Output Gaps

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Abstract

What is the output gap? There are many definitions in the economics literature, all of which have a long history. I discuss five alternatives: the deviation of output from its long-run stochastic trend (i.e., the "Beveridge-Nelson cycle"); the deviation of output from the level consistent with current technologies and normal utilization of capital and labor input (i.e., the "production-function approach"); the deviation of output from "flexible-price" output; the deviation of output from its "natural rate": and an efficiency gap, the deviation of output from a "frictionless" or "distortion-free" level. Estimates of each concept are presented from a dynamic-stochastic-general-equilibrium (DSGE) model of the U.S. economy used at the Federal Reserve Board. Three points are emphasized: The efficiency, natural rate, and flexible-price levels are highly dependent on modeling assumptions, and each of these levels of output converge to the Beveridge-Nelson trend; the Beveridge-Nelson concept and the production-function approach yield quite similar gaps; and the DSGE model's estimate of the Beveridge-Nelson gap is very similar to gaps from policy institutions, but the DSGE model's estimate of potential growth has a higher variance and substantially different covariance with GDP growth.

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1 Introduction

What is the output gap? The question is simple, but the answer is not – in part because economist's employ quite different definitions. I consider five definitions of the output gap:

- The deviation of output from its long-run stochastic trend (i.e., the "Beveridge-Nelson cycle", as defined in Beveridge and Nelson (1981));
- The deviation of output from the level consistent with current technologies and normal utilization of capital and labor input (i.e., the "production-function approach", as employed, for example, by the Congressional Budget Office (CBO) (CBO (2001)));
- The deviation of output from a "flexible-price" level;
- The deviation of output from a "natural rate" defined as the level that would prevail under price flexibility and constant markups;
- And the deviation of output from a "frictionless" or "distortion-free" level.[1]

This research presents estimates of each concept from a dynamic-stochastic-general-equilibrium (DSGE) model developed at the Federal Reserve Board and discusses the correspondence between these estimates and those produced elsewhere; the uses of each concept are also highlighted. The EDO model can produce estimates of each

[1] Notions related to the last three concepts have a long intellectual pedigree. For example, Plosser and Schwert (1979) highlight the difficulty of using the production-function approach in policy applications, as its focus on the "supply-side" of the economy does not allow consideration of the multitude of factors that influence equilibrium production and hence affect the desirability of alternative paths for production, employment, etc. Gordon (1979) (in the same volume as Plosser and Schwert (1979)) suggested "natural" output as corresponding to his particular view of a desirable economic outcome – namely, stable inflation. The recent literature on the natural rate of output (e.g., Woodford (2003) and Edge, Kiley, and Laforte (2008a)) has adopted a related notion of natural output with a more explicit focus on microeconomic foundations, discussed in more detail below.

concept. However, the concepts, in and of themselves, do not play a central role in EDO (where decisions are based on utility and profit maximization problems, and the gap measures are determined from definitions "outside the model" which do not enter private agents' decisions). As a result, it is important to consider the question at hand before deciding on a given output gap concept: The Beveridge-Nelson gap provides answers to some questions, the production-function approach provides answers to other questions, and the flexible-price/natural-rate/efficiency gaps provide yet again different information.

Key results from the analysis are the the following.

- The flexible-price/natural-rate/efficiency gaps are highly dependent on modeling assumptions, and their use in policy applications or forecasting requires a deep understanding of a specific model's structure. (This result is closely related to the critique of DSGE models of Chari, Kehoe, and McGrattan (2009), who highlight the sensitivity of policy applications of such models to controversial modeling assumptions).

- "Equilibrium" or trend *expected* growth is highly variable in the flex-price/natural-rate/efficient-rate case, implying that a focus on the current level of such gaps can be misleading in a policy discussion. In contrast, expected trend growth for the Beveridge-Nelson concept is exogenous and constant; moreover, all other notions of "trend" converge to the Beveridge- Nelson trend (by definition).

- The Beveridge-Nelson concept and the production-function approach yield quite similar gaps.

- The DSGE model's estimate of the output gap (according to either a Beveridge-Nelson or production-function approach) is very similar to gaps from the Congressional Budget Office or the Federal Reserve's large-scale macroeconometric model (FRB/US) model, but the DSGE model's estimate of potential growth is considerably more variable; the latter result stems from the significant degree of fluctuation in aggregate technology estimated by the DSGE model, a result consistent with the significant role such fluctuations play in model's descended from those of the real-business-cycle tradition (from Kydland and Prescott (1982)). Moreover, potential growth from the DSGE model covaries with GDP growth to a much more significant degree than does potential from either the CBO or the FRB/US model; this is again consistent with the model's roots in the quantitative tradition initiated by Kydland and Prescott (1982), and closely related to a large time-series literature on the covariance between potential and actual GDP growth.

Before proceeding to the main discussion, a brief introduction to the primary model considered in the analysis helps frame the discussion. The DSGE model employed is the EDO (Estimated, Dynamic, Optimization-based) model developed in (see Edge, Kiley, and Laforte (2007, 2008a, 2008b, 2009a, 2009b)). This model is ideally suited to address the questions of interest, as it includes

- A two-sector structure emphasizing the importance of fluctuations in aggregate and investment-specific technology for explaining long-run growth and cyclical fluctuations – implying a stochastic trend in production and expenditure;
- A rich array of other shocks to pricing decisions, preferences, and the desirability of smoothing consumption over time through capital accumulation that allow for temporary fluctuations in activity;
- A New-Keynesian structure with nominal rigidities in both prices and wages and variable utilization of capital input; and
- An empirical approach that ensures the model can provide a reasonable characterization of the sources of fluctuations over history.

Each of these features allows the model to capture commonly emphasized features of each output gap concept (e.g., stochastic trends imply a rich Beveridge-Nelson decomposition; variable utilization and stochastic technology imply a sophisticated modeling of the production-function approach; and nominal rigidities yield a New-Keynesian endogenous fluctuations in markups that affect the efficient-rate concept). Moreover, this combination of features, and the day-to-day use of the model in a policy environment, is unique in policy and academic circles.

The remainder of this paper is divided into five sections. Section 2 summarizes some related recent research. The third discusses the structure of the EDO model. The fourth section examines each output gap concept within EDO, and highlights the projection implications of the model-dependent (flexible-price/natural-rate/efficient-rate) concepts. The fifth section compares estimates from EDO to those of the CBO and from the Federal Reserve's FRB/US model – a traditional, large-scale econometric model. The sixth section discusses correlations of gaps with inflation and unemployment, an important area of policy discussion (and modeling confusion). A concluding section provides some thoughts for future research.

2 Related Research

Despite the ambiguity associated with the concept of the output gap suggested by the quite different concepts highlighted above, the related literature is deep and influential in policy circles.

Perhaps the cleanest definition of an output gap is that associated with the cycle in output introduced by Beveridge and Nelson (1981). According to this definition, the cycle in output, or the output gap, is the deviation of output from the level expected to prevail in the long run (i.e., as time, t, approaches ∞), with the effect of any deterministic aspects of the growth in output on its long-run level removed. This definition of the output gap has several advantages. First, it is not model-specific: Any approach capable of capturing the reduced-form time-series characteristics of output can provide an estimate of this definition of the output gap; as a result, univariate or multivariate time-series methods as well as structural economic models can, in principle, estimate the output gap.[2] Second, the Beveridge-Nelson approach provides information related to a very specific forecasting problem – in particular, the current estimate of the Beveridge-Nelson gap provides an estimate of how much economic growth will deviate from its deterministic (or, in some models, "steady-state") level going forward: An answer to this forecasting problem forms the basis of a long-standing academic approach to discussions of the gap (e.g., the discussions in Nelson (1964) and Thurow and Taylor (1966) of the growth outlook for the 1960s in the United States, or the discussion in CBO (2009) of the growth outlook from 2009-2019). Finally, this method often provides estimates of the output gap that correspond to widely held views on what is "reasonable", although this result depends on assumptions (e.g., the discussion in Morley, Nelson, and Zivot (2003)).

The EDO model provides an excellent framework for computation of the Beveridge-Nelson gap. As highlighted in the introduction, the inclusion of stochastic trends in both aggregate and investment-specific technology implies the model has a non-trivial Beveridge-Nelson permanent component to output, and connects the model to the burgeoning literature on empirical two-sector growth models (see Edge, Kiley, and Laforte (2008a, 2009b)). The neoclassical core of the model ensures that the model captures the long-run relationships between output, investment, and consumption: King, Plosser, Stock, and Watson (1991) demonstrated the usefulness of such information for estimation of the Beveridge-Nelson gap in a multivariate context; similarly, Cochrane (1994) emphasized the potential role for consumption in identifying trends in output (due to the dependence of consumption on permanent income). The estimation of EDO includes information on output and several components of consumption and investment, yielding a rich, multivariate information set for output gap estima-

[2] The related literature using time-series methods is large; notable contributions include Harvey (1985), Watson (1986), Clark (1987), Stock and Watson (1988), and Morley, Nelson, and Zivot (2003).

tion. Indeed, the information set is quite broad, including expenditure variables, labor input, real wages, inflation, and the federal funds rate. Previous work has highlighted how time-series decompositions of output into permanent and transitory components can exploit information on hours (e.g., Rotemberg and Woodford (1996)) and inflation (e.g., Kuttner (1994)).

While the Beveridge-Nelson concept is perhaps the cleanest definition, the most prevalent definition at policy institutions appears to be the production-function approach (e.g., the approach used at the CBO (2001) and in the Federal Reserve's FRB/US model). In this approach, the output gap is defined as the deviation of output from the level that would occur if capital and labor input were utilized at "normal" rates, given current technology. In general, this approach, as employed at policy institutions, involves some smoothing of measured total factor productivity in order to estimate "true" technology. In contrast, the level of true technology in EDO is estimated to be consistent with the observed behavior of a broad range of economic variables and the underlying structure of the model. In principle, EDO could deliver very volatile estimated levels of "true" technology; however, this result is not predetermined, as the EDO model includes features that could cause measured total factor productivity to deviate from underlying technology (such as variable capital utilization, which could cause measured capital input to deviate from true capital input, and imperfect competition which could distort total factor productivity computations). The primary advantage of considering the EDO estimate of this concept is to compare it to estimates of the same concept produced by policy institutions. While the preferences of policy institutions for this approach is quite clear from their modeling efforts, it is not obvious what question motivates this particular focus.

The last three approaches considered (the flexible-price/natural-rate/efficiency approaches) are the focus of some discussions in the research literature usinfg DSGE models. Most prominently, the version called the "natural-rate" approach in Woodford (2003) and Edge, Kiley, and Laforte (2008a) has been widely discussed. The natural-rate approach defines the gap as one that would arise in the absence of nominal rigities and shocks to "markups"; this approach is motivated in simple New-Keynesian models by the stucture of such simple models, in which nominal rigidities are the only (significant) distortion, implying that the removal of such distortions provides an estimate of the level of output that is economically efficient. However, I take a more general approach, and define the efficiency gap as the level of output that would prevail in the absence of all distortions, and discuss interpretations of the distortions that arise in the EDO model. Specifically, the potential distortions in EDO arise from the time-variation in the markups of prices over marginal cost and in real wages over the marginal rate of substitution between consumption and leisure due to nominal price and wage rigidities (e.g., the gap between the marginal product of labor and the marginal rate of substitution between consumption and leisure), as in the simple natural-rate analysis of Woodford (2003); distortions also arise because of markup shocks, which also affect the gap between the the marginal product of labor and the marginal rate of substitution between consumption and leisure; finally, EDO contains risk premia shocks that drive a wedge between the marginal rate of transformation (or marginal rate of technical substitution) between consumption currently and in the future and the marginal rate of substitution between consumption currently and in the future, and such a wedge is distortionary (to the extent it reflects time-variation in, for example, the asymmetric information problems underlying the financial accelerator, as in Bernanke, Gertler, and Gilchrist (1999), Gilchrist, Ortiz, and Zakrajsek (2009), or Christiano, Motto, and Rostagno (2009)). As this discussion makes clear, the behavior of a flexible-price/natural-rate/efficiency gap measure will be highly dependent on the model's structure – specifically, on the types of imperfections and shocks included in the model. For example, EDO has two sectors, and nominal rigidities in the prices and wages prevailing in both sectors; as a result, its estimate of the natural rate of output may differ substantially from those of a model with one sector or with only nominal rigidities in prices or wages. Justiniano and Primiceri (2008) also discuss the factors that influence efficiency gaps relative to those that simply remove wage and price rigidities in a simpler model.

The analysis highlights that consideration of the implications of the efficiency gap are complex. In a simple one-sector model without markup or inefficient risk-premia shocks, stabilization of the efficiency, or natural-rate, gap would imply stabilization of inflation (e.g., Woodford (2003)). In EDO, the world is more complicated. There are two sectors, both with nominal rigidities and which are not symmetric (as one produces only a capital good and the other produces a good that can be used for consumption and as a capital good). As a result, stabilization of output at the efficient level does not stabilize inflation (as the distribution of output across sectors matters as well, e.g. Aoki (2001) and Erceg and Levin (2006)). In addition, EDO has nominal wage rigidities in each sector, again implying that stabilization of the efficiency gap need not stabilize inflation (e.g., Erceg, Henderson, and Levin (2000)). Finally, EDO has markup shocks, which also induce a tradeoff between output gap and inflation stabilization (e.g., Clarida, Gali, and Gertler (1999)). Each of these features seems at least potentially important, implying that great care should be taken when considering the implications of a given estimate of the efficiency gap.

The sharp differences across each definition should be readily apparent from this discussion. As a result, academic and policy discussions need to be quite clear about what type of gap they are considering or comparing, as there is no reason to think that the different concepts of the gap have similar relationships with other macroeconomic variables, with economic welfare, or with the economic outlook.

3 The EDO Model

The EDO model contains a detailed description of domestic production and expenditures decisions. The heart of the model is a two-sector production structure. In particular, we assume the economy consists of a consumption goods and an investment goods sector. We discuss the motivation for this basic structure in detail in Edge, Kiley, and Laforte (2007, 2008a, 2008b, 2009a, 2009b). I present the most recent version of the EDO model; more complete documentation is available in Chung, Kiley, and Laforte (2009).

Figure 1 provides a graphical overview of the economy described by our model. The model possesses two final goods: slow-growing "CBI" goods—so called because *most* of these goods are used for consumption (C) and because they are produced by the business and institutions (BI) sector—and fast-growing "KB" goods—so called because these goods are used for capital (K) accumulation and are produced by the business (B) sector. The goods are produced in two stages by intermediate- and then final-goods producing firms (shown in the center of the figure). On the model's demand-side, there are four components of spending (each shown in a box surrounding the producers in the figure): consumer non-durable goods and services (sold to households), consumer durable goods, residential capital goods, and non-residential capital goods. Consumer non-durable goods and services and residential capital goods are purchased (by households and residential capital goods owners, respectively) from the first of economy's two final goods producing sectors, while consumer durable goods and non-residential capital goods are purchased (by consumer durable and residential capital goods owners, respectively) from the second sector. We "decentralize" the economy by assuming that residential capital and consumer durables capital are rented to households while non-residential capital is rented to firms. In addition to consuming the non-durable goods and services that they purchase, households supply labor to the intermediate goods-producing firms in both sectors of the economy.

The disaggregation of production (aggregate supply) leads naturally to some disaggregation of expenditures (aggregate demand). We move beyond a model with just two categories of (private domestic) final spending and disaggregate the four categories of private expenditure mentioned earlier: consumer non-durable goods and non-housing services, consumer durable goods, residential investment, and non-residential investment.

This remainder of this section provides an overview of the decisions made by each of the agents in our economy. Given some of the broad similarities between our model and others, our presentation is selective.

3.1 The Final Goods Producers' Problem

The economy produces two final goods and services: slow-growing "consumption" goods and services, X_t^{cbi}, and fast-growing "capital" goods, X_t^{kb}. These final goods are produced by aggregating (according to a Dixit-Stiglitz technology) an infinite number of sector-specific differentiated intermediate inputs, $X_t^s(j)$ for $s = cbi, kb$, distributed over the unit interval. The representative firm in each of the consumption and capital goods producing sectors chooses the optimal level of each intermediate input, taking as given the prices for each of the differentiated intermediate inputs, $P_t^s(j)$, to solve the cost-minimization problem:

$$\min_{\{X_t^s(j)\}_{j=0}^1} \int_0^1 P_t^s(j) X_t^s(j) dj \text{ subject to } \left(\int_0^1 \left(X_t^s(j)\right)^{\frac{\Theta_t^s - 1}{\Theta_t^s}} dj \right)^{\frac{\Theta_t^s}{\Theta_t^s - 1}} \geq X_t^s, \text{ for } s = cbi, kb. \tag{1}$$

The term Θ_t^s is the stochastic elasticity of substitution between the differentiated intermediate goods inputs used in the production of the consumption or capital goods sectors. Letting $\theta_t^s \equiv \ln \Theta_t^s - \ln \Theta_*^s$ denote the log-deviation of Θ_t^s from its steady-state value of Θ_*^s, we assume that

$$\theta_t^s = \epsilon_t^{\theta,s}, \text{ for } s = cbi, kb, \tag{2}$$

where $\epsilon_t^{\theta,s}$ is an i.i.d. shock process. A stochastic elasticity of substitution introduces transitory markup shocks into the pricing decisions of intermediate-goods producers.

3.2 The Intermediate Goods Producers' Problem

The intermediate goods entering each final goods technology are produced by aggregating (according to a Dixit-Stiglitz technology) an infinite number of differentiated labor inputs, $L_t^s(j)$ for $s = cbi, kb$, distributed over the unit interval and combining this aggregate labor input (via a Cobb-Douglas production function) with utilized non-residential capital, $K_t^{u,nr,s}$. Each intermediate-good producing firm effectively solves three problems: two factor-input cost-minimization problems (over differentiated labor inputs and the aggregate labor and capital) and one price-setting profit-maximization problem.

In its first cost-minimization problem, an intermediate goods producing firm chooses the optimal level of each type of differential labor input, taking as given the wages for each of the differentiated types of labor, $W_t^s(i)$, to solve:

$$\min_{\{L_t^s(i,j)\}_{i=0}^1} \int_0^1 W_t^s(i) L_t^s(i,j) di \text{ subject to } \left(\int_0^1 \left(L_t^s(i,j) \right)^{\frac{\Theta_t^l - 1}{\Theta_t^l}} di \right)^{\frac{\Theta_t^l}{\Theta_t^l - 1}} \geq L_t^s(j), \text{ for } s = cbi, kb. \tag{3}$$

The term Θ_t^l is the stochastic elasticity of substitution between the differentiated labor inputs. Letting $\theta_t^l \equiv \ln \Theta_t^l - \ln \Theta_*^l$ denote the log-deviation of Θ_t^l from its steady-state value of Θ_*^l, we assume that

$$\theta_t^l = \epsilon_t^{\theta,l}. \tag{4}$$

where $\epsilon_t^{\theta,l}$ is an i.i.d. shock process. A stochastic elasticity of substitution introduces transitory wage markup shocks into the wage decisions of households.

In its second cost-minimization problem, an intermediate-goods producing firm chooses the optimal levels of aggregated labor input and utilized capital, taking as given the wage, W_t^s, for aggregated labor, L_t^s (which is generated by the cost function derived the previous problem), and the rental rate, $R_t^{nr,s}$, on utilized capital, $K_t^{u,nr,s}$, to solve:

$$\min_{\left\{L_t^s(j), K_t^{u,nr,s}(j)\right\}} W_t^s L_t^s(j) + R_t^{nr,s} K_t^{u,nr,s}(j)$$
$$\text{subject to } \left(Z_t^m Z_t^s L_t^s(j)\right)^{1-\alpha} \left(K_t^{u,nr,s}(j)\right)^{\alpha} \geq X_t^s(j), \text{ for } s = cbi, kb, \text{ but } Z_t^{cbi} \equiv 1. \quad (5)$$

The parameter α is the elasticity of output with respect to capital, while the Z_t variables denote the level of productivity. The level of productivity has two components. The first, Z_t^m, is common to both sectors and thus represents the level of economy-wide technology. The second, Z_t^s, is sector specific; we normalize Z_t^{cbi} to one, while Z_t^{kb} is not restricted.

The exogenous productivity terms contain a unit root, that is, they exhibit permanent movements in their levels. We assume that the stochastic processes Z_t^m and Z_t^{kb} evolve according to

$$\ln Z_t^n - \ln Z_{t-1}^n = \ln \Gamma_t^{z,n} = \ln\left(\Gamma_*^{z,n} \cdot \exp[\epsilon_t^{z,n}]\right) = \ln \Gamma_*^{z,n} + \epsilon_t^{z,n}, \;\; n = kb, m \qquad (6)$$

where $\Gamma_*^{z,n}$ and $\epsilon_t^{z,n}$ are the steady-state and stochastic components of $\Gamma_t^{z,n}$. The stochastic component $\epsilon_t^{z,n}$ is an i.i.d shock process.

The unit-root in technology in both sectors yields a non-trivial Beveridge-Nelson permanent/transitory decomposition. The presence of capital-specific technological progress allows the model to generate differential trend growth rates in the economy's two production sectors. In line with historical experience, we assume a more rapid rate of technological progress in capital goods production by calibrating $\Gamma_*^{z,kb} > 1$, where (as is the case for all model variables) an asterisk on a variable denotes its steady-state value.

In its price-setting problem (or profit-maximization), an intermediate goods producing firm chooses its optimal nominal price and the quantity it will supply consistent with that price. In doing so it takes as given the marginal cost, $MC_t^s(j)$, of producing a unit of output, $X_t^s(j)$, the aggregate price level for its sector, P_t^s, and households' valuation of a unit of nominal profits income in each period, which is given by $\Lambda_t^{cnn}/P_t^{cbi}$ where Λ_t^{cnn} denotes the marginal utility of non-durables and non-housing services consumption. Specifically, firms solve:

$$\max_{\{P_t^s(j),X_t^s(j),X_t^s(j)\}_{t=0}^{\infty}} \mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{\Lambda_t^{cnn}}{P_t^{cbi}} \Big\{ P_t^s(j)X_t^s(j) - MC_t^s(j)X_t^s(j) \\ - \frac{100 \cdot \chi^p}{2} \left(\frac{P_t^s(j)}{P_{t-1}^s(j)} - \eta^p \Pi_{t-1}^{p,s} - (1-\eta^p)\Pi_*^{p,s} \right)^2 P_t^s X_t^s \Big\}$$

subject to $X_\tau^s(j) = (P_\tau^s(j)/P_\tau^s)^{-\Theta_\tau^s} X_\tau^s$ for $\tau = 0, 1, ..., \infty$ and $s = cbi, kb$. (7)

The profit function reflects price-setting adjustment costs (the size which depend on the parameter χ^p and the lagged and steady-state inflation rate). The constraint against which the firm maximizes its profits is the demand curve it faces for its differentiated good, which derives from the final goods producing firm's cost-minimization problem. This type of price-setting decision delivers a new-Keynesian Phillips curve. Because adjustment costs potentially depend upon lagged inflation, the Phillips curve can take the "hybrid" form in which inflation is linked to its own lead and lag as well as marginal cost.

3.3 The Capital Owners' Problem

We now shift from producers' decisions to spending decisions (that is, those by agents encircling our producers in Figure 1). Non-residential capital owners choose investment in non-residential capital, E_t^{nr}, the stock of non-residential capital, K_t^{nr} (which is linked to the investment decision via the capital accumulation identity), and the amount and utilization of non-residential capital in each production sector, $K_t^{nr,cbi}$, U_t^{cbi}, $K_t^{nr,kb}$, and U_t^{kb}. (Recall, that the firm's choice variables in equation 5 is utilized capital $K_t^{u,nr,s} = U_t^s K_t^{nr,s}$.) The mathematical representation of this decision is described by the following maximization problem (in which capital owners take as given the rental rate on non-residential capital, R_t^{nr}, the price of non-residential capital goods, P_t^{kb}, and households' valuation of nominal capital income in each period, $\Lambda_t^{cnn}/P_t^{cbi}$, and the exogenous risk premia specific to non-residential investment,

A^{nr}_{t+1}/A^{nr}_t):

$$\max_{\{E^{nr}_t(k),K^{nr}_{t+1}(k),K^{nr,cbi}_t(k),K^{nr,kb}_t(k)U^{cbi}_t(k),U^{kb}_t(k)\}^{\infty}_{t=0}}$$

$$\mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{A^{nr}_0}{A^{nr}_t} \frac{\Lambda^{cnn}_t}{P^{cbi}_t} \Big\{ R^{nr}_t U^{cbi}_t(k) K^{nr,cbi}_t(k) + R^{nr}_t U^{kb}_t(k) K^{nr,kb}_t(k) - P^{kb}_t E^{nr}_t(k)$$
$$-\kappa \left(\frac{U^{cbi}_t(k)^{1+\psi} - 1}{1+\psi} \right) P^{kb}_t K^{nr,cbi}_t - \kappa \left(\frac{U^{kb}_t(k)^{1+\psi} - 1}{1+\psi} \right) P^{kb}_t K^{nr,kb}_t \Big\}$$

subject to

$$K^{nr}_{\tau+1}(k) = (1-\delta^{nr}) K^{nr}_\tau(k) + E^{nr}_\tau(k) - \frac{100 \cdot \chi^{nr}}{2} \left(\frac{E^{nr}_\tau(k) - E^{nr}_{\tau-1}(k) \Gamma^{y,kb}_t}{K^{nr}_\tau} \right)^2 K^{nr}_\tau \text{ and}$$
$$K^{nr,cbi}_\tau(k) + K^{nr,kb}_\tau(k) = K^{nr}_\tau(k) \text{ for } \tau = 0, 1, ..., \infty. \tag{8}$$

The parameter δ^{nr} in the capital-accumulation constraint denotes the depreciation rate for non-residential capital, while the parameter χ^{nr} governs how quickly investment adjustment costs increase when $(E^{nr}_\tau(k) - E^{nr}_{\tau-1}(k)\Gamma^{y,kb}_t)$ rises above zero. The variable A^{nr}_{t+1}/A^{nr}_t is a stochastic element reflecting a risk premium on non-residential investment. Letting $a^{nr}_t \equiv \ln A^{nr}_{t+1}/A^{nr}_t$ denote the log-deviation of A^{nr}_{t+1}/A^{nr}_t from its steady-state value of unity, we assume that:

$$a^{nr}_t = \rho^{nr} a^{nr}_{t-1} + \epsilon^{nr}_t. \tag{9}$$

Higher rates of utilization incur a cost (reflected in the last two terms in the capital owner's profit function). We assume that $\kappa = R^{nr}_*/P^{kb}_*$, which implies that utilization is unity in the steady-state.

The time-variation in utilization, along with the imperfect competition in product and labor markets, implies that direct measurement of total factor productivity may not provide an accurate estimate of technology; as a result, the EDO model can deliver smoother estimates of technology that might be implied by a real-business-cycle model.

The problems solved by the consumer durables and residential capital owners are slightly simpler than the non-residential capital owner's problems. Since utilization rates are not variable for these types of capital, their owners make only investment and capital accumulation decisions. Taking as given the rental rate on consumer durables capital, R_t^{cd}, the price of consumer-durable goods, P_t^{kb}, and households' valuation of nominal capital income, $\Lambda_t^{cnn}/P_t^{cbi}$, and the exogenous risk premia specific to consumer durables investment, A_{t+1}^{cd}/A_t^{cd}, the capital owner chooses investment in consumer durables, I_t^{cd}, and its implied capital stock, K_t^{cd}, to solve:

$$\max_{\{E_t^{cd}(k),K_{t+1}^{cd}(k)\}_{t=0}^{\infty}} \mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{A_0^{cd}}{A_t^{cd}} \frac{\Lambda_t^{cnn}}{P_t^{cbi}} \left\{ R_t^{cd} K_t^{cd}(k) - P_t^{kb} E_t^{cd}(k) \right\}$$

subject to

$$K_{\tau+1}^{cd}(k) = (1-\delta^{cd}) K_\tau^{cd}(k) + E_\tau^{cd}(k) - \frac{100 \cdot \chi^{cd}}{2} \left(\frac{E_\tau^{cd}(k) - E_{\tau-1}^{cd}(k) \Gamma_\tau^{x,kb}}{K_\tau^{cd}} \right)^2 K_\tau^{cd}$$

for $\tau = 0, 1, ..., \infty$. (10)

The residential capital owner's decision is analogous:

$$\max_{\{E_t^{r}(k),K_{t+1}^{r}(k)\}_{t=0}^{\infty}} \mathcal{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{A_0^{r}}{A_t^{r}} \frac{\Lambda_t^{cnn}}{P_t^{cbi}} \left\{ R_t^{r} K_t^{r}(k) - P_t^{cbi} E_t^{r}(k) \right\}$$

subject to

$$K_{\tau+1}^{r}(k) = (1-\delta^{r}) K_\tau^{r}(k) + E_\tau^{r}(k) - \frac{100 \cdot \chi^{r}}{2} \left(\frac{E_\tau^{r}(k) - E_{\tau-1}^{r}(k) \Gamma_\tau^{x,cbi}}{K_\tau^{cd}} \right)^2 K_\tau^{cd}$$

for $\tau = 0, 1, ..., \infty$. (11)

The notation for the consumer durables and residential capital stock problems parallels that of non-residential capital. In particular, the asset-specific risk premia shocks, A_{t+1}^{cd}/A_t^{cd} and A_{t+1}^{r}/A_t^{r}, follow an autoregression process similar to that given in equation (9).

3.4 The Households' Problem

The final group of private agents in the model are households who make both expenditure and labor-supply decisions. Households derive utility from four sources: their purchases of the consumer non-durable goods and non-housing services, the flow of services from their rental of consumer-durable capital, the flow of services from their rental of residential capital, and their leisure time, which is equal to what remains of their time endowment after labor is supplied to the market. Preferences are separable over all arguments of the utility function. The utility that households derive from the three components of goods and services consumption is influenced by the habit stock for each of these consumption components, a feature that has been shown to be important for consumption dynamics in similar models. A household's habit stock for its consumption of non-durable goods and non-housing services is equal to a factor h multiplied by its consumption last period E_{t-1}^{cnn}. Its habit stock for the other components of consumption is defined similarly.

Each household chooses its purchases of consumer non-durable goods and services, E_t^{cnn}, the quantities of residential and consumer durable capital it wishes to rent, K_t^r and K_t^{cd}, its holdings of bonds, B_t, its wage for each sector, W_t^{cbi} and W_t^{kb}, and supply of labor consistent with each wage, L_t^{cbi} and L_t^{kb}. This decision is made subject to the household's budget constraint, which reflects the costs of adjusting wages and the mix of labor supplied to each sector, as well as the demand curve it faces for its differentiated labor. Specifically, the ith household solves:

$$\max_{\left\{E_t^{cnn}(i),K_t^{cd}(i),K_t^{r}(i),\{W_t^s(i),L_t^s(i)\}_{s=cbi,kb},B_{t+1}(i)\right\}_{t=0}^{\infty}}$$

$$\mathcal{E}_0\sum_{t=0}^{\infty}\beta^t\Big\{\varsigma^{cnn}\ln(E_t^{cnn}(i)-hE_{t-1}^{cnn}(i))+\varsigma^{cd}\ln(K_t^{cd}(i)-hK_{t-1}^{cd}(i))$$
$$+\varsigma^{r}\ln(K_t^{r}(i)-hK_{t-1}^{r}(i))\ -\varsigma^{l}\frac{(L_t^{cbi}(i)+L_t^{kb}(i))^{1+\nu}}{1+\nu}\Big\}.$$

subject to

$$\frac{B_{\tau+1}(i)}{R_\tau\Omega_\tau}=B_\tau(i)+\sum_{s=cbi,kb}W_\tau^s(i)L_\tau^s(i)+\mathit{Capital\ and\ Profits\ Income}_\tau(i)-P_\tau^{cbi}E_\tau^{cnn}(i)$$
$$-R_\tau^{cd}K_\tau^{cd}(i)-R_\tau^{r}K_\tau^{r}(i)-\sum_{s=cbi,kb}\frac{100\cdot\chi^w}{2}\left(\frac{W_\tau^s(j)}{W_{\tau-1}^s(j)}-\eta^w\Pi_{\tau-1}^{w,s}-(1-\eta^w)\Pi_*^w\right)^2W_\tau^sL_\tau^s$$
$$-\frac{100\cdot\chi^l}{2}\left(\frac{L_*^{cbi}\cdot W_\tau^{cbi}}{L_*^{cbi}+L_*^{kb}}+\frac{L_*^{kb}\cdot W_\tau^{kb}}{L_*^{cbi}+L_*^{kb}}\right)\left(\frac{L_\tau^{cbi}(i)}{L_\tau^{kb}(i)}-\eta^l\frac{L_{\tau-1}^{cbi}}{L_{\tau-1}^{kb}}-(1-\eta^l)\frac{L_*^{cbi}}{L_*^{kb}}\right)^2\frac{L_\tau^{kb}}{L_\tau^{cbi}}.$$
$$L_\tau^{cbi}(i)=\left(W_\tau^{cbi}(i)/W_\tau^{cbi}\right)^{-\Theta_t^l}L_\tau^{cbi},\ \text{and}\ L_\tau^{kb}(i)=\left(W_\tau^{kb}(i)/W_\tau^{kb}\right)^{-\Theta_t^l}L_\tau^{kb},$$
$$\text{for}\ \tau=0,1,...,\infty. \tag{12}$$

In the utility function the parameter β is the household's discount factor, ν denotes its inverse labor supply elasticity, while ς^{cnn}, ς^{cd}, ς^{r}, and ς^{l} are scale parameter that tie down the ratios between the household's consumption components.

The stationary, unit-mean, stochastic variable Ω_t represents an aggregate risk-premium shock that drives a wedge between the policy short-term interest rate and the return to bonds received by a household. Letting $\omega_t \equiv \ln\Omega_t - \ln\Omega_*$ denote the log-deviation of Ω_t from its steady-state value of Ω_*, we assume that

$$\omega_t = \rho^\omega\omega_{t-1} + \epsilon_t^\omega. \tag{13}$$

The variable ϵ_t^ω is an i.i.d. shock process, and ρ^ω represents the persistence of Ω_t away from steady-state following a shock to equation (13).

The household's budget constraint reflects wage setting adjustment costs, which depend on the parameter χ^w and the lagged and steady-state wage inflation rate, and the costs in changing the mix of labor supplied to each sector, which depend on the parameter χ^l. The costs incurred by households when the mix of labor input across sectors changes may be important for sectoral comovements.

3.5 Gross Domestic Product

The demand and production aspects of the model are closed through the exogenous process for demand other than private domestic demand and the GDP identity. $\widetilde{X}_t^{HG}$ represents exogenous demand (i.e., GDP other than private domestic demand, the aggregate of E_t^{cnn}, E_t^{cd}, E_t^{r}, and E_t^{nr}). Exogenous demand is assumed to follow the process:

$$\ln \widetilde{X}_t^{HG} - \ln \widetilde{X}_*^{HG} = \rho^{HG} \left(\ln \widetilde{X}_t^{HG} - \ln \widetilde{X}_*^{HG} \right) + \epsilon_t^{HG}.$$

We assume that the exogenous demand impinges on each sector symmetrically, and specifically that the percent deviation of exogenous demand proportionally affects demand for each sector's ($s = cbi, kb$) output via the share of exogenous demand in total demand, ω_{HG}.

The rate of change of Gross Domestic Product (real GDP) equals the Divisia (share-weighted) aggregate of production in the two sectors (and of final spending across each expenditures category), as given by the identity:

$$H_t^{gdp} = \left(\left(\frac{X_t^{cbi}}{X_{t-1}^{cbi}} \right)^{P_*^{cbi} X_*^{cbi}} \left(\frac{X_t^{kb}}{X_{t-1}^{kb}} \right)^{P_*^{kb} X_*^{kb}} \right)^{\frac{1}{P_*^{cbi} X_*^{cbi} + P_*^{kb} X_*^{kb}}} . \tag{14}$$

3.6 Monetary Authority

We now turn to the last important agent in our model, the monetary authority. It sets monetary policy in accordance with an Taylor-type interest-rate feedback rule. Policymakers smoothly adjust the actual interest rate R_t to its target level $\bar{R}_t$

$$R_t = \left(R_{t-1} \right)^{\phi^r} \left(\bar{R}_t \right)^{1-\phi^r} \exp \left[\epsilon_t^r \right], \tag{15}$$

where the parameter ϕ^r reflects the degree of interest rate smoothing, while ϵ_t^r represents a monetary policy shock. The central bank's target nominal interest rate, $\bar{R}_t$

depends the deviation of output from its stochastic trend ($\tilde{X}^{bn}$, the output gap as defined by Beveridge and Nelson (1981))

$$\tilde{X}_t^{bn} = \mathcal{E}_t \left[\sum_{\tau=-\infty}^{t} H_\tau^{gdp} - \sum_{\tau=-\infty}^{\infty} H_\tau^{gdp} \right]. \tag{16}$$

In equation 16, the deterministic, or steady-state, levels of growth are suppressed. Consumer price inflation and the change in the output gap also enter the target. The target equation is:

$$\bar{R}_t = \left(\tilde{X}_t^{bn}\right)^{\phi^Y} \left(\tilde{X}_t^{bn}/\tilde{X}_{t-1}^{bn}\right)^{\phi^{\Delta Y}} \left(\frac{\Pi_t^c}{\Pi_*^c}\right)^{\phi^\pi} R_*. \tag{17}$$

In equation (17), R_* denotes the economy's steady-state nominal interest rate and ϕ^Y, $\phi^{\Delta Y}$, ϕ^π, and $\phi^{\Delta\pi}$ denote the weights in the feedback rule. Consumer price inflation, Π_t^c, is the weighted average of inflation in the nominal prices of the goods produced in each sector, $\Pi_t^{p,cbi}$ and $\Pi_t^{p,kb}$:

$$\Pi_t^c = (\Pi_t^{p,cbi})^{1-w_{cd}} (\Pi_t^{p,kb})^{w_{cd}}. \tag{18}$$

The parameter w^{cd} is the share of the durable goods in nominal consumption expenditures.

3.7 Summary of Model Specification

Our brief presentation of the model highlights several important points. First, although our model considers production and expenditure decisions in a bit more detail, it shares many similar features with other DSGE models in the literature, such as imperfect competition, nominal price and wage rigidities, and real frictions like adjustment costs and habit-persistence. The rich specification of structural shocks (to aggregate and investment-specific productivity, aggregate and sector-specific risk premia, and mark-ups) and adjustment costs allows our model to be brought to the data with some chance of finding empirical validation.[3]

[3]Interestingly, a common criticism of large econometric models like the FRB/US has been their reliance on adjustment costs; DSGE models similar to that herein have increasingly relied on similar

Within EDO, fluctuations in all economic variables are driven by eleven structural shocks. For the discussion of each concept of the output gap, it is most convenient to summarize these shocks into broad categories:

- Permanent technology shocks: This category consists of shocks to aggregate and investment-specific (or fast-growing sector) technology.
- Transitory shocks that affect flexible-price output: This category consists of all shocks except monetary shocks. For example, markup and risk premia shocks affect flexible price output.
- Transitory shocks that affect the natural rate of output: this category excludes monetary shocks, markup shocks, and the aggregate risk-premia shock (but includes the sector-specific risk premia; the distinction between aggregate and sector-specific risk premia arises because the aggregate risk premia simply affects the gap between the nominal funds rate and the (nominal) stochastic discount factor of the representative agent).
- Transitory shocks that affect the efficient rate of output: This category excludes all transitory shocks except shocks to autonomous demand – that is, it also excludes shocks to sector-specific risk-premia in addition to the shocks in the previous category. Shocks to risk premia, as we specify them, could also be interpreted as distortions driving a wedge between the marginal rate of substitution between consumption in the current and next period and the marginal rate of transformation (or marginal rate of technical substitution) between producing consumption between the current and next period (due, for example, to asymmetric information like the external finance premia from the financial accelerator in Bernanke, Gertler, and Gilchrist (1999)). Under this interpretation, such shocks would be distortionary. Chari, Kehoe, and McGrattan (2007,

mechanisms when required to fit macroeconomic data, which may be a cause for concern regarding the "structural" interpretation of such models.

2009) discuss how these, and other, types of "wedges" could have efficient and inefficient interpretations. For example, under the interpretation that these shocks represent productive frictions associated with capital intermediaries in our model that would influence a social planner's allocation. This issues are discussed more fully below.

Using this categorization, only technology shocks affect the Beveridge-Nelson permanent component; of course the Beveridge-Nelson gap reflects the influence of all shocks (and technology shocks imply movements in the gap, as the economy does not instantaneous adjust to the long-run implications of a shock to technology for standard neoclassical adjustment reasons and because of the short-run impediments to adjustment created by wage and price rigidities). The definition of the efficient rate depends on the interpretation of risk-premia shocks. This ambiguity is a standard feature of New-Keynesian DSGE models (discussed, for example, in Smets and Wouters (2007)). Chari, Kehoe, and McGrattan (2009) are highly critical of this ambiguity, and suggest that DSGE models must find some method for identifying whether such shocks are distortionary or non-distortionary before such models can be used in policy applications; one possibility they mention is to explore microeconomic implications of these shocks/distortions. While I agree that such research is essential to definitively answer some questions of policy interest, I view the forecast performance (e.g., Edge, Kiley, and Laforte (2009a)) and range of policy-relevant stories that can be discussed with such models (e.g., Edge, Kiley, and Laforte (2008a)) as suggesting that such models are currently useful, when analyzed with care. (As an aside, the critique of Chari, Kehoe, and McGrattan (2009) is not particularly novel; for example, Clarida, Gali, and Gertler (1999) emphasize how New-Keynesian models may provide a useful guide to underlying structural relationships even if their welfare implications and the interpretation of structural disturbances in such models may be somewhat controversial).

3.8 Estimation Strategy and Results

The empirical implementation of the model takes a log-linear approximation to the first-order conditions and constraints that describe the economy's equilibrium, casts this resulting system in its state-space representation for the set of (in our case 11) observable variables, uses the Kalman filter to evaluate the likelihood of the observed variables, and forms the posterior distribution of the parameters of interest by combining the likelihood function with a joint density characterizing some prior beliefs. Since we do not have a closed-form solution of the posterior, we rely on Markov-Chain Monte Carlo (MCMC) methods.

The model is estimated using 11 data series over the sample period from 1984:Q4 to 2008:Q4. The series are:

1. The growth rate of real gross domestic product;
2. The growth rate of real consumption expenditure on non-durables and services excluding housing services;
3. The growth rate of real consumption expenditure on durables;
4. The growth rate of real residential investment expenditure;
5. The growth rate of real business investment expenditure;
6. Consumer price inflation, as measured by the growth rate of the Personal Consumption Expenditure price index;
7. Consumer price inflation, as measured by the growth rate of the Personal Consumption Expenditure price index excluding food and energy prices;
8. Inflation for consumer durable goods, as measured by the growth rate of the Personal Consumption Expenditure price index for durable goods;
9. Hours, which equals hours of all persons in the non-farm business sector from the Bureau of Labor Statistics;[4]

[4]We scale up this measure of hours by the ratio of nominal spending in our model to nominal non-farm business sector output in order to model a level of hours more appropriate for the total

β	α	ψ	δ^{nr}	δ^{cd}	δ^{r}	Θ_*^{cbi}	Θ_*^{kb}	Θ_*^{l}	ω_{HG}
0.990	0.260	5	0.030	0.055	0.004	7.000	7.000	7.000	0.20

Table 1: Calibrated Parameters

10. The growth rate of real wages, as given by compensation per hour in the non-farm business sector from the Bureau of Labor Statistics divided by the GDP price index;
11. The federal funds rate.

Our implementation adds measurement error processes to the likelihood implied by the model for all of the observed series used in estimation except the nominal interest rate series.

Our estimation results depend upon our specification of priors and calibration of certain parameters. A number of parameters are calibrated. As reported in table 1, we fix the household's discount factor (β), the Cobb-Douglas share of capital input (α), the curvature parameter associated with costs of varying capital utilization (ψ), the depreciation rates (δ^{nr}, δ^{cd}, δ^{r}), and the elasticities of substitution between differentiated intermediate goods and labor input ($\Theta_*^{x,cbi}$, $\Theta_*^{x,kb}$, Θ_*^{l}). We assume that the share of exogenous demand in overall expenditure (ω_{HG}) equals 20 percent. We also calibrate the steady-state growth rates of aggregate technology, investment-specific technology, and the rate of consumer price inflation (at 0 percent, 4.5 percent, and 2 $\frac{1}{4}$ percent (all at annual rates), respectively); these calibrations ensure our model matches the average behavior of our data over the estimation sample.

Table 2 presents the prior distributions we assume for the estimated parameters and the posterior mode and standard deviation about that mode from our estimation. The parameter values echo results elsewhere in the literature. With regard to

economy. Moreover, we remove a low-frequency trend from hours via the Hodrick-Prescott filter with a smoothing parameter of 6400; our model is not designed to capture low frequency trends in population growth or labor force participation.

monetary policy, smoothing is important (ϕ^R near 0.7), the coefficient on the change in the output gap is large ($r^{\triangle y}$ near 0.3), and the coefficients on inflation and the level of the output gap take values near those of Taylor (r^{π} near 1.5, r^y near 1/4, where the division by 4 converts from annual rates to quarterly rates). There is only modest "indexation" in the price and wage Phillips curves (η^p and η^w near 1/4). Finally, habits and adjustment costs are important (e.g., h near 0.6).

4 Output Gap Estimates

4.1 The Beveridge-Nelson Gap

As implicit in the definition of the Beveridge-Nelson trend above, the Beveridge-Nelson gap is defined as

$$\tilde{X}_t^{bn} = \mathcal{E}_t\left[-\sum_{\tau=t+1}^{\infty} H_{\tau}^{gdp}\right], \tag{19}$$

i.e., as the forecast of GDP growth in excess of its steady-state level going forward. This measure is computed for the EDO model given the implied reduced-form vector autoregressive/moving average representation of the model in terms of the observable variables used in its estimation.

Figure 2 presents the estimate of the Beveridge-Nelson gap from the EDO model in the upper panel; the shading represents National Bureau of Economic Research (NBER) recession periods. It is clear that this measure of the gap captures the cyclical peaks in activity as identified by the NBER well; it is also clear that the EDO Beveridge-Nelson output gap has continue to widen following the NBER-identified end of recent recessions – consistent with the generally agreed upon view that these periods have been sluggish or "jobless" recoveries. The picture of the Beveridge-Nelson gap implied by EDO also shows a fairly smooth evolution of the gap; this contrasts with much of the literature on univariate time-series estimates of the Beveridge-Nelson gap (e.g., the discussion in Morley, Nelson, and Zivot (2003)), but echoes the result from

Table 2: Prior Distribution and Posterior Mode for Estimated Parameters

Parameter	Prior Dist.	Prior mean	Prior s.d.	Posterior mode	s.d.
h	N	0.000	0.3300	0.5985	0.0231
ν	G	2.000	1.0000	0.1960	0.1407
r^{π}	N	1.500	0.0625	1.4606	0.0580
r^{y}	N	0.250	0.1250	0.2097	0.0223
$r^{\triangle y}$	N	0.000	0.1250	0.3380	0.0814
χ^{p}	G	4.000	1.0000	2.5107	0.2177
χ^{H}	G	4.000	1.0000	3.8191	1.8914
χ^{w}	G	4.000	1.0000	2.1701	0.2203
χ^{nr}	G	4.000	1.0000	0.2361	0.0425
χ^{cd}	G	4.000	1.0000	0.3610	0.0436
χ^{r}	G	4.000	1.0000	8.5190	1.1504
η^{p}	N	0.000	0.5000	0.2860	0.1122
η^{w}	N	0.000	0.5000	0.2499	0.1262
ϕ^{r}	N	0.500	0.2500	0.6723	0.0354
ρ^{ω}	N	0.000	0.3300	0.7897	0.0205
ρ^{nr}	N	0.000	0.3300	0.8243	0.0156
ρ^{cd}	N	0.000	0.3300	-0.2107	0.0828
ρ^{HG}	B	0.500	0.0150	0.9186	0.0270
ρ^{r}	N	0.000	0.3300	0.8304	0.0114
σ_{ω}	I	1.000	2.0000	0.3749	0.0298
σ_{HG}	I	1.000	2.0000	1.3735	0.2311
σ_{θ_l}	I	1.000	2.0000	1.5774	0.1456
σ_{R}	I	0.200	2.0000	0.1535	0.0121
$\sigma_{z,kb}$	I	0.250	2.0000	0.8801	0.1207
$\sigma_{z,m}$	I	0.250	2.0000	0.4014	0.0555
$\sigma_{\theta_{cbi}}$	I	0.200	2.0000	0.3094	0.0338
$\sigma_{\theta_{kb}}$	I	0.200	2.0000	0.4581	0.0955
$\sigma_{a,r}$	I	1.000	2.0000	0.4942	0.0504
$\sigma_{a,cd}$	I	1.000	2.0000	7.0820	0.8578
$\sigma_{a,nr}$	I	1.000	2.0000	0.4846	0.0416

Notes:

1. B denotes the Beta distribution; G denotes the Gamma distribution; I denotes the Inverted Gamma distribution; and N denotes the Normal distribution. For the Gamma distribution, hyperparameters are shown. The posterior standard deviations are based on the negative inverse hessian evaluated at the posterior mode.

(at least some) multivariate time series approaches (e.g., Rotemberg and Woodford (1996)).

The middle panel of figure 2 presents the percent change from four-quarters earlier in the Beveridge-Nelson permanent component implied by these gap estimates; the bottom panel presents the one-quarter percent change (at an annual rate). These panels show that the variation in the growth rate of the permanent component is considerable. Of course, the permanent component depends solely on the technology shocks – implying that the variation shown is consistent with a view that permanent technology shocks have considerable quarter-to-quarter volatility. The figures also show that recession periods do not appear very tied to low realizations of technology – that is, recessions are not primarily driven by technology shocks in this DSGE model; Edge, Kiley, and Laforte (2008b, 2009b) discuss the sources of business cycles in more detail, and there results highlight only a moderate role for technology shocks in cyclical fluctuations, despite the considerable volatility of technology relative to the smooth view embedded in some production-function approaches to potential GDP (as discussed in the section 5).

4.2 The Production-Function Approach

Production in each sector of the EDO model is governed by a Cobb-Douglas production function for each sector. In the production function approach to measuring the output gap, the gap is defined as the deviation of output from the level that would occur if labor input (per capita) and utilization rates equaled their steady-state values (where these steady-state values, denoted with a $*$, are constant, with the latter equal to one). As a result, the production-function gap is given by the Divisia-weighted (i.e., share-weighted) aggregate of the production-function gaps in each sector, which are defined by

$$\tilde{X}_t^{S,PF} = \ln((L_t^s/L_*)^{1-\alpha}\,(U_t^s)^{\alpha});\ \ s = cbi, kb, \tag{20}$$

Several points are noteworthy. First, variable utilization of capital and capital adjustment costs, in addition to imperfect competition in product and labor markets, imply that simple "growth acccounting" may not accurately measure the production-function gap. For EDO, the production function gap is inferred by imposing the model's structural restrictions and using the data on all unobservables to infer this gap. In addition, the production function gap, as written above, does not depend on any smoothing of technology: In EDO, the cyclical movements in total factor productivity (properly measured, after accounting for imperfect competition and the effects of variable utilization and capital adjustment costs) are solely a function of utilization, which enters equation 20; production-function based methods that do not rely on an entire model's structure to control for cyclical movements in total factor productivity, such as those of the CBO or the Federal Reserve's FRB/US model, may smooth their measures of total factor productivity according to some method, and such effects would enter equation 20 through the utilization term (although alternative presentations of the production-function method may include such adjustments as a separate term in their accounting). Because labor input and utilization move to their steady-state values in the long run and production always lies on the production function for each sector (by definition), the production function gap differs from the Beveridge-Nelson gap solely because of deviations of the (aggregate productive) capital stock from its long-run level. To the extent that the contribution of capital stock deviations from long-run levels contribute only moderately to overall deviations of production from its long-run level, it is reasonable to expect that the production function gap and the Beveridge-Nelson gaps will be similar.

Figure 3 presents the estimate of the production function gap from EDO, along with the Beveridge-Nelson gap. It is clear that these measures of the gap move together, and both capture the cycle identified by the NBER.

The middle and bottom panels of figure 2 presents the percent changes from four-quarters earlier and from the previous period in the production-function approach and the Beveridge-Nelson permanent components. These series move together in broad terms. But the magnitude of quarter-to-quarter fluctuations in the Beveridge-Nelson permanent component is a bit higher than that for the production-function approach. This occurs because long-run capital stock levels are strongly affected by quarter-to-quarter movements in technology, but actual capital stock levels move slowly; as a result, capital stock deviations from long-run levels can move considerably, boosting the volatility of the Beveridge-Nelson permanent component.

4.3 The Flexible-price Approach

The flexible-price appraoch considers the deviation of output from the level that would occur absent wage and price rigidities. The EDO estimate of this approach is shown in figure 4. As can be seen in the solid line, this gap measure is very volatile (relative to, for example, the Beveridge-Nelson gap, the red-line). This occurs because markup shocks have large output effects in a flexible-price environment (even though such effects are small in a sticky-price environment). Justiniano and Primiceri (2008) also highlight this result.

4.4 The Natural-rate Approach

The next definition is the natural-rate gap, which is the gap between output and the level that would prevail absent wage and price rigidities and markup shocks – that is, it removes markup shocks from the flexible-price measure. This is the concept emphasized in Woodford (2003), largely because the analysis of Woodford considers only distortions associated with nominal rigidities and markup shocks (so that the natural rate is the efficient rate)

As can be seen in figure 5, the natural-gap is closely related to the Beveridge-Nelson cycle, but to a lesser degree late in the sample. For example, the natural-rate gap is positive in 2008, whereas the Beveridge-Nelson gap is deep in negative territory. This is consistent with the idea that the downturn in economic activity was driven by an increase in (sector-specific) risk premia in financial markets: The Beveridge-

Nelson gap turns negative with such shocks because they do not have permanent effects on output, but the natural-rate of output fluctuates with such risk premia. Whether such fluctuations are desirable (e.g., pareto optimal) depends on whether the movements in risk premia reflect, for example, preferences or distortions associated with informational asymmetries.

4.5 The Efficient Rate Approach

The final approach I highlight is the efficient rate approach. The efficient rate of output is defined as the level of output that would occur in the absence of time-variation in two distortions: The wedge between the marginal product of labor and the marginal rate of substitution between consumption and leisure; and the wedge between the marginal rate of substitution between consumption in the current period and consumption in the next period and the marginal rate of transformation (or marginal rate of technical substitution) between consumption over the same periods.[5]

In EDO, there are several such distortions. This can be seen by looking at the relevant first-order conditions. Consider the following set of first-order conditions from the cost-minimization problem of intermediate good producers, the capital-intermediaries profit maximization problem, and the households' utility maximization problem (at the symmetric equilibrium of the model).

[5]The central role of these efficiency conditions is highlighted in standard microeconomic texts, e.g. Kreps (1990), page 167.

$$L_t^s = (1-\alpha)\cdot X_t^s \cdot \frac{MC_t^s}{W_t^s} \qquad \text{for } s = cbi, bk \tag{21}$$

$$K_t^{nr,s} = \alpha \cdot X_t^s \cdot \frac{MC_t^s}{R_t^{nr}} \qquad \text{for } s = cbi, kb. \tag{22}$$

$$Q_t^{nr} = \beta\mathcal{E}_t \left\{ A_t^{nr} \frac{\Lambda_{t+1}^{cnn}/P_{t+1}^{cbi}}{\Lambda_t^{cnn}/P_t^{cbi}} \left(R_{t+1}^{nr} U_{t+1}^s + (1-\delta^{nr}) Q_{t+1}^{nr} \right) \right\} \text{ for } s = cbi, kb. \tag{23}$$

$$\begin{aligned} P_t^{kb} = {} & Q_t^{nr} \left[1 - 100 \cdot \chi^{nr} \left(\frac{E_t^{nr} - E_{t-1}^{nr}\Gamma_t^{x,kb}}{K_t^{nr}} \right) \right] \\ & + \beta\mathcal{E}_t \left\{ A_t^{nr} \frac{\Lambda_{t+1}^{cnn}/P_{t+1}^{cbi}}{\Lambda_t^{cnn}/P_t^{cbi}} \cdot Q_{t+1}^{nr} \cdot 100 \cdot \chi^{nr} \cdot \Gamma_{t+1}^{x,kb} \left(\frac{E_{t+1}^{nr} - E_t^{nr}\Gamma_{t+1}^{x,kb}}{K_{t+1}^{nr}} \right) \right\} \end{aligned} \tag{24}$$

$$\frac{\Lambda_t^{cnn}}{P_t^{cbi}} = \beta R_t \Omega_t \mathcal{E}_t \left\{ \frac{\Lambda_{t+1}^{cnn}}{P_{t+1}^{cbi}} \right\} \tag{25}$$

Equations 21 equates the marginal product of labor to the real wage, adjusted for variation in markups/marginal cost that arise from markups shocks and nominal price rigidities. Because of this latter adjustment, price rigidities lead to an inefficient wedge; similar inefficiencies occur because of nominal wage rigidities (first-order conditions not shown), and the combination of these factors causes the inefficiencies emphasized in the New-Keynesian literature on price and wage rigidities (e.g., Woodford (2003), Erceg, Henderson, and Levin (2000), and Chari, Kehoe, and McGrattan (2007)). And these distortions occur at the sectoral level, as nominal prices are rigid sectorally. The efficiency gap removes these sources of distortions (that is, removes nominal rigidities and markup shocks for prices and wages).

Equations 22 shows that these same considerations distort capital decisions. In addition, 23, 23, and 25 show that the gap between the households' discount rate and the capital intermediary's discount rate induced by the risk premia shock (A^{nr}), as well as the gap between the federal funds rate and the households' return on nominal bond holdings (Ω), introduces a wedge between the marginal rate of technical substitution and the marginal rate of substitution of consumption across time. (This wedge is related to the *investment wedge* of Chari, Kehoe, and McGrattan (2007)). This interpretation is consistent with the idea that fluctuations in such premia reflect, for example, information imperfections that make external finance more costly than internal funds, as in Bernanke, Gertler, and Gilchrist (1999). A social planner aware of such information imperfections would ignore such factors in its efficient allocations. As a result, we also exclude variation induced by such shocks from the efficient rate of output.

However, time-variation in the risk premia shocks in EDO certainly could reflect other factors – for example, changes in the productive efficiency of the intermediation sector. Under such an interpretation, a social planner would accommodate such fluctuations in its allocations. (For some, this ambiguity may be discomfiting, but models at this level of abstraction can only point out where the exogenous "wedges" arise to match the data. Research may provide more insight into this ambiguity. For a related discussion, see Smets and Wouters (2007) discussion of this ambiguity regarding their "labor supply shocks". Chari, Kehoe, and McGrattan (2009) also discuss such shocks, under the rubric *labor wedge*).

Figure 6 presents the efficient-rate gap, with the Beveridge-Nelson gap. Several points should be readily apparent. First, the efficiency gap is very closely related to the Beveridge-Nelson cycle in EDO. And second, the efficiency gap is not the same as the natural rate, and this can at times be very important. For example, the downturn in economic activity in 2008 was driven by an increase in risk premia in financial markets, pushing the Beveridge-Nelson and effieciency gaps deep into negative territory: The Beveridge-Nelson gap turns negative with such shocks because they do not have permanent effects on output; the efficient-rate gap turns negative because such shocks are distortionary (by assumption); but the natural-rate gap did not fall into deep negative territory, as the decline in output did not stem distortions associated with nominal rigidities, but rather from distortions in financial markets. Of course, the assumption that risk premia shocks are distortions was made "outside the model", as the shocks are simply wedges designed to match the data. These types of judgments are unavoidable in EDO – but could be made more explicit in a more complicated, micro-founded model of risk premia.

The notion that the efficient-rate gap may show a traditional cycle, as is quite clear from our comparison to the Beveridge-Nelson gap, is consistent with the analysis of Justiniano and Primiceri (2008), whose model is similar (albeit with a simpler structure). However, the most notable point regarding efficient rates is their dependence on model assumptions. Of course, all results from a given model will rest on the assumptions underlying the model. But consideration of the efficient rate from a given model is particularly dependent on assumptions regarding which shocks are distortionary, and there is no consensus regarding such decisions across economists or models. The strong dependence of the nature of the efficient-rate (or natural-rate) gap on specific model features implies that great care must be taken in using such estimates.

Finally, discussions of such an efficient-rate concept cannot proceed without (at least one) caveat. The presentation above highlighted the potential inefficiency associated with "wedges" between the marginal rates of substitution and technical substitution between current and future consumption. It is important to remember in a monetary policy discussion that the presence of such wedges need not imply that monetary policy should act forcefully to counteract the effects of such wedges. For example, it was noted above that a social planner, with the power to simply determine real allocations, may wish to see through the information imperfections that lead to such inefficiencies. But imposing such real allocations assumes that a social planner has the instruments to induce such real allocations. A policymaker constrained to induce allocations through a given set of instruments may not be able to implement such allocations, and such implementation constraints are central in practical policy design. For example, Carlstrom and Fuerst (2009) present a simple model of financing frictions and examine the optimal monetary policy given such frictions; their analysis presents examples where monetary policy acts to mitigate only a small portion of the (output) effects of financial frictions, because monetary policy does not have the tools to implement the efficient allocation. [6]

4.6 Using The Flexible-Price/Natural-Rate/Efficient-Rate Approaches

A final important issue arises in any practical use of the flexible-price/natural-rate/efficient-rate approaches. Specifically, none of these measures is a simple "point-in-time" concept that can easily be translated to policy discussions. This occurs because each of these measures depends on the evolution of all exogenous and endogenous state variables in the model used to estimate these concepts, and any model capable of explaining the data and stock-flow dynamics (associated with investments in many different types of business and household capital will have a complex state space.

To consider these difficulties more concretely, consider the Beveridge-Nelson cycle and trend. As emphasized by Beveridge and Nelson (1981), their definition of trend implies that the growth of the trend going forward is a constant (which, in the EDO DSGE model, is a function of the expected rate of aggregate and investment-specific technological progress and the expected population growth rate). As a result, the EDO model, at the parameter estimates presented above for the growth rates of technological progress and assuming a population growth rate of 0.7 percent per year, implies that the expected growth rate of the Beveridge-Nelson trend is 2.9 percent per year.

All other concepts of "equilibrium" output must converge to the Beveridge-Nelson trend at some far horizon (as that is the definition of the Beveridge-Nelson trend). And the projection of output from a DSGE model like EDO is a function of economic fundamentals (e.g., capital stocks, technology, markups, risk premia, etc.) and

[6] Carlstrom and Fuerst (2009) present a model without capital, and hence their financial frictions enter in quite a different manner than teh intertemporal wedges discussed above. Nonetheless, their presentation is a nice example of the difference between efficient allocations and the constrained optimal monetary policy.

Table 3: Gaps and Projected Trend Growth Associated with Different Definitions (1)

		Trends	
Definition	*Gap*	$2009Q4/Q4$	$2009Q4/Q4$
Beveridge-Nelson	-4.0	2.9	2.9
Natural-rate	1.0	3.6	4.5
Efficient-rate	-5.8	2.3	2.6

1. Gap in percent. Figures for projected trends in 2009 and 2010 refer to Q4/Q4 percent changes.

is not affected by "equilibrium" concepts of output like the flexible-price, natural-rate, or efficient-rate of output. Consequently, the projections of these equilibrium measures will tend to fluctuate significantly over time, and as a result discussions of the economic outlook or the potential policy implications of alternative measures of "equilibrium" output must take into account both the current level of such concepts and their projected evolution.

Table 3 illustrates these points by presenting, for the Beveridge-Nelson definition, the natural-rate definition, and the efficient-rate definition, the 2008Q4 measures of the output gap and the projected change in the "equilibrium" or trend output level associated with those definitions for 2009 and 2010 (on a Q4/Q4 basis).

The Beveridge-Nelson gap is -4.0 percent of GDP as of the fourth quarter of 2008, and projected growth in the associated trend is 2.9 percent – the constant expected growth rate associated with this concept. In contrast, the natural-rate gap is 1.0 percent – output in the fourth quarter of 2008 was actually one percent above the flexible-price, constant-markup level consistent with the EDO model and other estimated shocks. But the level of actual GDP is the same across definitions, and output converges to the Beveridge-Nelson trend; as a result, the "trend" or "equilibrium" level of output associated with this definition is projected to rise very rapidly in 2009 and 2010, at rates of 3.6 and 4.5 percent, respectively. My impression is that some policy discussions, at least superficially, can focus on the level of an output gap without reference to the growth outlook for the associated trend/equilibrium level, and this focus is clearly inappropriate when the trend/equilibrium level definition can be expected to move significantly, as with the natural-rate or efficient-rate approaches. (To close, the efficient-rate gap is more negative than the Beveridge-Nelson gap, and hence its trend/equilibrium level is projected to grow more slowly).

5 Comparing Gaps from EDO to Other Estimates

Figure 7 and 8 present the production-function based output gaps from the CBO and from the Federal Reserve's FRB/US model, along with the Beveridge-Nelson cycle from the EDO model, in the upper panels. These gaps are both highly correlated with the Beveridge-Nelson cycle from the EDO model (with correlation coefficients of 0.80 for both measures).

The lower panels of these figures present the percent change from the previous quarter in the estimate of trend (at an annual rate), along with the change in the Beveridge-Nelson permanent component from EDO. While the gaps in the upper panels are highligh correlated, the trend estimates from the FRB/US model and especially from the CBO are much smoother. In short, EDO has a much more variable "potential" growth rate.

Of course, the data on GDP is the same for the EDO Beveridge-Nelson gap, the CBO gap, and the FRB/US model gap. Moreover, the growth rate of GDP equals the sum of the change in the gap and potential GDP growth. As a result, similar movements in the gap for all three measures, and quite different movements in potential, must imply quite different *covariances* between actual growth, the change in the gap, and potential growth. (For example, the variance of GDP growth equals the sum of the variance of the change in the gap, the variance of potential growth, and twice

Table 4: Variance and Covariance of Gap and Permanent Component (1)

	Variance		Covariance
Gap measure	$\Delta(gap)$	$\Delta(trend)$	$\Delta(gap)$, $\Delta(trend)$
Beveridge-Nelson	0.18	0.23	-0.06
CBO	0.34	0.01	-0.01
FRB/US	0.34	0.08	-0.06

1. Sample 1985q4-2008q4.

the covariance of the change in the gap and potential growth; similar mixes of variances and covariances could be done for other combinations of actual/gap/potential). Table 4 reports variances and covariances for each gap and potential estimate. As shown in the first row, the covariance between the growth rate of potential and the change in the gap according to the EDO Beveridge-Nelson measure is somewhat negative, whereas this covariance is essentially zero for the CBO measure. The lack of covariance between the change in the gap and the growth rate of potential is "close" to an assumption in the CBO measure; for example, the CBO explicitly attempts to remove movements in the elements of their production-function approach to potential that are correlated with the cycle. By contrast, the covariance in EDO is determined by the model's structure and parameter estimates, which will generally not imply a covariance of zero.

Of course, such a variance/covariance decomposition of GDP growth is not simply a matter of accounting: For example, these covariances also imply a strong positive covariance of actual GDP growth with potential GDP growth in EDO – so that incoming data on GDP (as well as all the other variables entering the model) provides considerable information on potential growth; in contrast, these correlations are much lower (e.g. zero) for the CBO approach, implying that the CBO modeling strategy sees little information for potential growth from incoming data on GDP.

Finally, I would note that this discussion is closely related to the time-series literature that estimates permanent/transitory components of GDP. For example, Beveridge and Nelson (1981) simply assumed an ARIMA representation of GDP growth, which imposes no restrictions on the (true) innovations to the trend and cycle; Clark (1987) and other research assumed an unobserved components structure for GDP growth with an assumption of zero correlation between the (true) innovations to the trend and cycle; and Morley, Nelson, and Zivot (2003) discuss in detail the role of such assumptions and the strength of evidence for/against a correlation between (true) innovations to trend and cycle. (As an aside, it is worth noting that the EDO correlations above are the smoothed estimates of the trend and cycle. In real-time filtering, the correlations between the estimated innovations for trend and cycle will not share the correlation properties of the true innovations, and this is also true for the smoothed innovations. Moreover, the EDO estimates are based on a multivariate filter, so the strong implications of a univariate filter (i.e., that estimated filtered innovations to trend and cycle are perfectly negatively correlated) are not applicable. Given these complications and the fact that the FRB/US model and CBO approaches do not lend themselves naturally to simple time-series representations, it seemed more appropriate to simply report the covariances for the smoothed estimates in table 4 and to couch the discussion in those terms, rather than to focus on the differences between filtering and the underlying model structure. Morley, Nelson, and Zivot (2003) discuss these issues and reference other relevant discussions).

6 Correlations with other macroeconomic variables

Given the sharp differences across the Beveridge-Nelson cycle from EDO and the natural-rate gaps, in addition to the differences from output gap estimates from the CBO or Federal Reserve's FRB/US model, it is worthwhile stepping back from the estimates for a moment and considering their relationship to other macroeconomic

Table 5: Granger causality from Gaps to Unemployment and Core Inflation (1)

Gap measure	Change in Unemployment rate
Beveridge-Nelson	0.00
Efficient rate	0.00
Natural rate	0.00
CBO	0.04
FRB/US	0.00

1. Each column contains the p-value associated with the null that the variable does not Granger cause the change in the unemployment rate (Sample 1985q4-2008q4, with two lags).

variables in a reduced-form sense – i.e., outside the EDO model. Two simple relationships involve the correlation of such measures with movements in the unemployment rate (e.g., Okun's law (Okun(1962)) and with inflation.

Table 5 presents the p-values associated with Granger causality tests running from each gap measure to the change in the unemployment rate.

All the measures of cycles show the Okun's law relationship – that is, lagged values of these measures of the output gap Granger cause changes in the unemployment rate over the 1985Q4 to 2008Q4 period. This should not be surprising – deviations of output from long-run levels must be associated with movements in labor input, and the lead of hours over unemployment is a well-known regularity.

Given the New-Keynesian structure of the EDO model, it should be clear that no simple measure of the output gap has a structural relationship with inflation; rather, it is real marginal cost that is related to inflation. Of course, output gaps may be correlated with (leads and lags) of marginal cost, implying some reduced form relationship.

To see the rather loose relationship between gaps, marginal cost, and inflation,

Table 6: Correlations Between Gaps, Marginal Cost (MC), and Core Inflation (Π) (1)

	Gap, Π	Π, MC	Gap, MC
Data (FRB/US gap)	-0.23	0.42	0.03
EDO (BN gap)	-0.25	0.47	0.12
"Supply" Shocks only			
EDO (BN gap)	-0.88	0.45	-0.32
"Demand" Shocks only			
EDO (BN gap)	-0.10	0.50	0.34

1. For the data, the sample is 1985q4-2008q4.

Table 6 presents the correlations of the output gap (in EDO, using the Beveridge-Nelson definition, and in the data, using the FRB/US gap), real marginal cost (in EDO and in the data, as measured by the labor share in the nonfarm business sector), and the four-quarter moving average of core PCE inflation.[7].

As can be seen in the first row, the data (and the FRB/US output gap) show a slight negative correlation between the output gap and inflation, a strong positive correlation of marginal cost (labor's share) and inflation, and little correlation between the gap and marginal cost. EDO shows these same correlations, as should be expected from an estimated model designed to match the data. These unconditional correlations mask important differences associated with "supply" and "demand" shocks (the last two rows). "Supply shocks" – defined as technology and price and wage markup shocks – induce a negative correlation between the output gap and marginal cost; "Demand" shocks – all other shocks in EDO – induce a positive correlation. Indeed,

[7]For EDO, the correlations are computed from stochastic simulations of the model ignoring measurment error (with simulation length of 25000 periods, and hence representative of the population correlations implied by the model)

different demand shocks can induce different correlations. As a result, discussions of the inflation outlook in EDO can be informed by looking at gaps and marginal cost, but are better understood by looking at the model's estimates of the underlying factors driving fluctuations than by appeal to reduced-form correlations.

7 Conclusion

My analysis suggests three conclusions:

- Flexible-price/natural-rate/efficient-rate gaps are highly dependent on modeling assumptions, and their use in policy applications or forecasting requires a deep understanding of a specific model's structure. (This result is closely related to the critique of DSGE models of Chari, Kehoe, and McGrattan (2009), who highlight the sensitivity of policy applications of such models to controversial modeling assumptions).

- "Equilibrium" or trend *expected* growth is highly variable in the flex-price/natural-rate/efficient-rate case, implying that a focus on the current level of such gaps can be misleading in a policy discussion. In contrast, expected trend growth for the Beveridge-Nelson concept is exogenous and constant; moreover, all other notions of "trend" converge to the Beveridge- Nelson trend (by definition).

- The Beveridge-Nelson concept and the production-function approach yield quite similar gaps.

- The DSGE model's estimate of the output gap (according to either a Beveridge-Nelson or production-function approach) is very similar to gaps from the Congressional Budget Office or the Federal Reserve's large-scale macroeconometric model (FRB/US) model, but the DSGE model's estimate of potential growth is considerably more variable; the latter result stems from the degree of fluctuation in aggregate technology estimated by the DSGE model, a result consistent with the significant role such fluctuations play in model's descended from those of the real-business-cycle tradition. Moreover, the DSGE model estimates reveal a strong negative correlation between changes in the gap and potential growth – in contrast to the CBO or FRB/US approaches.

On balance, the results suggest that the ability of a DSGE model like EDO to capture the trend/cycle decomposition of output that drives much of the discussion of macroeconomic stabilization policy is quite good – as should be suspected given the forecasting performance of such models (e.g., Edge, Kiley, and Laforte (2009a)). Moreover, the DSGE model's structure and parameter estimates imply a negative correlation between changes in the gap and potential growth, shedding light (through a structural approach) on an issue that looms large in time-series approaches to trend/cycle decompositions (as discussed in Morley, Nelson, and Zivot (2003)). Finally, the DSGE model's Beveridge-Nelson gap has relationships with the unemployment rate or inflation similar to those of gaps from CBO or the FRB/US model. Moreover, the inflation/gap relationship, a reduced-form correlation, is best understood by looking at the factors underlying fluctuations (e.g., technology or risk-premia shocks, etc.) rather than through a one-size-fits-all lens – i.e., the relationship between the gap and inflation depends on "supply" and "demand" shocks.

But the success along these empirical dimensions do not carry over to the policy realm quite as directly, as the model's estimate of the natural rate or efficient rate of output is dependent on assumptions. For example, the efficient-rate gap is quite negative in late 2008 because the intertemporal disturbances affecting the relationship between the marginal rate of substitution between current and future consumption and the mraginal rate of technical substitution between current and future consumption (i.e., risk premia shocks) are assumed to be distortionary. But such "wedges" could reflect "efficient" or "distortionary" factors. To paraphrase Edge, Kiley, and Laforte (2008a) and Chari, Kehoe, and McGrattan (2009) in their discussions of markup shocks, which is it?

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Figure 1: Model Overview

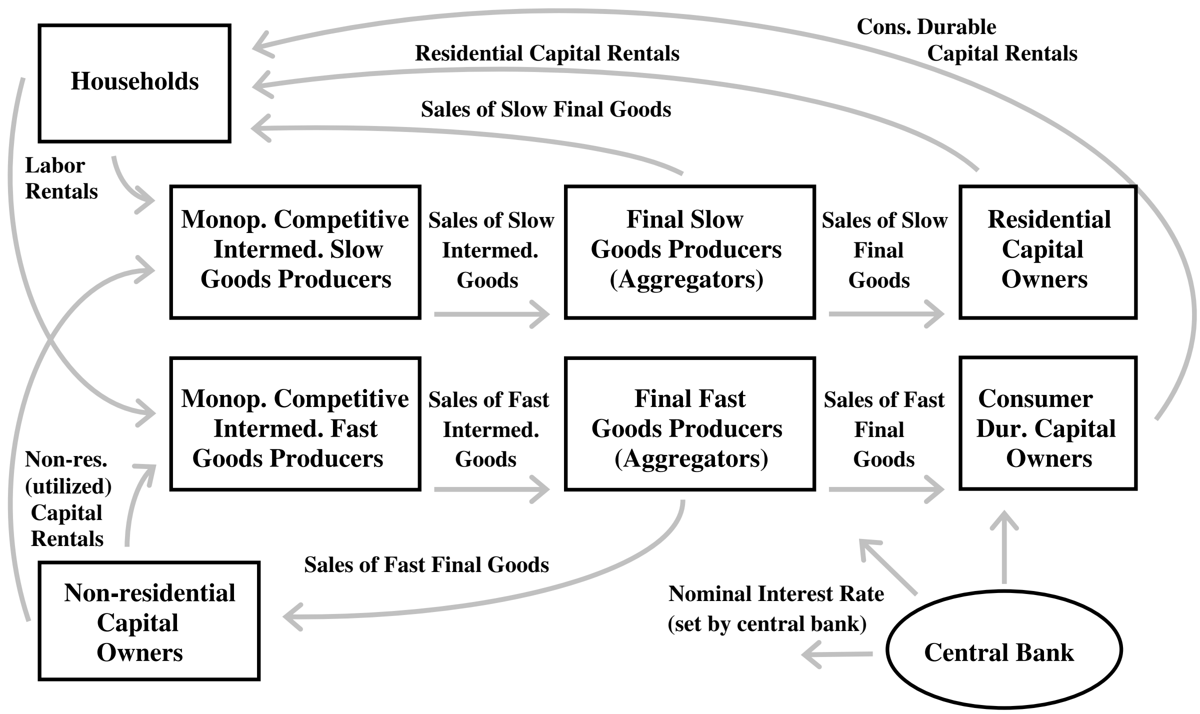

Figure 2: Beveridge-Nelson Gap

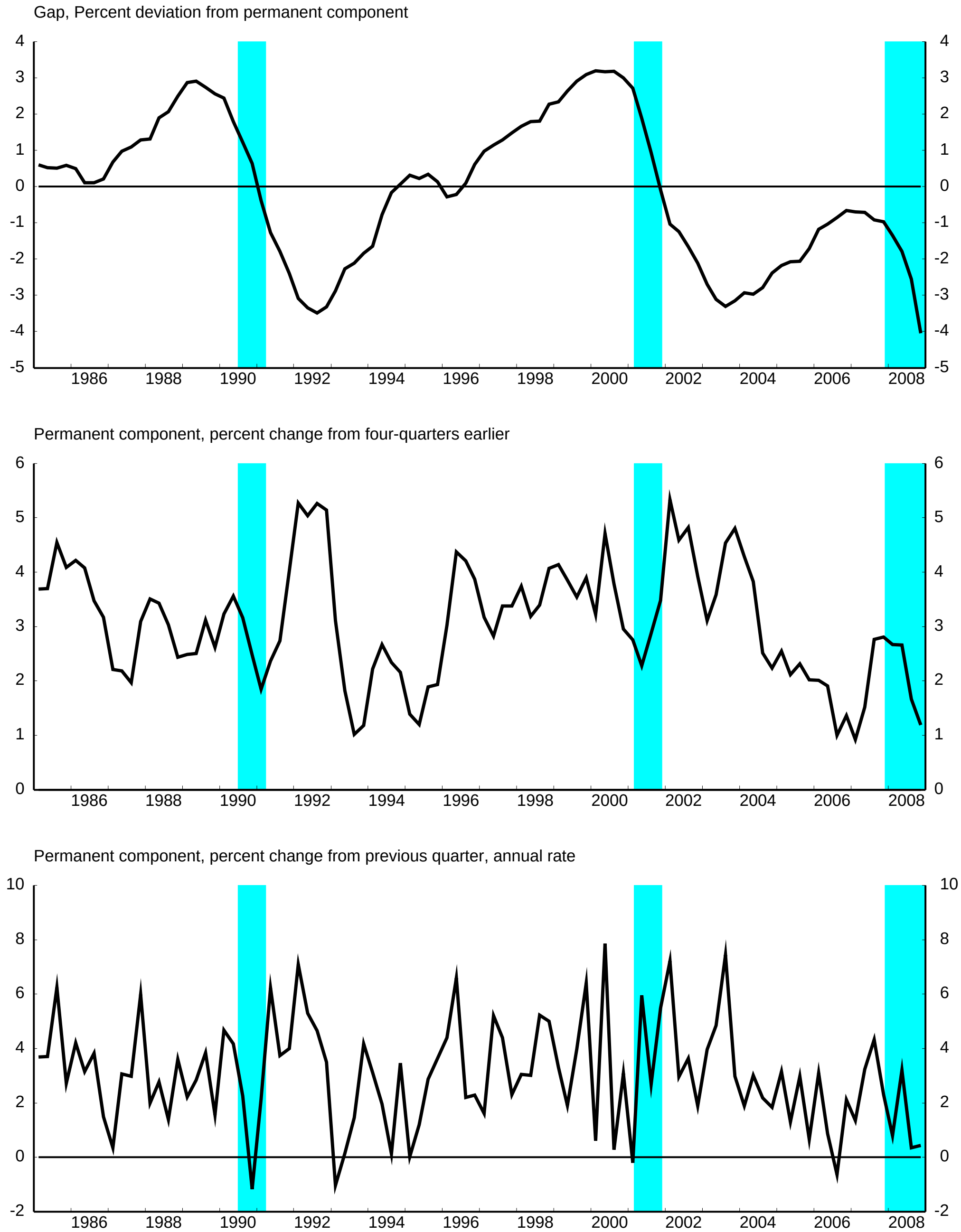

Figure 3: Production-Function Gap

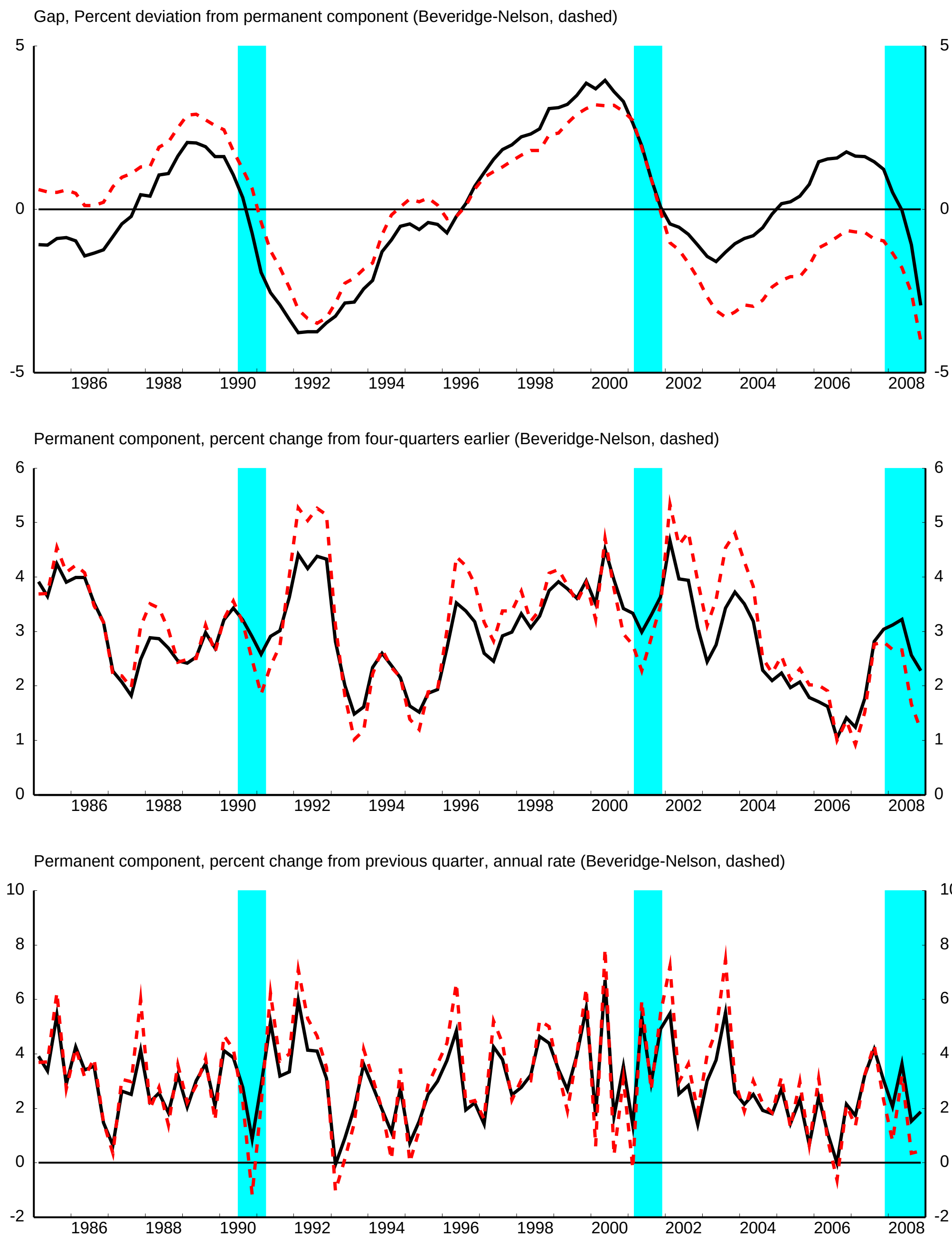

Figure 4: Flexible-price Gap

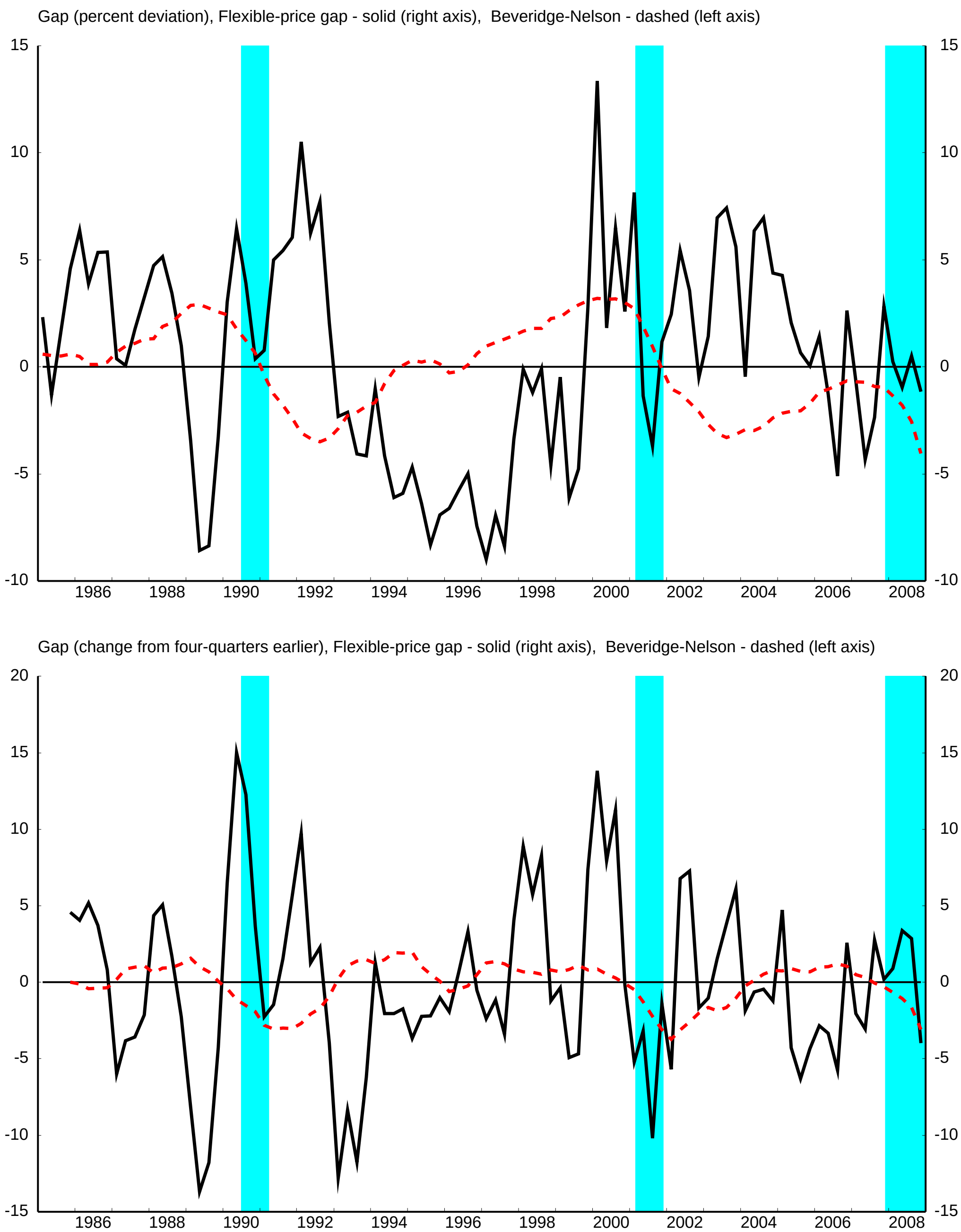

Figure 5: Natural-Rate Gap

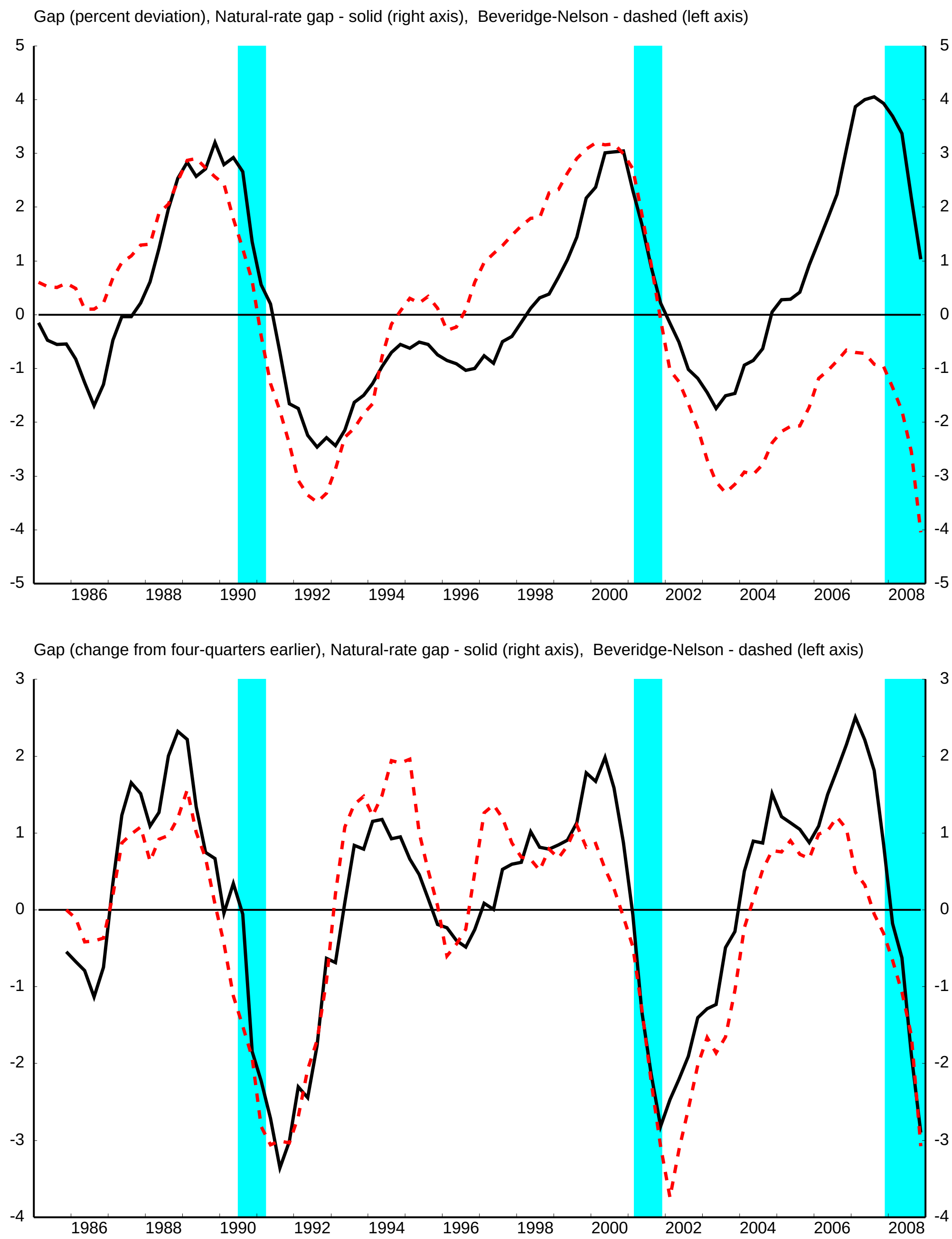

Figure 6: Efficient-Rate Gap

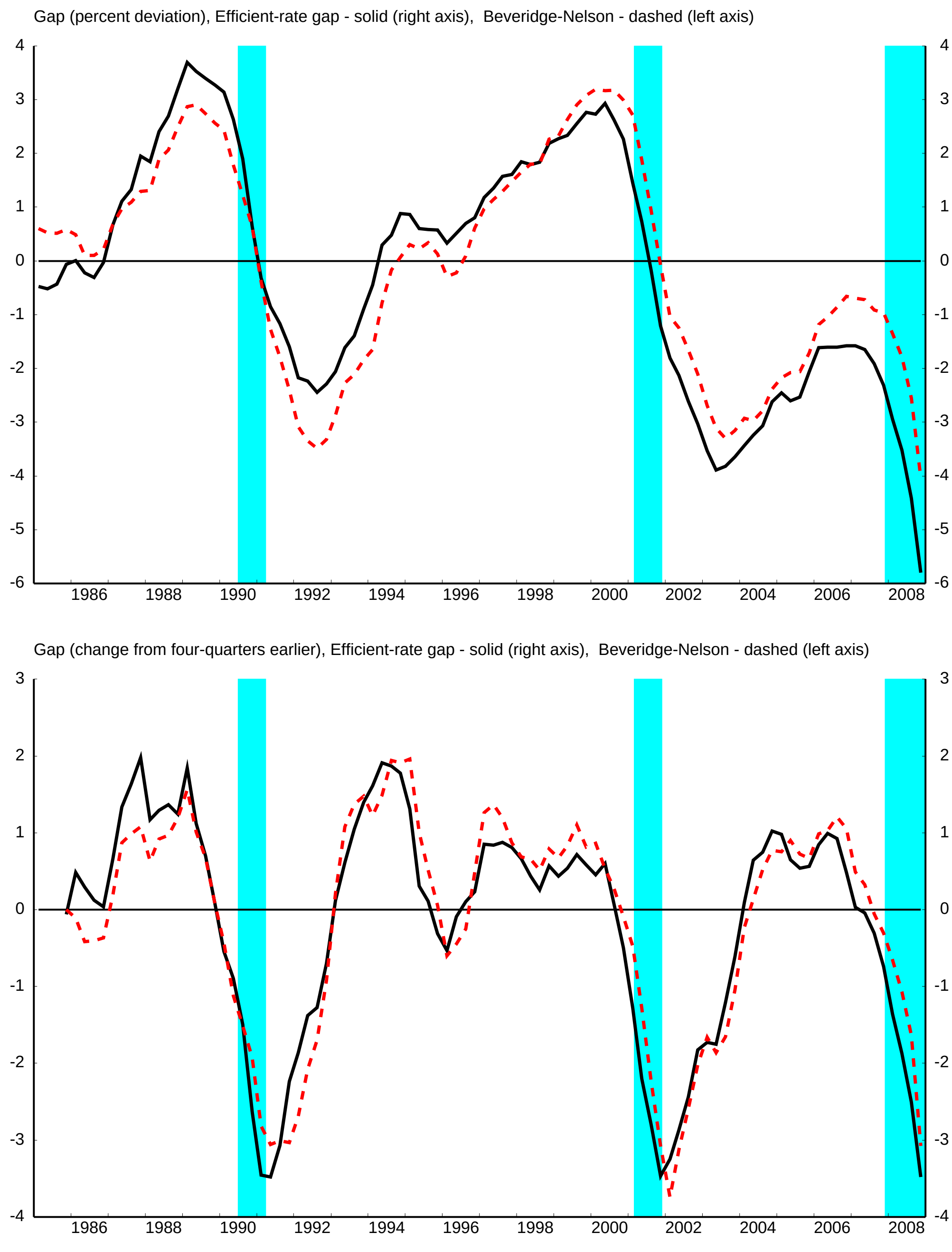

Figure 7: CBO Gap

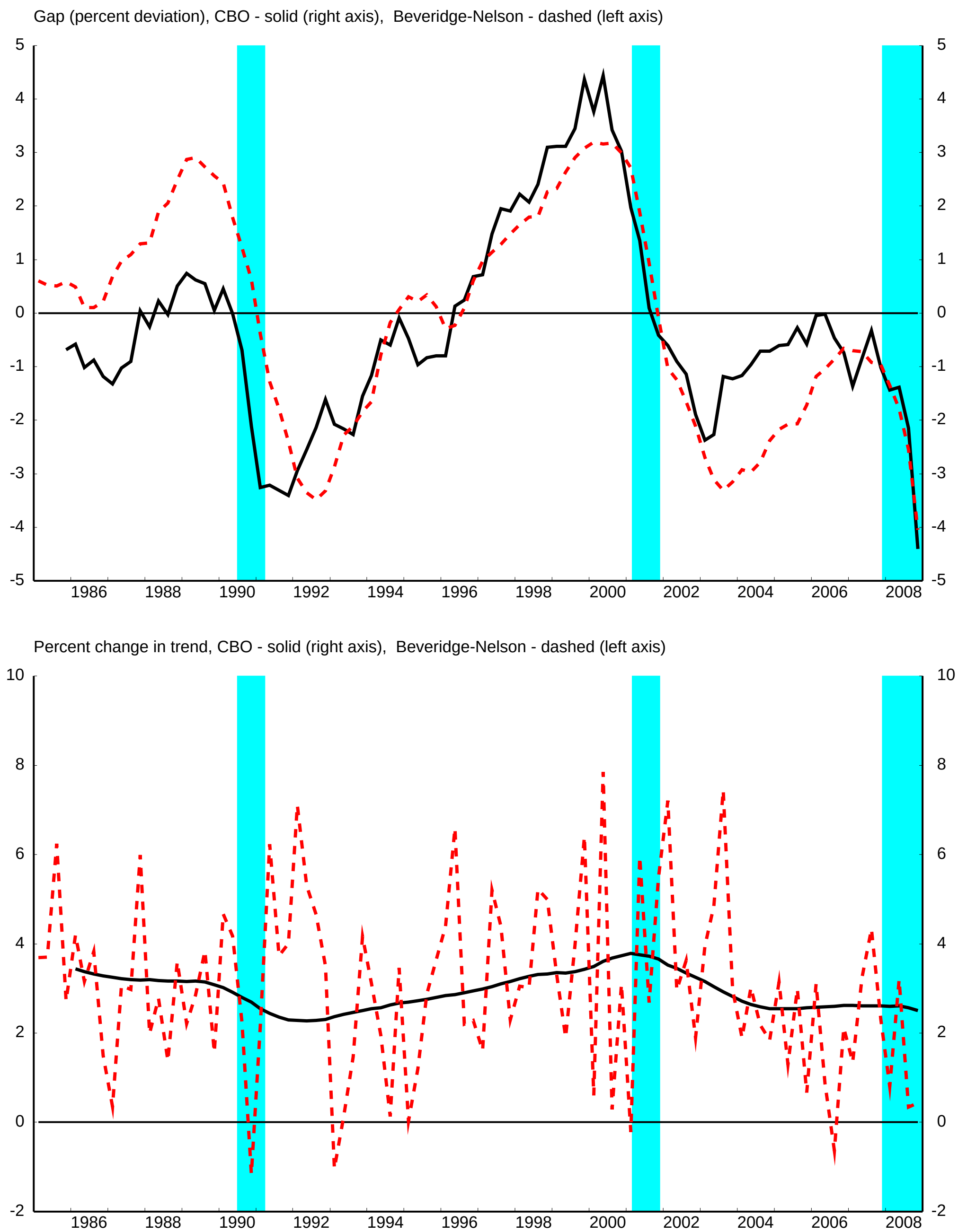

Figure 8: FRB/US Gap