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Abstract

The recent financial crisis and ensuing recession appear to have put the productive capacity of the economy on a lower and shallower trajectory than the one that seemed to be in place prior to 2007. Using a version of an unobserved components model introduced by Fleischman and Roberts (2011), we estimate that potential GDP in late 2014 was about 7 percent below the trajectory it appeared to be on prior to 2007. We argue that a significant portion of the recent damage to the supply side of the economy plausibly was endogenous to the weakness in aggregate demand—contrary to the conventional view that policymakers must simply accommodate themselves to aggregate supply conditions. Endogeneity of supply with respect to demand provides a strong motivation for a vigorous policy response to a weakening in aggregate demand, and we present optimal-control simulations showing how monetary policy might respond to such endogeneity in the absence of other considerations. We then discuss how other considerations—such as increased risks of financial instability or inflation instability—could cause policymakers to exercise restraint in their response to cyclical weakness.

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The collapse of a housing market bubble in the United States and the ensuing financial crisis led to the steepest drop in real GDP and the largest increase in the unemployment rate since the end of World War II. The fallout from these events on credit availability, balance sheets, and confidence arguably continues to weigh on aggregate demand, restraining the pace of recovery in the housing market, firms' willingness to hire and invest, and spending by consumers and state and local governments. In addition, these demand effects have probably diminished the productive capacity of the economy.

In this paper, we examine recent developments in potential output in the United States and discuss the implications for U.S. monetary policy. We begin our analysis by using a standard production-function framework and an unobserved components statistical model to estimate the extent of supply-side damage in recent years, and to identify the components of aggregate supply where the damage has been most acute; this analysis builds on previous work by Fleischman and Roberts (2011) and is similar in spirit to an exercise performed by Kuttner and Posen (2001) to decompose the forces driving Japan's "Lost Decade." Our results suggest that the level of potential GDP was about 6¼ percent below its pre-crisis trend in 2013:Q4, with a 95 percent confidence interval ranging from 4¼ percent to 8¼ percent; the model projects the shortfall to widen to 7 percent by 2014:Q4. We also show that, in real time, this modeling apparatus would have recognized the decline in potential output relative to its pre-crisis trend only gradually, reflecting both surprises in the incoming data as the severe recession and subsequent slow recovery unfolded, and substantial revisions to the national income and product data. Although the model has revised down its estimate of potential output since before the crisis, the downside surprise with respect to actual output has been considerably greater; as a result, the model sees actual output as still running significantly below its potential as of the third quarter of 2014.

In terms of the components of aggregate supply, the model estimates the largest shortfall relative to the pre-recession trajectory to have been in trend labor productivity, reflecting both a steep decline in capital accumulation and slower growth in multifactor productivity. However, trend growth in the labor force also appears to have slowed after 2008, suggesting that the deep recession resulted in some structural damage in the labor market.

We then examine the implications of these findings for the distinction that is commonly presumed to exist between "supply" and "demand" aspects of the economy. In many macroeconomic models, aggregate supply shocks are assumed to be exogenous—and specifically as outside the range of influence of monetary policy. However, if some elements of aggregate supply are significantly affected by the condition of aggregate demand, they may also be susceptible to influence from monetary policy. As discussed by Blanchard and Summers (1986), Ball (1999), Kuttner and Posen (2001), and Blanchard (2003) some time ago, and investigated more recently by Stockhammer and Sturn (2012) and Erceg and Levin (2013), adverse demand shocks can have long-lasting effects on unemployment duration and labor force attachment that monetary policy might be able to check. Moreover, monetary policy may be able to influence potential output over the medium term through its effect on new business formation and research and development. Finally, overall aggregate demand clearly influences the supply-side of the economy through business investment and its implications for the pace of capital deepening. In short, through a variety of channels, the distinction between aggregate demand and aggregate supply appears to more blurry than commonly supposed.

In the final section of the paper, we examine the implications of this blurring for the "optimal" conduct of monetary policy in the context of the FRB/US model. Taken alone, the possibility that potential output will be affected by adverse demand shocks through hysteresis-like effects leads optimal monetary policy to be more activist, in order to mitigate the possible damage to the current and future supply side of the economy.[2] However, other considerations may militate toward restraint in the conduct of monetary policy; these considerations include concerns about the possibility of undermining financial stability or causing inflation expectations to become unmoored. Thus, in an uncertain world, a monetary policymaker's actions will depend not only on the extent to which he or she believes a demand shock is likely to affect potential GDP and employment, but also on his or her view of the risks associated with actively trying to offset these adverse supply-side developments.

I. Recent Supply-Side Developments: Evidence from a State-Space Model

The marked decline in the U.S. unemployment rate from its peak in late 2009 despite only sluggish growth of real GDP, coupled with observations by Cerra and Saxena (2008) and Reinhart and Rogoff (2010) that past financial crises in a variety of countries tended to be followed by persistent shortfalls in real GDP relative to pre-crisis trends, have led many to speculate that the financial crisis and ensuing recession left a permanent imprint on the productive capacity of the U.S. economy.[3] To assess the implications of the events of recent years for potential output, we examine the behavior of real GDP and unemployment in the

[2] Kienzler and Schmid (2013) and Ikeda and Kurozumi (2014) reach a similar conclusion in the context of DSGE models with hysteresis dynamics.

[3] See, for example, CBO (2012). Similarly, the European Central Bank (2011) estimates that the financial crisis led to a permanent drop in the level of potential output in the Euro area, but argues that the effects on potential growth going forward are more uncertain. In related work, Martin and Wilson (2013) "find that severe recessions have a sustained and sizable impact on the level of output."

context of an aggregate production function. This approach allows us to decompose changes in potential output into changes in potential labor input (including changes in the natural rate of unemployment), capital deepening, and multifactor productivity. To help identify the unobserved productive potential of the economy, the model that we use in this estimation exercise incorporates an inflation equation that is similar in spirit to a new-Keynesian Phillips curve, and thus embeds a relationship between economic slack and inflation—concepts that are of central importance to the conduct of monetary policy in the United States.[4]

Specifically, we use a version of an unobserved components model of the supply-side of the economy developed by Fleischman and Roberts (2011); this model in turn builds on earlier work by Blanchard and Quah (1989), Kuttner (1994), and Basistha and Starz (2008).[5] In particular, we first define (log) output in terms of the components that comprise an aggregate production function:

$$y_t \equiv \Sigma x_{it},$$

where the x_i's include the various determinants of labor input (e.g., population, labor force participation, the employment rate, and the workweek), the factors influencing labor productivity (e.g., capital deepening, labor quality, and multifactor productivity), and a variety of technical factors that account for the different measurement systems used to construct the data series we use in estimation. (In addition, actual output is unobserved in the model but is identified by the comovements of real GDP, real non-farm business output, and real non-farm business income.[6])

[4] A production-function approach is also used by the CBO, the IMF, the ECB, and the OECD in developing their estimates of potential output. See also Fernald (2012), Basu and Fernald (2009), Clark (1987), and Gordon (2003).
[5] The state-space model that we use has, with some modifications, been embedded in the Federal Reserve's large-scale econometric model of the US economy, FRB/US. See http://www.federalreserve.gov/econresdata/frbus/us-models-package.htm for further details.
[6] Nalewaik (2010) shows that elements from the income side of the national income and product accounts have substantial incremental information content relative to elements from the product side.

We then specify each element of the production function as the sum of a cyclical component, a trend component, and an idiosyncratic residual:

$$x_{it} = \lambda_i(L)\, cyc_t + x_{it}^* + \mu_{it}.$$

Finally, as noted above, we augment the production function equations with a new-Keynesian-style inflation equation. This equation relates current-period inflation to a survey-based measure of long-run inflation expectations, lagged inflation, economic slack (as measured by the same cycle variable that appears in the decomposition of each element of the production function), and changes in the relative prices of energy, food, and imports:

$$\Delta p_t = \omega \Delta p_t^e + (1\text{-}\omega)\Delta p_{t-1} + \beta cyc_t + Z_t \Gamma + \varepsilon_t.$$

Our use of a survey-based measure of long-run inflation expectations as an explanatory variable in the equation is motivated by Clark (2011), Del Negro, Giannoni, and Schorfheide (2013), and Ascari and Sbordone (2013), who find that such measures well capture the low-frequency stochastic trend component of U.S. inflation over the past fifty years.[7]

Following Fleischman and Roberts, we assume that each of the trend variables follows a random walk with drift,

$$x_{it}^* = \alpha_{i,t} + x_{i,t-1}^* + \eta_{it}\ .$$

For some trend variables (e.g., the natural rate of unemployment) the drift parameter is constrained to equal zero or an estimated constant, but for most trend terms the drift parameter is assumed to follow the AR(1) process $\alpha_{i,t} = .95\ \alpha_{i,t-1} + \varepsilon_{i,t}$. The common cyclical component follows an AR(2) process,

[7] From 1990 through the present, Δp_t^e equals the median projection of inflation over the next ten years reported quarterly in the Survey of Professional Forecasters; from 1980 through 1989, it equals the average expected rate of inflation ten years ahead reported in the Hoey survey of financial market participants. Where necessary, both survey measures are adjusted to put them on a PCE price index basis. Prior to 1980, Δp_t^e is inferred from the low frequency movements in actual inflation.

$$cyc_t = \delta_1 cyc_{t-1} + \delta_2 cyc_{t-2} + \xi_t \,.$$

We use standard maximum likelihood methods for state-space models—specifically, the Kalman filter—to estimate the parameters. (See the appendix for additional details of the model.)

Results from the state-space model based on current-vintage data are shown in Table 1 and Figure 1. According to the point estimates from the model, as indicated in the top row of the table and the upper-right panel of the figure, potential GDP growth slowed from 2.6 percent per year in the 2000-2007 period to 1.6 percent per year on average from 2008 through 2013; the slowdown in estimated growth was particularly pronounced from 2010 to 2012. As shown in the upper left panel of the figure and the right-most column of the table, the *level* of potential GDP as of 2013:Q4 is estimated to be about 6¼ percent below the trajectory that appeared to be in place based on the average pace of growth estimated over the 2000-2007 period; the model projects the shortfall to widen to more than 7 percent by the end of 2014.[8]

Lines 2 through 4 of the table and the remaining panels of the figure provide some evidence from the model on the sources of the reduction in the potential growth rate of the U.S. economy. The largest contribution to the slowdown in potential output growth is from trend labor productivity (line 3), reflecting both a sharp decline in the contribution to labor productivity from capital deepening (capital services per trend employee hour) and smaller increases in trend multifactor productivity since the financial crisis.[9] The trend growth rate of labor input (line 2) has also slowed in recent years, according to the model, owing to somewhat less rapid population growth, a modest increase in the natural rate of unemployment, and a

[8] The estimation period for the state-space model is 1963Q2 to 2014Q3, where the latter date is the most recent quarter for which published national account data are available.

[9] The estimated deceleration in trend MFP is noticeable from 2010 on, and presumably reflects the weak readings on actual labor productivity recorded from 2011 through 2014. In the eyes of the state-space model, these weak readings imply slow trend growth in MFP because they occurred while the unemployment rate was falling steadily and growth in capital services was recovering.

steepening of the trend decline in the labor force participation rate; these factors are substantially offset by a flattening out of the workweek, which had been declining over the 2000-2007 period. Even with the estimated slowdown in potential growth, the model's estimate of the output gap (shown in the upper panel of Figure 2) is consistent with a sharp drop in resource utilization in 2008 and 2009 and only a gradual—and as of 2014:Q3, still incomplete—recovery thereafter.

With regard to the slowdown in potential GDP growth and its components reported in Table 1, a critical issue is its timing. Did the slowdown begin after the onset of the financial crisis and the start of the recession, indicating a potential link with weak aggregate demand conditions? Or did it instead precede these events? On balance, the answer seems to be mostly "after." As shown in the upper-left panel of Figure 3, the deceleration in capital services (the biggest contributor to the slowdown) clearly began after the recession started. And although trend MFP presents a somewhat less clear picture, as growth dipped in the two years prior to the recession but then recovered for a time, since the recession started in late 2007 it has expanded at an average pace that is slower than the average rate of growth recorded over the previous 25 years, resulting in a cumulative 1¼ percent shortfall by late 2014. In contrast, most of the recent shifts in trend labor input appear to have been either transitory (the temporary rise in the natural rate of unemployment), or primarily driven by exogenous demographic factors (the declines in population growth and the labor force participation rate). That said, on a demographically-adjusted basis the trend labor force participation has declined enough since late 2007 to shave ½ percent off the 2014:Q3 level of potential output. Moreover, some of the deceleration in population since 2007 reflects less net migration from abroad—a development that presumably was importantly influenced by the weak state of the U.S. economy, and by itself subtracts another ¾ percent off the late 2014 level of potential output.[10]

It took some time for these changes to the supply side of the economy to become fully apparent in the data, and consequently many economists did not initially adjust down their estimates of potential output in the United States following the financial crisis despite the international evidence reported by Reinhart and Rogoff (2010) and Cerra and Saxena (2008) for earlier financial crises. To illustrate the discrepancy between the perceived effects of the crisis as they unfolded over time versus how they appear from the perspective of late 2014, we estimate the state-space model described above using the data for real activity and inflation that were available in early June of each year between 2008 and 2013, and we use the model to generate estimates of supply-side conditions through the first quarter of the year in question. In addition, for each of the six years, we use the estimated model to project the path of potential GDP and the natural rate from the second quarter of the year forward, conditional on the assumption that the contribution of capital deepening to growth would gradually return to its historical average.[11] These "real-time" results are then compared to our baseline estimates computed using data through 2014Q3.

The upper two panels of Figure 4 present the results of this exercise for the estimated level and rate of change of potential output. Initially, the state-space model did not interpret the available data as suggesting much of a change in the economy's overall productive capacity; in

[10] See Aaronson et al (2006, 2014) for a discussion of the contribution of demographic trends to the recent decline in the labor force participation rate. For a discussion of the effects of immigration on U.S. population growth, see Frey (2014).

[11] Because the state-space model does not forecast capital deepening (in contrast to, say, trend labor force participation), any real-time projection of potential GDP beyond the current quarter requires some assumption for the future path of capital services. Similar considerations apply to population, which in these real-time calculations is assumed to continue rising at the average pace observed over the previous year.

fact, the historical and projected path of potential GDP revised up slightly between the 2008 and 2009 data vintages.[12] However, data vintages beginning in 2011 painted a considerably darker picture, and the model's estimates of potential GDP revised down accordingly. Similarly, as illustrated in the lower left panel of the figure, the model did not initially detect much of an increase in the natural rate of unemployment. Despite all that, and taking into account the vast scale of the recession, the real-time estimates would have proven reasonably consistent in terms of the measured unemployment gap (lower right panel). Other analysts also marked down their estimates of potential output growth over time, although the timing and the extent of these markdowns varied considerably.[13] Interestingly, the receipt of the 2014 vintage of data caused the model's estimate of the natural rate of unemployment to drop appreciably in 2013 and 2014, reflecting a decline in the actual unemployment rate during these two years that outstripped what would have normally been expected given the accompanying modest growth in real GDP.[14]

[12] Comparing potential GDP estimates based on the June 2008 and June 2009 vintages of data to those based on subsequent vintages is somewhat difficult because the measures of real output and income used to calculated potential GDP were rebased from 2000 dollars to 2005 dollars beginning in July 2009. In figure 4, the 2008 and 2009 real-time estimates of the level of potential GDP are rescaled by a constant multiplicative factor that has the effect of making these vintages' historical estimates of real GDP from the late 1940s through the late 1990s closely match those published at a later date.

[13] For example, in 2008 the IMF projected that average growth of U.S. potential output in 2009-2010 would be 2.1 percent; by 2013, it had marked down its estimate of growth in 2009-2010 to only 1.3 percent. Over the same period, the OECD revised down its estimate for U.S. potential output growth in 2009-2010 from 2.3 percent to 1.6 percent, the CBO from 2.4 percent to 1.7 percent, and the CEA from 2.7 percent to 2.0 percent. Some analysts judgmentally marked down their supply-side estimates in the wake of the financial crisis on the grounds that such events typically result in persistent supply-side damage. Judgmental assessments of this sort raise the question: Should the specification of a "good" state-space model allow for discrete shifts in parameters and shocks following the onset of a financial crisis? While the answer to this question is almost certainly "yes" in principle, the practical difficulty of doing so is quite high owing to the rarity of such crises domestically and the uncertainties of calibrations based on international experience.

[14] A somewhat similar phenomenon occurred with the receipt of the 2009 and 2010 vintages of data. Over this period, the unemployment rate rose by more than the state-space model would have predicted given actual GDP growth and prior estimates of potential output growth. In response to these and other surprises, the model revised down its estimate of potential GDP growth while simultaneously revising up its estimate of the natural rate. Such a pattern of revisions helps to reduce the error in Okun's Law (which is implicitly embedded in the model's structure) without appreciably increasing the prediction errors in the model's Phillips curve, whose slope is estimated to be quite flat.

Of course, considerable uncertainty attends all of these estimates of potential output growth and the natural rate. As indicated by the blue shaded region in the upper-right panel of Figure 1, the 95 percent confidence band around the state-space model's mid-2014 estimate of the four-quarter change in potential real GDP is ±1 percentage point, while the comparable confidence band around the estimated natural rate of unemployment (middle-left panel) ranges from about 3¾ percent to 6¼ percent. Moreover, these ranges undoubtedly understate the true uncertainty surrounding our model-based estimates as they do not account for the susceptibility of the data to revision, uncertainty about the specification of the state-space production-function model, or the possibility that other altogether-different frameworks might yield different estimates of supply-side damage.[15]

These concerns notwithstanding, experiments with different versions of the state-space model suggest that our potential output estimates are reasonably robust to alternative specifications. Figure 5 compares our baseline supply-side estimates to results from three of the alternatives we investigated. The first alternative takes account of research by Aaronson et al. (2014) indicating a sizable demographic component to recent declines in the labor force participation rate by treating this factor as an exogenous force affecting trend labor input. The second version adopts a more flexible timing structure for the response of aggregate output and labor market conditions to movements in the latent "cycle" variable by adding four lags of this term to all the signal equations. The third alternative allows for a break in the slope of the

[15] The real-time estimates presented in Figure 4 are consistent with the claim that data revisions are a significant source of uncertainty, in that data revisions in 2009 and 2010 account for a sizable portion of the downward adjustments to the state-space model's estimates and projections of potential output growth.

model's Phillips curve in 1995. As can be seen in the figure, estimates from these alternative specifications are similar to those obtained from our baseline model.[16]

II. The Potential Endogeneity of Recent Supply-Side Developments

Although considerable uncertainty attends any estimate of potential output and its components, the preceding analysis strongly suggests that the U.S. economy has experienced significant supply-side damage since 2007; broadly speaking, these results are consistent with the claim that major financial crises tend to reduce a nation's productive potential. However, we argue in this section that the implications for monetary policy may differ sharply from what is commonly presumed because much of the supply-side damage could be an endogenous response to weak aggregate demand. If so, then an activist monetary policy may be able to limit the amount of supply-side damage that occurs initially, and potentially may also help to reverse at a later stage a portion of such damage as does occur. By themselves, such considerations militate toward a more aggressive stance of policy in response to a financial crisis and associated recession. In section III, we discuss other considerations that may incline policymakers toward a less aggressive policy response.

Contrasting views

In setting monetary policy, central banks have traditionally tried to distinguish between trend and cyclical movements by disentangling the effects of exogenous "supply" shocks (which are assumed to influence the economy's long-run equilibrium) from the effects of "demand" shocks (which are assumed to drive the economy away from its steady state). The rationale for

[16] Aside from these three variants of the state-space model, we also considered versions in which we dropped the Phillips curve from the model, replaced all the AR(1) growth rate specifications with random walks, and excluded aggregate non-farm income. As documented in the working paper version of this paper, none of these changes appreciably changed our estimates of potential output.

this distinction is presumably rooted at least partly in the assumed long-run neutrality of monetary policy: However important it may be in influencing the paths of real variables in the short run, monetary policy cannot affect output, employment, or unemployment once prices have fully adjusted and the effects of other nominal rigidities have faded away. For this reason, monetary policymakers have to accept the real long-run equilibrium of the economy as something that is determined outside the sphere of monetary influence, and they need to recognize that it would be fruitless or even outright damaging to seek a different set of real outcomes. (See Barro and Gordon, 1983.)

The standard textbook presentation of a vertical Phillips Curve has this flavor: In the long run, output must return to a level that is determined by the location of the vertical aggregate supply curve, and is invariant with respect to the conduct of monetary policy. The aggregate demand curve may be buffeted by various factors including the stance of monetary policy, but in the long run, the location of the aggregate demand curve matters only for the value of the equilibrium real interest rate consistent with stable inflation.[17]

While the sharp separation between supply shocks and demand shocks—and the identification of the first with circumstances that monetary policymakers must accept as given and the second as factors that they may be able to usefully counteract—is characteristic of particularly simple models, it greatly oversimplifies the real world. As Blanchard and Summers (1986) noted many years ago in the European context, weak real activity may give rise to long-

[17] Dornbusch and Fischer (1978), the first edition of their macro text, describes the expectations-augmented Phillips curve in this manner (pp. 404-405) and specifically references a long-run vertical Phillips curve (page 410). For the first known presentation of the standard textbook vertical supply curve to the Federal Open Market Committee, see page 25 of the document provided at: http://www.federalreserve.gov/monetarypolicy/files/FOMC19831115material.pdf. To be sure, ideas along these lines had been presented and discussed among Federal Reserve staff for more than a decade, as illustrated by an "accelerationist" version of the Board's MPS model developed by William Poole (1971) and a paper that Robert Lucas gave at a 1971 conference hosted at the Board (Lucas, 1972).

lived hysteresis effects in labor markets, thereby providing a strong motivation for governments to implement policies (fiscal or otherwise) to both check the magnitude of economic downturns and so limit the supply-side damage that occurs, and to later boost the pace of activity as the economy recovers to repair whatever damage has occurred. Ball (1999) subsequently expanded on this idea by examining cross-country evidence on the role of monetary policy in influencing the magnitude of unemployment hysteresis effects, and concluded that policy-related supply-side effects were substantial for many European economies—a conclusion that has been reaffirmed in empirical work by Stockhammer and Sturn (2012).

We would go beyond this literature, however, and argue that the potential endogeneity of supply-side developments extends well beyond the labor market and includes such factors as multifactor productivity and capital deepening. To this end we review below several mechanisms that all have the characteristic of blurring the distinction between supply and demand, and therefore prompt a careful consideration of the factors that monetary policy must accommodate versus those it can counteract.

Before describing these mechanisms, we should note that the statistical methods commonly used to distinguish "cycle" from "trend" may exacerbate the blurring problem in severe recessions and slow recoveries. Most if not all of these statistical methods identify the "trend" with low-frequency movements in the variables of interest; the remaining movements are assumed to be cycle or noise. In a typical model of this type, the dividing line between "cyclical" frequencies and "trend" frequencies is roughly five or six years. That distinction may be appropriate for the dynamics of most recessions, but the adjustment of labor force participation, the unemployment rate, capital services, and productivity to the events of the last few years arguably will play out over an even longer span of time. For example, the recession and slow recovery may impair job matching and other aspects of labor market functioning for quite a few years. Moreover, these same conditions may lead a significant number of older workers to drop out of the labor force permanently at an earlier age than otherwise would have occurred, thereby depressing the participation rate for possibly a decade or more. In both cases, the distinction between cyclical and "trend" movements in the participation rate and related variables—and in particular, the idea that the trend is independent of the cycle—is not as clear as would be suggested by standard filtering methods.

Three mechanisms for blurring

Among the mechanisms blurring the delineation between the factors that monetary policymakers must accept versus those they can influence are the potential effects of weak aggregate activity on potential labor supply. As many policymakers and analysts have noted, an important and unusual aspect of the recent recession and the subsequent slow recovery—and one that heightens the risk that structural labor market damage may have been sustained already or may yet emerge—is the sharp increase in long-term unemployment since the onset of the financial crisis. As shown in Figure 6, the number of individuals unemployed for more than 26 weeks as a share of the labor force rose to 4.3 percent in April 2010 and is still near 2 percent, as compared with ¾ percent in 2007; likewise the share of the unemployed who have been out of work more than 26 weeks (not shown in the figure) peaked at about 45 percent in early 2011 and remains above 30 percent today, well above the levels experienced during any previous post-World War II recession. Long-term unemployment is of particular concern because individuals out of work for extended periods of time may find that their skills, reputations, and networks deteriorate, resulting in a persistently higher level of structural unemployment or a steeper downtrend in the labor force participation rate as some individuals discouraged by their job prospects throw in the towel and permanently exit the labor force.[18] Although such hysteresis effects do not appear to have been important in the United States in the past, they have been evident in other advanced economies, and the unprecedented durations of unemployment during the present episode in the United States may reduce the relevance of historical experience in this country. In principle, hysteresis in labor markets could cause a period of slack demand to have long-lasting adverse implications for the productive capacity of the economy. Accordingly, the ultimate effects of a financial crisis on the potential supply of labor could depend critically on the degree to which monetary policy can limit the initial contraction in real activity, and the speed with which it is able to restore aggregate demand to its normal and sustainable level.

A second channel through which persistent weak aggregate demand could affect aggregate supply involves some aspects of multifactor productivity. Evidence suggests that new-business formation suffers disproportionately during business-cycle downturns, and it is certainly the case that the annual number of start-ups has fallen noticeably since 2007 (upper panel of Figure 7). Moreover, employment growth at young firms has also been extremely weak by historical standards over the past few years (lower panel). Haltiwanger et al. (2012) show that young and small businesses were especially hard-hit during the recession and weak recovery, reflecting credit constraints and the steep drop in house prices, which reduced the ability of entrepreneurs to finance startups or expansions with home equity. If start-ups play a disproportionate role in promoting innovation because they embody the latest technologies, then

[18] It is well known that individuals with longer spells of unemployment find it more difficult to become reemployed. In the past, however, researchers have found it difficult to separate the effects of unobserved heterogeneity in the individuals experiencing long spells of unemployment from duration dependence. To address this issue, Kroft, Lange, and Notowidigdo (2013) recently conducted an experiment and found that, all else equal, potential employers were much less likely to call back job applicants with longer spells of unemployment than otherwise identical applicants with shorter spells, evidence that is consistent with duration dependence in unemployment. Although the aggregate implications of this finding are unclear, under some interpretations employers' aversion to long unemployment spells could result in hysteresis.

the "demand" factors that have restrained new business formation since the onset of the financial crisis are also probably working to damp growth in multifactor productivity.

Additionally, cyclical changes in research and development (R&D) can have long-lasting effects on multifactor productivity. Simple models generate the prediction that R&D investment will be countercyclical as businesses shift resources toward investments with longer-term payoffs when the opportunity costs of allocating resources away from current production is lower. Empirically, however, R&D investment appears to move in a procyclical manner.[19] If so, then recessions likely have a persistent adverse effect on the growth of multifactor productivity. Relatedly, Shleifer (1986) finds that new technologies diffuse more slowly in recessions than in expansions. In light of this research, and given that real R&D stocks have increased only 3.2 percent per year since late 2007, as compared to 5.1 percent on average from 1990 through 2007, it seems reasonable to assume that at least some of the cumulative reduction in trend MFP over the last few years is an endogenous response to weak aggregate demand. Indeed, the Bureau of Labor Statistics estimates that the contribution from R&D to MFP growth slowed from 0.24 percentage point per year from 1990 to 2007 to 0.19 percentage point from 2007 to 2012; if the latter pace was maintained over the following two years, then the implied cumulative shortfall in the level of potential GDP from this factor alone would be 0.35 percent by late 2014.[20]

Finally, aggregate demand, and hence monetary policy, can influence the economy's productive potential through its effects on capital deepening. Under the production-function approach to supply-side estimation discussed earlier and employed by the Congressional Budget

[19] See, for example, Comin and Gertler (2006). Barlevy (2007) argues that the procyclicality of R&D reflects externalities that cause firms to undertake more R&D in economic booms than would be optimal. In contrast, Aghion (2012) shows that credit constraints can limit the capacity for firms to invest in R&D during recessions if profits—and thus internal funds—are too low to finance such investments directly.
[20] See http://www.bls.gov/mfp/rdtable.pdf.

Office (2001), the International Monetary Fund (2010), the ECB (2010), and many other official institutions, the current level of the capital stock is a key determinant of potential output. Thus, in this accounting framework, the substantial cutback in business outlays on equipment and structures that typically occurs in response to the diminished sales prospects, heightened uncertainty, and tight credit conditions of deep recessions acts not only to reduce current aggregate demand but also to lower the estimated productive capacity of the economy in the future.[21] Although such demand-induced capital deepening effects are presumably not literally permanent, they are likely to persist for many years given the substantial adjustment costs that characterize business investment.[22]

Some alternative approaches to measuring resource utilization attempt to side-step this issue by estimating potential output using an "equilibrium" concept of the capital stock rather than the actual level. For example, it is common practice in DSGE modeling to define economic slack using a flex-price concept of potential output, which is computed by simulating how the economy would have evolved over history in the absence of both wage-price frictions and markup shocks. (See Neiss and Nelson, 2003.) This approach yields measures of the equilibrium capital stock and potential output that, at least in theory, are exogenous to the transitory fluctuations in aggregate demand and accompanying changes in monetary policy that

[21] In theory, the reduced pace of business capital deepening in the United States seen since mid-2008 could be the result of technology shocks that have reduced the marginal return on capital. Arguing against this interpretation, however, is the elevated level of profitability. Alternatively, one might argue that the decline in business investment has been driven at least in part by reduced access to capital associated with permanently tighter underwriting standards and other structural changes in credit markets. Whether the latter phenomenon is best thought of as a technological rather than a demand development is open to debate, however; in any event, the restrictions on credit availability that have emerged since the financial crisis have been more important for households than for businesses (especially large ones). For these reasons, we believe that most of the observed slowdown in business investment is primarily a response to a weak demand environment and heightened uncertainty about the future pace of recovery.

[22] Such drawn-out capital accumulation dynamics are a standard feature of estimated macro models, including the Federal Reserve Board's FRB/US model and its two DSGE models, EDO and SIGMA.

occur in the wake of a financial crisis, while allowing the "efficient" effects of changes in tastes and technology on productivity, the composition of output, and other real factors to show through. Thus, policymakers who employ the flex-price concept of potential output arguably have the advantage of seeing through the transitory (albeit drawn out) swings in capital deepening when crafting policy.[23]

While we think it important to distinguish permanent movements in capital from transitory fluctuations, we nonetheless believe that standard flex-price calculations of potential output are problematic. As Woodford (2003) has pointed out, an important rationale for allowing the actual (rather than equilibrium) level of capital services to affect the estimated level of potential output is that firms' marginal costs and productive capacity, and thus aggregate inflation, depend on the actual capital stock, which evolves slowly relative to the time horizons that are relevant for monetary policy. This line of argument suggests to us that central banks should design their policies with an eye to both the predicted future path of capital and the effects of their policy actions on that path (and hence the evolution of potential output, actual employment, and inflation).[24] Moreover, the standard flex-price calculation ignores the potential for movements in aggregate demand to influence potential labor input and trend multifactor productivity—effects that in turn will alter any calculation of the equilibrium capital stock—

[23] On the surface, purely statistical methods for extracting trend output, such as the Beveridge-Nelson decomposition or the Hodrick-Prescott filter, might also seem to avoid this issue because they do not condition on any measure of the capital stock. For the reasons discussed earlier, however, such methods have the problem of ascribing to the "trend" any movements in output associated with drawn-out fluctuations in capital services and other inputs, whether or not they are endogenous.

[24] Even if an estimate of potential output generated by a DSGE model is based on the actual business capital stock, comparing that estimate to one based on the production-function approach may be problematic because the model's measure of capital may differ noticeably from the official government measure. In part, such differences can arise because DSGE models often define business capital to include residential capital and the stock of consumer durable goods, unlike the non-farm business sector measure used in the state-space analysis discussed earlier. In addition, DSGE models may implicitly use a different methodology for translating the business capital stock into an aggregate flow of capital services. Finally, DSGE models often treat the capital stock as an unobserved variable, an assumption that can result in yet more differences from the official series.

because these channels are not accounted for in the standard models used by central banks, DSGE or otherwise. Finally, we would note that completely delinking the estimated level of potential output from the actual capital stock, and instead basing it entirely on a theoretical calculation of what the stock would be in the absence of all nominal frictions and mark-up shocks, suffers from the problem that the identification of frictions and shocks, and hence the estimated level of potential output, can be quite sensitive to model specification and assumptions about the nature of shocks—a point discussed by Kiley (2012).

Quantitative assessment

The foregoing discussion leads to the obvious question: How much of the reduction in aggregate supply during the past several years has represented an endogenous response to weak aggregate demand that monetary policy should strive to mitigate, versus an exogenous development to which monetary policy probably had to acquiesce? Of course it is difficult to pinpoint the composition of what happened in the past several years, but the state-space model analysis we described earlier suggests that a reduction in capital deepening—which we view as almost entirely an endogenous response to weak demand—caused half of the cumulative shortfall in potential output from its pre-crisis trend. As for the other possible channels, the available evidence indicates a modest adverse shift in the basic parameters of the labor market expected to prevail over the longer run. For example, based on the timing analysis presented in the previous section, demand-related reductions in population growth and the trend labor force participation rate may have shaved more than 1 percent off the 2014:Q3 level of potential output—although we stress that it is far too early to rule out the possibility that evidence of more substantial effects may emerge before the economy has fully recovered. Finally, the underlying causes—and likely persistence—of the apparent recent deceleration in trend multifactor productivity relative to its long-run trend are murky, as some have argued that it reflects a secular phenomenon associated with a faltering pace of technological innovation; see Gordon (2012). Nevertheless, we think it probable that the depressive effects of the recession and reduced credit availability on the rate of new business formation and on R&D expenditures have played some role in the estimated 1¼ percent cumulative shortfall of trend MFP relative to its longer-run trend.

As we noted at the start of this section, our assessment that much of the recent supply-side damage is endogenous has potentially important implications for the conduct of monetary policy. In particular, such damage provides an additional rationale for policymakers to take highly accommodative actions in response to sharp contractions in real activity. In the next section, we illustrate this result using simulations of a financial crisis under "optimal" policy analysis. In carrying out this analysis, however, we also consider some additional factors that may act to push monetary policy in a less accommodative direction.

III. Optimal Policy and Endogenous Supply-Side Effects

The relevance of the endogeneity discussed in the previous section for monetary policy relates to the possibility that policymakers may be able craft strategies with an eye to influencing both the supply and the demand sides of the economy. In particular, such policies might differ appreciably from standard strategies that treat the natural rate of unemployment, trend labor force participation, multifactor productivity, and other components of potential output as if they were exogenous. Along these lines, Adolfson *et al.* (2011) have used simulations of the Riksbank's macro model to show that "optimal" strategies that define potential output using the actual (endogenous) capital stock differ noticeably from ones that define potential GDP using the flex-price equilibrium (and thus policy-invariant) capital stock. Similarly, Ikeda and Kurozumi (2014) show that, in the context of a DSGE model, the welfare-maximizing monetary policy rule becomes much more aggressive in trying to offset downturns in real activity when total factor productivity growth is partially endogenous, because doing so provides substantial longer-run gains in increased output.

In a similar spirit, we conduct simulations using the Federal Reserve's workhorse FRB/US macro model that allow for the possibility that a financial crisis and the resulting shortfall in aggregate demand endogenously cause a reduction of potential labor input, trend multifactor productivity, and capital deepening, along the lines of what may have happened during the Great Recession and the subsequent slow recovery in the United States. Leaving aside some potentially important countervailing considerations, we find that when policymakers recognize the endogeneity of supply-side conditions and optimize accordingly, they adopt a more aggressive approach to the conduct of policy in response to a recession. However, we also emphasize that these other considerations—including concerns that an aggressive policy stance may lead to an increased risk of financial instability or unacceptably high inflation —may appropriately cause policymakers to exercise greater caution.

The FRB/US model

FRB/US is a large-scale model of the economy that has been used extensively by the staff of the Federal Reserve Board since the mid-1990s to study a wide range of monetary and fiscal policy issues. Although FRB/US does not have the tight micro-foundations of a DSGE model, its equations are grounded in the assumption that households and firms are forward-looking and engage in optimization subject to adjustment costs and habit persistence. Roughly 25 percent of consumer spending is estimated to be carried out by rule-of-thumb consumers, while the rest is attributable to life-cycle households who discount the future at a high rate owing to idiosyncratic income risk. The model is very detailed and includes equations for eleven different components of private consumption, investment, exports, and imports; standard asset pricing equations for a variety of long-term interest rates, the stock market, and the exchange rate; a comprehensive accounting of government spending and taxation at both the federal and the state and local levels; and a small-scale foreign sector. Wage and price dynamics are characterized by a new-Keynesian Phillips curve in which marginal costs move with the unemployment gap, defined as the actual unemployment rate less the current value of the natural rate (which, as discussed below, will be augmented to include hysteresis effects).[25]

In the version of FRB/US used in this paper, all financial market participants and agents involved in wage-price setting are assumed to be rational, and monetary policymakers enjoy complete credibility; furthermore, these particular private-sector expectations are assumed to incorporate perfect foresight about the future path of the economy once shocks hit.[26] These expectational assumptions are important for our analysis because the fallout from the illustrative financial crisis that we simulate, in line with the real-world experience of the past few years, is sufficiently severe and protracted to cause short-term interest rates to be constrained by the zero lower bound (ZLB) for several years. As a result, and because for simplicity we leave aside the possibility of large-scale asset purchases, the main tool available to monetary policymakers for

[25] For more information on FRB/US, including equation documentation, sample simulation code and links to research papers employing the model, see http://www.federalreserve.gov/econresdata/frbus/us-models-about.htm.

[26] Other private-sector expectations—most importantly, households' assessments of future income—are generated using a small-scale VAR model, implying that their forward-looking expectations are based on the average historical behavior of the economy. We believe that this characterization of household beliefs is more realistic than the standard assumption of rational (model-consistent) expectations, which assume a complete understanding of the dynamics of the economy, including how they are altered by the zero lower bound on nominal interest rates. That said, making all private-sector expectations model-consistent would have had no appreciable qualitative effects on the results reported in this paper. For a further discussion of expectational effects in the FRB/US model, see Brayton *et al*. (1997).

stimulating the economy in the near term is to promise to keep the federal funds low in the future, thereby putting downward pressure on long-term interest rates. In the model, this pressure in turn reduces the borrowing costs of households and firms, boosts corporate equity prices and other types of household wealth, and promotes net exports through a lower real exchange rate.

Calibration of hysteresis effects

To facilitate the study of endogenous supply-side effects, we modify the standard version of FRB/US (which already includes capital accumulation equations) to incorporate illustrative hysteresis-like responses of the natural rate of unemployment (*U**), the trend labor force participation rate (*LFPR**), and trend multifactor productivity (*MFP**) to persistent economic slack, as follows:

$$U_t^* = .90U_{t-1}^* + .10U^{**} + .02H(U_{t-1} - U_{t-1}^*)$$

$$LFPR_t^* = .96LFPR_{t-1}^* + .04LFPR^{**} - .00015H(U_{t-1} - U_{t-1}^*)$$

$$\log MFP_t^* = .96 \log MFP_{t-1}^* + .04 \log MFP_t^{**} - .00035H(U_{t-1} - U_{t-1}^*)$$

These equations have several key properties. First, following any disturbance to *U**, *LFPR**, or *MFP**, the three supply-side factors will gradually converge back to their respective steady-state means or trends, where the latter exclude any effects of hysteresis; these steady-state means and trends are denoted by double asterisks (e.g., *U***).[27] Such error-correction dynamics are consistent with the idea that, although financial crises and deep recessions can have persistent effects on, for example, labor supply by disrupting labor market functioning, impairing

[27] In the standard version of FRB/US, which incorporates a state-space model similar to the one discussed in the first section of the paper, the equivalents to *U***, *LFPR***, and *MFP*** are subject to permanent shocks; these shocks are idiosyncratic and unrelated to shortfalls in aggregate demand. Such shocks are not relevant for the analysis considered in this section of the paper, however, and so are suppressed here to simplify the analysis.

unemployed workers' skills, and causing pre-mature permanent departures from the labor force, such events do not alter demographic conditions, the social safety net, or other fundamental determinants of longer-run conditions in the labor market.[28]

Second, the magnitude of the hysteresis "impulse" depends on the level of slack in a non-linear way defined by the function *H(·)*. As indicated by both the blue and red lines of Figure 8, we assume that resource utilization has essentially no effect on either potential labor input or trend multifactor production as long as the unemployment rate is no more than 1 percentage point above its natural rate. As the unemployment gap widens past this point, however, the incremental effect of slack on supply-side conditions becomes noticeable, and eventually begins to rise linearly with the level of the gap. Accordingly, accommodative monetary policy can limit the amount of endogenous damage to the supply-side of the economy if it can limit the amount of time the unemployment gap is above a threshold of 1 percentage point. Although this specification is *ad hoc*, such "threshold" behavior in general seems consistent with the observation that warning signals that figure prominently in today's landscape, such as a marked increase in long-duration unemployment and a persistent fall in labor force participation, were largely missing in the milder recessions seen earlier in the post-World-War-II period in the United States.

A third key property of our baseline specification of hysteresis—denoted as Type 1 in Figure 8—is that policymakers cannot undo supply-side damage once it has occurred, but must instead wait for it to fade away on its own accord; in other words, there is no special advantage, given this specification, to running a high-pressure economy along the lines suggested by Okun

[28] The Scandinavian labor markets do appear to have changed permanently after their financial crisis, but these long-run changes plausibly reflected legislative changes to labor laws and other aspects of the social safety net.

(1973).[29] Such quasi-irreversibility seems consistent with both the tendency for older workers who leave the labor force prematurely on account of unemployment to never return and the persistent stigma experienced by the long-term unemployed. However, Erceg and Levin (2013) argue that the experience of the late 1990s in the United States demonstrates that a sufficiently robust labor market can draw some individuals into the labor force who otherwise would not have sought employment. In addition, it seems plausible that innovations delayed or foregone during a prolonged slump could be implemented more quickly than might otherwise occur in the context of a strong economy. For these reasons, we consider an alternative form of hysteresis (Type 2) in which above-normal levels of resource utilization generate favorable supply-side effects.

An illustrative severe contraction in demand with hysteresis effects

Using the modified FRB/US model, we now consider an illustrative scenario involving a severe contraction in aggregate demand; by design, the macroeconomic effects of this shock are broadly similar to those seen to date since late 2007. In the scenario, the economy experiences a sequence of highly adverse and persistent shocks that boost risk premiums on a range of financial assets, reduce house prices, and directly reduce consumption, investment, and hiring.[30]

[29] The specification of *H(.)* as well as the coefficients of the three equations have been calibrated to yield endogenous movements in *U**, *LFPR** and *MFP** that, in the context of the "severe demand shock" scenario discussed below, appear roughly consistent with the experience of the last few years. Arguably, it would have been better to estimate these equations (and the shape of the scaling function) rather than calibrate them. However, given the lack of historical evidence for hysteresis effects in the United States prior to the current episode, and given that our simulations are intended to explore the *possible* implications of recent events (as opposed to the most likely ones), we doubt that results from any time-series exercise would be particularly illuminating.

[30] These direct shocks are presumed to reflect those effects of a financial crisis that operate through channels not formally accounted for in the model's structure, such as reduced access to credit as a result of tighter lending standards and persistent balance-sheet problems, increased uncertainty about future household income and corporate earnings, and a general deterioration in consumer and business confidence. In the context of many DSGE models (including the Fed's EDO model), the effects of such disruptions are typically captured through an economy-wide risk premium shock intended to provide a theoretical explanation for the correlated downturn in consumption and investment. Nevertheless, like FRB/US, current DSGE models do not really provide a satisfactory accounting of the various linkages between financial markets and the real economy that come into play during a financial crisis.

The effects of these adverse events are exacerbated by endogenous supply-side effects arising from both reduced capital deepening and baseline (Type 1, or quasi-irreversible) hysteresis effects on the natural rate, trend labor force participation, and trend multifactor production; in addition, ZLB restrictions markedly limit the ability of monetary policymakers to counteract the weakness in aggregate demand. (For simplicity, in this simulation and the others that follow we ignore the possibility that monetary policymakers could use large-scale asset purchases to mitigate the constraint imposed by the zero lower bound, or that the fiscal authorities could undertake discretionary countercyclical tax and spending actions.)

Results (expressed as deviations from a steady-state baseline) for this scenario under an inertial policy rule[31] are summarized by the black lines in the various panels of Figures 9A and 9B.[32] As can be seen in Figure 9A, the shocks are sufficient to cause real GDP to contract more than 9 percent and the unemployment rate to rise more than 4 percentage points at the peak of the contraction in the second year. Past this point, the direct shocks to the economy fade away rapidly but their adverse effects on the level of real activity persist for many years, reflecting costly adjustment of consumption, investment, and employment, as well as the effects of persistent reductions in potential output. As shown in Figure 9B, the level of potential GDP is more than 4½ percent below baseline after four years, reflecting reduced capital services (which deduct about 2¾ percent from the economy's productive potential), a noticeable reduction in trend multifactor productivity, a ½ percentage point transitory rise in the nature rate of

[31] Specifically, the rule is $R(t) = .85\ R(t\text{-}1) + .15\ \{2 + \pi(t) + 0.5\ [\pi(t) - 2] + 1.0\ Y(t)\}$, where R is the nominal funds rate, π is the four-quarter rate of core PCE inflation, and Y is the output gap. A non-inertial version of this rule is discussed in Taylor (1999).

[32] In the baseline, the unemployment rate, PCE inflation, and the nominal federal funds rate are constant at 5.35 percent, 2 percent, and 3.75 percent, respectively, consistent with the mid-points of the central tendencies of the longer-run forecasts reported by the FOMC in the September, 2014 Survey of Economic Projections. The results reported in this section are largely insensitive to these baseline assumptions, with the critical exception of nominal interest rates. Because the simulations incorporate the zero lower bound constraint, the baseline setting of the federal funds rate has an important bearing on the ability of monetary policy to offset the financial crisis.

unemployment, and a modest but quite persistent reduction in trend labor force participation. Under these conditions, and as shown in Figure 9A, inflation falls more than a full percentage point below baseline. Monetary policy, following the prescriptions of the inertial rule, holds the federal funds rate at its effective lower bound for three years and then tightens policy only gradually thereafter.

Optimal-control policy responses to a severe contraction with baseline hysteresis effects

While the inertial policy rule prescribes a fairly aggressive response to the economic downturn, it nevertheless does not prevent the unemployment rate from remaining elevated for years nor inflation from running persistently below target by an appreciable margin. Policymakers who recognize the likely magnitude and persistence of the crisis at the onset would obviously be interested in policies that would deliver better outcomes. As discussed by Svensson (2003 and 2005), one standard approach to this problem is to use optimal control (OC) techniques. Under this approach, policymakers first specify a loss function that reflects their preferences regarding outcomes for employment, inflation, and other conditions. They then solve for the path of the funds rate that minimizes the loss function, conditional on the dynamics of the economy (as approximated by some model) and the expected evolution of the underlying shocks to the economy.[33]

OC policy prescriptions are, perhaps not surprisingly, sensitive to the characterization of policymakers' objectives as embedded in the specification of the loss functions. Consider the range of possible responses to a severe economic contraction that is expected to result in a persistent reduction in potential output owing to adverse movements in capital deepening,

[33] See Brayton, Laubach and Reifschneider (2014), http://www.federalreserve.gov/econresdata/notes/feds-notes/2014/optimal-control-monetary-policy-in-frbus-20141121.html, for a discussion of OC policy responses to recent economic developments and the sensitivity of those responses to alternative assumptions. Also, see Svensson and Tetlow (2005) for a discussion of its use in FOMC briefing documents.

multifactor productivity, and trend labor input. One possible policy approach would be to aim to close the gap between the unemployment rate and a measure of the natural rate that is endogenously influenced by the strength of aggregate demand. A policymaker who pursued this approach may inadvertently acquiesce to a considerable loss in employment and output as a result of failing to understand and counteract the implications of weak aggregate for the natural rate. In contrast, a policymaker who instead aims to return employment or output to its pre-recession trend is likely to respond more aggressively to the weakness in aggregate demand in an attempt to reduce adverse spillovers to the supply side of the economy.

We illustrate this sensitivity by computing OC policies based on three different specifications of the policymaker's loss function, all of which are broadly consistent with the FOMC's dual mandate of maximum employment and price stability. In our baseline specification, *U** targeting, policymakers at time *t0* (the onset of the contraction in aggregate demand) are assumed to wish to find the path for the federal funds rate *R* over the next *M* quarters that would be expected to minimize a quadratic loss function *L* that penalizes (a) squared deviations of the unemployment rate from the natural rate U*; (b) squared deviations of inflation from the Federal Reserve's 2 percent goal; and (c) squared changes in the policy rate.[34] Formally, the loss function in this case is:

$$L_{t0} = E_{t0} \sum_{j=0}^{N} \beta^{j} \left\{ \alpha_1 \left(U_{t0+j} - U^{*}_{t0+j} \right)^2 + \alpha_2 \left(\pi_{t0+j} - 2 \right)^2 + \alpha_3 \left(\Delta R_{t0+j} \right)^2 \right\}.$$

[34] In addition to aiming to keep unemployment near its natural rate and inflation near the FOMC's 2 percent target, the loss function penalizes quarter-to-quarter movements in the federal funds rate. In reality, such movements would be destabilizing and thus would have adverse effects on financial markets and the broader economy, implying that such movements would be avoided in optimal-control simulations because of their effects on the unemployment gap. However, the FRB/US model does not incorporate any mechanism for such volatility to affect financial conditions and real activity through risk premiums or some other channel, so the third term is added to the loss function to prevent unrealistically large quarterly movements in short-term interest rates in the optimal-control simulations.

Alternatively, policymakers might instead choose to define their real activity objective in terms of the pre-crisis trend in either employment (*E*** targeting) or output (*Y*** targeting), where the targets are measured excluding hysteresis effects. Under these OC strategies, the unemployment gap term $(U\text{-}U^*)^2$ of the loss function would be replaced either by $(E\text{-}E^{**})^2$ or by $(Y\text{-}Y^{**})^2$, where *E* and *Y* denote employment and GDP, respectively, expressed in logs and multiplied by 100. [35,36]

As indicated by the red lines in Figures 9A and 9B, OC policy under *U** targeting is much more accommodative than the inertial policy rule even though policymakers are not directly concerned with mitigating endogenous supply-side damage. In particular, this type of OC policy holds the federal funds rate at its effective lower bound for about seven years, four years longer than the simple policy rule. Despite the binding constraint of the zero lower bound in the first few years, this particular OC strategy provides considerable additional stimulus to the macroeconomy during the initial phase of the contraction because financial market participants, foreseeing that monetary policy will keep short-term rates lower for longer in the future, mark down long-term interest rates today. Near-term financial conditions are also improved by the expectation that inflation will be somewhat higher in future, which in the first few years puts additional downward pressure on *real* long-term interest rates while also checking undesirable

[35] In our optimal-control analysis, *M* (the number of quarters in the optimized path of R) is always set to 60 quarters while *N* (the number of quarters over which the loss function is evaluated) is set to 80 quarters; in addition, the discount factor β is set to .99 and the three α loss weights are all set to unity. Increasing the value of either *M* or *N* would have relatively little effect on our simulation results, as would modestly changing the discount factor or altering the relative loss weights. Beyond quarter *t0+M*, when the OC path ends, the federal funds rate is assumed to follow the prescriptions of the inertial policy rule.

[36] Optimal-control strategies of this sort raise issues of time consistency and how policy should be reoptimized in light of previous commitments and incoming data surprises. These questions are beyond the scope of this paper, however, and in the simulations discussed below we assume that policymakers do not re-optimize the trajectory for the path of the funds rate beyond *t0*.

disinflationary effects. As a result, employment and output recover more quickly than under the inertial policy rule while inflation averages close to the 2 percent objective.

A noteworthy feature of OC policy under *U** targeting is that it does a reasonably good job of mitigating the endogenous damage to potential GDP that occurs under the inertial policy rule, even though this type of OC policy does not formally have this objective in mind. Instead, the more rapid recovery in capital services, multifactor productivity and potential labor input under this strategy is largely a by-product of the desire to close the unemployment gap. But as one might expect, the mitigation of supply-side damage becomes even greater when policy explicitly aims at restoring the pre-crisis trends in employment or output, because doing so requires providing even more accommodation by pledging to keep the funds rate low for even longer, thereby increasing the downward pressure on real long-term interest rates and the upward pressure on inflation through expectational effects. Under *E*** targeting (the blue lines), for example, the federal funds rate is held at zero for a year longer than under *U** targeting, while under *Y*** targeting (the green lines), the funds rate is held at its lower bound for an additional four years. As a result of this additional accommodation, monetary policy is able to generate somewhat stronger recoveries in employment and output relative to what occurs under *U** targeting, accompanied by inflation that runs slightly above target for a few years.

OC policy responses to a severe contraction under other types of hysteresis

Under the baseline (Type 1) specification of hysteresis effects, policymakers can attempt to limit the amount of supply-side damage that accompanies a severe contraction in aggregate demand but cannot actively reverse it once it occurs. Figures 10A and 10B explore how OC policy changes when policymakers have more scope for undoing reductions in potential output and employment after the fact, as illustrated by the Type 2 hysteresis discussed earlier. Perhaps surprisingly, OC policy and associated outcomes are essentially unaltered by this modification to hysteresis dynamics, although a comparison of Figures 9B and 10B reveals somewhat stronger out-year recoveries in trend multifactor productivity and trend labor input, especially when OC policy aims at restoring the pre-crisis trend in either employment or output.

Several factors explain the unimportance of hysteresis reversibility, at least in the context of these simulations. First, the bulk of the endogenous supply-side damage in the scenario results from a reduction in capital deepening, a factor that substantially reverses regardless of whether monetary policymakers aim to accomplish that objective. (Economic recoveries typically feature a marked strengthening in business fixed investment, and that strengthening substantially restores the contribution of the growth of capital services to the growth of potential GDP.) Second, under the assumed specification of *H(.)*, monetary policy would have to push the unemployment rate well below the natural rate for a prolonged period of time in order to *rapidly* generate favorable hysteresis effects on the natural rate, trend labor force participation, and multifactor productivity—an important consideration given that past adverse supply-side effects are assumed to erode away on their own accord (albeit at a slow rate). Third, the supply-side advantages accrued by holding U persistently below U* would be at least partially offset by the rise in inflation that would result. Finally, the symmetric nature of the loss function means that policymakers by assumption do not want to push the level of real activity above its normal longer-run level on a sustained basis.

In contrast to reversibility, other modifications to hysteresis dynamics do have a noticeable influence on OC policy and its effects on the economy. For example, increasing the magnitude of hysteresis effects by boosting the coefficients multiplying the hysteresis function in the *U**, *LFPR**, and *MFP** equations, or by slowing the speed at which past supply-side damage erodes away, increases the incentive to keep interest rates low for longer when targeting *E*** and *Y*** relative to what occurs under *U** targeting. Symmetrically, lowering the magnitude of hysteresis effects has the opposite effect. This behavior is illustrated by Figure 11, which shows the macroeconomic effects of the severe demand shock in the absence of all hysteresis effects, including those operating through reduced capital deepening.[37] As can be seen, under these conditions OC policy and its effects on real activity and inflation are essentially the same regardless of whether policymakers target *U**, *E***, or *Y***.

Offsetting considerations and other caveats

By themselves, the preceding simulation results would seem to suggest that monetary policymakers should consider adopting more-aggressive responses to deep recessions than would be suggested by standard policy rules or standard optimal control specifications in order to mitigate endogenous supply-side effects. This conclusion, however, overlooks the fact that policymakers may have countervailing concerns that have not been accounted for in the optimal-control exercises. In particular, policymakers may be worried that pursuing a highly accommodative monetary policy for a long time could inadvertently sow the seeds of a future financial crisis. Such a development might occur if persistently low interest rates were to prompt firms to take on increasing amounts of leverage—thereby decreasing the stability of the financial system—or prompt investors to take on an inappropriate amount of risk in a reach for yield. In light of these risks, policymakers might appropriately opt for a more conservative response to a major economic downturn, even if they recognized the potential adverse effects on the supply side of the economy.

[37] This latter effect is achieved by artificially cutting the link between business investment and capital services.

The willingness of policymakers to pursue an aggressive monetary response to a severe recession should also depend on their views about the likely efficacy of their policy actions. That is, policymakers should be engaged in a cost-benefit calculation that balances, on the one hand, the expected macroeconomic benefits from greater monetary accommodation and hence stronger aggregate demand and diminished supply-side damage, and on the other hand, the expected losses from sparking a future crisis. The more effective that a marginal easing in the stance of monetary policy is in checking undesirable reductions in employment and inflation during an economic downturn, the more that policymakers should engage in such easing—even if there are collateral costs in terms of reduced financial stability. And, of course, the converse statement holds.

Threats to financial stability are not the only offsetting concern that might limit policymakers' willingness to fight endogenous supply-side damage; for example, they may also be reluctant to implement a highly accommodative strategy because of concerns about its potential adverse effects on inflation expectations and inflation dynamics more generally. In the optimal-control exercises reported earlier, wage and price expectations are rational, policymakers enjoy complete credibility, and the parameters of the new-Keynesian inflation process are stable and invariant to changes in monetary policy—assumptions that almost certainly do not hold in reality. And even though Kiley (2007), Laforte (2007), and others have found that empirical new-Keynesian inflation models of the sort used in FRB/US and in DSGE models do provide a reasonable approximation to the observed behavior of inflation over the past twenty years or so, policymakers might well worry that inflation dynamics could evolve in a highly undesirable and costly direction if monetary policy were to depart markedly from recent historical norms, perhaps even returning to the instability seen during the 1970s.

Finally, we should stress that the optimal-control exercises that we have conducted here ignore policymaker uncertainty, which is ubiquitous in the real world.[38] In the wake of a financial crisis, real-world policymakers cannot be sure about the extent of supply-side damage that has occurred even well after the fact, let alone the proportion that reflects an endogenous response to weak aggregate demand. In addition, they cannot be sure about the ability of a more-accommodative policy stance to check the initial damage that occurs or to subsequently repair it, particularly in an environment in which the ability of monetary policy to influence aggregate demand may be impaired. Finally, the effects of persistently accommodative monetary policy on financial stability and the stability of inflation expectations are also highly uncertain. How policymakers should respond to such pervasive uncertainty is not obvious, especially if they (or the private agents on whose behalf they act) are not risk-neutral. On the one hand, Brainard-type considerations might argue for taking a more cautious approach to trying to head off supply-side damage than suggested by the optimal-control simulations shown earlier, given uncertainty about the effectiveness of monetary policy in mitigating supply-side damage. On the other hand, a robust control approach might call for a more aggressive response if the adverse tail event of primary concern involved endogenous supply-side damage.[39] In any event, uncertainty about both the extent and nature of supply-side damage, as well as about the possible side effects of a persistently accommodative stance of policy, greatly complicates the decision-making process

[38] As is well known, uncertainty has little or no role to play in optimal-control decision-making when preferences are well described by a quadratic loss function and the economy is linear. (In our analysis, we have sidestepped the fact that the FRB/US model is not strictly linear, especially in the presence of the zero lower bound.) In reality, however, the actual economy sometimes exhibits highly non-linear dynamics; moreover, policymakers' concerns are not adequately captured by a simple loss function, and certainty about the specification of the model is a poor approximation. For these and other reasons, uncertainty assuredly plays an important role in policymaker deliberations in the real world.

[39] Of course, if policymakers were instead concerned about minimizing the risk of a future financial crisis, then robust control might argue for a less activist strategy.

because it forces policymakers to weigh the costs and probabilities associated with a range of risks and possible outcomes.

IV. Conclusions

This paper has presented estimates from one particular model suggesting that the U.S. economy sustained considerable damage to its supply side in the wake of the financial crisis. In the labor market, the natural rate of unemployment apparently rose somewhat and trend labor force participation appears to have moved noticeably lower relative to what would have been expected based on pre-crisis trends. In addition, the capital stock and trend multifactor productivity are appreciably lower than would have been predicted in 2007. Our point estimates suggest that, in combination, these developments—whose eventual magnitude was arguably apparent only in hindsight—shaved roughly 7 percent off the level of potential output in 2014:Q4 relative to what would have been implied by a continuation of the trend observed over the period from 2000 to 2007. Of course, considerable uncertainty surrounds this point estimate for the hit to the level of potential GDP, and estimates of the effect on the growth of potential GDP are similarly uncertain.

The paper has also argued—following in the tradition of several precursors in the literature—that at least some of the damage to the supply side of the economy incurred during the past several years may have reflected the historic weakness of aggregate demand. The Federal Reserve acted with unprecedented speed and force, and deployed a range of instruments to help stem the collapse of economic activity. Our results suggest that the damage to the supply side of the economy probably would have been much worse had the Fed not acted in so aggressive a manner. We have also explored some of the implications of supply-side endogeneity for the conduct of policy going forward. As our simulation analysis illustrates, optimal monetary policy becomes noticeably more accommodative when the gap in resource utilization is wide, and when the natural rate of unemployment, trend labor force participation, and multifactor productivity are perceived to be subject to hysteresis-like effects that policy might be able to mitigate. However, we have also argued that policymakers may appropriately adopt a more restrained response to a deep recession if they fear the attendant risks to financial stability, or are concerned that inflation expectations may become unanchored. More generally, the pervasive uncertainty in which policymakers operate may encourage them to proceed with caution.

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Table 1. Baseline State-Space Model Estimates of Recent Changes in U.S. Supply-Side Conditions

	1990 to 1999	2000 to 2007	2008	2009	2010	2011	2012	2013	Cumulative Post-2007 Shortfall[1]
1. Potential GDP growth (Q4/Q4 percent change)	3.1	2.6	2.6	1.7	1.1	1.2	1.0	1.7	-6.3
Contribution to growth of movements in:[2]									
2. Trend labor input	1.3	0.5	0.8	0.1	0.4	0.5	0.1	0.2	-0.8
2a. Population	1.1	1.2	1.1	1.1	1.0	1.0	1.0	1.0	-1.0
2b. Labor force participation rate	0.0	-0.3	-0.2	-0.3	-0.4	-0.5	-0.6	-0.7	-0.9
2c. Natural rate	0.0	0.0	0.0	-0.5	-0.2	0.2	0.0	0.3	-0.4
2d. Workweek	-0.1	-0.2	0.1	0.0	0.1	0.0	-0.1	-0.1	1.1
2e. Private payroll vs. HH employment wedge	0.1	-0.3	-0.2	-0.2	-0.2	-0.2	-0.2	-0.2	0.3
3. Trend labor productivity	2.2	2.5	1.8	1.9	1.0	1.0	1.4	1.5	-6.2
3A. Labor quality	0.4	0.3	0.2	0.2	0.2	0.2	0.1	0.1	-0.8
3B. Capital deepening	0.8	0.8	0.4	0.0	0.0	0.2	0.5	0.5	-3.2
3C. Multifactor productivity[3]	1.0	1.5	1.3	1.7	0.9	0.7	0.8	0.9	-2.3
4. GDP-NFB output wedge	-0.4	-0.3	-0.2	-0.3	-0.3	-0.3	-0.4	0.0	0.5
5. Natural unemployment rate[4]	5.1	5.2	5.2	5.6	5.8	5.6	5.6	5.4	
6. Trend labor force participation rate[4]	67.0	66.1	65.4	65.2	65.0	64.6	64.3	63.8	

1. Cumulative shortfall in potential GDP growth and its components from 2008:Q1 through 2013:Q4 relative to average growth over the 2000-07 period.
2. Contributions expressed as annualized log changes. Contributions may not sum to totals because of rounding and differences between percent changes and log changes.
3. Includes the effects of trend movements in energy intensity of domestic production.
4. Figures for the 1990-1999 and 2000-2007 periods are annual averages; other figures are fourth-quarter averages.

Figure 1. State-Space Model Estimates of Potential GDP and its Components
(shaded region denotes 95% confidence interval)

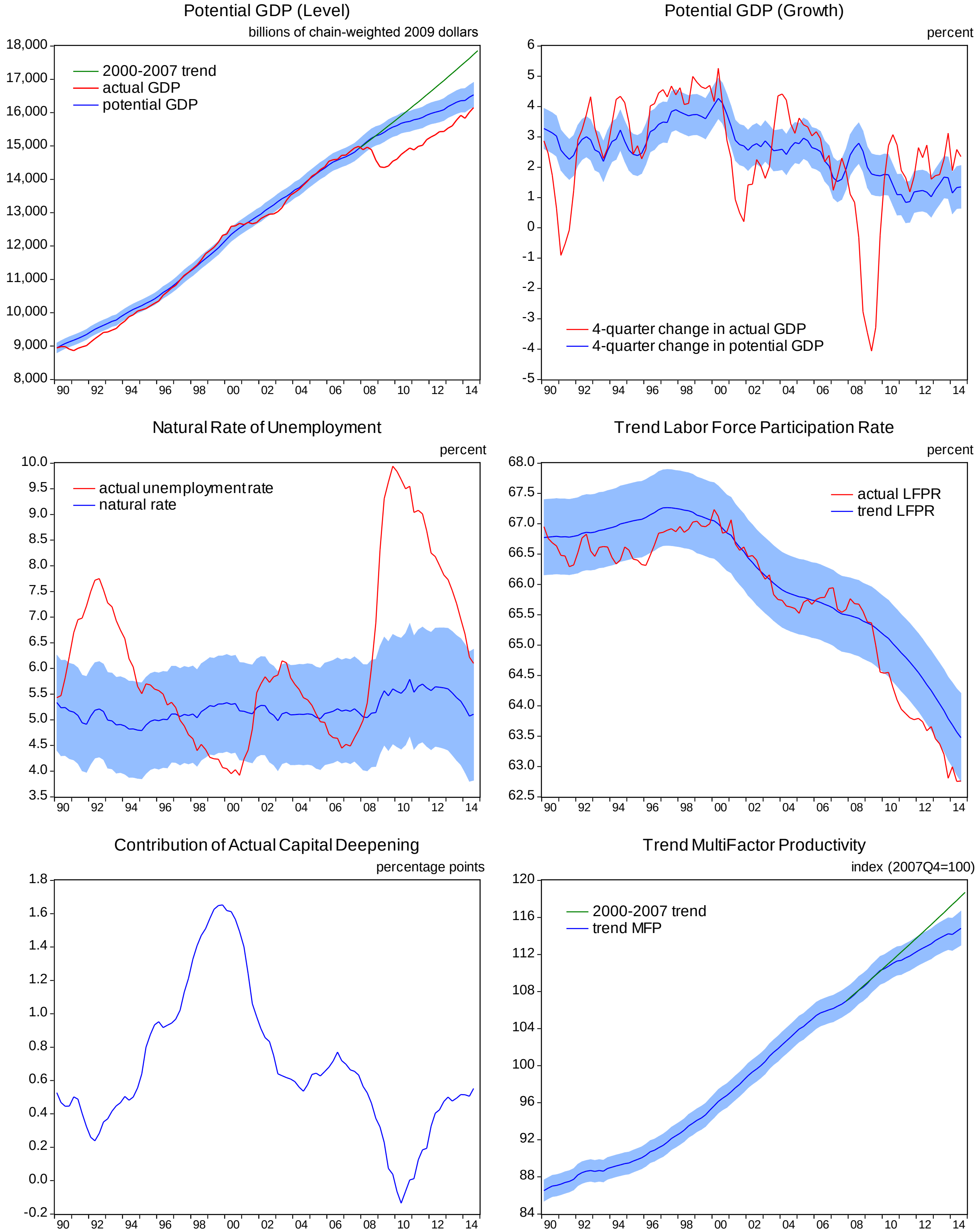
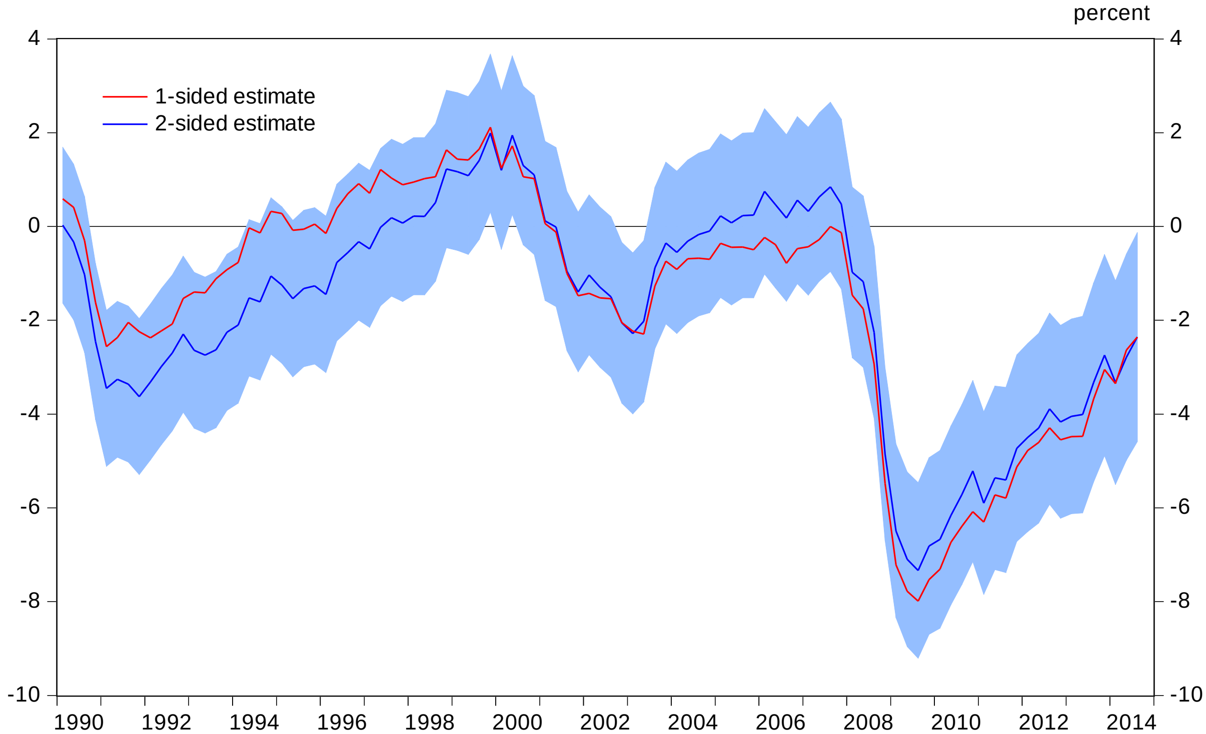


Figure 2. Estimates of Resource Utilization
(shaded region denotes 95% confidence interval)

Output Gap



Unemployment Gap

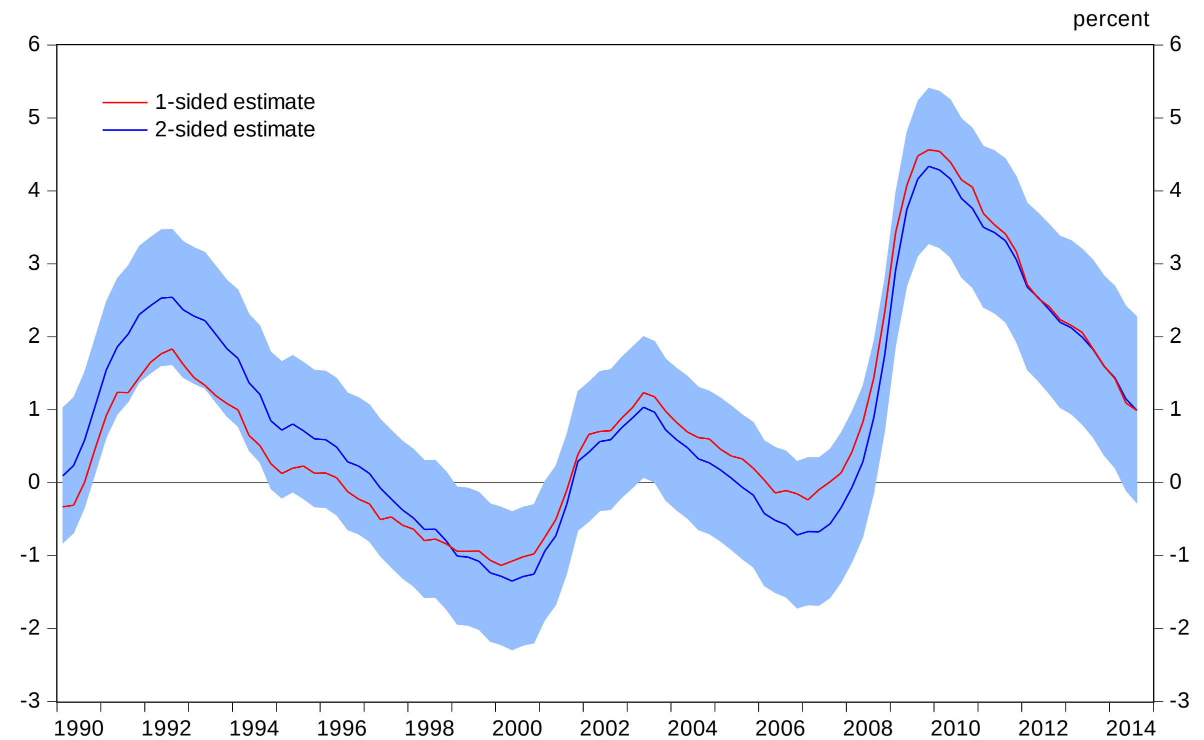


Figure 3. Assessing the Timing of the Slowdown in the Components of Potential GDP

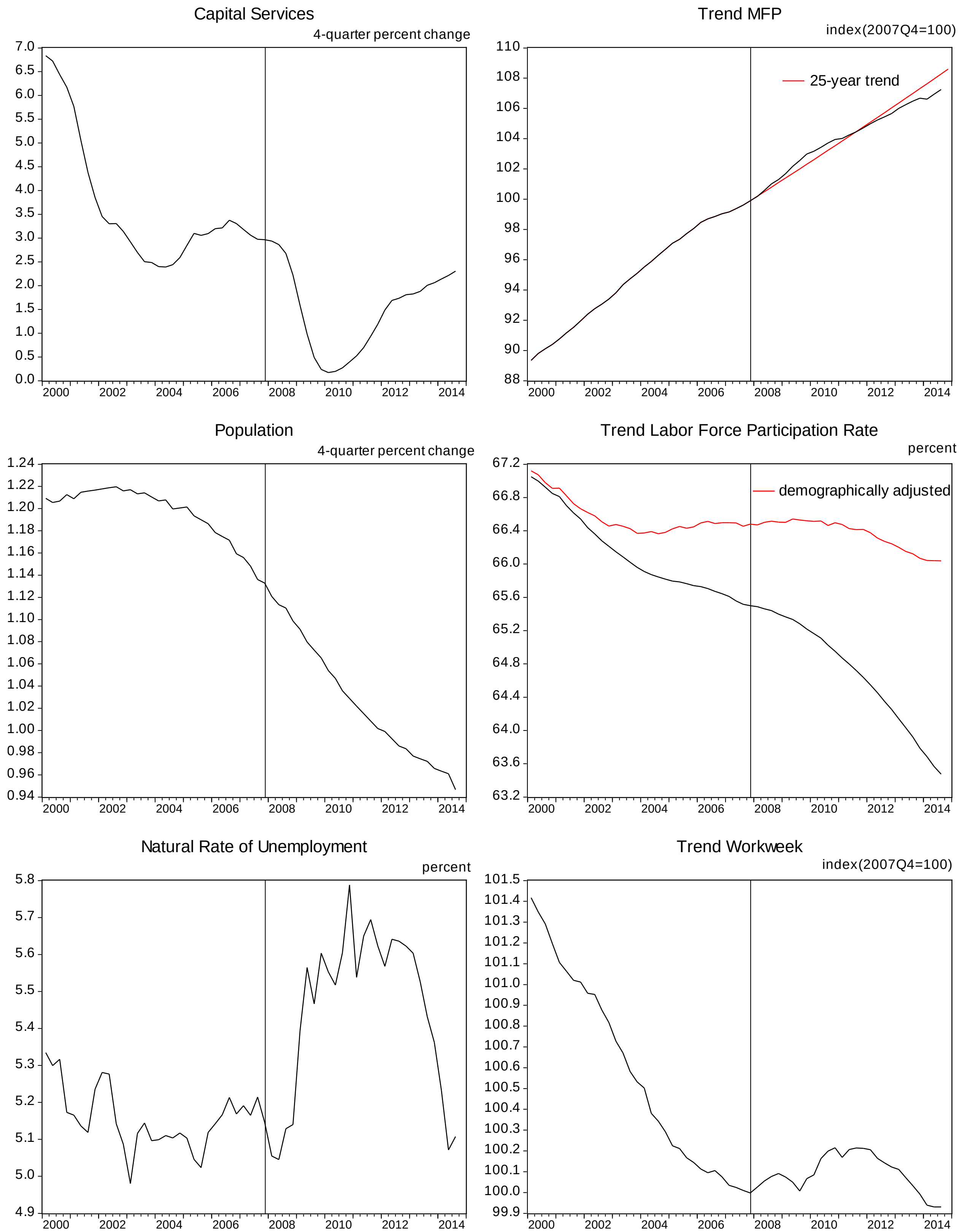


Figure 4. Real-Time Estimates and Projections of Potential Output and the Natural Rate

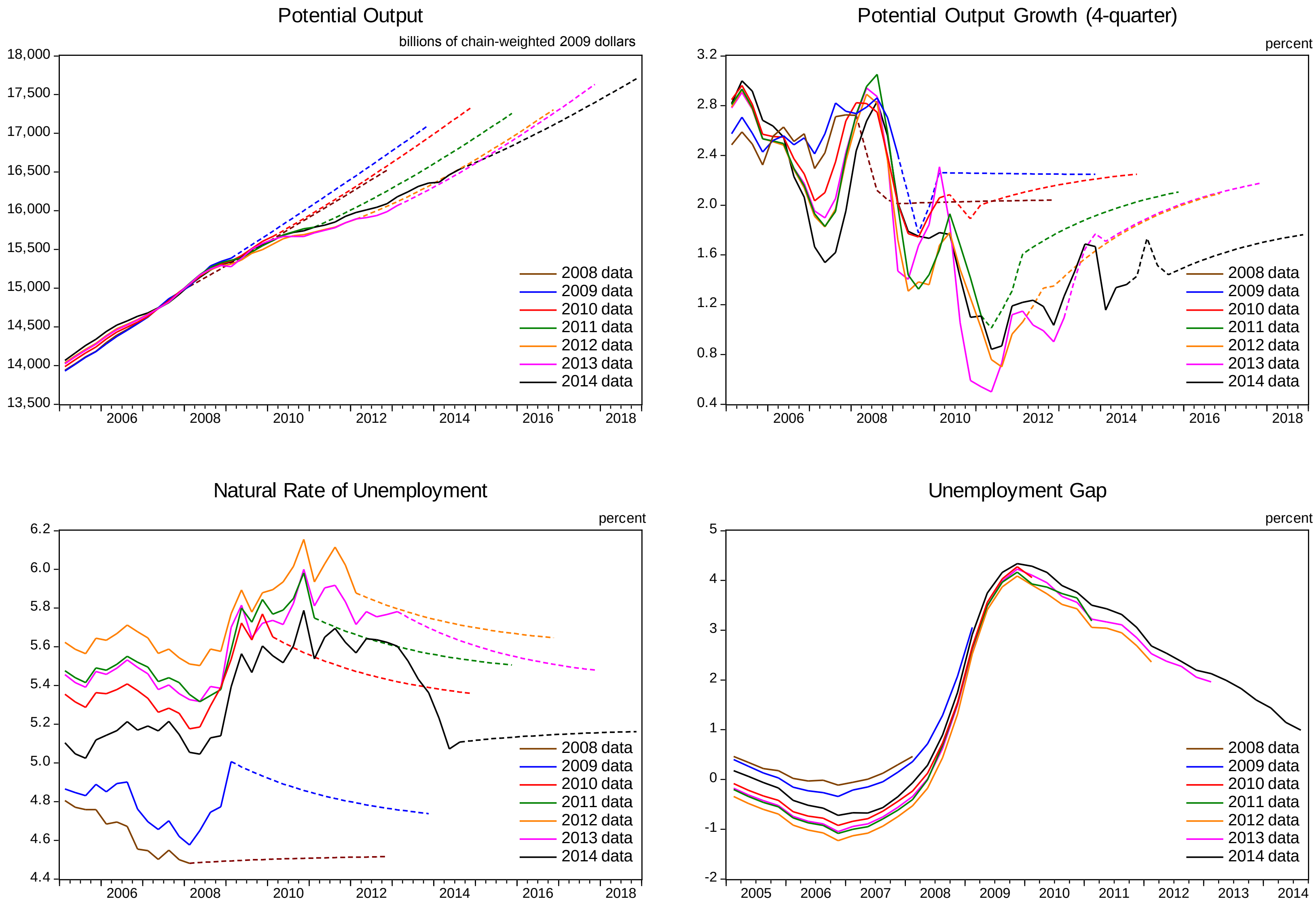


Figure 5. Estimates of Potential GDP and Its Components from Alternative Specifications of the State-Space Model

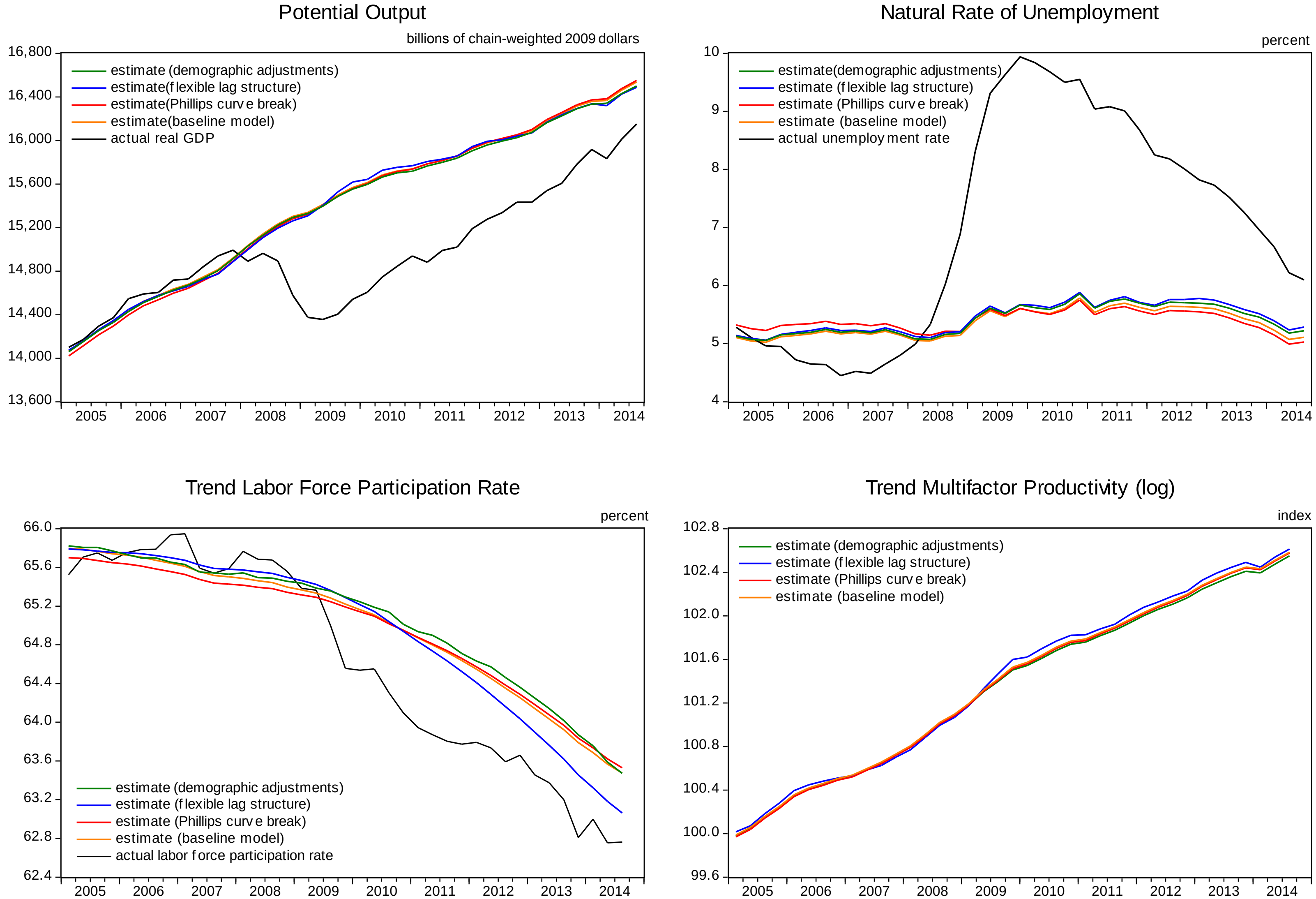
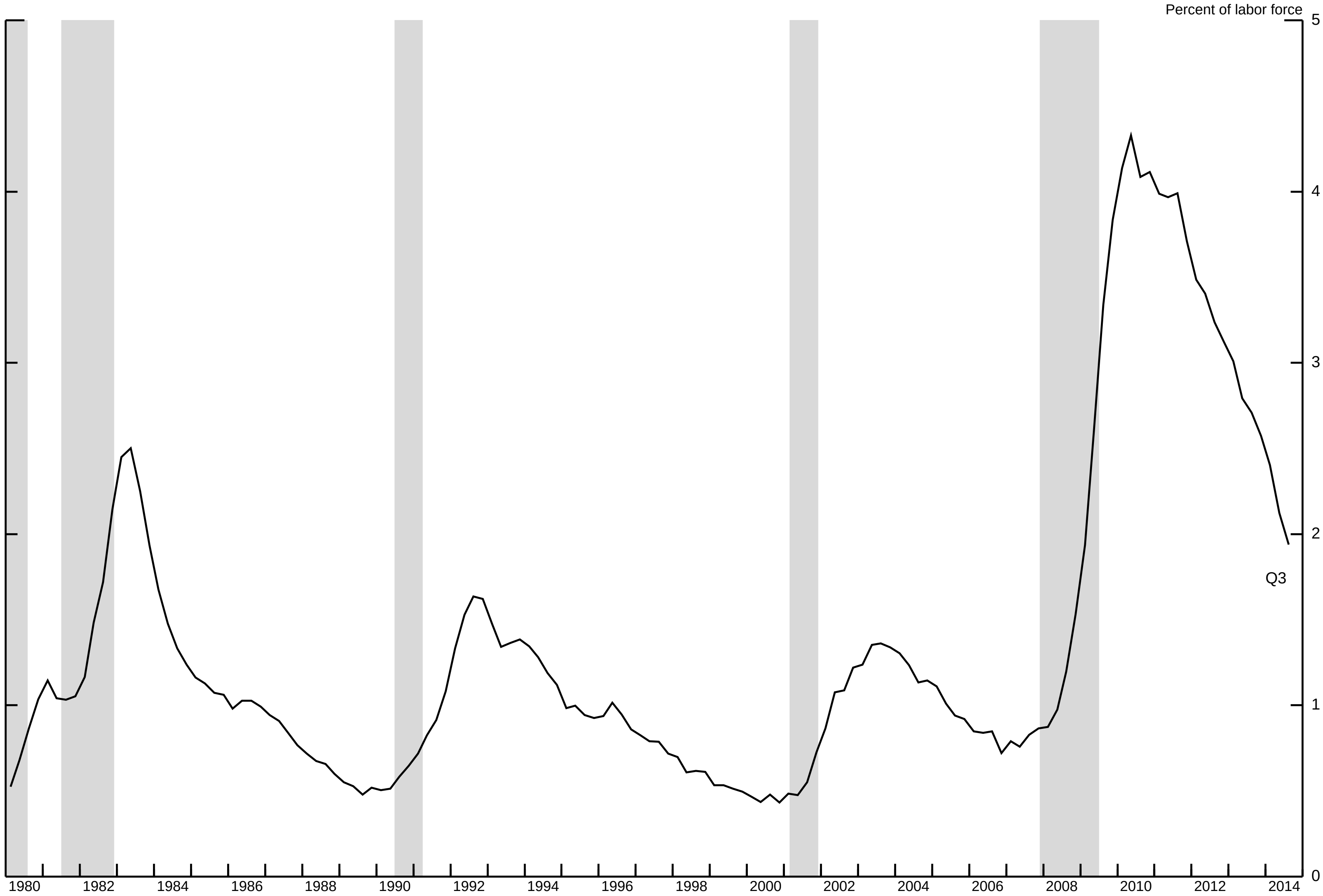
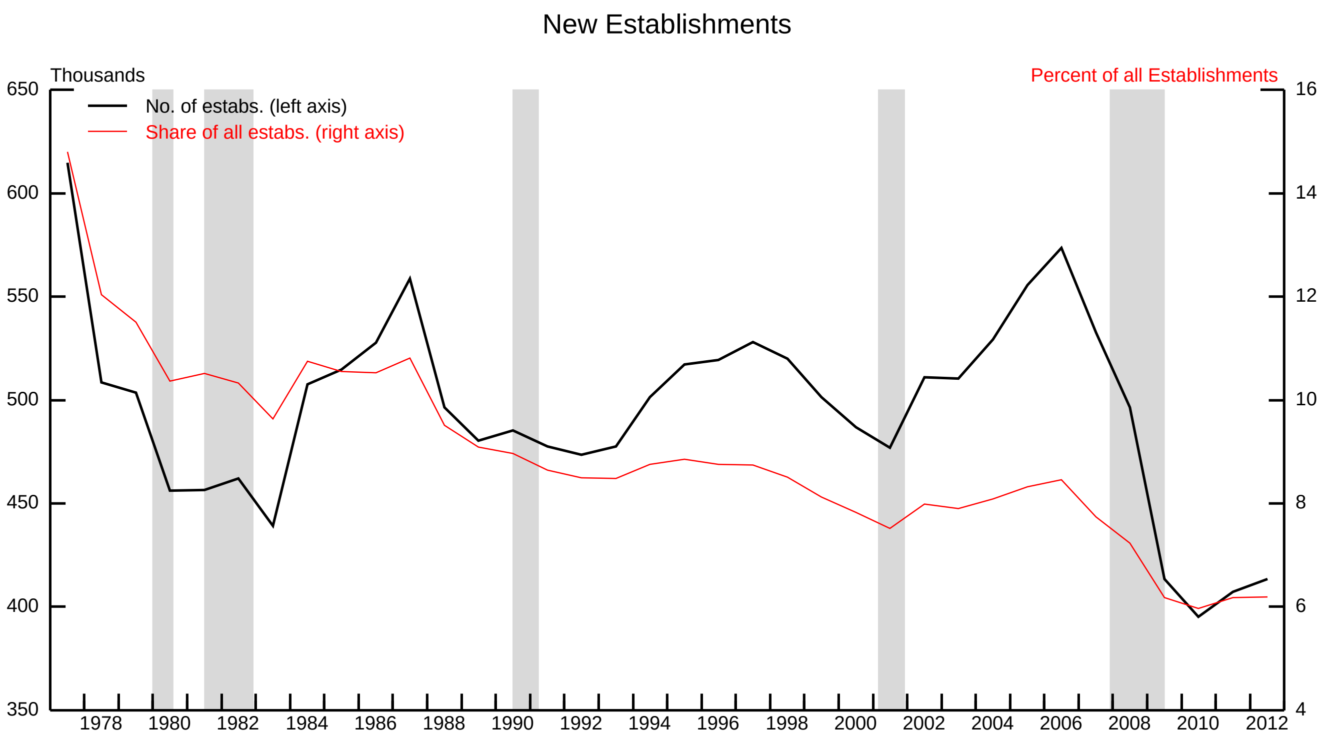


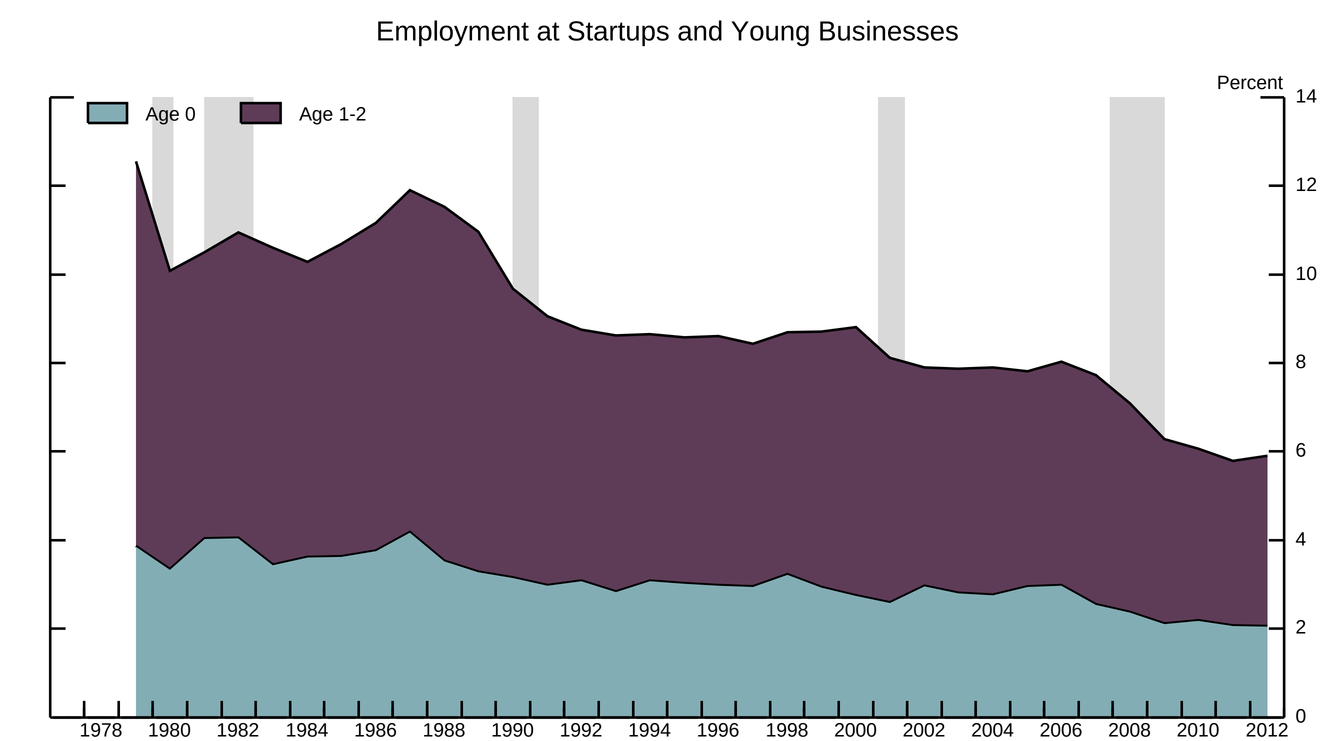
Figure 6 - Long-Term Unemployment



Note: Shaded areas are NBER dated recessions.

Figure 7 - Startups and Young Business Employment





Note: Shaded areas are NBER dated recessions.
Source: U.S. Census Bureau, Business Dynamics Statistics.

Figure 8
Illustrative Relationship Between the Level of Slack
and the Relative Strength of Incremental Hysteresis Effects

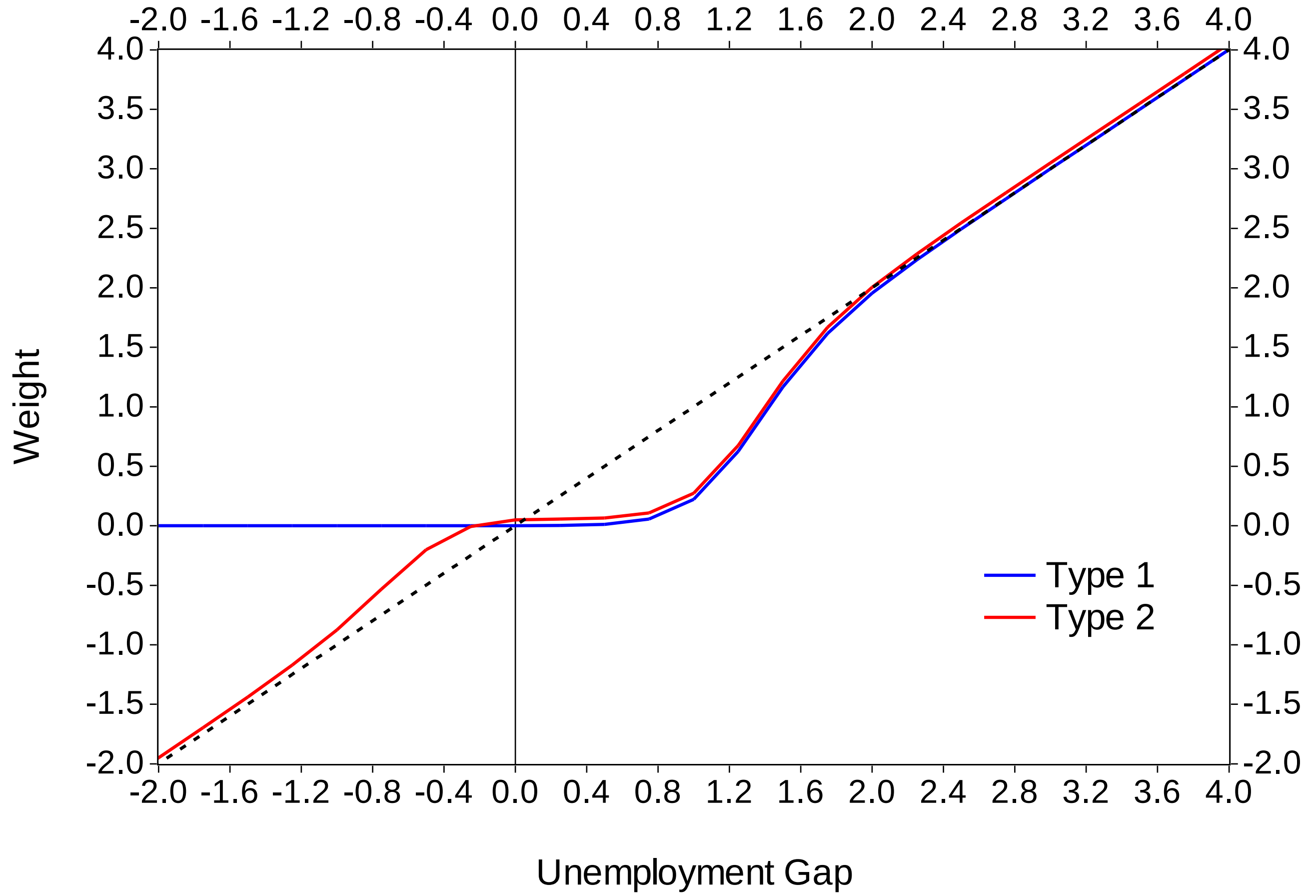


Figure 9A. Macro Effects of a Severe Demand Shock With Type 1 Hysteresis Under Different Policies
(resulted expressed as deviations from baseline)

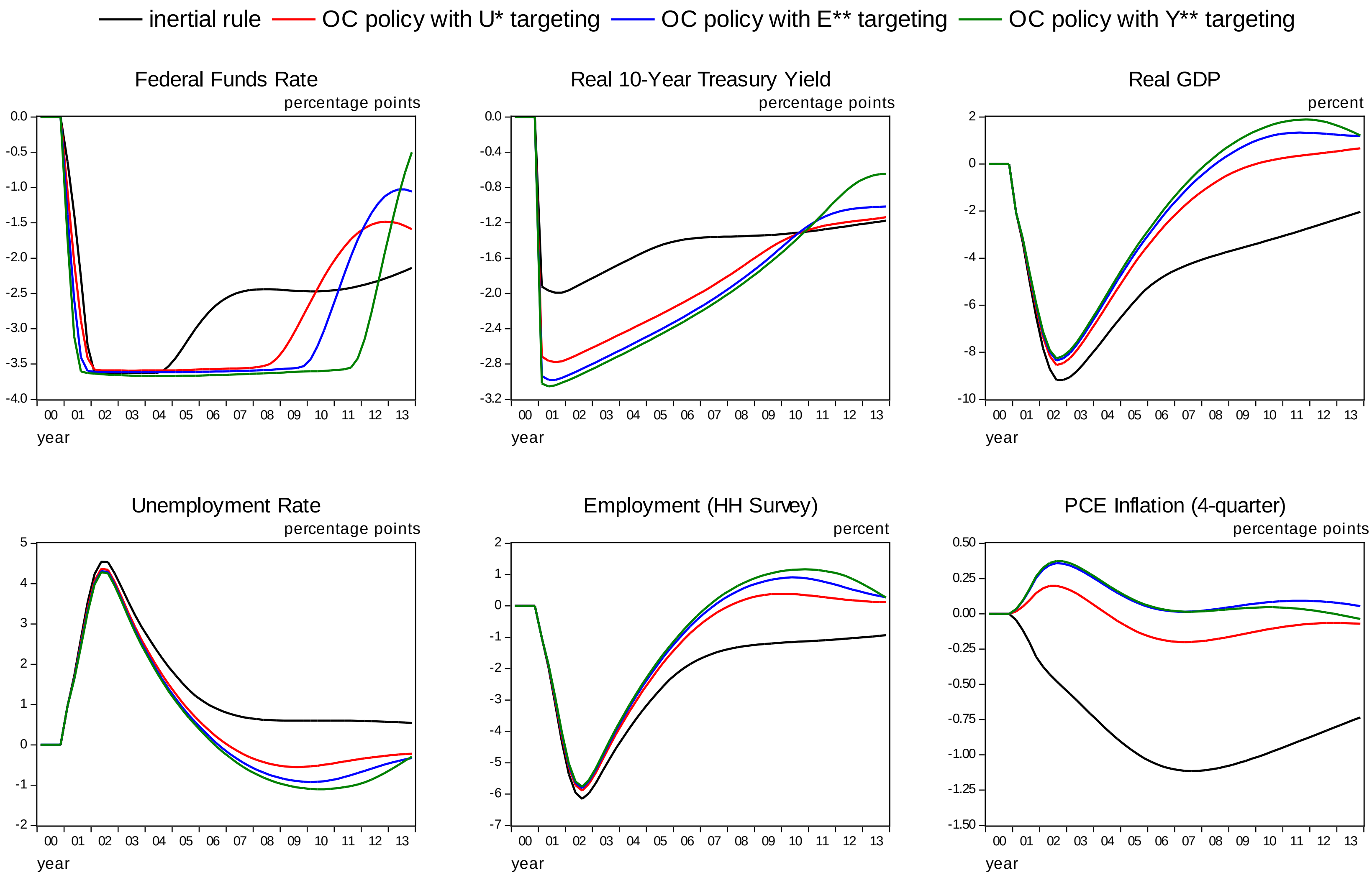


Figure 9B. Supply-Side Effects of a Severe Demand Shock With Type 1 Hysteresis Under Different Policies
(resulted expressed as deviations from baseline)

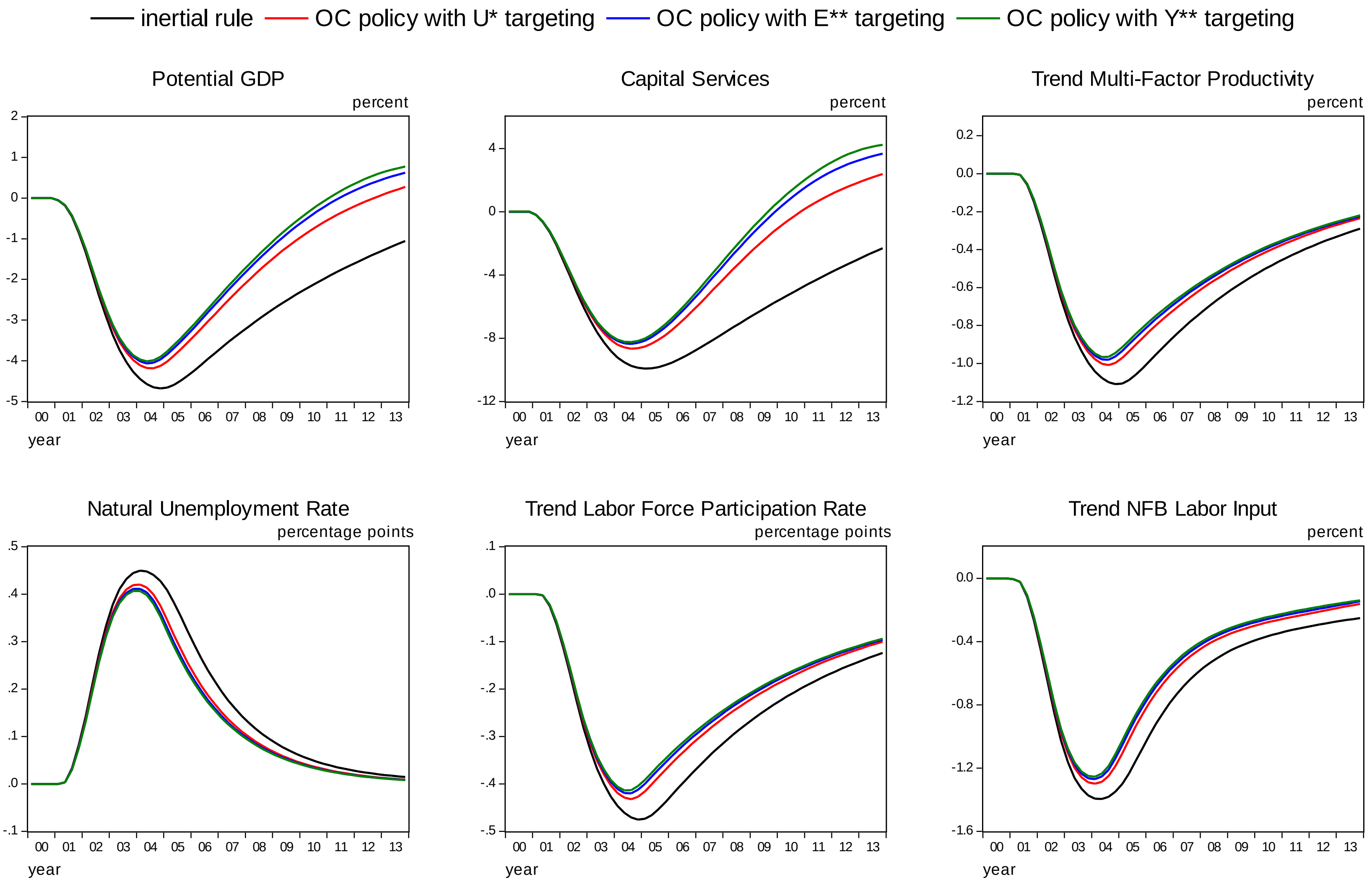


Figure 10A. Macro Effects of a Severe Demand Shock With Type 2 Hysteresis Under Different Policies
(resulted expressed as deviations from baseline)

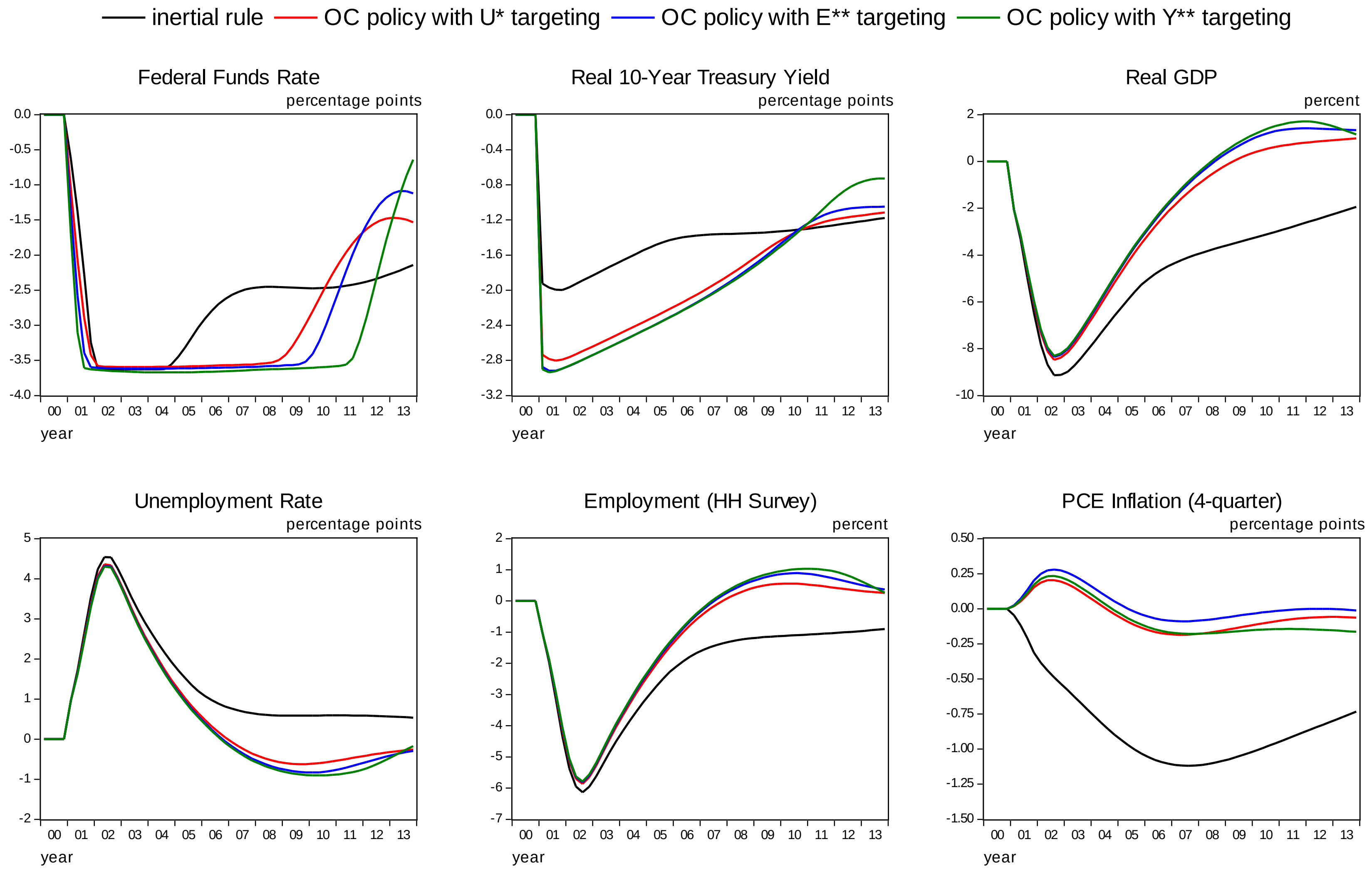


Figure 10B. Supply-Side Effects of a Severe Demand Shock With Type 2 Hysteresis Under Different Policies
(resulted expressed as deviations from baseline)

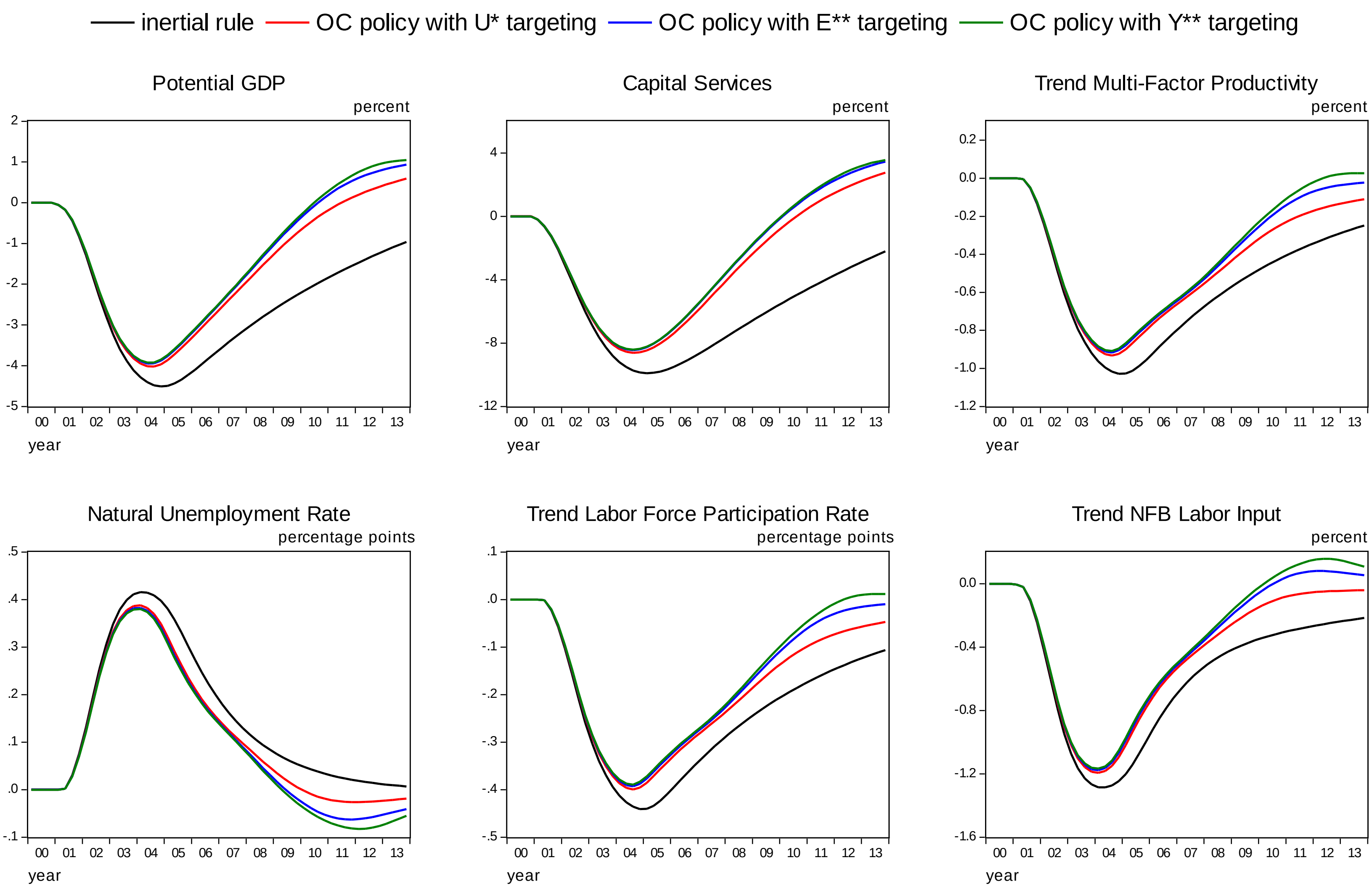
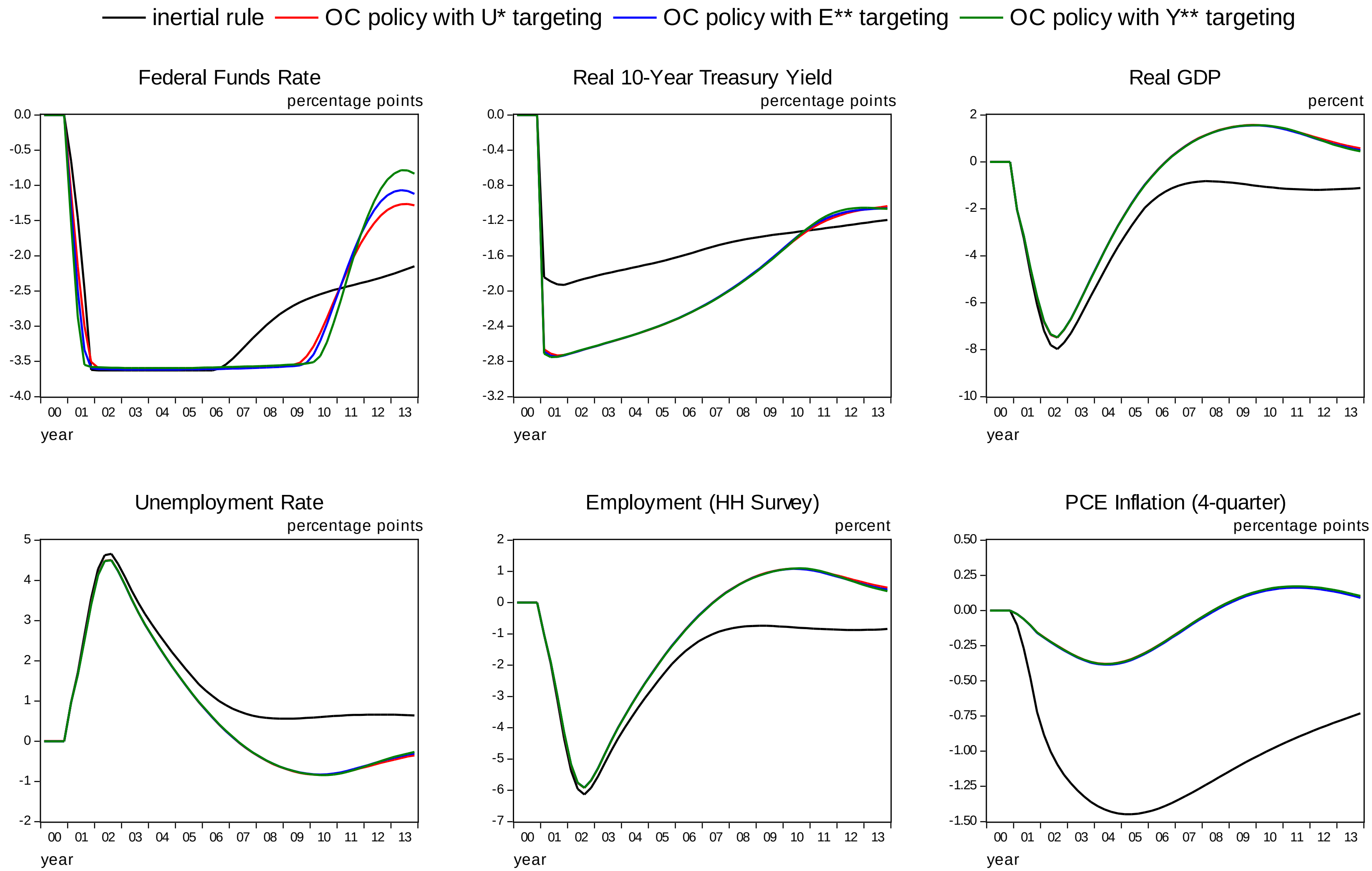


Figure 11. Macro Effects of a Severe Demand Shock Without Hysteresis Under Different Policies
(resulted expressed as deviations from baseline)



Appendix. The State Space Model

1. *Real GDP (per capita, logged)*

   gdp = wedge1 + tmfp/.965 + (.035/.965)*lveoa + .725*(terate + tlfpr + tww + wedge2) + .275*lks + .725*lqualt + cycle + β11*β6 + β11*e_nfbp + [white-noise error, var=$β100^2$]

2. *Real non-farm business output (per capita, logged)*

   nfbp = tmfp/.965 + (.035/.965)*lveoa + .725*(terate + tlfpr + tww + wedge2) + .275*lks + .725*lqualt + β10*cycle + β6 + e_nfbp

3. *Real non-farm business income (per capita, logged)*

   nfbi = tmfp/.965 + (.035/.965)*lveoa + .725*(terate + tlfpr + tww + wedge2) + 0.275*lks + .725*lqualt + β10*cycle – β6 + e_nfbi

4. *Workweek, nonfarm business sector (logged)*

   wwnfb = tww + 0.72*[wwnfb(-1)-tww(-1)] + ϕ20*[cycle-cycle(-1)] + ϕ(22)*cycle + [white-noise error, var=$β104^2$]

5. *Employment, nonfarm business sector (per capita, logged)*

   enfb = terate + tlfpr + wedge2 + ϕ30*cycle + ϕ31*[enfb(-1)-terate(-1)-tlfpr(-1)-wedge2(-1)] + [white-noise error, var=$β105^2$]

6. *Employment-to-population ratio (logged)*

   erate = terate + ϕ50*cycle + ϕ51*[erate(-1)-terate(-1)] + [white-noise error, var=$β106^2$]

7. *Labor force participation rate (logged)*

   lfpr = tlfpr + ϕ40*cycle + ϕ41*[lfpr(-1)-tlfpr(-1)] + [white-noise error, var=$β107^2$]

8. *Core PCE inflation*

   pcex = β401*pcex(-1) + (1-β401)*epi(-1) + β404*[.50*cycle + .33*cycle(-1) + .17*cycle(-2)] + β405*MA(rpe(-1),6) + β406*MA(d84*rpe(-1),6) + β408*rpm + β409*rpm(-1) + β407*wpc + [white noise error, var=$β109^2$]

   Note: MA(X,n) denotes the n-quarter moving average of X

9. *Business cycle (state variable)*

   cycle = β1*cycle(-1) + β2*cycle(-2) + [white noise error, var=$β111^2$]

10. *Nonfarm business output error (state variable)*

    e_nfbp = β602*e_nfbp(-1) + [white noise error, var=$β125^2$]

11. *Nonfarm business income error (state variable)*

    e_nfbi = β602*e_nfbi(-1) + [white noise error, var=$β126^2$]

12. *Trend level of the GDP-NFB output wedge (state variable)*

    wedge1 = wedge1(-1) + .25*gwedge1 + [white-noise error, var=$β112^2$]

13. *Trend growth rate of the GDP-NFB output wedge (state variable)*

    gwedge1 = .95*gwedge1(-1) + .05*β213 + [white-noise error, var=$(4*.03326*β112)^2$]

14. *Trend level of multi-factor productivity (state variable)*

tmfp = tmfp(-1) + .25*gtmfp + [white-noise error, var= $\beta114^2$]

15. *Trend growth rate of multi-factor productivity (state variable)*

gtmfp = 0.95*gtmfp(-1) + 0.05*β214 + [white-noise error, var= $\beta115^2$]

16. *Trend NFB workweek (state variable)*

tww = tww(-1) + .25*gtww + [white-noise error, var=.01]

17. *Trend growth rate of the NFB workweek (state variable)*

gtww = .95*gtww(-1) + .05*β216 + [white-noise error, var=$\beta117^2$]

18. *Trend level of the wedge between household and NFB payroll employment (state variable)*

wedge2 = wedge2(-1) + 0.25*gwedge2 + [white-noise error, var=$(.01*\beta118)^2$]

19. *Trend growth rate of the wedge between household and NFB payroll employment (state variable)*

gwedge2 = .95*gwedge2(-1) + [white-noise error, var=$\beta119^2$]

20. *Trend level of the labor force participation rate (state variable)*

tlfpr = tlfpr(-1) + 0.25*gtlfpr + [white-noise error, var=.0025]

21. T*rend growth rate of the labor force participation rate (state variable)*

gtlfpr = 0.95*gtlfpr(-1) + [white-noise error, var=$\beta123^2$]

22. *Natural rate of employment (state variable)*

terate = terate(-1) + [white-noise error, var=$\beta124^2$]

Exogenous variables

lveoa	trend energy-output ratio (logged)
lks	capital services (per capita, logged)
lqualt	labor quality (logged)
rpe	PCE energy prices relative to core PCE prices, weighted by energy share of consumer spending
rpm	non-oil import prices relative to core PCE prices, weighted by import share of domestic spending
wpc	wage-price controls (1971q3 to 1974q1 =1, 1974q2 to 1974q4 = -3.67, =0 otherwise)
d84	dummy variable (= 1 from 1985q1 on, = 0 otherwise)
epi	expected long-run inflation (as reported in the Survey of Professional Forecasters from 1990 to the present and in the Hoey survery from 1981 to 1990; prior to 1981 expectations are inferred by a trend extraction procedure using actual inflation)

Table A.1 Estimation Results for the State-Space Model
(Sample period 1963:Q2 to 2014:Q3)

	Coefficient	Standard Error	z-Statistic	Probability		Coefficient	Standard Error	z-Statistic	Probability
β1	1.4987	0.0618	24.24	0.00	β126	0.4202	0.0363	11.59	0.00
β2	-0.5324	0.0614	-8.67	0.00	β213	-0.3566	0.0616	-5.79	0.00
β6	0.2349	0.3306	0.71	0.48	β214	1.0016	0.2392	4.19	0.00
β10	1.3954	0.0259	53.80	0.00	β216	-0.1826	0.1084	-1.69	0.09
β11	0.7213	0.0299	24.15	0.00	β401	0.5610	0.0604	9.29	0.00
β100	0.0433	0.0135	3.21	0.00	β404	0.1077	0.0296	3.64	0.00
β104	0.2270	0.0140	16.27	0.00	β405	0.5352	0.1924	2.78	0.01
β105	0.1767	0.0132	13.37	0.00	β406	-0.3438	0.3187	-1.08	0.28
β106	0.0827	0.0158	5.24	0.00	β407	-0.4919	0.0945	-5.21	0.00
β107	0.2263	0.0141	16.09	0.00	β408	0.2626	0.1376	1.91	0.06
β109	0.7820	0.0387	20.20	0.00	β409	0.2721	0.1560	1.74	0.08
β111	0.5569	0.0415	13.42	0.00	β602	0.9201	0.0337	27.32	0.00
β112	0.1176	0.0171	6.90	0.00	φ20	0.2534	0.0387	6.54	0.00
β114	0.2266	0.0518	4.38	0.00	φ22	0.0507	0.0129	3.93	0.00
β115	0.1267	0.0610	2.08	0.04	φ30	0.4411	0.0271	16.27	0.00
β117	0.0557	0.0246	2.26	0.02	φ31	0.6765	0.0249	27.12	0.00
β119	0.0787	0.0391	2.01	0.04	φ40	0.0298	0.0127	2.35	0.02
β123	0.1283	0.0306	4.19	0.00	φ41	0.9106	0.0362	25.15	0.00
β124	0.1374	0.0194	7.10	0.00	φ50	0.2955	0.0184	16.05	0.00
β125	0.5061	0.0426	11.88	0.00	φ51	0.5515	0.0293	18.81	0.00
Log likelihood		-651.265	Akaike info criterion			6.711314			
Parameters		40	Schwarz criterion			7.357503			
Diffuse priors		0	Hannan-Quinn criterion			6.97654			