Output Gaps and Inflation in DSGE Models

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Summary

The Philadelphia-Richmond memo "Gaps and Monetary Policy," hereafter the "PR memo," argues that output gaps based on Dynamic Stochastic General Equilibrium (DSGE) models cannot be taken seriously for three reasons. First, the output gaps that emerge from these models are sensitive to the underlying assumptions and it is difficult to choose among alternative assumptions. Second, fluctuations in DSGE models are typically driven in large part by shocks of indeterminate origin, hence anything derived from them is inherently suspect. Third, in practice output gaps from these models are not useful in guiding policy.

Research over the past 18 months, in a collaboration between the Chicago Fed and Northwestern University, has direct bearing on these points. We describe it here. This research demonstrates that many of the problems highlighted in the PR memo stem from challenges in dealing with low and high frequency movements in hours, wages and inflation that all applied macro theories must confront. These movements can be explained with identifiable, albeit non-structural shocks. Once the low frequency trends and high frequency fluctuations are addressed head-on, then a very close association between model-based measures of the output gap and inflation emerges.

The Role of Shocks in DSGE Models

Before describing this research it is instructive to return to the issues raised in the PR memo about the inclusion of shocks in DSGE models. All DSGE models have recognizable structural shocks. The more data the model attempts to explain, the more it becomes necessary to introduce disturbance terms with little or no structural interpretation. In any structural empirical macroeconomic analysis one is faced with a trade-off between parsimony and realism. The trade-off is particulary challenging in DSGE analysis. These models attempt to understand *all* fluctuations in a large

[1]Federal Reserve Bank of Chicago. We thank Spencer Krane for very helpful comments.

number of variables. The models thus need a large number of shocks in order to fit all aspects of the data and to avoid stochastic singularity.[2] Ideally, we would like to have ready structural interpretations for all of these shocks. But, parsimony dictates leaving out features of the economy's structure that cannot be modeled without introducing considerable complexity. So non-structural disturbance terms naturally take the place of the un-modeled features.

There are three areas in which such unmodeled shocks are major issues for DSGE analysis. First, there are demographic trends, such as changes in rates of labor force participation, that influence the supply of labor and wage determination. Most analysts have not attempted to model these factors because they are not necessarily crucial for understanding business cycle fluctuations. Second, there are obvious low frequency movements in inflation which are likely to have been heavily influenced by changes in monetary policy. Modeling the low frequency dynamics of policy formation is an enormously challenging task, which is naturally set aside for the sake of parsimony. Third, wages and inflation are subject to high frequency fluctuations which one might suspect have little to do with the fundamental forces driving the real economy, and so are left unmodeled. In all these circumstances it is natural to include reduced form shocks to address the missing model structure.

The research in Justiniano and Primiceri (2008) and Justiniano and Primiceri (2009) is a case in point. They specify a version of the Christiano, Eichenbaum, and Evans (2005) model which includes disturbances to neutral technology, the efficiency of investment, the representative agent's discount factor and labor supply, wage markups, price markups, inflation drift, the Taylor-type rule, and government (plus net export) spending.[3] In line with the discussion above, we view some of these shocks as structural and others as reduced form proxies for complexities beyond the scope of the model. The labor disutility shock is designed to account for the low frequency trend in hours, the inflation drift shock accounts for the low frequency component of inflation, and the wage and price markup shocks account for the high frequency movements in wages and inflation. The government spending shock should also be viewed as a reduced form disturbance. It is included to make up the difference

[2]Stochastic singularity refers to the absence of at least as many shocks as observable variables used for inference, in which case at least some of the variables must be perfectly co-linear.

[3]For details of the model described here see Justiniano, Primiceri, and Tambalotti (2009).

between observed consumption plus investment, and output. The interpretation of discount factor shocks is less clear. However, there is a long tradition in real business cycle analysis of considering these shocks.[4]

The Role of Shocks in Explaining Output Gaps and Inflation

It is possible to decompose the endogenous variables in the model into components accounted for by each of the disturbances. In what follows we focus on a decomposition of inflation across different categories of shocks.[5]

Figure 1 displays quarterly GDP deflator inflation (solid, grey line) along with the component of inflation driven solely by the inflation drift term (dashed, black line) that we call "trend." The role of this shock in picking up low frequency variation in inflation is clear. Figure 2 displays model-detrended inflation (solid, grey line), that is inflation less trend inflation from Figure 1. It also shows what Justiniano and Primiceri (2009) call *fundamental inflation* (dashed, black line).[6] Table 1 summarizes this definition of inflation as well as other concepts discussed below. Fundamental inflation corresponds to the component of inflation driven by shocks to neutral technology, the efficiency of investment, the representative agent's discount factor and labor supply, the Taylor-type rule, and government spending. Put another way, fundamental inflation is model-detrended inflation after removing the influence of the wage and price markup shocks. The difference between the solid and dashed lines thus indicates the role played by the markup shocks in explaining high frequency fluctuations in inflation.

Figure 3 displays fundamental inflation (dashed, black line) along with the model-based output gap (solid, grey line).[7] The output gap is defined as the difference between actual observed GDP and the model-based estimate of potential output. Potential output is defined as the level of output obtained at the estimated model parameters after eliminating the nominal rigidities, the markup shocks, the inflation drift term and the Taylor-type rule shock. That is, the level of output in an economy driven entirely by real disturbances and with complete price flexibility.

[4] Two examples include Eichenbaum and Singleton (1986) and Fisher and Hornstein (2000).

[5] The model is estimated on the sample 1962q1 to 2009q2. Similar results are obtained using the post-1984 sample.

[6] Means also have been removed from the variables before plotting them.

[7] Means again have been removed from the variables before plotting them.

The high degree of co-movement between the output gap and fundamental inflation in Figure 3 is striking (the correlation is 0.86).[8] The co-movement between the gap and fundamental inflation seems to be better before the mid-1990s than after. Still, in the recent period there is also a high degree of co-movement. So, while this measure of the output gap is clearly not a sufficient statistic for fundamental inflation, Figure 3 suggests that it could be a valuable summary indicator of inflationary pressures.

Even if this output gap co-moves strongly with a suitably filtered measure of inflation, one may still be skeptical of its use depending on what ends up explaining this co-movement. Table 2 addresses this question. This table shows fractions of business cycle variation (fluctuations of period 6 to 32 quarters) of various endogenous variables attributable to markup shocks (column A), the inflation drift shock (column B), shocks to the Taylor-type rule, labor supply and government spending (column C), and shocks to neutral technology, the efficiency of investment, and the discount factor (column D).

The main real variables, output and hours, are driven almost entirely (80 percent) by shocks to neutral technology, investment efficiency and the discount factor. The first two account for 67 and 65 percent of output and hours fluctuations on their own (not shown). Shocks to the Taylor-type rule, government spending and labor supply account for less than 10 percent of fluctuations in these variables. Combined, these results stand in contrast to the findings in Chari, Kehoe, and McGrattan (2009) who argue that the bulk of business cycle fluctuations in output and hours are driven by shocks to markups, labor supply, government spending, and the discount factor.

A large fraction of inflation, even at business cycle frequencies, is driven by markup shocks, which highlights the need to understand these disturbances. Nonetheless the fraction of inflation fluctuations at business cycle frequencies that is driven by shocks to neutral, investment efficiency and the discount factor exceeds 20 percent. And, by definition, all of *fundamental* inflation is driven by shocks other than to markups or the inflation drift.

As seen in the bottom panel of Table 2, the model-based output gap at business

[8] Obviously these are two endogenous variables so this correlation does not reflect causation. We address causation below by decomposing the variability in these series across the model's shocks.

cycle frequencies is mostly driven by shocks other than to markups or the inflation drift. This means that an alternative version of this gap that excludes the influence of the markup and inflation drift shocks (to put the gap on a comparable basis to fundamental inflation) strongly resembles the one plotted in Figure 3 and thus still tracks fundamental inflation closely (the correlation is 0.90).

Furthermore, the output gap is strongly correlated with model-based and empirical measures of marginal cost.[9] This is reflected in Table 2 where we see that model-based marginal cost is 62 percent driven by shocks other than to the markup and the inflation drift. Given that the New-Keynesian Phillips curve equation is sitting inside the model and marginal cost is a key term in this equation, then the correlation between the model-based output gap and marginal cost should not be surprising.

Finally, the model-based output gap bears some resemblance to simple statistical output gaps. This is demonstrated in Figure 4 which displays the model-based output gap along with linearly detrended GDP (the correlation is 0.44).[10]

Conclusion

Overall, these results build confidence in the usefulness of the model-based output gap as an indicator of underlying inflationary pressures. The underlying determinants of inflation are the model's shocks; but, the output-gap itself appears to be a useful summary statistic for these shocks.

Obviously, results depend on the assumptions. All economic analysis involves assumptions. What matters is how compelling the assumptions are. We think the arguments supporting the modeling choices driving the results here are compelling. They are driven by reasonable considerations of empirical exigency and model parsimony. This suggests that the issues raised in the PR memo are more about poor model specification than a fundamental flaw in the DSGE methodology.

We do not wish to suggest this is the end of the story. Justiniano and Primiceri have not concluded their research. It is unclear at this stage what optimal policy looks like. And, there are many parts of the current generation of DSGE models that can be improved on. In particular, the treatment of wage and price setting, financial

[9]For example, real unit labor costs in the non-farm business sector as published by the BLS.

[10]This might be surprising in light of the results in Gali and Gertler (1999).

markets, and commodity prices needs work. However, until there is a viable alternative, the research described in this memo suggests that there is useful information for policymakers in state-of-the-art DSGE models.

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Table 1: Definitions of Potential Output and Fundamental Inflation

Series	Nominal Rigidities Included	Exogenous Shocks Included: Markups	Exogenous Shocks Included: Monetary Policy: shocks to Taylor-type rule and drifting average inflation	Exogenous Shocks Included: All remaining disturbances[1]
Output[2]	Yes	Yes	Yes	Yes
Potential Output[3]	No	No	No	Yes
Inflation[4]	Yes	Yes	Yes	Yes
Fundamental Inflation[5]	Yes	No	No drifting average inflation	Yes

Notes to table 1:

[1] Shocks to neutral technology, investment efficiency, discount factor, government and labor supply.

[2] Output corresponds to real GDP per-capita.

[3] Potential output is the model-based level of output that would prevail in an economy without nominal rigidities, and, with constant markups in prices and wages.

[4] Inflation corresponds to the 400 times the quarterly log-difference in the GDP deflator.

[5] Fundamental inflation is the model-based measure of inflation explained by all shocks except for the markup shocks in prices and wages and the shock to drifting average inflation.

Table 2: Model-based Variance Decomposition over the Business Cycle[1]

	Percentage of variation explained by exogenous shocks[2]			
Column	A	B	C	D
Shocks	Markups	Drifting Average Inflation	Taylor-type rule, Government and Labor Supply[3]	Neutral Technology, Investment Efficiency and Discount Factor[3]
Actual Data[4]				
Output	7	2	9	82
Hours	7	2	9	81
Inflation	56	18	3	23
Nominal Interest	10	5	29	55
Model-Generated Data[5]				
Output Gap	13	4	29	55
Marginal Cost	37	1	2	60

Notes to table 2:

[1] Defined as cycles of between 6 and 32 quarters.

[2] May not add up to 100 due to rounding.

[3] This presents a more disaggregated taxonomy of shocks than in table 1.

[4] Corresponds to the level of GDP per-capita (although the model is estimated using the first difference of this series), hours per-capita, quarterly inflation in the GDP deflator and the effective Federal Funds rate.

[5] The model-based output gap is defined as the difference between observed output and potential output, where the latter is described in table 1. Marginal cost is in real terms.

Figure 1: Observed Inflation and Model−Based Trend Inflation

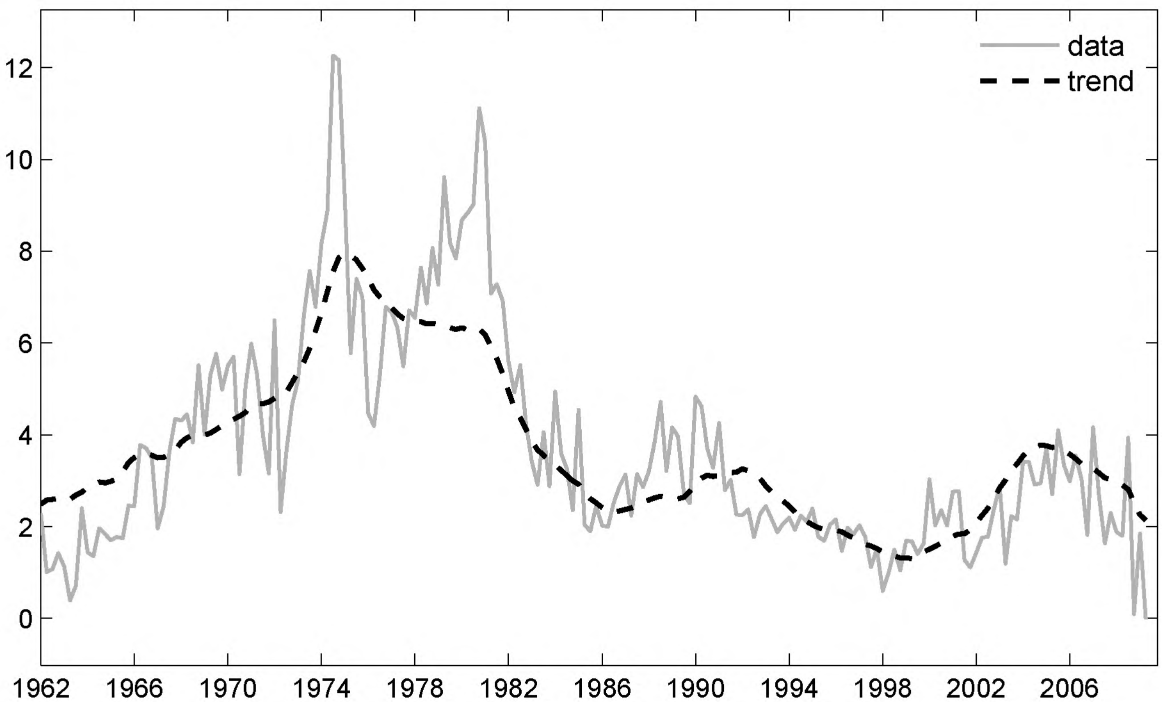

Figure 2: Model−Based Detrended and Fundamental Inflation

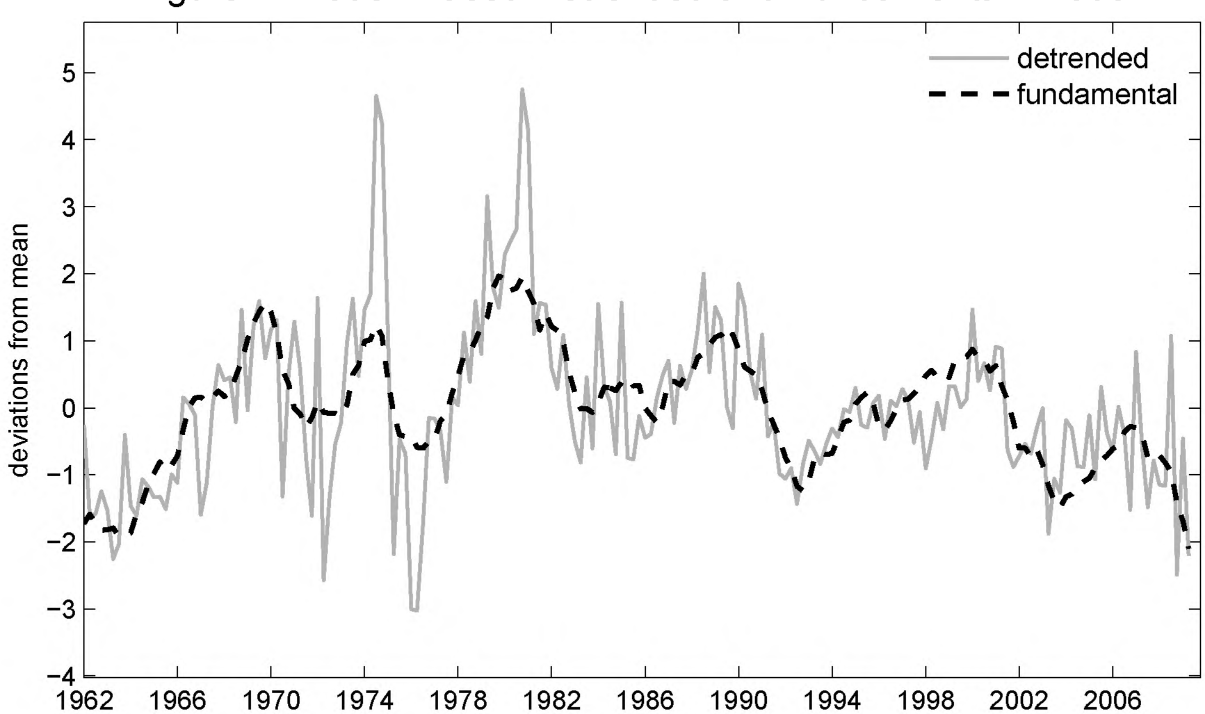

Figure 3: Model−Based Output Gap and Fundamental Inflation

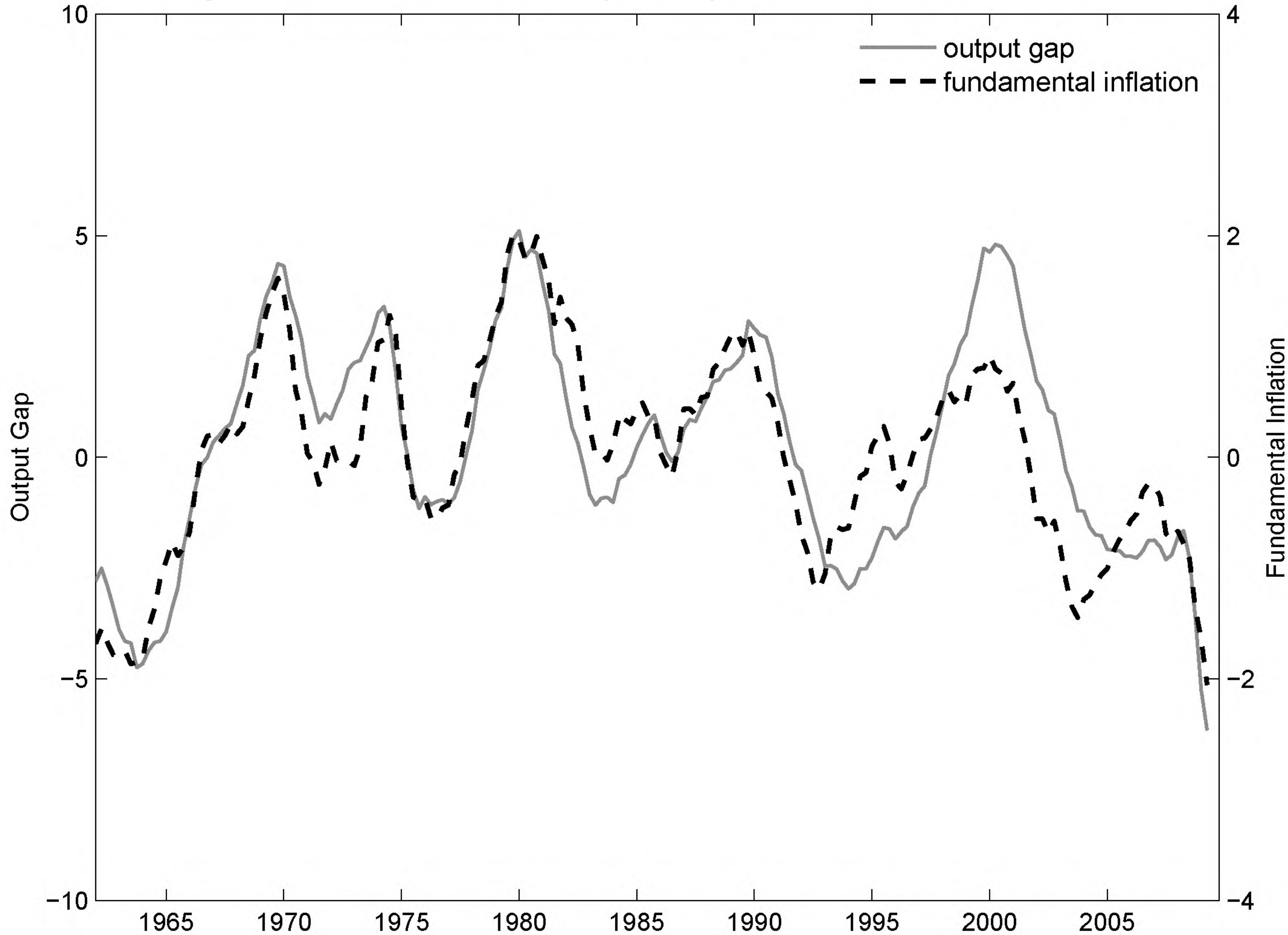

Figure 4: Model−Based Output Gap and Observed Output Deviations from a Linear Trend