contains the expression.

The analytic expression for forecast innovations (24) is a function of the innovation(s) in the state vector from the initial observation date t_{i-1} to all future dates that determine (A9) for the ending observation date t_i. For example, assume that one of the random variables on the right of (A9) is realized as of t_i and none are realized at the earlier date t_{i-1}. Then (24) depends on two overlapping innovations in the state vector. One is the innovation from the state vector observed at t_{i-1} to the date of the realization and the other is from the state vector observed at t_{i-1} to the state vector observed at t_i. The Internet Appendix contains the general expression.

The formula for the covariance matrix of innovations (26) is also in the Internet Appendix. It consists of repeated applications of (A7), with the forecast horizons determined by the state-vector innovations in (24).

C. Estimation Details

For simplicity, the main text considers only the case of six forecast innovations at each Greenbook date, from $j = -1$ through $j = 4$. However, the maximum forecast innovation horizon for 17 of the observations is $j = 3$. For these observations, the variance of measurement error for four-quarter-ahead forecasts is excluded from the parameter vector. Denote by N_i the number of output forecast innovations observed at Greenbook i. Denote by $\sigma^2_{i,err}$ the vector of measurement error variances for these N_i innovations.

The covariance matrix of the observed vector (27) is

$$C_{total}(t_i, j_{i,min}, j_{i,max}) \equiv E(\hat{}_i \hat{}_i) = C(t_i, j_{i,min}, j_{i,max}) + C_{i,err},$$

$$C_{i,err} = \begin{matrix} \mathrm{diag}(\sigma^2_{i,err}) & 0_{N_i \times 4} \\ 0_{4 \times N_i} & 0_{4 \times 4} \end{matrix} .$$

Dropping constant terms, the log-likelihood function is

$$l(\hat{}_1, \ldots, \hat{}_T; \psi) = -\frac{1}{2} \sum_{i=1}^{T} \left(\log C_{total}(t_i, j_{i,min}, j_{i,max}) + \hat{}_i C_{total}^{-1}(t_i, j_{i,min}, j_{i,max}) \hat{}_i \right). \tag{A10}$$

Four observations of the one-year ex ante risk-free yield are missing. (The appropriate measures of expected inflation are unavailable in the Greenbook forecasts.) These four Greenbook dates are included in the sum of (A10) by dropping the relevant row and column from the model-implied covariance matrix. Estimation of the information matrix excludes these four dates.

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Supporting Information

Additional Supporting Information may be found in the online version of this article at the publisher's website:

Appendix S1: Internet Appendix.
Replication Code.