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Gaps and Monetary Policy

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In this memo we discuss how economic theory based on nominal rigidities informs our thinking about monetary policy. We concentrate on two concepts that play a role in FOMC discussions: inflation persistence and output gaps. These seemingly disparate concepts are linked through the Phillips curve. Both concepts can be used to refer to purely statistical objects, or they can be given a structural interpretation using one form or another of the Phillips curve. We argue that theoretical interpretations of inflation persistence and output gaps derived from Phillips curve models are sensitive to assumptions made in estimating models and assumptions made about the nature of shocks entering models. Unfortunately, we do not always have a sound basis for choosing among candidate assumptions.

In the past 15 years, the subject of inflation persistence has received considerable attention in the applied literature on monetary policy. We do not pretend to provide a survey of that literature. Instead, we will discuss inflation persistence from the perspective of the New Keynesian Phillips curve, which provides a convenient framework for elucidating two points. First, economic measures of real economic activity may affect short-term fluctuations of inflation, but statistical measures of output gaps are not necessarily related to these economic measures of real activity. Second, observed inflation persistence may be the result of monetary policy and thus for policy purposes cannot be relied on as a structural feature of the economy.

After examining inflation persistence, we will indicate why we also believe that the concept of an output gap, be it a statistical or model-based concept, is not particularly useful in making policy. Statistical output gaps can be misleading from a theoretical perspective, while theoretical output gaps that are based on explicit quantitative models rely on questionable identifying assumptions. Quantitative models assume the existence of certain distortions in the economy that reduce welfare, for example, nominal rigidities, and they attribute variations in output to shocks, both distortionary and nondistortionary. Model-based gaps define potential output as that level of output that could be attained in the absence of inefficiencies and distorting shocks. Given the current state of knowledge, assumptions about what constitutes distortions are often tenuous, as is the classification of shocks as distortionary or nondistortionary.

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Inflation Persistence and Monetary Policy

Forecasting Inflation

We are interested in inflation persistence because it is a statistical measure that has been used to support particular theoretical models and particular policy positions. In many of those discussions, the issue of the forecastability of inflation is lurking in the background, as persistence can often be a close cousin to forecastability. The finding that inflation is a persistent process has been used to infer that there are large economic costs, sometimes referred to as sacrifice ratios, in lowering inflation. We find that this view is sensitive to the underlying reason for persistence, that is, whether persistence is an outcome of policy or a fundamental feature of the propagation mechanism embodied in the economy's structure.

Regarding forecasting there is no shortage of literature on forecasting inflation, and that literature has found that inflation is difficult to forecast in general, and the difficulties have become greater over time (see Stock and Watson, 1999, 2007, and 2008). The relative forecasting performance of univariate statistical models and Phillips curves (PCs), that is, statistical models that include additional information such as output gaps or unemployment gaps, has been changing over time, but on average, inflation is well represented as a random walk with time-varying volatility (Stock and Watson, 2008). From the mid 1980s to the late 1990s it is hard to beat a simple random walk, as shown by Atkeson and Ohanian (2001). Stock and Watson (2008) conjecture that Phillips curve models tend to do better in recessions, when statistical output gap measures are large and negative.

Drifting Average Inflation

Eyeballing the time series of inflation suggests that the mean of inflation has varied over time. Arguing that trend inflation has changed over time does not mean that inflation is beyond the control of monetary policy. Rather we think that the converse is true, namely, that monetary policy is very likely the one element that can affect trend inflation. Not surprisingly, whether or not one accepts that possibility will have striking consequences for whether one views observed inflation persistence as a structural feature of the economy. Next we turn to a simple theory to investigate what accounts for inflation persistence.

The New Keynesian Phillips Curve

We use a simplified version of the model in Ireland (2007).[2] The model introduces nominal rigidities through a quadratic cost of price adjustment, which depends on an index of lagged inflation and trend inflation.[3] From the nominal rigidities, the monopolistically competitive market structure, and the assumption that firms face common marginal costs, one can derive a New Keynesian Phillips curve (NKPC) relating inflation to past inflation, expected future inflation, trend inflation, marginal cost, and a (mark-up) shock.

[2] We simplify Ireland's model in that we shut down the feedback from the model's shocks to the inflation target.

[3] Quadratic costs of nominal price adjustment are a simpler way to model nominal rigidities than the more common Calvo-price adjustment mechanism. Both approaches yield the same type of NKPC.

Monopolistically competitive agents set their price as a markup over marginal cost. Since the price setters face costs to re-optimize their prices, they set their prices taking into account that future aggregate inflation will erode their markup. Aggregate inflation then depends on marginal cost and expected future inflation. The dependence on past inflation and the inflation trend comes through the assumed indexation scheme. Mark-up shocks are interpreted as random changes to the firms' demand elasticity.

The NKPC accounts for deviations of inflation from average—or trend inflation. If trend inflation is changing over time and is modeled as changing over time, then the NKPC needs to account only for the deviations of inflation from a changing trend, not for overall inflation. By construction, deviations from trend inflation are less persistent than inflation; thus a NKPC estimated for deviations from trend inflation will predict less backward-looking indexation or shock persistence, e.g., Cogley and Sbordone (2008).

We discuss the sources of inflation persistence and the extent to which real activity affects inflation in a simple reduced form of the NKPC. For this purpose we assume that marginal cost, the real activity variable, is exogenous and follows a simple AR(1) process. This allows us to eliminate inflation expectations from the NKPC and we obtain

$$ln\Pi_t = \alpha ln\Pi_{t-1} + (1-\alpha)ln\Pi_t^* + \kappa mc_t + \lambda e_t,$$

where Π_t is the gross inflation rate, Π_t^* is the inflation trend, mc is marginal cost, and e is a mark-up shock.

We would like to make two observations. First, real activity is related to inflation through an economic variable, marginal cost, and not a statistical construct like the output gap. Second, there are various reasons why inflation might be persistent. Inflation can be persistent because marginal cost is persistent, because mark-up shocks are persistent, because prices are indexed to past inflation (α), or because inflation is indexed to the inflation trend (1-α), and that trend is itself a persistent process. As in Ireland (2007) we model the inflation trend as a random walk.

<u>Marginal Cost, the Output Gap, and the NKPC</u>

As we have just noted, theory predicts that statistical output gaps belong in a Phillips curve only to the extent that they stand in for marginal cost (see Gali and Gertler (1999) and Sbordone (2002)). Indeed estimated model-based measures of marginal cost are correlated with inflation in line with the NKPC. However, this correlation is far from perfect because NKPC estimates typically assign an important role to exogenous mark-up shocks in accounting for inflation volatility.

Because the NKPC is part of a general equilibrium specification, we can use the rest of the model to define economic output gaps that are related to marginal cost. The tightness of the relationship between marginal cost and model-based output gaps depends on the specific definition of the model-based output gap. For a particular DSGE model of the U.S. economy, Sill (2009) shows that there exists a definition of the model-based output gap and an estimated model-based marginal cost series for which the two variables are strongly correlated. However, the model-based output gap series is only weakly correlated with statistical output gaps – as will be discussed further below.

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Sources of Inflation Persistence in the NKPC

We estimate the simplified model of Ireland (2007) for the postwar U.S. (1954-2009) to see how the specification of trend inflation affects our assessment of the sources of inflation persistence. We use data on output, inflation, the nominal interest rate, and employment. Small scale models are usually estimated without using data on employment. Indeed, using data on employment does not matter much for our estimates of the sources of exogenous inflation persistence, though it matters greatly for model-based estimates of output gaps.

We are interested in how estimates of the model vary for two specifications for the inflation trend: a specification with a fixed inflation target and a specification with a random walk inflation target. However, the two sources of inflation persistence that are *not* directly related to monetary policy are potentially difficult to disentangle, those being the indexation to lagged inflation and the autocorrelation coefficient of mark-up shocks. Whether these parameters are identified for estimation purposes depends on the overall model specification and not just the NKPC alone. For this reason we estimate three versions of the model: one where we try to estimate mark-up persistence and indexation separately, one where we impose no indexation to past inflation, and one where we impose zero autocorrelation for mark-up shocks.

Our estimates are in Table 1. Independent of the assumptions on mark-up persistence and indexation, and the use of employment data, we find that allowing for a random walk inflation target reduces the overall contribution of indexation and mark-up shocks to inflation persistence as in Cogley and Sbordone (2008).

Conclusion on Inflation Persistence

To summarize, persistence of inflation (or the lack thereof) is determined by the interaction of policy with the structure of the economy and the shocks hitting the economy. We interpret our results as implying that the persistence in inflation has been driven mostly by policy. Supporting this point, Benati (2008) examines particular countries and/or time periods according to their monetary regime and finds that inflation persistence depends on the monetary regime. In particular, inflation persistence is lower in countries that are on a gold standard or where the central bank targets inflation. Further, according to this view, historical persistence of inflation is a good guide to future persistence only if policy remains unchanged. A change in policy is fully capable of changing the behavior of inflation independent of the underlying economic structure. More important, past evidence on inflation persistence does not imply that controlling or reacting aggressively to inflation is associated with large economic costs, especially if inflation expectations are well anchored.

Output Gaps and Monetary Policy

Introduction

In this section we assess the usefulness of output gaps for conducting policy. Broadly speaking, output gaps refer to the deviation of output from a level deemed to be desirable. Thus, assessing output gaps' usefulness for policy requires one to take a stand on the desired level of output, often referred to as potential output. As mentioned at the outset, there are two primary approaches to defining and measuring potential output: those based on statistical procedures (with perhaps some broad guidance from theory) and those based on explicit theoretical models.

Statistical measures of potential output are constructed either as smoothed versions of actual output or by using a production-function approach that also does some smoothing. A common rationale for statistical gaps is the idea that sharp fluctuations in output are inherently undesirable, so policy should generally aim at some smoothing of output fluctuations. See Armenter (2009), Kiley (2009), or Sill (2009) for detailed discussions of these methods.

A second approach to constructing potential output relies on estimated theoretical models. In a dynamic stochastic general equilibrium (DSGE) model, equilibrium outcomes depend on the structure of the economy and the exogenous shocks buffeting the economy. Some features of the economy's structure and some of the shocks hitting the economy may give rise to inefficient outcomes. That is, in the absence of these features and shocks, the welfare of the economy's agents would be higher. For example, monopolistic price setting and nominal rigidities — common features in DSGE models used for monetary policy analysis — both introduce distortions relative to an economy with perfect competition and flexible prices. In addition, mark-up shocks introduce inefficient fluctuations. This suggests defining potential output as that output that could be obtained in the absence of distortions and inefficient shocks, but allowing for shocks that are classified as efficient. In simple versions of these models a monetary policy that minimizes the difference between actual output and the model-based definition of potential output, that is, the model-based output gap, is welfare maximizing. In more complicated versions of these models the output gap is no longer a sufficient statistic to evaluate the welfare implications of monetary policy; see, e.g., Woodford (2003, Ch.8.2.3).

Statistical Gaps Can Be Misleading from the Perspective of Theory

To illustrate the fundamental point that statistical output gaps need not be closely related to model-based gaps, we will use the example of a productivity shock in a model with nominal rigidities.

Consider a productivity increase in an economy with fixed nominal prices and fixed nominal demand. With fixed prices and fixed nominal demand, output cannot change, but higher productivity means employment must fall. A statistical measure of the output gap would indicate no change, because there is no change in actual output. In order to know what happens to the model-based output gap, we need to know what happens to potential output. For this example – since the shock does not represent a distortion – potential output is the output that would occur if prices were flexible in the presence of the same productivity increase. With flexible prices, real output increases, and it is likely that employment increases as well. Thus, we have a negative model-based output gap: output is below potential.

Of course this example is contrived; in reality, neither nominal prices nor nominal demand is fixed, even in the short run. However, the basic point of the example — that productivity shocks open up a negative output gap because they raise actual output less than they raise potential output — can carry over to estimated DSGE models. In Figure 1 we display the response of output (solid blue line) and model-based potential output (green dashed line) to a productivity shock in the estimated model described in section 2.[4] Output rises in response to the shock, suggesting an increase in the statistical output gap, but output would rise even more in the flexible-price economy. Thus, the model-based output gap (red dashed-dot line) falls, an opposite response to the statistical gap.

Models and Monetary Policy

Currently, economists are developing and using medium-sized New Keynesian models to examine monetary policy. At this stage, there is no agreed upon model, but the basic methodology is to formulate and then estimate a particular model with specific structural shocks. The estimation can then inform a policymaker about the shocks that are affecting the economy. For example, in the DSGE model developed at Philadelphia, a significant fraction of the current fall in output is due to investment-specific technology shocks. If the shocks have been correctly identified, the model can be used to guide policy.

A significant problem is that alternative models may assign different weights to various shocks in accounting for the data and may not even include the same shocks. Also, alternative models may have different implications regarding the correct policy response for similar shocks. Discussing policy responses in terms of output gaps does not resolve this issue; rather it just hides the underlying disagreements. The key insight is that we can use different models to formalize disagreement and thus add coherence to policy discussions.

Models Not Ready for Prime Time

The example above does a good job of illustrating why statistical gaps are not necessarily a good guide to model-based gaps. Nonetheless, current models are not advanced enough that we feel comfortable with their implications for output gaps. Our discomfort is related to the important quantitative role played by shocks whose economic interpretation is unclear.

In the process of fitting models to data we introduce shocks in places where our model does not exactly fit the data. What do we mean by that? Models impose restrictions on variables that should hold *always*, but that are clearly violated by the data we use to estimate the model. For example, given data on output, employment, and capital and a parametric production function, we need to introduce a productivity disturbance such that the production relation holds for all data points. In a sense, the productivity shock reflects the extent to which our theory is not exactly true – the "measure of our ignorance" in Moses Abramowitz's words (1956). Should

[4] We plot the percentage deviations of actual and model-based potential output from their respective steady-state values in response to a one-percentage-point innovation to the productivity growth rate.

this estimated productivity shock be treated as structural for the model and for policy purposes? On the one hand, there are certainly changes to the production process that are exogenous with respect to monetary policy; i.e., the shock is structural. On the other hand, we may think that the model of production is misspecified, for example, because it omits variation in capital utilization. In this case the measured productivity shock conflates endogenous movements that may respond to policy with exogenous shocks. If we do not have direct measures of capital utilization, we have to come up with a model of capital utilization to extract the "true" exogenous shocks.

We have come to accept productivity shocks as structural, although, ideally, with some correction for endogenous utilizations. However, we have not yet reached that comfort level with many of the new "structural" shocks coming out of DSGE models. (See Chari, Kehoe, and McGrattan (2009) for a forceful presentation of the view that we have not reached that comfort level.) Now, let's consider some examples of these shocks.

Mark-up shocks are used in the estimation of the NKPC. As discussed in part 1, the magnitude of the shocks depends on other identifying assumptions, in particular, whether we allow for a random walk in the inflation target. Even if we are comfortable with these other identifying assumptions, do we believe in the structural interpretation of the mark-up shocks? Monopolistically competitive price-setting is one of the central features of most DSGE models, and to the extent that mark-up shocks are quantitatively important for the behavior of inflation, we do not have a good model of inflation.

Estimated shocks will typically be bigger and more persistent the more the model is misspecified. If large persistent shocks are necessary to fit the data, the shocks should not be treated as structural – they are partly standing in for endogenous mechanisms that have been left out of the model. These shocks should not then be included in the determination of potential. But removing quantitatively important shocks from the definition of potential is problematic as well: we then define the desirable level of output as the outcome of a model that fails at explaining the data.

How do output gap series from estimated DSGE models actually behave? From the discussion thus far, it is perhaps not surprising that there can be significant variation depending on the particular model, the assumptions made in estimating the model, and the definition used for potential output. In Figure 2 we plot the output gaps from three models. The solid blue line represents the output gap from our small scale model used in Section 1, where potential is defined as output corresponding to flexible prices, no mark-up shocks, and no shocks to the inflation target. This small scale model ignores issues related to capital accumulation. The long dashed green line is the output gap from a medium scale DSGE model described in Sill (2009).

This model introduces investment and capital accumulation, and it includes efficiency shocks to the rate at which investment adds to the capital stock. Here potential is defined as output in the absence of nominal rigidities, but it allows for the presence of mark-up shocks and all other shocks. Finally, the two red lines represent alternative output gaps from the Board's larger scale EDO model, which distinguishes between three types of investment: nonresidential business fixed investment, residential structures, and durable consumption goods.[5] The two

[5] We would like to thank Michael Kiley for making the data available to us.

output gap definitions from the EDO model both eliminate nominal rigidities and mark-up shocks from the definition of potential output; they differ according to whether they eliminate inter- and intratemporal preference shocks. Note the following features of this figure:

1. For our small scale model, the output gap is quite close to deviations from an HP trend (not plotted). This result depends crucially on the use of employment data when estimating the model. Typically, small scale DSGE models are estimated using only data on output, inflation, and interest rates. For this smaller set of variables, estimated potential output is sensitive to sample periods and the specification of the inflation target. Estimates that use employment data together with output data bring the model closer to production function estimates of technical change and potential output, independently of sample period and other identifying assumptions.
2. The medium scale model displays substantial and persistent positive output gaps in the last 20 years. In this model investment efficiency shocks are an important determinant of output fluctuations and the magnitude of the output gap. In fact, these investment efficiency shocks are needed to account for the decline of investment during the current recession.
3. In EDO, intertemporal discount rate shocks for the investment problems are almost equivalent to investment efficiency shocks. The gap represented by the short dashed red line treats intratemporal and intertemporal preference shocks as efficient, whereas the gap represented by the dash-dot red line treats these shocks as inefficient, excluding them for the purpose of computing potential output. Again, it is apparent that investment efficiency shocks currently depress output significantly and they play a crucial role in the determination of the output gap.

If investment efficiency shocks are truly an important source of business cycle fluctuations, especially during the current recession, how should we interpret these shocks? A literal interpretation would take them as another productivity shock that determines how investment is transformed into productive capital. In this case, current low investment is the rational response to a state where the construction of new capital goods is relatively inefficient. Another interpretation is that these shocks reflect the ability of the financial sector to allocate investment goods to their most appropriate use. While this interpretation may make sense for some of the more recent declines in investment, it is not obvious that there have been large scale fluctuations in the financial sector's efficiency in the years before the recent episode. Furthermore, it is not obvious that under this alternative interpretation we should define potential output as output obtained in the absence of these shocks. Doing so would, at a minimum, presuppose that we know what the true underlying cause of the reduced-form investment efficiency shocks is and that there is some policy instrument available that can address the underlying cause.

By this discussion we do not mean to imply that medium scale DSGE models are useless in accounting for possible sources of economic fluctuations for a given theoretical framework. However, given the ambiguous interpretation of many of the important shocks in this framework, it seems more appropriate that policy discussions proceed based on these shocks, rather than the implied reduced-form gaps.

Conclusions Regarding Output Gaps

To summarize, we are left with broad discomfort about using any output gap measure, be it statistical or model-based, as an important indicator for policy for the following reasons

1. Although one is free to believe that a statistical output gap represents the deviation of output from a desirable level, this is not a consensus conclusion from state-of-the-art DSGE models. Even if a statistical output gap was highly correlated with a model-based output gap in the past, one cannot treat this relationship as structural for two reasons:
    a. First, statistical and model-based output gaps can be highly correlated and yet there can be particular shocks that move the two gaps in opposite directions.
    b. Second, just as with inflation persistence, any historical correlation of statistical and model-based output gaps was conditional on a particular policy rule. Deviations from that policy rule can result in different comovement between statistical and model-based output gaps.
2. Even though we would prefer model-based output gaps to statistical output gaps in principle, we are not confident that, given the current state of knowledge, one can rely on model-based gaps as sufficient indicators for monetary policy. These model-based gaps are sensitive to assumptions about identification and shock classification for which theory and econometrics do not provide clear guidance.

On a more positive note, we believe that a general lesson from our models is that it is not enough to know that output is high or low relative to trend to conclude that output is high or low relative to potential; rather one needs to know something about the shocks hitting the economy and the assumed structure of the economy. From this we conclude that the use of models in policy discussions is beneficial, since it formalizes disagreement.

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Table 1. Estimates of Indexation and Markup Persistence

		Indexation α		Markup Persistence ρ_ε		Markup Volatility σ_ε	
Prior Mean		0.5		0.1		0.002	
		Posterior		Posterior		Posterior	
		Mean	90% Interval	Mean	90% Interval	Mean	90% Interval
		Fixed Inflation Target					
Without	1	0.24	[0.09, 0.37]	0.74	[0.63, 0.87]	0.0033	[0.0029, 0.0039]
employment data	2	NA	NA	0.85	[0.81, 0.90]	0.0035	[0.0030, 0.0039]
	3	0.69	[0.53, 0.82]	NA	NA	0.0043	[0.0037, 0.0049]
With	1	0.39	[0.25, 0.52]	0.53	[0.46, 0.67]	0.0035	[0.0031, 0.0040]
employment data	2	NA	NA	0.66	[0.60, 0.73]	0.0032	[0.0028, 0.0035]
	3	NA	NA	NA	NA	NA	NA
		Random Walk Inflation Target					
Without	1	0.30	[0.14, 0.47]	0.00	[0.0, 0.0001]	0.0032	[0.0028, 0.0037]
employment data	2	NA	NA	0.0001	[0.0, 0.0001]	0.0028	[0.0024, 0.0032]
	3	0.34	[0.14, 0.54]	NA	NA	0.0032	[0.0028, 0.0038]
With	1	0.27	[0.09, 0.43]	0.00	[0.0, 0.0001]	0.0029	[0.0025, 0.0032]
employment data	2	NA	NA	0.0001	[0.0, 0.0001]	0.0028	[0.0024, 0.0031]
	3	0.27	[0.12, 0.44]	NA	NA	0.0030	[0.0026, 0.0035]

Model specifications: (1) estimate both, α and $\rho_{\varepsilon,;}$ (2) estimate ρ_ε and fix α =0; (3) estimate α and fix ρ_ε =0

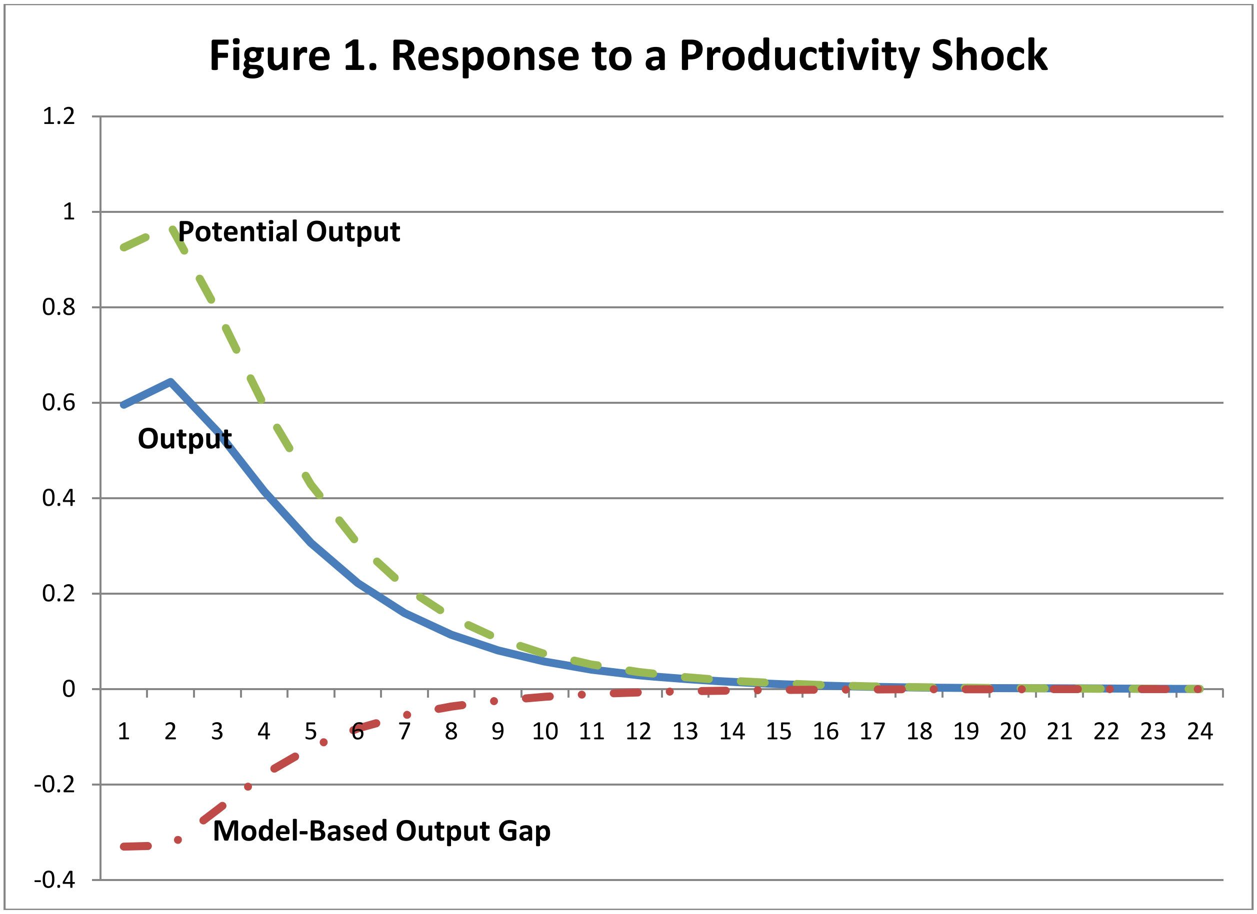
Figure 1. Response to a Productivity Shock
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Potential Output
Output
Model-Based Output Gap

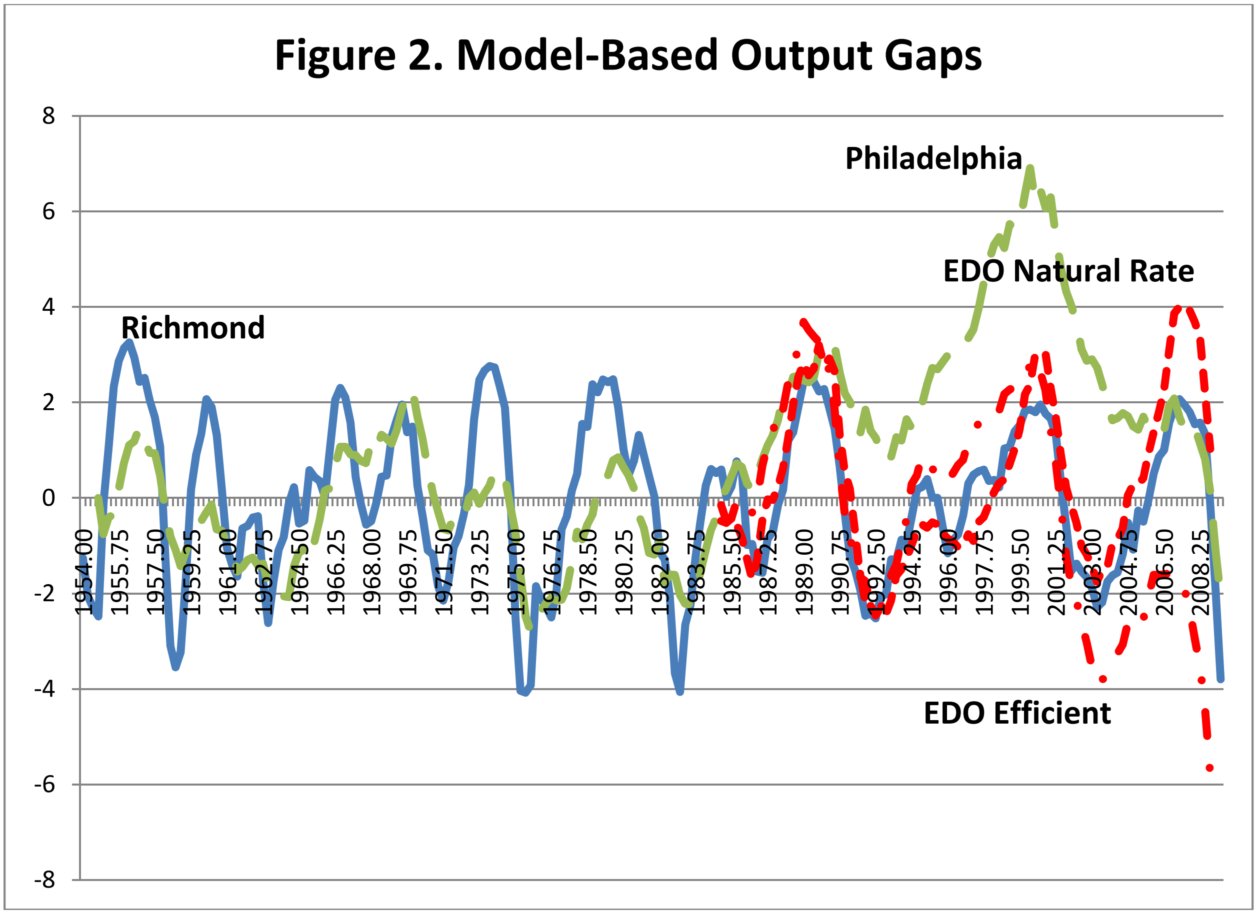
Figure 2. Model-Based Output Gaps
8
6
4
2
0
-2
-4
-6
-8
Philadelphia
EDO Natural Rate
Richmond
EDO Efficient
1954.00
1955.75
1957.50
1959.25
1961.00
1962.75
1964.50
1966.25
1968.00
1969.75
1971.50
1973.25
1975.00
1976.75
1978.50
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