

# **U.S. Monetary Policy Forum 2007**

## **Understanding the Evolving Inflation Process**

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## **Abstract**

This report uses international comparisons to understand U.S. inflation dynamics since 1960. We decompose each G-7 country's inflation path into a time-varying trend plus a transitory component, each with time-varying volatility. The level and volatility of trend inflation display coincident hump-shaped patterns that allow us to date the start of the Great Inflation in the late 1960s and a synchronized Inflation Stabilization in the mid 1980s. This temporal clustering narrows the set of G-7-wide economic developments which could have triggered the excessive monetary policy accommodation that was the ultimate source of the Great Inflation. We present evidence suggesting that the most likely explanation is a change in monetary regime. Another robust feature of the data is that changes in inflation are negatively serially correlated. Conventional versions of a workhorse macroeconomic model regularly used by central banks cannot account for this pattern. Finally, we show that several survey measures of inflation expectations help forecast the estimated trend of U.S. core CPI inflation, and that the trend also influences these survey measures over time.

## Executive Summary

This report employs international comparisons to examine the evolution of U.S. inflation dynamics since 1960, and to draw simple policy conclusions to aid in keeping inflation low. We begin by decomposing each G-7 country's inflation path into a time-varying trend and a transitory component, each with time-varying volatility.

This exercise yields the following somewhat surprising result: The level and volatility of the inflation trend in each of the G-7 countries follows a hump-shaped pattern which rises and falls nearly in unison. This synchronization leads us to a data-driven dating of the Great Inflation (in the late 1960s), when inflation rose and became volatile, and of the Inflation Stabilization (around the mid-1980s), when inflation receded and steadied. This coincident timing: (1) narrows the set of G-7-wide economic developments that may have triggered the excessive policy accommodation of the Great Inflation; and (2) distinguishes the Inflation Stabilization from the Great Moderation of G-7 output growth volatility, which does not exhibit the same temporal clustering.

We present evidence that several mono-causal explanations of the U.S. Great Inflation fall short. First, misestimates of the economy's capacity appear insufficient to account for the scale and 15-year duration of the Great Inflation. Combined with the availability of means to improve estimates of the economy's deviation from potential, the fact that inflation remained so high for so long also casts doubt on the simplest policy learning models. Second, explanations relying on the evolution of policymaker understanding of the U.S. economy must be squared with the different paths followed in Germany and, to a lesser extent, Japan. The low estimated level and volatility of the inflation trend in these two countries highlights them as important outliers. Third, the Inflation Stabilization appears inconsistent with an "expectations trap" model: Even in the absence of a new policy "precommitment" mechanism, and despite overestimated sacrifice ratios, G-7 central bankers eventually acted to end the Great Inflation.

Like other observers, we link the Great Inflation and Inflation Stabilization to changes in the monetary policy regimes of several G-7 countries. These regimes are represented by the deviations of policy interest rates from a simple Taylor rule. The deviations imply excessive accommodation throughout the Great Inflation era.

Since macroeconomic models based on the New Keynesian Phillips Curve (NKPC) have become part of the standard policy evaluation toolkit in the major central banks, we examine the ability of a simple version of such a model to mimic a robust property of estimated G-7 inflation dynamics. With a standard calibration, the model *cannot* replicate the negative serial correlation of inflation changes that intensified after the Inflation Stabilization. Matching this feature of the data requires that we change key model parameters substantially, making interest rate shocks (those in the monetary policy reaction function) very small *and* assuming that price setters are nearly entirely forward looking.

Finally, we study the relationship between the estimated trend of U.S. core CPI inflation and various measures of inflation expectations. Several measures of inflation expectations help to improve forecasts of the inflation trend, while the trend also influences these survey measures

over time. These findings suggest that policymakers are correct to view a potential rise of survey inflation expectations as a meaningful threat to price stability, while a rise of inflation that is not accompanied by a rise of survey expectations is less likely to persist.

Overall, our results should temper any temptation on the part of monetary policymakers to exploit the low persistence of inflation that has been observed over the past decade. While our statistical model mimics the widely-touted drop of persistence since the Great Inflation ended, there is nothing structural about this change. Indeed, the policy regime analysis suggests that the current low persistence of inflation is itself a result of the rule-like policy behavior that has predominated since the 1980s. If the credibility dividend of the low-inflation era were to foster policy complacency in the face of unpleasant inflation news – or if perceptions of political interference in policy-setting were to arise – then the volatility of trend inflation could rebound.

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“The fault, dear Brutus, is not in our stars, but in ourselves...”

*Julius Caesar* (anticipating the Great Inflation?)

“Happy families are all alike. Every unhappy family is unhappy in its own way.”

*Anna Karenina* (anticipating the Inflation Stabilization?)

## 1. Introduction

Over recent decades, industrial country central banks, including the Federal Reserve, have made great strides in lowering and steadying inflation, following the Great Inflation of the 1970s and early 1980s. Many observers believe that this success also has contributed to the Great Moderation of output volatility. Nevertheless, we still have much to learn about the dynamics of inflation. And a better understanding of these dynamics naturally would be useful in keeping inflation low.

This report aims to describe U.S. inflation dynamics since 1960 and to draw simple policy conclusions that may help preserve the benefits of the low-inflation era. Of course, this subject already has been a rich field of research for many years, so that we benefit from a vast literature. Encouraged by recent analysis of common global factors in inflation, we also compare the U.S. experience with inflation patterns in other countries. Both the commonalities and the differences are revealing and help us illuminate alternative explanations of U.S. inflation patterns.

Theory also has much to say about inflation dynamics. We ask how well the inflation dynamics from a simple workhorse model of the economy compare with observed regularities. And we examine how the usual model parameters would need to be altered to satisfy key stylized facts about inflation in the G-7.

Finally, we ask how observable various measures of inflation expectations influence and are influenced by estimates of inflation's trend and the volatility of the trend.

The statistical analysis in this paper is based on Stock and Watson's (2002, 2006) unobserved components model with stochastic volatility (UC-SV model) that approximates inflation as the sum of a persistent and a transitory component. The persistent component captures the trend in inflation, while the transitory component captures deviations of inflation from its trend value. The trend component is non-stationary and is the model's optimal forecast at time  $t$  of future inflation. The variability of both the trend and temporary components are allowed to change over time. In estimating the model, an observed rise (decline) of overall inflation persistence is reflected in a rising (declining) share of overall volatility that is attributed to the trend innovation. We use both the estimated trend and the estimated volatility of its innovation (hereafter described as the trend's volatility) to characterize the post-1960 inflation patterns in the United States and other G-7 countries.

The volatility of the trend reveals both striking similarities and notable differences across G-7 countries. It follows a hump pattern where the initial rise from a low volatility to a high volatility is tightly clustered in the late 1960s. In most cases, the restoration of low volatility is clumped around the mid-1980s. These patterns suggest a data-driven, cross-country dating scheme for the

Great Inflation, along with a new nomenclature – the Inflation Stabilization – for its end. Exceptional patterns in Germany and Japan also help narrow the kinds of explanations for the Great Inflation and the Inflation Stabilization that should be acceptable. In recent years, the trend volatilities have fallen so low across the G-7 that such univariate measures no longer distinguish between the inflation dynamics in these countries, regardless of whether their central banks target inflation.

Most of the paper exploits this new data set – both the level and volatility of the inflation trend – for purposes of understanding past inflation patterns, comparing various explanations of these patterns across countries, examining the performance of a standard economic model, and assessing the impact of and influence on relevant economic indicators (including measures of inflation expectations).

We highlight five major conclusions. First, the clustering of the Great Inflation and Inflation Stabilization narrows the range of G-7-wide economic developments that may have prompted the monetary policy choices which generated these inflation patterns. The timing of the Great Inflation and the Inflation Stabilization also differs in important ways from that of the Great Moderation of output growth. While time-varying estimates of the volatility of real growth show a marked decline across the G-7 countries, the timing does *not* cluster tightly in the way that it does for most countries' inflation processes. This difference suggests both that: (1) real-side explanations for inflation dynamics will be difficult to square with our evidence; and (2) improved monetary policy is not the sole factor behind the Great Moderation of output growth.

Second, we argue that several mono-causal accounts of the U.S. Great Inflation are insufficient, and that changing policy preferences or political influences probably played a role in addition to other developments, including changing understanding of the economy. Some analysts have ascribed the policy errors which triggered the U.S. Great Inflation to misestimates of the economy's deviation from potential. However, newly-constructed estimates of U.S. resource utilization – employing information that was available to contemporary policymakers – suggest that miscalibrations were too small to explain the scale and duration of the Great Inflation in the United States. In light of these measures, it also would be surprising to find that a policy learning process alone (without a change in policy preferences or in the political environment) accounts for both the Great Inflation *and* the long delay before the Inflation Stabilization.

Across countries, too, either the pace of learning of policymakers differed sharply, or policy preferences and related political influences (especially the tolerance for an extended episode of high unemployment) played a distinguishing role in the inflation processes, or (as we suspect) both. Without such factors, it is difficult to explain both the long duration of the Great Inflation in most countries, and the very different patterns in Germany and (to a lesser extent) Japan. In particular, our volatility measure is consistent with the conventional assessment that Germany kept inflation relatively low and stable because its central bank had a strong preference for low inflation that was reflected in a credible policy commitment.

Third, we present evidence that shifts in the monetary policy regime were associated with both the Great Inflation and the Inflation Stabilization. In several G-7 countries – Japan, the United Kingdom, and the United States, but less so in Germany – systematic accommodative deviations

from simple policy rules were associated with the Great Inflation (including both inflation's trend and the trend volatility), while the past two decades have been characterized by much smaller deviations from these rules. The policy deviations also are positively correlated with our measure of trend inflation, so that larger deviations are associated with a higher trend.

Fourth, our empirical results pose some challenges for a workhorse macroeconomic model based on a hybrid New Keynesian Phillips curve (NKPC) that has become part of many policymakers' toolkit. A standard calibration of such a model, in which backward- and forward-looking elements have roughly equal weight, is not capable of replicating a fundamental property of G-7 inflation dynamics; namely, the negative first-order autocorrelation of changes in inflation. According to the data, an increase in inflation today is followed by a decline tomorrow (with the scale of the decline larger in the low-inflation era). To mimic this pattern in the model, we must assume both that: (1) agents are very forward looking; *and* (2) monetary policy has very little noise.

On its face, the NKPC model also suggests that – provided a central bank satisfies the Taylor principle – the intensity of policymakers' inflation response, the degree to which their inflation target drifts in response to realized inflation, and the slope of the Phillips curve all have little impact on inflation persistence. However, the model does not take account of the extent to which central bank behavior might alter the proportions of forward- and backward-looking agents. Moreover, by assuming full information about policy's target and behavioral parameters, the model eliminates any learning dynamics.

Finally, we examine the relationship between our estimate of the time-varying U.S. inflation trend and various measures of inflation expectations. Several survey measures help to forecast the inflation trend, and the trend also influences the evolution of these measures. The results support the view that a rise of survey inflation expectations is a meaningful threat to price stability. Conversely, a rise of inflation that is *not* accompanied by a rise of survey expectations would be less likely to persist.

The paper proceeds as follows. Section 2 discusses the literature on the U.S. Great Inflation and highlights key differences in the prominent explanations. It also summarizes relevant conclusions from the recent literature on global aspects of inflation.

Section 3 presents the statistical model for inflation and estimates of the model in the G-7 countries since 1960. It highlights the evolution of the trend of inflation and of the trend's volatility and shows how the data reveal a natural dating mechanism for the Great Inflation and the Inflation Stabilization. It also distinguishes the dynamics of the Inflation Stabilization from the Great Moderation of output volatility.

Section 4 utilizes the model's time-varying estimates of the level and volatility of inflation, comparing the data-driven timing of the Great Inflation and Inflation Stabilization against a variety of candidate factors that occasionally have been cited as inflation drivers or as triggers for monetary policy errors. It narrows substantially the list of relevant factors.



Section 5 presents evidence that the UC-SV estimates of inflation's trend and trend volatility are associated with a changing monetary policy regime, as represented by sustained deviations from a simple policy rule in several countries.

Section 6 describes a three-equation macro model including a New Keynesian Phillips curve and shows the challenges of calibrating the model consistently with the properties of the inflation process that are often used to summarize inflation dynamics.

Section 7 explores the empirical relationship between the estimated trend and trend volatility of U.S. CPI inflation and various measures of inflation expectations.

The final section presents suggested implications for policy setting and highlights areas for future research.

## 2. The State of the Debate

This paper builds on several strands in the empirical literature that examines inflation dynamics. As a descriptive exercise, we rely on the univariate unobserved components model with a stochastic volatility (UC-SV model) described in the following section to characterize the inflation process and examine its evolution. The flexible properties of this model also have begun to find use in multivariate settings to describe U.S. inflation dynamics (see Cogley and Sargent [2007]). We employ the UC-SV model for the first time to examine inflation data from outside the United States. One aim is to use international developments to help identify key properties of the U.S. inflation pattern.

Our analysis links two strands of literature: (1) U.S. accounts of the Great Inflation and the Inflation Stabilization; and (2) recent analysis of the global character of inflation. The univariate UC-SV model's data characterization provides some stylized facts that generally should inform accounts of the Great Inflation and Inflation Stabilization. In particular, it provides a useful model-based approach for dating the Great Inflation and the Inflation Stabilization internationally, and highlights the extent to which these developments were common across the Group of Seven, while revealing important international differences as well. In effect, the new Inflation Stabilization nomenclature is suggested by the data.

We argue that the common factors call for a common explanation that should be consistent with the highlighted international differences. Several patterns appear key: the international clustering in time of the start of the Great Inflation and of the Inflation Stabilization, based on the national inflation trends and the volatility in the innovations of these trends; the extended duration of the Great Inflation in most G-7 countries; and the key exceptions to these patterns, particularly Germany and Japan. Later we will use these stylized facts to examine various factors that may or may not have contributed to the policies that fostered the Great Inflation and the Inflation Stabilization.

In this section, we first briefly review some of the basic assessments provided by prior analyses of the U.S. Great Inflation and Inflation Stabilization, including the policy ignorance (“ideas-driven”) descriptions of De Long [1996], Nelson [2005 and 2006], and Romer and Romer [2002], the regime-switch models of Clarida et al. [2000] and Taylor [2002] and the related learning models of Cogley and Sargent [2001, 2005a, 2005b, and 2006], the miscalibration explanation of Orphanides [2002 and 2004], Primiceri's [forthcoming] focus on the underestimation of inflation persistence, the intermediate money-targeting procedural arguments of Kozicki and Tinsley [2007], the political account of Meltzer [2005a and 2005b], and the “expectations trap” hypothesis of Christiano and Gust [2000]. These hypotheses are all summarized in Table 2.1. One conclusion of this paper is that these descriptions can and should be checked against the ex-U.S. G-7 experiences as a means of assessing their significance. To date, only Nelson appears to have pursued this approach. This section then concludes with a brief description of some of the relevant findings in the recent “global inflation” literature.

**Table 2.1 Alternative Descriptions of the Great Inflation and Inflation Stabilization**

Sources of Policy Error	Probable Form of Policy Reaction	Resulting Inflation Patterns
<p>1. Stable Regime With Miscalibrations</p> <p>a. Serial correlated misestimates of output gap or NAIRU</p> <p>b. Additional error in estimating persistence</p>	<p>Stable policy reaction function with errors in variables</p> <p>Reaction function turns less accommodative only after learning persistence</p>	<p>Serial correlation of policy errors Inflation Stabilization occurs when measurement error declines</p> <p>Further delays Inflation Stabilization Adds to scale of Great Inflation</p>
<p>2. Exploit pre-accelerationist Phillips Curve (PC)</p> <p>a. Without learning</p> <p>b. Learning about long-run PC slope</p>	<p>Stable reaction function with higher inflation target</p> <p>Time-varying reaction coefficients Learning reduces accommodation</p>	<p>Inflation steadies at higher target Provides no reason for higher volatility</p> <p>Policy not accommodative after Inflation Stabilization, which occurs after learning long-run PC is vertical</p>
<p>3. Expectations Trap</p>	<p>Accommodative reaction function</p>	<p>Inflation bias persists without change of policy framework: lack of precommitment</p>
<p>4. Intermediate Targeting of U.S. Monetary Aggregates in 1970s</p>	<p>Interest rate policy responds to intermediate money targets, not directly to economic activity or inflation</p>	<p>Trend inflation rises to higher <i>effective</i> target in 1970s and then declines gradually after 1979 shift to lower <i>effective</i> target</p>
<p>5. "Ideas Driven" Policy confusion with stable goals</p>	<p>Changing understanding of economy prompts model confusion or time-varying model, including doubts about demand management as tool for disinflation</p>	<p>No stable monetary regime during Great Inflation Failed reliance on nonmonetary means to disinflate</p>
<p>6. Political influences and changing goals/preferences</p>	<p>Institutional and political influences foster policy accommodation. Preferences regarding unemployment and inflation change over time.</p>	<p>Great Inflation and Inflation Stabilization partly reflect changing political attitudes and policy preferences</p>

All of these accounts view the Great Inflation as a result of monetary policy error and the Inflation Stabilization as a restoration of more effective monetary policy. They consider monetary policy too accommodative during the Great Inflation, and share the judgment – explicitly or implicitly -- that sizable inflations cannot endure without such accommodation.

None of the analyses in the literature treat the Great Inflation as a result of a period of bad luck that was preceded and succeeded by more favorable environments. More specifically, earlier authors do not attribute the Great Inflation to oil or commodity shocks or to other cost-push episodes per se. This approach appears to be accepted even by some who view the post-1983 Great Moderation of output volatility largely as a result of good fortune (see, for example, Stock and Watson [2003]).

Yet, while these explanations overlap, they also differ considerably. The policy ignorance and learning accounts of Great Inflation have several variants. One version argues that policymakers in the latter 1960s were tempted to try to exploit a pre-accelerationist Phillips curve, only to learn over time that the short-run relationship between inflation and unemployment (or the output gap) was unstable while the long-run Phillips curve was vertical (see, for example, De Long [1997], Cogley and Sargent [2001] and Taylor [2002]).<sup>1</sup> The shift to a less-accommodative Fed policy in 1979 – reflected in a positive real interest rate response to inflation news (see Clarida et al. [2000]) – resulted from this learning.

Nelson challenges this version, suggesting that policymakers aiming at a higher inflation target in an effort to exploit a short-run Phillips curve still would have responded more aggressively to above-target inflation, in contrast with the observed negative response of short-term real interest rates to inflation news prior to 1979. Some of the learning models also suggest that U.S. policymakers should have understood by the early 1970s that the long-run Phillips curve was vertical. Yet, U.S. inflation generally drifted higher in that decade, and routinely exceeded predictions.

Based on a reading of the records of the Federal Reserve and the Council of Economic Advisers, Romer and Romer argue that policy confusion was deeper than the Phillips-curve exploitation hypothesis implies. They describe recurrent changes in policymakers' economic understanding over the postwar period, but claim that the fundamental goals of high growth, low inflation and economic stability were unchanged. Having allowed inflation to rise in the late 1960s in an effort to boost growth, policymakers limited monetary tightening in the 1970s because they "believed that inflation was almost impervious to slack in real economic activity."<sup>2</sup> By the 1980s, they returned to an assessment that had prevailed in the 1950s, according to which "the economy's capacity was clearly limited, that efforts to push the economy beyond that capacity would quickly produce inflation, and that inflation had substantial and rapid costs." Policymakers also

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<sup>1</sup> Cogley and Sargent [2001] also find evidence for Taylor's concern – namely, that the recent period of low inflation and perceptions of low inflation persistence could tempt policymakers again to misinterpret the short-run Phillips curve as exploitable. However, it is not clear how this view squares with the widespread phenomenon that measured sacrifice ratios have risen.

<sup>2</sup> Cogley and Sargent [2005] model a case in which policymakers are reluctant to disinflate because of perceived high sacrifice ratios.

eventually concluded that “nontraditional policies would not work” and “traditional policies would.”

In the same spirit, Nelson [2005] attributes the U.S. policy failure to a faulty non-monetary cost-push model of inflation determination that viewed wage-price controls – rather than demand management – as an appropriate antidote. He emphasizes similar errors in the U.K. experience, but Nelson [2006] finds that Germany and Japan were less inclined to engage in controls and more willing to rely on conventional monetary policy restraint, allowing them to end the Great Inflation at an earlier date. Issing [2005] goes further, arguing that there was no Great Inflation in Germany because monetary policy began to limit accommodation as soon as Bretton Woods ended, with the Bundesbank *publishing* money stock targets as early as December 1974.

In contrast to all these errors of understanding, which rely on ignorance of the underlying economic model, Orphanides [2002] suggests that the policy failure arose from model miscalibration: namely, from repeated real-time underestimations of the natural rate. A variant of this view would be a policy delay in recognizing the post-1973 U.S. productivity slowdown, resulting in repeated overestimation of the economy’s capacity. Having made such a calibration error, policymakers might temporarily interpret the resulting rise of inflation as a series of one-off cost-push or supply shocks, until they learn the new natural rate (or productivity trend) and respond accordingly. Orphanides emphasizes the hazards of “activist” stabilization efforts arising from the potential to misestimate labor market equilibrium or supply capacity. The current environment of a relatively flat, noisy Phillips curve and uncertainty about the productivity trend increases the challenge of accurate calibration.

Primiceri (2005) suggests that an additional policy error – namely, an initial underestimate of inflation’s persistence – is necessary for Orphanides-like miscalibrations to produce the scale and duration of an episode like the U.S. Great Inflation. Policymakers eventually correct both misapprehensions (and even overestimate persistence for a time), but the combination of errors prompts them to delay disinflation until “the perceived inflation-output trade-off becomes favorable, relative to the level of inflation.”

In a recent paper, Kozicki and Tinsley [2007] argue that the Fed’s intermediate money-targeting procedures in the 1970s helped sustain the inflation that began earlier. The procedure was vulnerable to trend changes in money velocity and productivity, both of which occurred in the 1970s, resulting in a higher *effective* inflation target. However, Kozicki and Tinsley downplay the role of shifts in the productivity growth rate, arguing that “mismeasurement of the degree of economic slack was largely irrelevant for explaining the Great Inflation....” They emphasize, instead, the impact of velocity changes, optimism about interest-rate elasticities, heightened uncertainty about money demand, and the loose connection between the Fed’s short-run policy options and longer-term predictions.

Finally, Meltzer [2005a and 2005b] suggests that knowledge of the economic model and of its calibration are necessary, but not sufficient, for policymakers to avoid the Great Inflation or implement the Inflation Stabilization. Meltzer emphasizes political and institutional factors that hindered Fed policymakers from preventing the Great Inflation and from ending it before the chairmanship of Paul Volcker. In contrast with both Romer and Romer and with Orphanides,

Meltzer also suggests that shifts in policymakers' goals fostered both the Great Inflation and the Inflation Stabilization. In a similar vein, De Long argues that a postwar Great Inflation was virtually inevitable in the United States, because there was no political consensus to tolerate the sustained high unemployment needed to combat inflation until inflation had proved sufficiently disruptive. De Long attributes this political constitution to the influence of the Great Depression on U.S. policymakers.

A separate hypothesis (see Christiano and Gust [2000]) maintains that U.S. monetary policy fell into an "expectations trap" in the early 1970s that propagated the late-1960s inflation. By emphasizing the high cost of disinflation and their desire for economic stabilization, U.S. authorities fostered rising inflation expectations that could only be countered at the cost of a painful recession which they appeared unwilling to tolerate. Christiano and Gust argue further that the institutional framework was inadequate to make anti-inflationary monetary policy credible. The idea is that institutional constraints prevented policymakers from committing themselves to a low inflation policy, so that positive inflationary shocks were accommodated.

With the exception of Nelson's "monetary neglect" hypothesis, none of these accounts have been examined for their utility in explaining the Great Inflation-Inflation Stabilization pattern outside the United States. Indeed, there may be no foreign equivalent of the U.S. intermediate targeting procedure emphasized by Kozicki and Tinsley. Yet, it has always been known that the high-inflation episode was an international phenomenon. By the early 1970s, it was commonplace to attribute the rise of inflation outside the United States at least in part to the monetary constraint imposed by the Bretton Woods regime (Emminger [1973]), although domestic factors almost certainly played a role as well (Darby and Stockman [1983]). Casual observers also tended to associate the Great Inflation with the large oil and commodity price shocks of the 1970s that resulted in the postwar inflation peaks in many countries.

To foreshadow our conclusions, we argue that none of these hypotheses *alone* provide a full accounting of the Great Inflation and Inflation Stabilization. Moreover, some of the accounts appear less compelling than others. For example, the "expectations trap" does not appear consistent with the onset of the Inflation Stabilization. Moreover, while miscalibration is an ever-present policy risk, our empirical analysis suggests that misestimates of the output gap are insufficient to account for the Great Inflation. Similarly, hypotheses that rely solely on a policy learning process, on doubts about the efficacy of demand management, or on judgments that the costs of disinflation would be prohibitive need to explain why most G-7 countries did not learn from the relatively early disinflations in Germany and (to a lesser extent) Japan. This pattern suggests that policy preferences – including a willingness to tolerate an extended period of high unemployment – also evolved over time.

This view does *not* imply that policymakers actively sought the outcomes that occurred. It also allows for the fact that some of the 1970s inflation – in the immediate aftermath of unfavorable supply shocks – was unavoidable. However, it does mean that central banks reacted too passively when confronted by unpleasant inflation surprises. Many factors – including the evolution of policy understanding and changing preferences – probably contributed to this passivity, which, in turn, unmoored the trend of inflation.

The conclusion that multiple factors contributed to the Great Inflation leaves an important puzzle: namely, why was the Inflation Stabilization synchronized in most (but not all) G-7 countries? One may speculate that the Fed's 1979 policy shift, followed not long after by a sharp political swing in the United Kingdom, helped prompt a policy review in the remaining G-7 countries that had not stabilized inflation. Or, perhaps, evidence that sacrifice ratios in several economies fell far short of fears altered the perceived policy tradeoff. Or, possibly, as Meltzer suggests, public attitudes in many countries shifted markedly against inflation. Detailed analysis of these and other alternatives is left to future research. For now, the broadly common timing of policy shifts still begs an explanation.

Separately, recent research has begun to emphasize the common factors in the inflation dynamics of industrial countries. Five results appear related to our analysis. First, Corvoisier and Mojon [2005] find that breaks in the levels of OECD national inflation rates cluster in three waves: around the years 1970, 1982 and 1992. Second, Ciccarelli and Mojon [CM, 2005] show that 70% of the variance in 22 OECD countries' inflation since 1960 is accounted for by a simple average of their inflation rates. Third, CM's common factor helps predict inflation and accounts for the apparent widespread reduction of its persistence. Mumtaz and Surico [MS, 2006] also find a common international factor (related to output growth) that accounts for the declines in the levels and apparent persistence of national inflation in 13 industrial economies. Fourth, CM find that the common factor has less impact in countries with a "stronger commitment to price stability." Finally, while MS associate inflation's high volatility in the 1970s and its subsequent decline with unsynchronized national factors, they link this to differences in monetary policy accommodation, noting Germany's low and stable national factor.

It would be incomplete to discuss international common inflation drivers without referring to globalization. Borio and Filardo [2007] claim that economic integration has shifted inflation's drivers from domestic to global conditions. However, there is good reason to believe that the influence on inflation of globalization – defined here as the cross-border movement of goods, services, and capital – has been exaggerated. From a theoretical perspective, Ball [2006] argues that the globalization hypothesis misinterprets relative price shifts as sustained changes in the rate of price inflation. One recent empirical analysis (Pain et al [2006]) concludes that – after taking account both of direct import effects and of indirect effects from increased demand for energy and commodities from key emerging producers – annual OECD consumer price inflation since 2000 would have been only slightly higher (between 0.0% and 0.2%) in the absence of increased globalization. Finally, Ihrig et al [2007] consistently reject global influences on inflation in various tests of the globalization hypothesis. In any case, most U.S. policymakers already appear to have concluded that the disinflationary impact of globalization is limited and could fade entirely if Asian currencies are allowed to float freely (see, for example, Kohn [2005] and Yellen [2006]).

### 3. Characterizing the Inflation Process

In this section, we examine the inflation process in the United States and the other G-7 countries using a statistical model that has two key features. First, we assume that inflation can be well approximated as the sum of a *persistent* and a *transitory* component. The persistent component captures the trend in inflation and the transitory component captures deviations of inflation from its trend value. The second key feature is that variability of both the trend and temporary components is allowed to change over time. This time variation captures the fact that trend inflation has been relatively stable in the G-7 over the past decade than it was in either the 1970s (when it rose) or the early 1980s (when it fell). A goal of this section is to estimate and characterize these time-varying inflation trends together with measures of their time-varying volatilities.

The details of the inflation model are described in the remainder of this section. Readers who are uninterested in the technical aspects of the model can skim the text in this section and focus on the figures and tables. To do this, all you need to know is the notation that we use:  $\pi$  denotes inflation,  $\tau$  denotes trend inflation,  $\sigma_\varepsilon$  is the standard deviation of the change in  $\tau$  (so  $\sigma_\varepsilon$  measures the volatility in the inflation trend), and  $\sigma_\eta$  represents the standard deviation in the temporary component of inflation. At the end of the section we present a summary of our conclusions.

#### 3.1 Stochastic Volatility Models for Inflation and for Growth of Real GDP

Stochastic volatility models are widely used by financial economists to characterize time-varying variances (“volatilities”) in asset prices, and recently macroeconomists have used these models to characterize the evolving variances of real variables and inflation (see Cogley and Sargent [2005], Primiceri [2005], Sims and Zha [2006], and Stock and Watson [2002, 2006]). In their simplest form, these models characterize the behavior of a serially uncorrelated stochastic process, say  $x_t$ , as  $x_t = \sigma_t \zeta_t$ , where  $\zeta_t$  is an i.i.d. process (typically Gaussian, or normally distributed) with mean zero and unit variance. The scale factor  $\sigma_t$  is the time  $t$  standard deviation of the process, which is assumed to follow a geometric random walk. Of course, macroeconomic time series show substantial serial correlation, so that the stochastic model must be suitably modified to characterize macro variables.

Following Stock and Watson [2002, 2006], we use an unobserved component model with stochastic volatility (UC-SV model) to characterize inflation, and an AR model with time-varying coefficients and stochastic volatility to characterize the growth of real GDP.

The UC-SV model for inflation has the form

$$\pi_t = \tau_t + \eta_t, \quad \text{where } \eta_t = \sigma_{\eta,t} \zeta_{\eta,t} \quad (3.1)$$

$$\tau_t = \tau_{t-1} + \varepsilon_t, \quad \text{where } \varepsilon_t = \sigma_{\varepsilon,t} \zeta_{\varepsilon,t} \quad (3.2)$$

where  $\pi_t$  is the inflation rate, and  $\zeta_{\eta,t}$  and  $\zeta_{\varepsilon,t}$  are mutually-independent i.i.d.  $N(0,1)$  stochastic processes. This model represents inflation as the sum of a random walk component,  $\tau$  (which



represents “trend” or “permanent” inflation), and a random disturbance  $\eta_t$ . The relative importance of the trend and random disturbances depends on the variances  $\sigma_{\eta,t}^2$  and  $\sigma_{\varepsilon,t}^2$ , which follow the processes:

$$\ln(\sigma_{\eta,t}^2) = \ln(\sigma_{\eta,t-1}^2) + v_{\eta,t} \quad (3.3)$$

$$\ln(\sigma_{\varepsilon,t}^2) = \ln(\sigma_{\varepsilon,t-1}^2) + v_{\varepsilon,t} \quad (3.4)$$

where  $v_{\eta,t}$  and  $v_{\varepsilon,t}$  are mutually independent, mean zero, and serially uncorrelated random variables. The variances of  $v_{\eta,t}$  and  $v_{\varepsilon,t}$  govern the magnitude of the time variation in  $\sigma_{\eta,t}^2$  and  $\sigma_{\varepsilon,t}^2$ . For example, when  $\text{var}(v_{\eta,t}) = 0$ , then  $\ln(\sigma_{\eta,t}^2) = \ln(\sigma_{\eta,t-1}^2)$ , so  $\sigma_{\eta,t}^2$  is constant and there is no stochastic volatility in  $\eta_t$ . On the other hand, when  $\text{var}(v_{\eta,t})$  is large,  $\sigma_{\eta,t}^2$  can undergo large period-by-period proportional changes. To allow for the possibility of infrequent large changes in the variances,  $v_{\eta,t}$  is modeled as a mixture of two normal distributions:  $v_{\eta,t} \sim N(0, \gamma_1)$  with probability  $p$  and  $v_{\eta,t} \sim N(0, \gamma_2)$  with probability  $1-p$ . Thus, with  $p$  large and  $\gamma_1 < \gamma_2$ , most draws of  $v_{\eta,t}$  are from a low variance distribution, with occasional draws from the large variance distribution. Typically, the changes in  $\ln(\sigma_{\eta,t}^2)$  are relatively small (with variance  $\gamma_1$ ), but there are occasional large changes in  $\ln(\sigma_{\eta,t}^2)$  (with variance  $\gamma_2$ ). The same model is used for  $v_{\varepsilon,t}$ .

As discussed in Stock and Watson [2006], the UC-SV inflation model has two noteworthy features. First, the inflation rate has a “unit root” or random walk component (which is inherited from  $\tau_t$ ), and the importance of the unit root changes over time with changes in  $\sigma_{\varepsilon,t}^2$ . Second, when  $\sigma_{\eta,t}^2$  and  $\sigma_{\varepsilon,t}^2$  are constant, inflation follows an IMA(1,1) model, a popular time series model for inflation. Thus, in the UC-SV model, inflation follows a local IMA(1,1) process with a moving average coefficient that depends on the relative variances of  $\sigma_{\eta,t}^2$  and  $\sigma_{\varepsilon,t}^2$ . We will return to this below.

Real GDP growth rates are well characterized, at least locally, by low-order autoregressive (AR) models, and this suggests the model

$$y_t = \alpha_{0t} + \sum_{j=1}^p \alpha_{jt} y_{t-j} + e_t, \quad \text{where } e_t = \sigma_{e,t} \zeta_{e,t} \quad (3.5)$$

$$\alpha_{jt} = \alpha_{jt-1} + b_t \quad (3.6)$$

$$\ln(\sigma_{e,t}^2) = \ln(\sigma_{e,t-1}^2) + v_{e,t} \quad (3.7)$$

where  $y_t$  denotes the growth rate of real GDP, the values of  $\alpha$  are four AR coefficients ( $p$  is set to 4), and  $e_t$  is the AR regression error term. The AR coefficients are allowed to drift through time as shown in equation (3.6), where  $b_t$  is an i.i.d. zero-mean error term, and the regression error follows the same volatility process introduced above. This formulation is extremely flexible, as

the persistence and volatility of growth can both vary over time: the  $\alpha$ 's evolve *and*  $\sigma_e$  evolves.<sup>3</sup> Stock and Watson (2005) found that this model provides a good characterization of real GDP growth rates for the G-7 countries for 1960-2002. We present updates of their estimates below.

In the inflation model, we focus on the behavior of the trend level of inflation  $\tau_t$  and on the standard deviations  $\sigma_{\eta,t}$  and  $\sigma_{\varepsilon,t}$ . Estimates of these random variables are constructed from the inflation data using nonlinear filtering methods analogous to the Kalman filter; Stock and Watson (2002, 2006) provide the details. In this section, we look primarily at the properties of the date  $t$  estimates of  $\tau$ ,  $\sigma_{\eta}$ , and  $\sigma_{\varepsilon}$  that are functions of the inflation data over the entire sample. We refer to these estimates as two-sided or “smoothed” estimates. We think of the smoothed estimates as our best estimate of what happened in the past as we look back from today’s vantage point. Later in this section, as well as in section 7, we work with the one-sided (or “filtered”) estimates in which the date  $t$  values are estimated only using inflation through time  $t$ . These filtered estimates are what would have been available in real time, so they are our best guess of what could have been known at the time.<sup>4</sup>

Because real GDP growth rates follow an AR model, the variance depends on the values of the AR coefficients and the variance of  $e_t$ . We present estimates of the variance of annual growth rates of GDP at time  $t$  by computing the implied variance from an AR model with parameter values estimated using the two-sided (smoothed) non-linear filter.

### 3.2 Inflation in the G-7

Using inflation measured as the annualized quarterly change in the GDP price deflator (in this case, 400 times the log difference of the deflator) for each country, we estimate the UC-SV model equations (3.1) to (3.4). Data for most countries begin in the early 1960s; the exceptions are Germany and Italy, where the data start in 1966 and 1970.<sup>5</sup>

In order to allow for straightforward comparisons and contrasts, we have chosen to model inflation in every G-7 countries using the same time-series process. Before proceeding, it is useful to know how well the model actually fits. As we noted above, this statistical representation is based on the idea that inflation can be decomposed into two components – one that is highly persistent and one that is transitory – whose relative importance changes over time. Furthermore, we observed that, under this characterization, inflation is well-represented by an IMA(1,1) process – that is, one in which the first-order autocorrelation is negative for the first

<sup>3</sup> The results in Cecchetti, Flores-Lagunes and Krause (2005) suggest that this AR model fits relatively well, so long as volatility is allowed to vary over time.

<sup>4</sup> Our estimates deviate from what a policymaker could have actually known at the time since we do not use real-time data.

<sup>5</sup> With the exception of Italian prices, all data are from the OECD database (dated August 2006). The GDP price deflator is formed as the ratio of nominal to real GDP. Data for inflation and real GDP for most countries begin in the early 1960s; the exceptions are Germany (where the data start in 1966) and Italy (where the real GDP data start in 1970). A change in Italy’s national income accounts in 1980 dramatically affected that country’s GDP deflator, which exhibited extremely high volatility during the 1970s. As a result, we chose to use the official Italian CPI, beginning in 1967. The growth rate of real GDP and the rate of inflation for Germany are set to zero in 1991 to accommodate the break in the data associated with reunification. An outlier in real GDP growth in France in 1968:II associated with the general strike was replaced with the centered two-year average value of GDP growth.

difference of inflation and all other autocorrelations are zero. Stock and Watson (2006) show that the UC-SV representation captures the important features of the U.S. inflation process. Table 3.1 presents estimated autocovariances for the first difference of inflation for each of the G-7 countries over two different sample periods. The first order autocorrelation is negative for each of the countries in both sample periods. Higher order autocorrelations are generally statistically insignificant. These results suggest that the unobserved components model in (3.1)-(3.2) provides a reasonable approximation to these inflation processes.

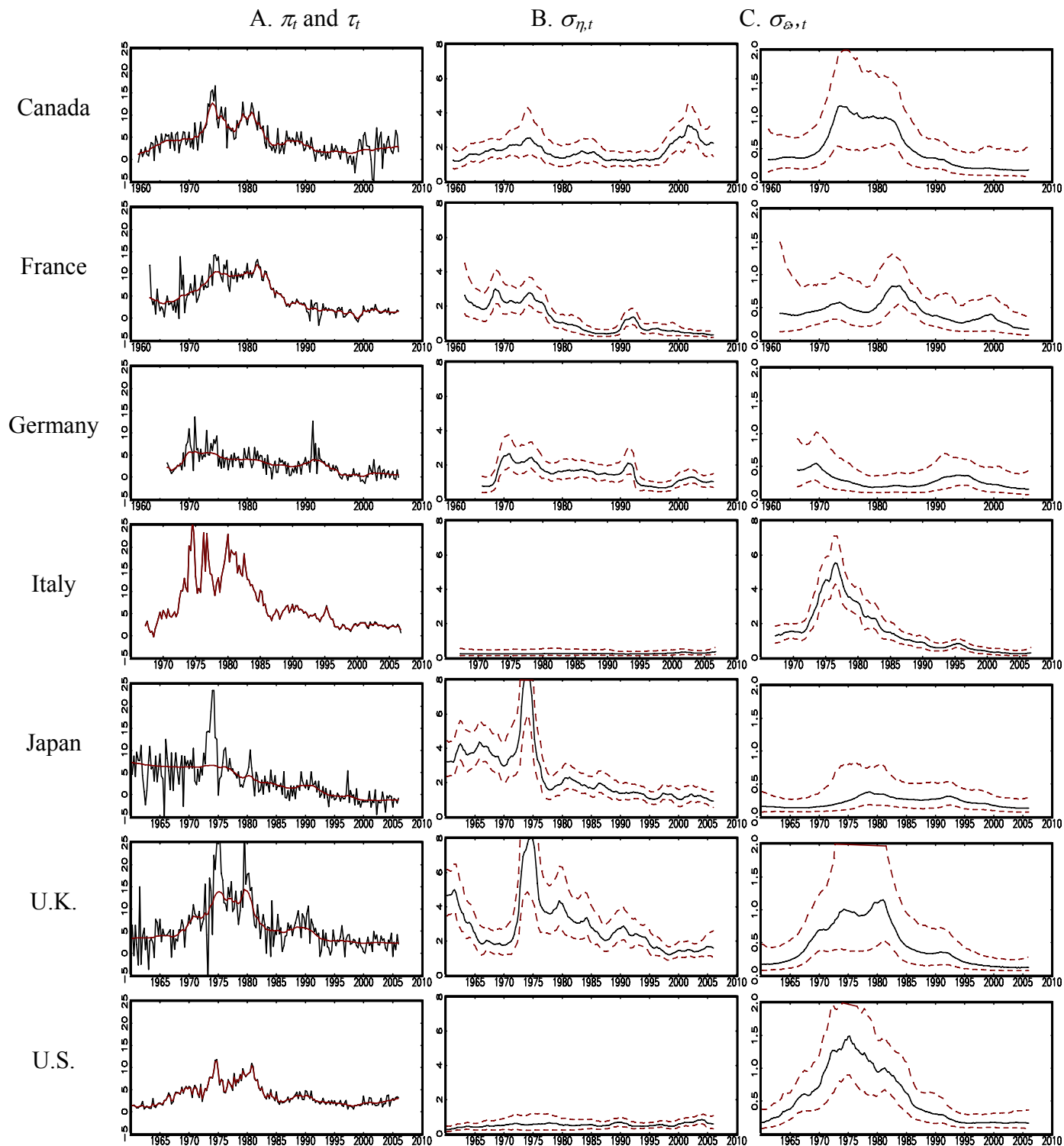
	Beginning of Sample to 4Q 83				1Q 84 to 1Q 06			
	Lag				Lag			
	1	2	3	4	1	2	3	4
Canada	<b>-0.42</b>	-0.09	0.15	-0.02	<b>-0.29</b>	<b>-0.25</b>	0.21	-0.22
France	<b>-0.48</b>	0.17	-0.17	-0.01	<b>-0.36</b>	0.06	-0.15	-0.00
Germany	<b>-0.60</b>	0.26	-0.30	0.28	<b>-0.56</b>	0.12	-0.05	0.03
Italy	-0.22	0.02	0.13	<b>-0.47</b>	-0.08	<b>-0.22</b>	0.20	<b>-0.25</b>
Japan	<b>-0.39</b>	0.09	-0.17	0.11	<b>-0.64</b>	-0.15	0.06	-0.09
U.K.	<b>-0.47</b>	-0.08	<b>0.26</b>	-0.16	<b>-0.58</b>	0.17	-0.17	0.14
U.S.	<b>-0.25</b>	-0.13	-0.02	<b>0.22</b>	<b>-0.42</b>	-0.12	-0.05	<b>0.29</b>

Entries in bold are statistically significant at the 5% significance level.  
 Inflation is measured by the GDP deflator, except for the use of the CPI in Italy. Samples begin in 1960 for the U.S., U.K. and Japan; 1961 for Canada; 1963 for France; 1966 for Germany; and 1967 for Italy.

The estimates for trend inflation,  $\tau_t$  (panel A),  $\sigma_{\eta,t}$  (panel B) and  $\sigma_{\varepsilon,t}$  (panel C) are plotted in Figure 3.2.<sup>6</sup> (Note that the scale for the Italian estimates of  $\sigma_{\varepsilon,t}$  goes from 0 to 8 rather than 0 to 2, as it does for the other six countries we study.) Summary measures across the decades and for the full sample are reported in Table 3.2. People knowledgeable of this period will not be surprised by the results: The inflation trend and the volatility of that trend both declined markedly since the 1970s. The average of the inflation trend has fallen from 8 percent in the 1970s to 1.5 percent in the current decade, while the median standard deviation has fallen from 0.93 to 0.17.

<sup>6</sup> These results are based on UC-SV model with parameter values  $p = 0.98$ ,  $\gamma_1 = 0.20^2$  and  $\gamma_2 = 0.80^2$ . Quantitatively similar results were obtained for other reasonable values of these parameters. The filtered and smoothed estimates were based on 5,000 Markov Chain Monte Carlo draws using the algorithm described in Stock and Watson (2006).

**Figure 3.1: Inflation and Inflation Volatility in the G-7**



Inflation is  $400 \times \ln(P_t/P_{t-1})$ , and the data for France and Germany have been adjusted for outliers as described in the text. Sample periods are begin in 1960 for the U.S., U.K. and Japan; 1961 for Canada; 1963 for France; 1966 for Germany; and 1967 for Italy. All samples end in 1Q 2006. Note that for Italy the graph scale for  $\sigma_{\delta,t}$  differs from the other countries.

In most cases, there is a broad coincidence of the rise of the inflation trend ( $\tau$ ) and the standard deviation of the trend ( $\sigma_\varepsilon$ ). The dating of this pattern is summarized in Table 3.3. Typically, increases in  $\tau$  and  $\sigma_\varepsilon$  cluster between 1968 and 1970. Aside from Germany and Japan, declines of  $\sigma_\varepsilon$  below the relevant benchmark (usually 0.5) cluster after mid-1984. With the exceptions of France and the United States, the drop of  $\tau$  below the 4% level *lags* the drop of  $\sigma_\varepsilon$  below its threshold.

<b>Average of Inflation Trend (<math>\tau</math>)</b>					
	<b>Full Sample</b>	<b>1970-79</b>	<b>1980-89</b>	<b>1990-99</b>	<b>2000-06</b>
<b>Canada</b>	4.36	8.03	5.29	1.86	2.42
<b>France</b>	4.84	8.81	6.69	1.50	1.58
<b>Germany</b>	2.80	4.81	3.03	1.89	0.65
<b>Italy</b>	7.34	11.43	10.82	4.09	2.40
<b>Japan</b>	3.05	5.80	2.44	0.22	-1.27
<b>U.K.</b>	5.68	10.94	6.56	3.26	2.35
<b>U.S.</b>	3.67	6.50	4.40	2.13	2.32
<b>Average</b>	4.53	8.05	5.60	2.14	1.49
<b>Median of St. Dev. of Trend (<math>\sigma_\varepsilon</math>)</b>					
<b>Canada</b>	0.36	0.98	0.57	0.21	0.17
<b>France</b>	0.41	0.48	0.60	0.32	0.22
<b>Germany</b>	0.23	0.28	0.20	0.33	0.18
<b>Italy</b>	1.19	3.50	1.51	0.63	0.29
<b>Japan</b>	0.21	0.24	0.27	0.23	0.14
<b>U.K.</b>	0.34	0.93	0.45	0.20	0.12
<b>U.S.</b>	0.37	1.23	0.63	0.17	0.17
<b>Median</b>	0.36	0.93	0.57	0.23	0.17

Data are those plotted in Figure 3.1. Full samples begin in 1960 for the U.S., U.K. and Japan; 1961 for Canada; 1963 for France; 1966 for Germany; and 1967 for Italy. All samples end in 1Q 06.

For the purpose of international comparison, we focus on high and low values for the time-varying standard deviation in trend inflation,  $\sigma_\varepsilon$ . When  $\sigma_\varepsilon$  is relatively high, it signals that trend inflation ( $\tau$ ) is unstable and is more likely to rise or fall. Analogously, a low value of  $\sigma_\varepsilon$  tells us that  $\tau$  is relatively stable, so it is more likely to stay where it is. In our sample, the estimated  $\sigma_\varepsilon$  typically performs like an on-off switch, rising above and falling below reasonable threshold values for defining the Great Inflation once in each country. The exception is France, where  $\sigma_\varepsilon$  crosses the threshold twice).

Start and End of the Great Inflation					Peaks in Annual Inflation					
					Peak		Secondary Peak		Tertiary Peak	
	$\sigma_\varepsilon > 0.5$	$\sigma_\varepsilon < 0.5$	$\tau > 4\%$	$\tau < 4\%$	Level	Date	Level	Date	Level	Date
<b>Canada</b>	2Q 70	4Q 85	4Q 65	1Q 89	12.8	4Q 74	10.5	1Q 81	4.7	3Q 88
<b>France</b>	2Q 71 <sup>a</sup>	2Q 87 <sup>a</sup>	1Q 68	3Q 86	13.9	1Q 75	12.3	2Q 82	3.7	3Q 88
<b>Germany</b>	3Q 68	2Q 70	2Q 69	3Q 78	8.3	1Q 70	7.9	4Q 74	5.4	2Q 80
<b>Italy</b>	1Q 69 <sup>b</sup>	3Q 84 <sup>b</sup>	3Q 69	1Q 96	25.6	3Q 75	23.3	Q3 76	22.9	1Q 90
<b>Japan</b>	3Q 77 <sup>c</sup>	3Q 79 <sup>c</sup>	1Q 60 Start	1Q 81	20.0	2Q 74	9.0	4Q 61	8.5	3Q 76
<b>UK</b>	3Q 68	3Q 84	1Q 68	1Q 92	25.0	2Q 75	20.3	2Q 80	8.2	3Q 90
<b>US</b>	2Q 66	1Q 86	4Q 67	1Q 83	10.4	1Q 75	9.7	1Q 81	4.0	3Q 90

Notes: The table shows the first occasion in the sample when  $\tau$  exceeded 4% and the *final* occasion when it declined below 4%.  
<sup>a</sup> In France,  $\sigma_\varepsilon$  falls below 0.5 in the interval between 1Q 75 and 1Q 80.  
<sup>b</sup> In Japan,  $\sigma_\varepsilon$  never reaches 0.5. The first two columns date when  $\sigma_\varepsilon$  rises above and sinks below 0.35.  
<sup>c</sup> In Italy, the estimates of  $\sigma_\varepsilon$  begin at 1.3; 1Q 69 and 3Q 84 are the dates when the estimated  $\sigma_\varepsilon$  crosses 1.5.

The results from estimation of the UC-SV models lead us to define the start of the Great Inflation, based on when  $\sigma_\varepsilon$  rose above 0.5, when  $\tau$  surpassed 4%, or both. The Inflation Stabilization (also considered the end of the Great Inflation) is designated as the occasion when  $\sigma_\varepsilon$  declined below the relevant benchmark (usually 0.5). Based on these definitions, the beginning of the Great Inflation clusters in a narrow time frame between 4Q 67 and 2Q 70, while the Inflation Stabilization occurs in the period between 3Q 84 and 3Q 86.

Germany and Japan are exceptions to the usual pattern. In Germany, the volatility of trend inflation,  $\sigma_\varepsilon$ , only briefly breaches the 0.5 threshold in 1969-70, while the level of the inflation trend remains above 4% for 1969 to 1980. Japan presents a starker contrast. There,  $\sigma_\varepsilon$  never reaches 0.5, while  $\tau$  exceeds 4% from the beginning of the sample in 1960 until 1981.

### 3.3 Properties of the Estimated Inflation Process

Three properties of the stochastic volatility model are worth noting:

1. The implied first-order autocorrelation of the *change* in inflation;
2. The implication of the time variation in volatility for estimating the first-order autocorrelation of the *level* of inflation as a measure of persistence;
3. The characteristics of inflation forecasts that are implied by the model.

Starting with the first property, as we noted earlier the model (3.1) to (3.4) implies that the first difference of inflation is a first-order moving average with a time-varying coefficient. To see this, note that:

$$\Delta\pi_t = \Delta\tau_t + \Delta\eta_t = \varepsilon_t + \eta_t - \eta_{t-1}, \quad (3.8)$$

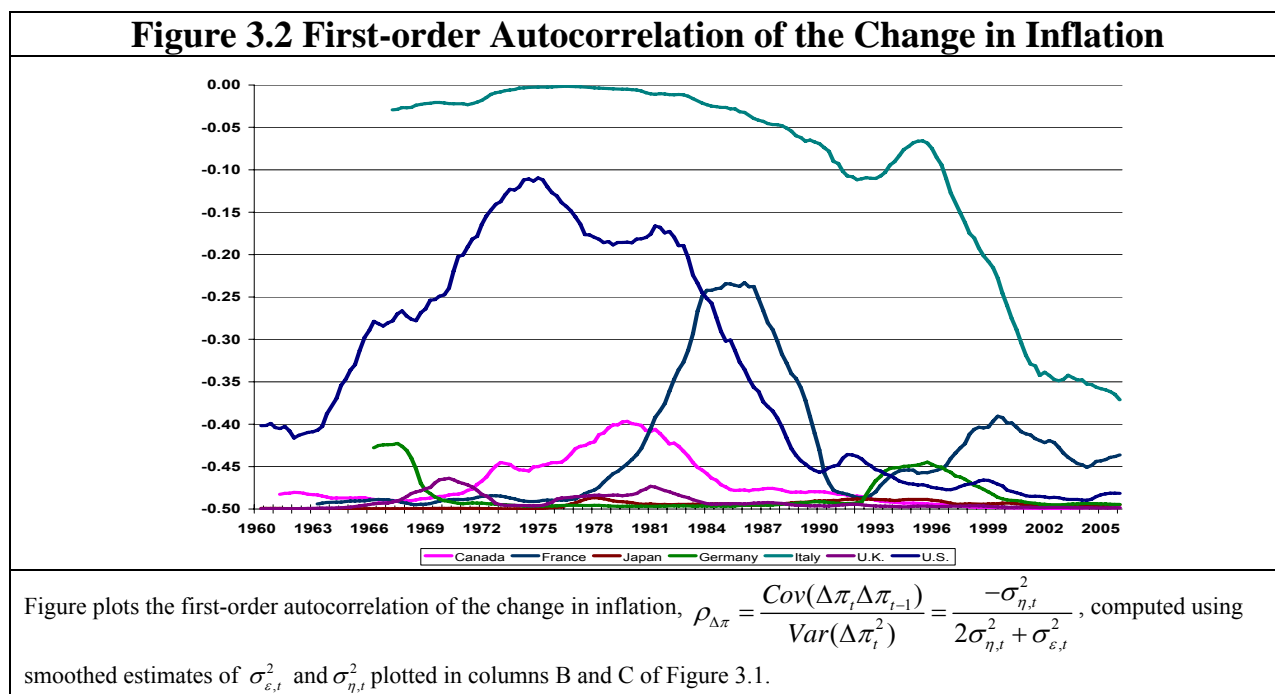
so that  $\Delta\pi_t$  has a negative first-order autocorrelation and zero higher-order autocorrelations. We think of this first-order autocorrelation as a summary of the persistence of the inflation process. The closer it is to

-0.5, the less persistent the inflation process. And, because the variances of  $\varepsilon$  and  $\eta$  change over time, this autocorrelation will change, too.

The magnitude of the first-order autocorrelation of the change in inflation summarizes the relative importance in the inflation process of the variances of the permanent and transitory components. To see this, we compute the analytical expression for this autocorrelation:

$$\rho_{\Delta\pi} = \frac{Cov(\Delta\pi_t, \Delta\pi_{t-1})}{Var(\Delta\pi_t^2)} = \frac{-\sigma_{\eta,t}^2}{2\sigma_{\eta,t}^2 + \sigma_{\varepsilon,t}^2} \quad (3.9).$$

First note that  $\rho_{\Delta\pi}$  ranges between -0.5 and zero. Second, we can see from (3.9) that the more important the permanent component, the higher  $\sigma_{\varepsilon}$  is relative to  $\sigma_{\eta}$ , the closer inflation is to a pure random walk and the closer the first-order autocorrelation of the change of inflation is to zero. By contrast, when  $\sigma_{\eta}$  is dominant, then inflation is close to a stationary white-noise process, and the first-order autocorrelation is close to -0.5.



The implied time-varying estimates of  $\rho_{\Delta\pi}$  for the G-7 are plotted in Figure 3.2. As the relative variance of the inflation trend falls, so that the stationary component of inflation is responsible for a large proportion of the variation, the first-order autocorrelation of the change of inflation declines toward -0.5. We see this in the figure: During the Great Inflation, the implied  $\rho_{\Delta\pi}$  typically rises, reaching values above -0.25 in a few cases, but remains very low in Germany and Japan. Following the Inflation Stabilization, the values  $\rho_{\Delta\pi}$  generally sink below -0.4. We will come back to this pattern in Section 6, when we discuss the ability of a simple structural model to match the properties of the inflation data. Naturally, we would like a structural model to be able to mimic this pattern, in which  $\rho_{\Delta\pi}$  has been consistently negative and is now between -0.4 and -0.5 for every country except Italy.

With regard to the second property of the UC-SV model, the observed time variation in the volatility of the components of inflation has important implications for the interpretation of first-order autocorrelation of the *level* of inflation as a measure of persistence. A substantial literature reports on the persistence properties of inflation data. Various authors note that measures like the autocorrelation of the level of inflation have fallen dramatically over the past few decades.<sup>7</sup> The UC-SV model implies that inflation has a unit root, so its true first-order autocorrelation is one (so long as  $\sigma_\varepsilon > 0$ ). In small samples, however, estimated autocorrelations of the level of inflation will be biased toward zero. Moreover, in our context, this small-sample bias intensifies as  $\sigma_\varepsilon$  becomes relatively less important.

All of the evidence in our sample confirms the dramatic change in the relative variance of  $\varepsilon$  and  $\eta$ . Over the estimation period, the ratio ( $\sigma_\varepsilon/\sigma_\eta$ ) ranges from a minimum of less than 0.02 (in Japan in 1973), to a maximum exceeding 24 (in the Italy in 1976). For most countries the ratio has peaked in the 1970s and early 1980s, and has since fallen substantially. Today, values range from 0.07 in Canada and the United Kingdom (the inflation-targeting countries) to 0.8 in Italy.

These results appear consistent with the conclusion of some studies that *observed* inflation persistence is not policy invariant.<sup>8</sup> At the same time, the decline of the ratio of  $\sigma_\varepsilon$  to  $\sigma_\eta$  has exaggerated the small-sample bias in estimates of the first-order autocorrelation of the level of inflation. To highlight the implications of this estimation bias for the usual measures of inflation persistence, we perform a simple experiment involving the estimation of the following AR(1) model:

$$\pi_t = \alpha + \rho_\pi \pi_{t-1} + \lambda_t \quad (3.10)$$

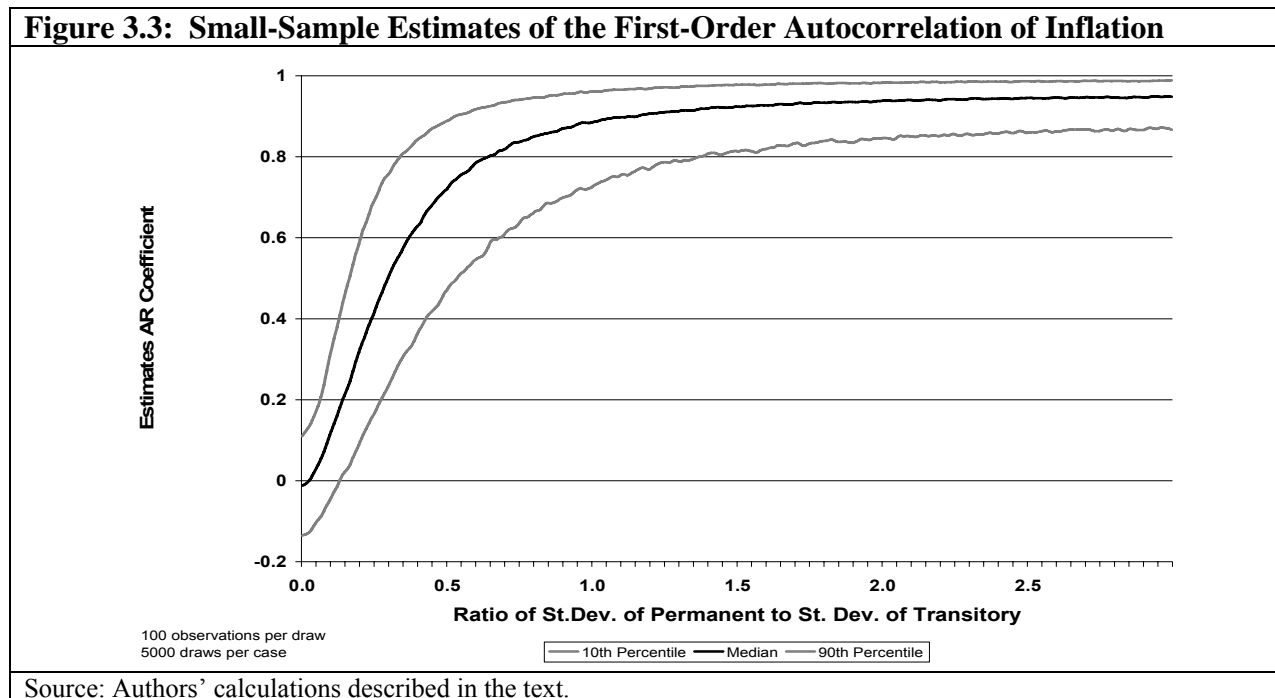
The experiment is as follows: First, we pick a constant value for the ratio  $\sigma_\varepsilon/\sigma_\eta$ . Then, using the model (3.1)-(3.4) we construct a time series of length 100, ignoring time variation in the variances, and run the regression (3.10). We replicate this 5000 times to obtain a distribution of estimated  $\hat{\rho}_\pi$ 's. Figure 3.3 plots the median, 10<sup>th</sup> and 90<sup>th</sup> percentiles of the distribution of  $\hat{\rho}_\pi$  for values of  $\sigma_\varepsilon/\sigma_\eta$  ranging from 0.005 to 3.0.

Figure 3.3 shows that, as the permanent component becomes less and less important, the estimated persistence of inflation goes to zero. As we noted above, this pattern is entirely a consequence of small-sample bias, as the true value for  $\rho_\pi$  is one so long as  $\sigma_\varepsilon$  is nonzero. This exercise has the important implication that, as  $\sigma_\varepsilon/\sigma_\eta$  declines from 2.5 to 0.2 (as it has in the United States), the estimate of  $\rho_\pi$  will fall from roughly 0.95 to less than 0.3, making inflation *appear* much less persistent.

<sup>7</sup> See, for example, Levin and Piger (2003), Gadzinski and Orlandi (2004), and Cecchetti and Debelle (2006).

<sup>8</sup> See, for example, the argument in Benati (2006) that inflation persistence is not “structural in the sense of Lucas.”





Source: Authors' calculations described in the text.

Finally, with regard to the third property of the UC-SV model, we examine the implications of our estimates for forecasts of inflation. The UC-SV model implies that the optimal inflation forecast is a constant equal to the current value of the trend regardless of the horizon. That is:

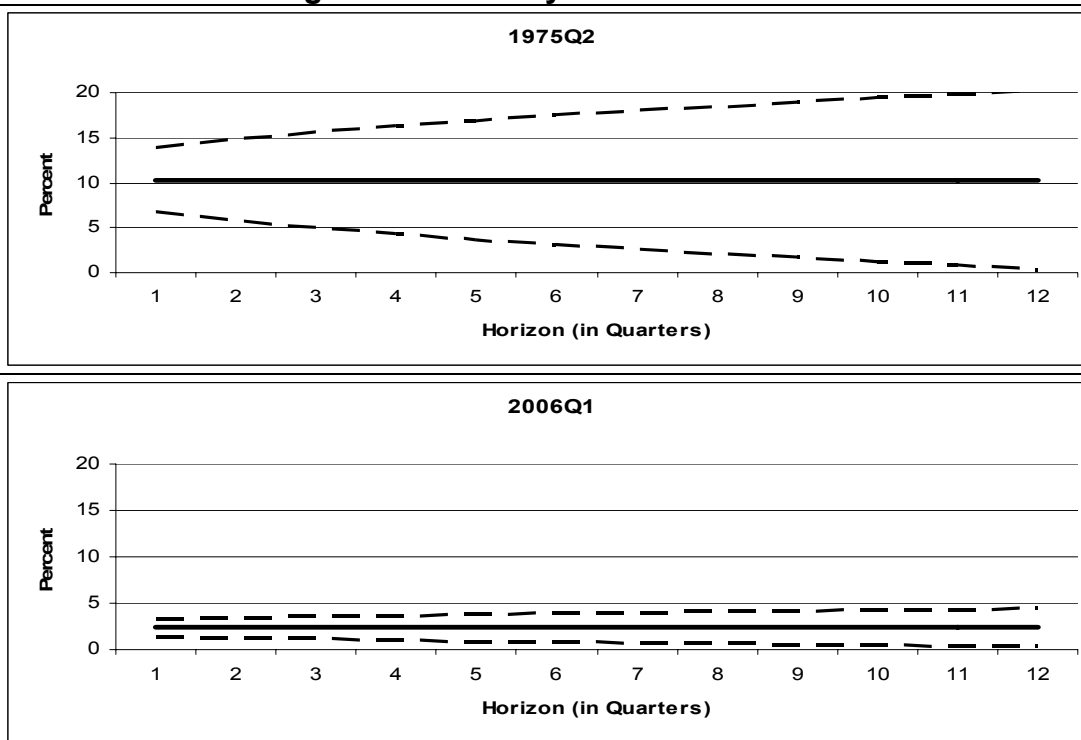
$$E_t \pi_{t+k} = \tau_{t/t} \tag{3.11}$$

where  $\tau_{t/t} = E_t \tau_t$  is the filtered value of  $\tau_t$ , which changes with  $t$  but is independent of  $k$ . The intuition for this relationship is fairly straightforward: Inflation is a random walk plus white noise. Over any horizon, the optimal forecast of a random walk is its current value. But, while the point forecast does not depend on the horizon, the confidence interval does. To see why, recall that the variance of a random walk rises linearly with time. Since inflation has a random walk component, we would expect the standard deviation of the forecast to increase with the horizon in a similar way. Looking at the model, we see that:

$$E_t [E_t \pi_{t+k} - \pi_{t+k}]^2 = (p_{t/t} + \sigma_\eta^2 + k \sigma_\varepsilon^2) \tag{3.12}$$

where  $p_{t/t} = E_t (\tau_{t/t} - \tau_t)^2$ . Thus, as  $k$  increases, the confidence band for  $\pi_{t+k}$  will widen. That is, the variance of the forecast rises so long as  $\sigma_\varepsilon$  is relatively large. As we saw, however, the variation in the permanent component of inflation has collapsed in the recent period.

**Figure 3.4: Inflation Forecasting:  
The Change in Uncertainty as the Horizon Increases**



The figures plot the forecast of U.S. inflation  $k$  quarters ahead,  $E_t \pi_{t+k} = \tau_t$ , for 2Q 75 and 1Q 06 together with the 90% confidence interval ( $1.65$  times the standard error,  $\sqrt{p_{1/t} + \sigma_\eta^2(t) + k\sigma_\varepsilon^2(t)}$ ) as a function of the forecast horizon.

Figure 3.4 compares the second quarter of 1975 with the first quarter of 2006 in the United States. During the mid-1970s, the U.S. inflation trend ( $\tau$ ) was roughly 10 percent and the standard deviation of the innovations to the trend ( $\sigma_\varepsilon$ ) was 1.7 percentage points.<sup>9</sup> Consequently, as the forecast horizon rose from 1 to 4 to 12 quarters, the 90 percent confidence interval for the inflation forecast widened from  $\pm 3\frac{1}{2}$  to  $\pm 6$  to  $\pm 10$  percentage points. By contrast, in early 2006 trend inflation was less than 2.5 percent and the standard deviation of innovations to that trend had fallen to 0.3 percentage points. As a result, the 90 percent confidence interval now starts  $\pm 1$  and widens to  $\pm 2$  percentage points as the forecast horizon increases from 1 to 12 quarters.<sup>10</sup>

### 3.4. Real GDP Growth in the G-7

Using data on annualized quarterly growth in real GDP (calculated as 400 times the log difference) we estimate the model of equations (3.5)-(3.7). Figure 3.3 shows the raw data in the left column, together with estimates of the standard deviation in the right column. These estimates show the well-known volatility decline. Importantly, though, the observed decline in the standard deviation of real growth occurs at different times in different countries. Table 3.4

<sup>9</sup> Since these are the filtered rather than the smoothed estimates of the level and volatility of the inflation trend, these numbers do not match the ones reported for the United States earlier in this section.

<sup>10</sup> Note another potentially important implication of the dramatic fall in the ratio of  $\sigma_\varepsilon$  to  $\sigma_\eta$  is that the inflation trend were to suddenly rise, it would take much longer to realize it today than it would have in the 1970s.

reports the median standard deviation of the growth across decades. This ordering reveals the clear fall from a level of nearly 3 percent to less than half of that (with the notable exception of Japan, where the decline is modest).

<b>Median of Standard Deviation</b>					
	<b>Full Sample</b>	<b>1970-79</b>	<b>1980-89</b>	<b>1990-99</b>	<b>2000-06</b>
<b>Canada</b>	2.30	2.32	2.56	1.58	1.32
<b>France</b>	1.41	2.69	2.00	1.12	0.66
<b>Germany</b>	2.18	2.70	2.08	2.33	2.23
<b>Italy</b>	1.64	3.55	1.89	1.52	1.33
<b>Japan</b>	1.41	1.69	1.41	1.31	1.25
<b>United Kingdom</b>	1.95	2.50	2.20	1.60	1.20
<b>United States</b>	2.11	2.78	1.81	1.43	1.32
<b>Median</b>	<b>2.11</b>	<b>2.69</b>	<b>2.00</b>	<b>1.52</b>	<b>1.32</b>

Summary statistics computed from data plotted in Figure 3.3.

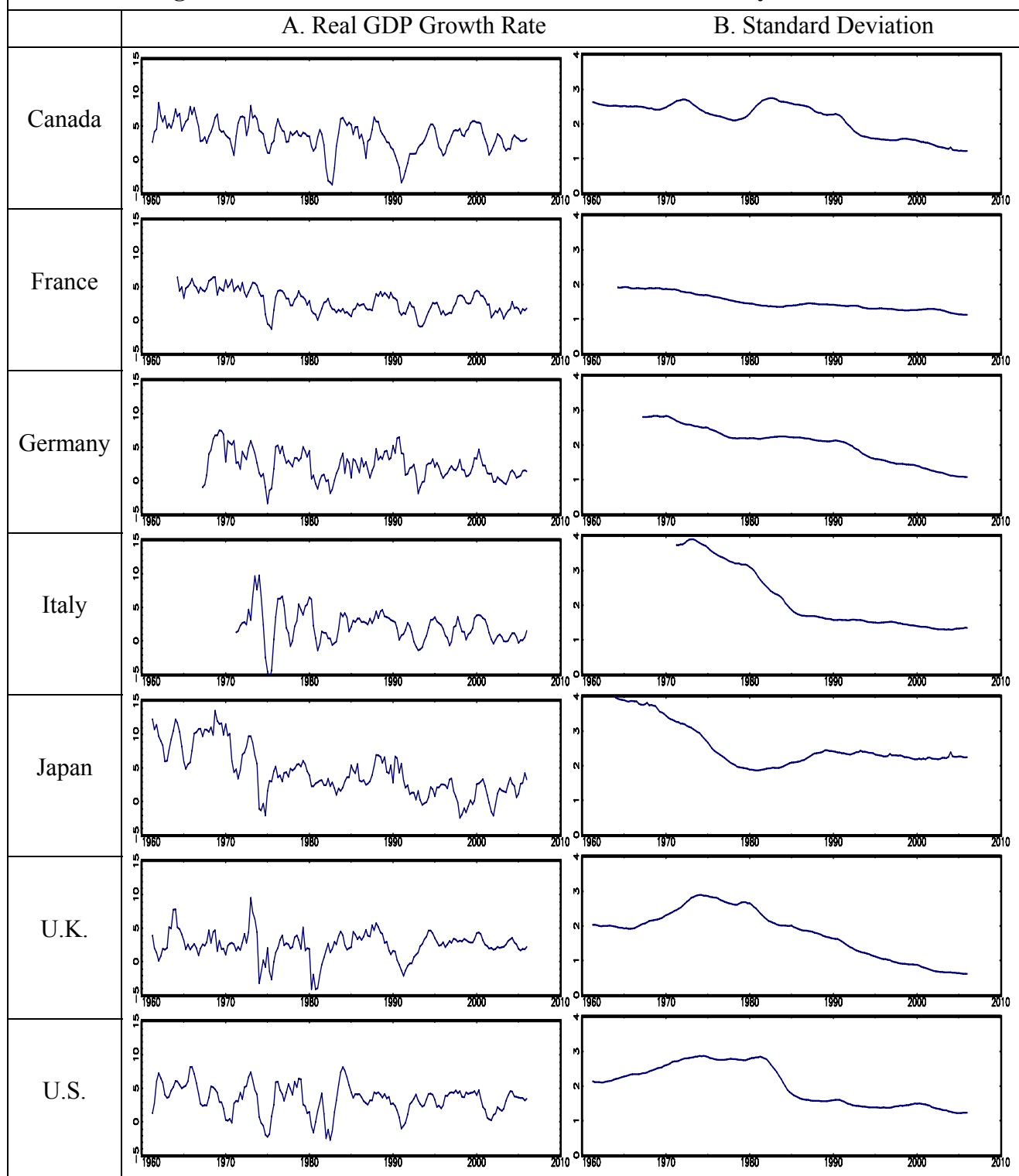
	<b>Maximum <math>\sigma_{\Delta GDP}</math></b>		<b>Minimum <math>\sigma_{\Delta GDP}</math></b>		
	<b>Date <math>\sigma_{\Delta GDP} &lt; 2</math></b>	<b>Level</b>	<b>Date</b>	<b>Level</b>	<b>Date</b>
<b>Canada</b>	4Q 91	2.75	4Q 82	1.21	3Q 05
<b>France</b>	3Q 94	2.90	1Q 74	0.61	3Q 05
<b>Germany</b>	3Q 78	4.37	3Q 61	1.87	4Q 80
<b>Italy</b>	3Q 84	3.91	2Q 73	1.29	1Q 04
<b>Japan</b>	4Q 78*	1.93	1Q 65	1.12	1Q 06
<b>United Kingdom</b>	2Q 93	2.85	4Q 68	1.07	1Q 06
<b>United States</b>	2Q 84	2.88	3Q 74	1.22	1Q 05

\*For Japan the threshold is 1.5.  
Source: Computed from data plotted in Figure 3.5.

Dating the beginning of the Great Moderation for the various G-7 economies is somewhat difficult. Based on a variety of methods in the literature, the U.S. start is mid-1984. That is also the date when the estimated standard deviation of annual GDP growth rates ( $\sigma_{\Delta GDP}$ ) in our model fell below 2 in the United States. Using this level as a benchmark, Table 3.5 locates the approximate start date of the Great Moderation in the remaining six countries. As is clear, some of these dates come well before the decline in the United States (Germany and Japan), some well after (Canada, France and the United Kingdom), and some are coincident (Italy). In sum, there is far less evidence of clustering than in the inflation process, a view that is buttressed by other dating schemes for the Great Moderation.<sup>11</sup> This different timing pattern should be important in assessing factors that can account for the Great Inflation and the Inflation Stabilization.

<sup>11</sup> Cecchetti, Flores-Lagunes and Krause [2005] use a battery of standard break-date tests to locate the changes in the volatility of real growth across a broad cross-section of countries. Because the model is somewhat different, the break dates are as well. But the conclusion remains that the moderation in growth in the G-7 countries came at distinctly different times. Summers [2005] also estimates a wide divergence of break dates for the growth moderation.

**Figure 3.5: Annual Real GDP Growth Rates and Volatility in the G-7**



Notes: Annual GDP growth rates are  $100 \times \ln(\text{GDP}_t / \text{GDP}_{t-4})$ , and the data for France, Germany and Italy have been adjusted for outliers as described in the text. Sample periods begin in 1960 for the U.S., U.K. and Japan; 1961 for Canada; 1963 for France; 1966 for Germany; and 1970 for Italy. All samples end in 1Q 2006.

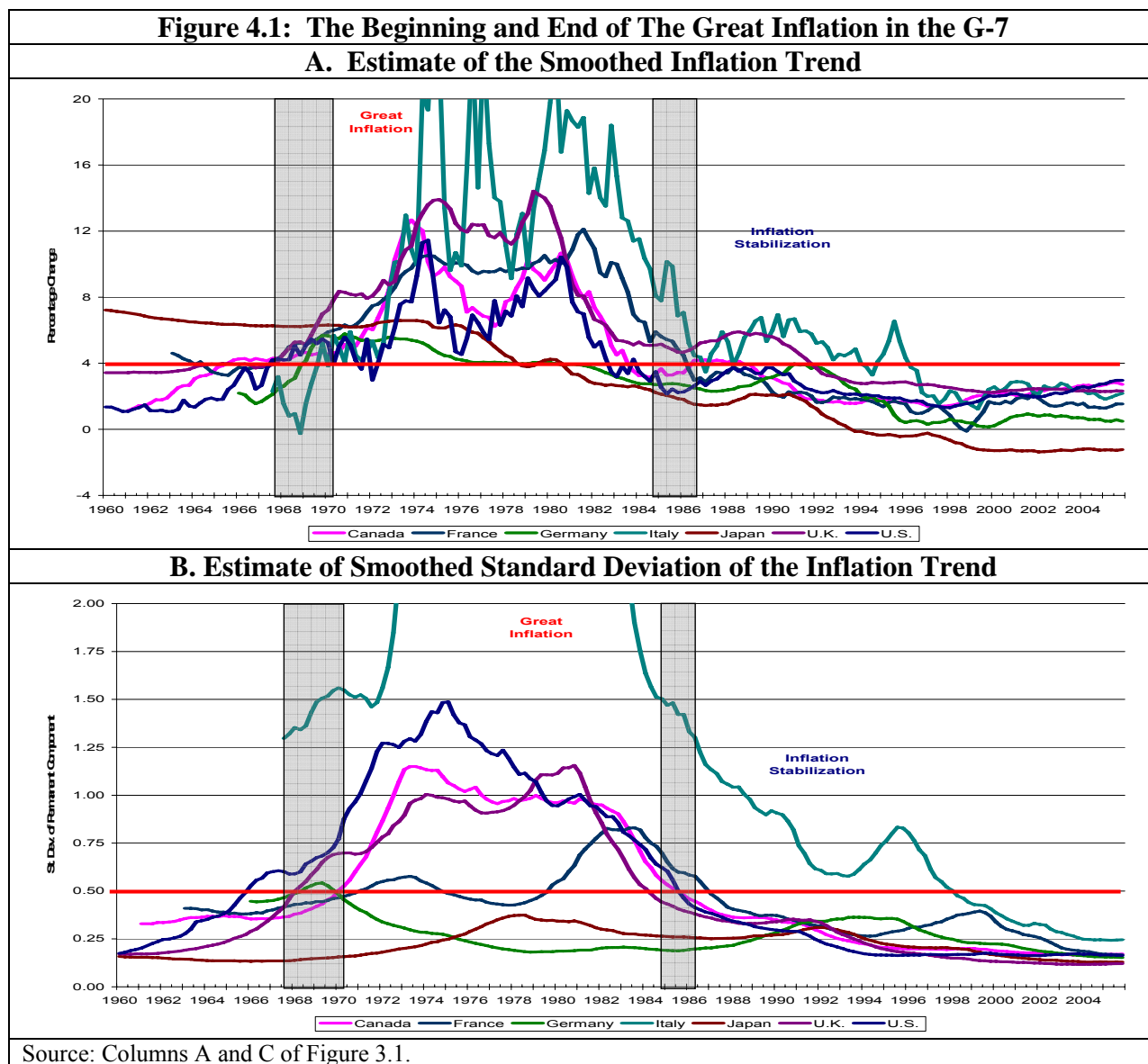
### 3.5 Summary

This section has presented estimates of trend inflation for the G-7 countries for the post-1960 period, along with estimates of the volatility of trend inflation. The estimates suggest three broad conclusions:

- The level and volatility of inflation typically rose in the late 1960s in G-7 countries and fell in the 1980s. In most of the G-7 countries, this pattern was synchronized. Germany and Japan appear to be significant outliers.
- The reduction in variability of real activity across the G-7 countries was far less synchronized.
- The stabilization of inflation in the G-7 countries means that the current estimate of the volatility of trend inflation is at or very near the sample low in each country and only modestly above zero.

### 4. The Changing Inflation Process across Countries: Candidate Influences

What can explain the change in the inflation process that occurred nearly simultaneously across countries? Is there some exogenous event, or set of them, that could have triggered the changes in monetary policy that brought about the Great Inflation and the subsequent Inflation Stabilization?<sup>12</sup> Before listing the possibilities, it is useful to plot the inflation trend and its standard deviation for all seven countries on the same picture. The result of this exercise is in Figure 4.1. This figure, which is complementary to the ones in the previous section, includes gray bars that denote the approximate beginning and end of the Great Inflation: 4Q 67 to 2Q 70 and 3Q 84 to 3Q 86.



<sup>12</sup> The view that monetary policy became more effective after the 1970s in stabilizing inflation is widely held. See, for example, Boivin and Giannoni (2006).

These dates do not necessarily correspond to conventional dating of the Great Inflation in the United States. For example, Meltzer argues for an earlier start around 1965, while most observers date the end of the Great Inflation from the advent of the Federal Reserve’s new procedures in October 1979. Nevertheless, this model-supported dating scheme provides a useful mechanism for international comparison, focusing attention on both the common start and long duration of the Great Inflation in most countries, and on the outliers of Germany and Japan.

Our primary objective in this section is to examine the likely causes of this common timing of the beginning and end of the Great Inflation. In doing so, we also cast some light on the Great Inflation explanations described in Section 2. Before we explore a list of possibilities, it is useful to note that real-side explanations are unlikely to account for this pattern. The reason is that, while the G-7 countries did experience changes in both the trend and volatility of their real growth rates, these shifts are not clustered in time. This conclusion is immediately evident from looking at column B of Figure 3.5 as well as the dating in Table 3.5, the estimates of the time-varying standard deviation of real growth. While volatility fell across the entire G-7, it did not do so in a synchronized fashion.

Returning to the question at hand, we are looking for economic factors that would have prompted G-7 monetary policymakers (excluding those in Germany and Japan): (1) to allow the Great Inflation to begin in the late 1960s; and (2) to end the Great Inflation by the mid-1980s.

The literature is replete with candidate explanations for these patterns. Based on theory and observation, we believe that the Great Inflation is a monetary phenomenon that could not have occurred without excessive policy accommodation on a sustained basis. Nevertheless, we include a variety of well-known cost-push candidates in our evaluation because it is possible that – as Nelson has argued – policymakers in some countries misread such factors as causes for sustained inflation, or – as Christiano and Gust suggest – these factors triggered “expectations traps,” or – as Orphanides has suggested – they were associated with large misestimates of key policy drivers.

<b>Table 4.1 Candidate Influences</b>	
<p><b><u>A. Stable Trends</u></b>                      Trade Openness (4.A1)                      Financial Openness (4.A2)                      Unionization Rates (Table 4.3)                      Services Share in Value Added (4.A3)                      Manufacturing Share in Value Added (4.A4)</p>	<p><b><u>B. Other Developments</u></b>                      Oil Shocks – Hamilton Filter (4.B1)                      Oil and Commodity Prices (4.B2)                      U.S. Fiscal Stance (4.B3)                      Exchange Rate Regime                      Labor Share (Pct. Dev. from Avg., 4.B4)                      Strike Days Lost (4.B5)                      Trend Productivity (4.B6)                      Unemployment Rate (Mov. Avg., 4.B7)                      Output Gap (Mov. Avg., 4.B8)                      U.S. 10 Yr. Yield and Volatility (4.B9)                      U.S. Inf. Expectations &amp; Volatility (4.B10)</p>
<p>Notations in parentheses refer to the figures in the appendices A and B. For example, (A1) is Appendix A, Figure A1.</p>	

Table 4.1 distinguishes two classes of candidate explanations. The first column identifies patterns that are characterized largely by a stable trend, as can be seen in the graphs in Appendix A and (with regard to unionization rates) in Table 4.2. Many of these trends have been highlighted in recent years as factors affecting the level or volatility of inflation in the industrial world. For example, Mumtaz and Surico [2006] find a negative relationship between trade openness and inflation. To the extent that financial openness allows the current account to buffer demand shocks, it also may be associated with reduced inflation pressure. Rogoff [2003] argues that the trend toward greater international competition has reduced policymaker incentives to accommodate inflation. Using OECD panel data, Bowdler and Nunziata [2005] find a positive link between unionization and inflation.<sup>13</sup> Finally, casual observers – in what may be seen as an “accounting” view of inflation – sometimes associate the reduced volatility of inflation with the rising share of services, which generally have lower price volatility.

	<b>1960</b>	<b>1970</b>	<b>1980</b>	<b>1990</b>	<b>2000</b>	<b>2003</b>
<b>Canada</b>	30	31.6	34.7	32.9	28.1	28.4
<b>France</b>	20	21.7	18.3	10.1	8.2	8.3
<b>Germany</b>	40	32.0	34.9	31.2	25.0	22.6
<b>Italy</b>	34	37.0	49.6	38.8	34.9	33.7
<b>Japan</b>	33	35.1	31.1	25.4	21.5	19.7
<b>United Kingdom</b>	45	44.8	50.7	39.3	29.7	29.3
<b>United States</b>	24	23.5	19.5	15.5	12.8	12.4

Sources: Jelle Visser, “Union Membership Statistics in 24 Countries,” *Monthly Labor Review*, January, 2006. 1960 figures are from Clara Chang and Constance Sorrentino, “Union Membership Statistics in 12 Countries,” *Monthly Labor Review*, December 1991. The U.S. figure for 1960 is interpolated from a comparison of two data sets in Chang and Sorrentino.

Yet, it is hard to see how any of these stable trends can individually or collectively explain the narrow cluster times of the Great Inflation and Inflation Stabilization, let alone the sustained pattern of excessive accommodation in most of the countries. The problem is two-fold. First, most of these explanations have been posited in response to the more recent apparent reductions in inflation pressures. For example, “globalization” has been put forth as a possible explanation for the downward price pressures experienced over the past decade.<sup>14</sup> For such an explanation to be tenable in the face of the pattern of inflation dynamics that we see in Figure 4.1, there would have to have been a *decline* in globalization during the late 1960s – something that we surely did not see.

A second difficulty with the explanations based on trade or financial openness, unionization rates, or the relative share of services in value added, is that there is no evidence that any of these factors display a marked break during the intervals when the Great Inflation started and ended. These various measures move too smoothly to explain the sudden and typically coincident shifts that we see in the inflation process.

<sup>13</sup> Bowdler and Nunziata do not control for wage indexation rates, which presumably are higher in more unionized economies, and which change markedly over time. Cecchetti [1987] found that government intervention in the wage-price process, rather than inflation per se, prompted changes in wage adjustment provisions of collective bargaining contracts.

<sup>14</sup> For the argument that economic integration has altered the determinants of inflation, see Borio and Filardo (2007). For the counterview, see Ball (2006) and Ihrig, et al (2007). For evidence that the rise over the past decade of major new low-wage producers had little impact on OECD inflation, see Pain et al (2006).



It is conceivable that such trends played an *indirect* role in what we see. One argument goes like this: If the temporal clustering of the Great Inflation-Inflation Stabilization reflected a leader-follower decision pattern among central banks, and such trend factors had a major influence on the leader, then the effect could be propagated geographically. The dating of the Great Inflation – prior to the end of Bretton Woods – is consistent with a leader-follower pattern in which U.S. inflation was transmitted abroad through the fixed exchange rate mechanism. However, none of these specific trend factors are prominent in the various accounts of U.S. monetary policy in the 1960s. And, with regard to the Inflation Stabilization, the different timing in Germany and Japan belies a leader-follower description of that episode.

Our list of “other developments” in the second column of Table 4.1 contains substantial nonlinearities or discontinuities that appear to offer greater chance of a link with the observed Great Inflation-Inflation Stabilization pattern. Nevertheless, they generally fall short.

For example, the 1970s oil and commodity price shocks – however measured – occur well *after* the beginning of the Great Inflation and, in the case of Germany, after the Inflation Stabilization. This timing is consistent with recent assessments that question the exogeneity of the oil and commodity price shocks (see Barsky and Kilian [2001] and Bernanke [2004]). To be sure, average inflation peaks coincide with these shocks in the 1970s even in the countries with the most disciplined monetary policies (see Table 3.2). Yet, in these countries, the peaks seem to represent one-off price-level events – corresponding to what the Bundesbank used to call “unavoidable inflation” in its annual monetary targeting regime. They do not correspond with sustained movements of  $\sigma_e$  in Germany or – after 1974 – in Japan. In particular, Japan’s vastly different economic experiences following the first and second oil shocks are consistent with a policy learning process about the costs of accommodation and with Japan’s relatively early Inflation Stabilization.

Continuing with the “B” list in Table 4.1, one might view high and rising bond yields as an incentive for policymakers to end the Great Inflation. However, inflation expectations appeared to undershoot regularly in the 1970s, at least in the United States. Consequently, U.S. 10-year real yields generally were low in the period, and rose sharply only *after* the Fed’s 1979 policy shift. Similarly, there is little evidence from the amplitude of output gap fluctuations of an incentive to end the Great Inflation.

Several B-list candidate explanations for the inflation pattern do seem plausible. First, as contemporary observers noted, the fixed exchange rate regime probably transmitted U.S. inflationary impulses abroad and curbed the ability of some monetary policymakers to restrain domestic price pressures, at least where capital controls were limited. In this sense, purely domestic candidates for U.S. monetary policy errors in the late 1960s – such as the pro-cyclical U.S. fiscal stance – also become relevant outside the United States.<sup>15</sup> In those countries where cross-border capital flows were not severely constrained, the advent of a floating currency regime became a *necessary* condition for inflation control.

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<sup>15</sup> According to the CBO measures of the U.S. cyclically adjusted fiscal stance and the output gap, the late 1960s still stand out as a period of very large fiscal stimulus amid large excess aggregate demand.

However, it is very unlikely that the international transmission of U.S. inflationary policies under the fixed-exchange rate mechanism served as the common cause of the Great Inflation throughout the G-7. Capital market openness varied substantially across the G-7 in the late 1960s. An openness measure constructed by Chinn and Ito (2005) suggests that only Canada, Germany and the United States allowed free cross-border capital flows by 1970. The other G-7 countries – France, Italy, Japan, and the United Kingdom – had varying degrees of controls. These results are consistent with the view that most large non-reserve countries retained considerable monetary independence even under Bretton Woods and that domestic developments had a significant influence on their policy stances.<sup>16</sup>

The fixed exchange rate regime may have played a key role in Germany's brief episode of inflation volatility in the late 1960s. Shortly after the demise of Bretton Woods, the German central bank acted quickly to establish a credible anti-inflationary framework. Outside Germany, however, the new floating regime proved insufficient to trigger such action, suggesting that other factors generally drove policy accommodation and delayed the Inflation Stabilization. In the United States, the exchange rate regime probably was inconsequential for the Great Inflation, but the dollar crisis of the late 1970s provided one incentive to end it.

Structural changes in labor markets and in productivity trends may have contributed to policy errors in many countries, either through faulty reliance on cost-push theories (as in Romer and Romer or Nelson), through expectations traps (as in Christiano and Gust), or through miscalibration (as in Orphanides). For example, there is some evidence of a pickup in the aggressiveness of wage demands in the late 1960s. With the exception of the United Kingdom, G-7 labor shares rose relative to their long-term averages between the late 1960s and early 1970s. Over the same period, the number of strike days lost per 1000 employees surged in several countries. Separately, the Inflation Stabilization corresponds in time with a geographically widespread reduction of strike days lost: To the extent that such strikes and lost production had resulted from impairment of the price signaling mechanism amid high and volatile inflation, they also provided an incentive for ending the Great Inflation.

Separately, consistent with the Orphanides view, most countries experienced a slowdown of productivity growth and a rise of trend unemployment around or not long after the Great Inflation that may have contributed to policy errors and delayed the Inflation Stabilization.<sup>17</sup> Japan experienced the sharpest productivity slowdown after the first oil shock, suggesting that this shift was an important factor in its policy learning process. Most countries also had become used to low unemployment rates in the 1960s, and probably underestimated how far and how long the equilibrium level of unemployment would rise.

Over time, however, the rising inflation trend in these cases should have alerted policymakers in countries that sought to keep unemployment too low or to grow beyond potential. Either very slow learning or a more complex mechanism would appear necessary to explain the duration of the Great Inflation in the typical G-7 economy. The examples of Germany and Japan underscore

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<sup>16</sup> See, for example, Darby et al. (1983).

<sup>17</sup> We note that there is the possibility that Orphanides has it backwards and that high inflation created the productivity slowdown. This is certainly consistent with the timing that we find, as the inflation trend rises prior to the decline in real growth.

that the learning process could have been quicker. The early disinflations in Germany and Japan ought to have posed a challenge to those G-7 policymakers who believed that demand management could not lower inflation or who expected the costs of disinflation to be intolerably high. That other countries did not follow Germany or Japan would appear consistent with Meltzer's view that political factors – especially the lack of acceptance for high unemployment episodes – played a significant role in delaying Inflation Stabilization elsewhere until the damage from inflation became politically overriding.

The Kozicki-Tinsley hypothesis – namely, that the U.S. Great Inflation resulted from the Fed's intermediate money-targeting procedures – is highly U.S.-specific. In favor of this view, the effectiveness of money targeting in Germany may have reflected greater stability of money demand than in the United States. However, that stability also may have been a result (rather than a cause) of a more effective inflation anchor. Moreover, policy procedures varied substantially across the G-7 during the 1970s. Consequently, the geographic breadth of the Great Inflation and the degree of synchronization of the Inflation Stabilization raises doubts about country-specific, idiosyncratic explanations like this one.

Thus far, we have only mentioned monetary policy implicitly, examining each of the candidate influences as a potential trigger for the change in policy that then brought on the change in the inflation process which we find in the data. In the next section, we turn to an explicit examination of central bank behavior and the framework used to conduct policy. The role of central bank behavior also is the subject of the remainder of this report.

Before moving on, however, it is worth making three observations that follow directly from the evidence presented thus far. First, no single factor appears sufficient to account for the policy accommodation that sustained the Great Inflation or for the common timing of the Inflation Stabilization. The outlier performance of Germany and Japan appears inconsistent with monocausal accounts (including several described in Section 2) that do not take account of different or changing policy preferences. At the same time, accounting for the common timing of the Great Inflation and Inflation Stabilization in most cases by a coincident shift of policy preferences is unsatisfying because it remains unclear what might have prompted such coincidence.

Second, the Inflation Stabilization occurred throughout the G-7 long before monetary economists developed their current consensus about how policy should be conducted. While central bankers may have intuitively understood that they should be raising real interest rates in the face of inflation increases and positive output gaps, the theoretical foundations for such reaction functions (what are now commonly known as Taylor rules) were a long way off. The same can be said of policy regimes like inflation targeting, first implemented in New Zealand in 1988; as well as the desirability of central bank independence, which only took hold firmly in the 1990s.

We make this observation not to belittle the valuable theoretical knowledge and the improved policy frameworks developed over the past two decades, but to highlight that they were not needed to end the Great Inflation. Moreover, the relative speed with which Germany and (to a lesser extent) Japan acted to disinflate suggests that the Great Inflation and the Inflation Stabilization were not solely a result of changing economic understanding.

Third, our estimates of the standard deviation of the trend ( $\sigma_{\varepsilon}$ ) are now so low in the entire G-7 that they do not distinguish between those countries that explicitly target inflation and those that don't – or those with common monetary policies and the rest. Put another way, simple measures of this type no longer suffice to distinguish levels of monetary policy credibility across the G-7.

## 5. Shifts in Policy Regimes and the Evolving Inflation Process

To recap, we have established that the beginning and end of the Great Inflation are remarkably synchronized across the G-7 countries, albeit with important and revealing exceptions. Further, we have shown that this timing, with a start in the late 1960s and an end in the mid-1980s, is inconsistent with a host of candidate explanations.

With that in mind, we now examine evidence for the proposition that changes in trend inflation and the variance of its innovation over time were the result of changes in central bank policy regimes. We consider evidence for the United States in some detail, and then look more briefly at Germany, Japan, and the United Kingdom. Our strategy is to follow Judd and Rudebusch (1998a and 1998b) and identify shifts in policy regime with large, sustained deviations in policy-controlled interest rates from a constant-coefficient Taylor rule. In other words, we look for periods when policymakers set interest rates at levels that differ substantially from those implied by a simple benchmark that has fit the policy rate history of the past two decades reasonably well.

### 5.1 Measuring the Economy's Deviation from Potential

We begin with John Taylor's original 1993 policy rule specification:

$$i^{\text{ff}} = 2 + \pi + \frac{1}{2}(\pi - 2) + \frac{1}{2}(y - y^*). \quad (5.1)$$

In this rule, the federal funds rate ( $i^{\text{ff}}$ ) is set equal to the assumed level of the long-run equilibrium real interest rate (2 percent) plus current inflation ( $\pi$ ) plus one-half of the gap between current inflation and an assumed target of 2 percent ( $\pi - 2$ ), plus one-half of the output gap (measured as the percentage deviation of  $y$  from  $y^*$ ). In computing the benchmark rule-implied interest rate path, we use the core Consumer Price Index. With the exception of seasonal factors, this series is not subject to historical revisions in the way that the Personal Consumption Expenditure Price Index and GDP deflator are.<sup>18</sup>

While use of the CPI avoids most real-time data problems for inflation measurement, the output gap is a very different story. One well-known problem is that both current and potential output are revised regularly, so there are important vintage effects in measuring the output gap. Rather than rely on one specific technique, we consider five measures of the economy's deviation from its potential: three based on the quantity of real output and two based on the level of unemployment. The first three are as follows:

- (1) Deviations of current GDP from the current Congressional Budget Office (CBO) estimates of potential output.

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<sup>18</sup> We do not build a dynamic model, so the deviations of actual from rule-implied interest rates can only be interpreted on a period-by-period basis. That is, we do not ask what the interest rate path would have been had policymakers been following the rule, since we do not model the impact of a different historical interest rate path on the current endogenous levels of inflation and output.

- (2) The real-time measure of the output gap computed by Orphanides (2003), which is based on output gaps published historically in the *Annual Economic Report* of the Council of Economic Advisers (CEA).
- (3) An alternative real-time measure of the output gap estimated using real-time data for real GDP from the Federal Reserve Bank of Philadelphia's website.<sup>19</sup>

As an alternative to the output gap, we also construct two measures of the unemployment gap.<sup>20</sup> These are:

- (1) The CBO's current estimate of the full-employment unemployment rate (NAIRU) minus the current measure of the unemployment rate.
- (2) A real-time estimate of the NAIRU minus real-time data on the unemployment rate, where the real-time NAIRU estimate is based on a Hodrick-Prescott (HP) filtered real-time unemployment rate prior to 1992 and on CBO's real-time NAIRU measure after 1992.

These various measures of the economy's deviation from potential are shown in Figure 5.1. Orphanides' real-time estimate shows much larger output gaps in the 1970s than the current data. It also remained consistently below zero during the 1960s and 1970s, whereas the current estimate tended to fluctuate around (both above and below) zero. Many observers in the 1960s believed the NAIRU was quite low (4% or less). The CEA assumed that it remained there during the 1970s. However, in contrast to current estimates of the NAIRU, the CEA concept may have been viewed more as an absolute lower bound for attainable unemployment, and the associated level of potential output viewed as an upper bound for real GDP.

In this sense, shortfalls of output from potential constructed during the period may not have been judged as large as they would seem today. Taylor (2000) has suggested that policymakers at the time took such gap estimates with a grain of salt, and that officials like Federal Reserve Board Chairman Arthur Burns and then-CEA Chairman Alan Greenspan did not base their policy decisions and advice on them. As evidence of political influence on these gap measures, Taylor reports that there was a move to lower estimates of potential output and raise those of the NAIRU shortly after the 1976 presidential election. Kozicki and Tinsley argue that the FOMC probably relied on unemployment, rather than estimates of potential output, to measure slack. They also note that "CEA natural rate estimates are infrequently cited in the FOMC Memorandum of Discussion during the 1970s, and do not appear to have been supported by staff forecasts."

In light of these considerations, we chose to construct estimates of the trend in real output and of the output gap using only real-time data on real output. That is, we calculate an underlying trend

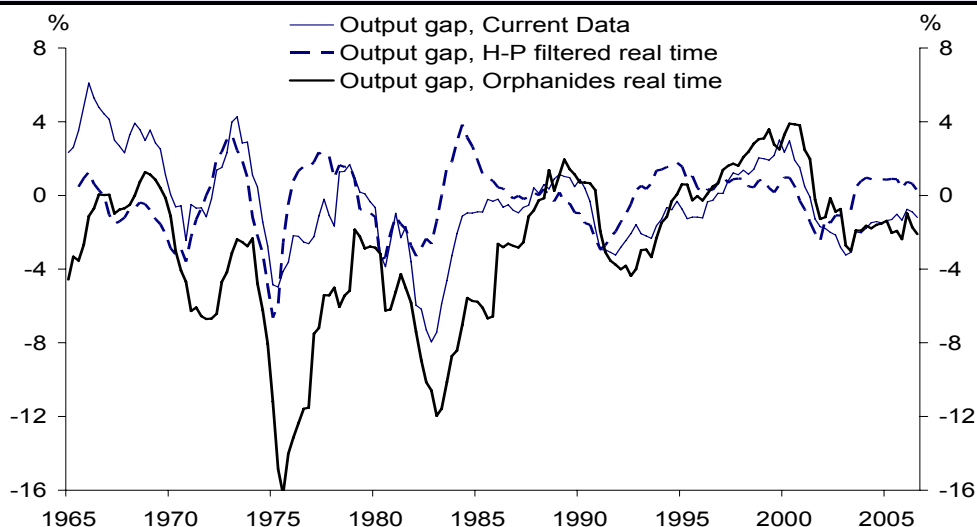
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<sup>19</sup> To compute the output gap for a given quarter, a Hodrick-Prescott (HP) filter, with a smoothing parameter of 1600, was estimated utilizing only data from 1959 to that quarter (and available during that quarter) to yield a measure of potential output for that quarter. The gap in that quarter is the percent deviation of real-time output from this real-time potential estimate.

<sup>20</sup> When using the unemployment gap in the Taylor rule, we double the coefficient on the output gap, assuming a standard Okun's Law relationship between output and unemployment gaps.

in real output using data that was available at each point in time in the past. While our technology for computing the trend (HP filter) was not available at the time, the capacity to compute trends in a more rudimentary fashion was. Our alternative measure (Figure 5.1) shows considerably smaller output gaps during the 1970s than the Orphanides measure and a clear tendency to fluctuate around zero.

**Figure 5.1 Output Gap Measures**

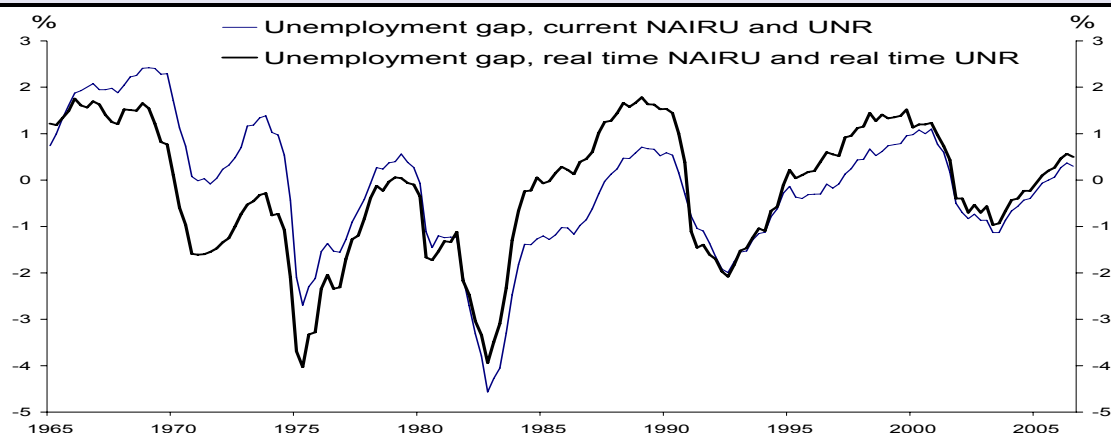


Note: Measures the percentage deviation of actual from various measures of potential output.  
Sources: Congressional Budget Office, Federal Reserve Bank of Philadelphia, Orphanides (2003) and authors' calculations.

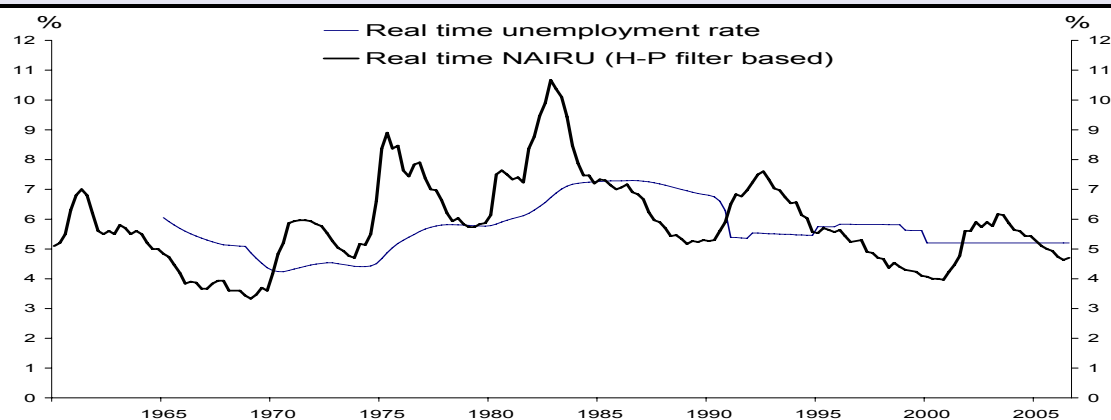
As noted above, we also constructed an unemployment gap by estimating the NAIRU at each point in time using a slowly-adjusting HP filter of *then-available* data on the unemployment rate.<sup>21</sup> This estimated “real-time” gap differs only modestly from one based on current data (Figure 5.2). The unemployment rate and our real-time NAIRU estimate are shown in Figure 5.3. The figure suggests that the trend of the unemployment rate during the 1970s would have been viewed as higher than the 4% NAIRU estimate held by the CEA during that period. In any event, while estimating economic slack usually is a challenging and error-prone exercise, we are skeptical that policymakers would have been misled by the data as much and as long as the Orphanides estimates suggest.

<sup>21</sup> In computing our real-time NAIRU, we employed a smoothing parameter  $\lambda$  equal to 10,000. This high value of  $\lambda$  is consistent with the view that analysts and policymakers would have been slow to adjust their estimate of NAIRU.

**Figure 5.2 Unemployment Gap Measures**



**Figure 5.3 HP Filter Estimate of Real-Time NAIRU**



Note: The HP-filter NAIRU series is spliced with CBO real-time measure around 1990.

## 5.2 Monetary Policy Regime Shifts and Inflation Trends in the U.S.

Do deviations of policy interest rates from the level implied by the Taylor rule foretell changes in the inflation process? We interpret large, persistent changes in the mean deviations as evidence of a shift in the policy regime. How do these deviations relate to the shifts in the trend and volatility of inflation ( $\tau$  and  $\sigma_\varepsilon$ ) that we observed in previous sections? To address these questions, we compute policy rate deviations as the Taylor rule-implied rate *minus* the actual federal funds rate,

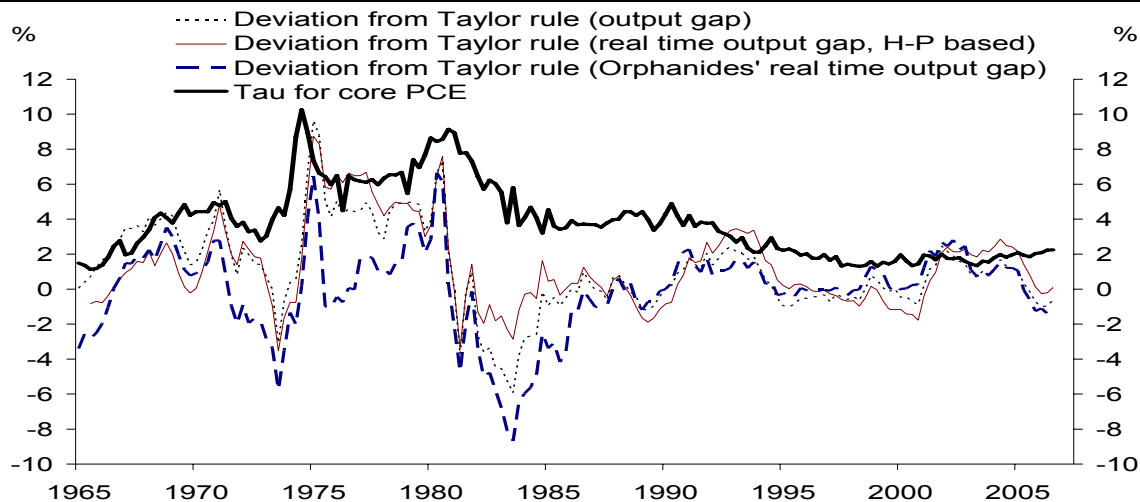
$$\text{Deviation} = [2 + \pi + \frac{1}{2}(\pi - 2) + \frac{1}{2}(y - y^*)] - i^{\text{ff}}, \tag{5.2}$$

for the various measures of  $(y - y^*)$  discussed above. This computation means that if we locate a period when the deviation is persistently positive, so that the rate implied by the rule is routinely above the actual funds rate, the policy regime is accommodative. Analogously, a persistently

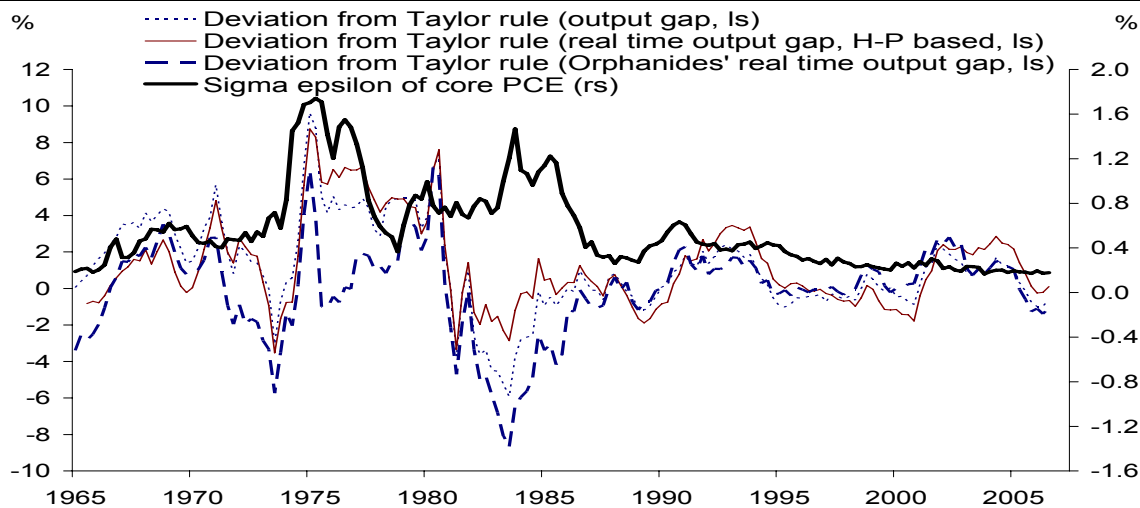


negative deviation, with the prescribed rate regularly below the actual rate, suggests a more restrictive regime.

**Figure 5.4 Trend Core PCE Inflation and Policy Rate Deviations from a Taylor Rule**



**Figure 5.5 Volatility of Trend Core PCE Inflation and Policy Rate Deviations from a Taylor Rule**



	Great Inflation 1965Q1-1980Q4		Inflation Stabilization 1981Q1-1989Q4		Low Inflation 1990Q1-2006Q3	
	Mean	Mean Absolute	Mean	Mean Absolute	Mean	Mean Absolute
	<b>Output Gap</b>					
<b>Current Estimate</b>	3.51	3.64	-1.38	1.61	0.52	0.96
<b>H-P Real Time</b>	3.15	3.43	-0.51	0.99	0.89	1.36
<b>Orphanides</b>	1.02	2.14	-2.77	2.83	0.70	0.94
	<b>Unemployment Gap</b>					
<b>Current Estimate</b>	3.78	3.96	-1.77	1.94	0.61	1.01
<b>H-P Real-Time</b>	2.51	2.94	-0.83	1.73	0.91	1.03

Deviation =  $[2 + \pi + \frac{1}{2}(\pi - 2) + \frac{1}{2}(y - y^*)] - i^{ff}$ , where  $\pi$  is the core CPI, and  $(y - y^*)$  is the various measure of the output or unemployment gap.

Figures 5.4 and 5.5 provide visual evidence of the linkage between the Taylor rule deviations based on alternative measures of output gaps and (smoothed) estimates of the trend and volatility of core PCE inflation.<sup>22</sup>

These figures reveal several points. First, positive policy rate deviations emerged during the latter 1960s (that is, the actual fed funds rate fell increasingly short of the Taylor rule), around the time of the rise in the filtered values of  $\tau$  and  $\sigma_\varepsilon$  for core PCE. This pattern suggests that a more accommodative policy regime was a “trigger” for the step-up in inflation during the late 1960s. However, the gap between current and real-time estimates of the output gap in that period leaves open the possibility that policy miscalibration played a significant role.

The policy rule deviations spike in the mid- and late-1970s, roughly the same time when  $\tau$  and  $\sigma_\varepsilon$  did. This pattern suggests that the combination of accommodative policy and large supply shocks contributed to the spiking of inflation. The deviations then plunged into negative territory during the early 1980s, as policy rates moved well above Taylor rule predictions following the implementation of new operating procedures under Chairman Paul Volcker. This period marked the onset of the Inflation Stabilization, as  $\tau$  and  $\sigma_\varepsilon$  plunged. After the Fed returned to an interest-rate targeting framework in the early 1980s, policy rate deviations have been much smaller, while both  $\tau$  and  $\sigma_\varepsilon$  have followed relatively smooth and subdued paths.<sup>23</sup>

The evidence about policy-regime shifts can be summarized by computing the average (and average absolute) deviations of the federal funds rate from the Taylor-rule implied level over different sub-periods (see Table 5.1). Visual inspection of the foregoing charts suggests that the deviations were moving up and were generally positive from the latter 1960s to 1980, were sharply declining or substantially negative through the 1980s, and fluctuated more narrowly around zero thereafter. These phases lead the periods that we have identified (based on  $\sigma_\varepsilon$  and  $\tau$ ) as the Great Inflation and the Inflation Stabilization. Such a time lead makes sense if one allows

<sup>22</sup> The patterns shown here for the trend and volatility in the core PCE inflation rate are virtually the same as those for the trend and volatility of the core CPI.

<sup>23</sup> Policy rate deviations from the Taylor rule prescriptions based on unemployment gaps tell much the same story.

for lags in the effects of monetary policy (including a widespread recognition of a change in the regime).

With the exception of the policy rate deviations computed using Orphanides' measure of the output gap, mean deviations from the Taylor rule were three to four times larger (in an accommodative direction) during the late 1960s and 1970s than they have been since 1990. The average deviations were substantially negative (restrictive) during the 1980s. While the Taylor-rule deviations based on Orphanides' output gap measure were significantly smaller than the other deviations during the Great Inflation, they were still significantly positive and larger on average during that period than in the recent period, and they showed a much larger shift in a negative direction during the Inflation Stabilization. As we noted earlier, there are reasons to think that the Orphanides-based policy rate deviations are biased downward.<sup>24</sup> Thus, while miscalibrations probably added to policy errors, they do *not* appear solely responsible for the dynamics of the Great Inflation. At the same time, the observed pattern may be consistent with Primiceri's suggestion that policymakers also misjudged inflation's persistence during the 1970s.

### 5.3 Monetary Policy Regime Shifts and Inflation Trends in Other Countries

In sections 3 and 4, we highlighted the commonality of shifts in inflation trends across most G-7 countries. Our findings in this section with regard to U.S. monetary policy raise the following question: Have similarly-measured shifts in policy regimes in other countries been fundamental contributors to the evolution of their inflation processes? To address this question, we examined policy rate deviations in Germany, Japan, and the United Kingdom. The Taylor rules used in these cases were simplified from estimates in Cukierman and Muscatelli (2003) as follows:

$$\text{Germany:} \quad i = 2.88 + \pi + \frac{1}{4}(\pi - 2.0) + \frac{1}{4}(y - y^*) \quad (5.3)$$

$$\text{Japan:} \quad i = 1.91 + \pi + \frac{1}{2}(\pi - 1.0) + \frac{1}{4}(y - y^*) \quad (5.4)$$

$$\text{United Kingdom:} \quad i = 3.63 + \pi + \frac{1}{4}(\pi - 2.0) + \frac{1}{2}(y - y^*) \quad (5.5)$$

The constant terms in each case were estimated so that the policy rate deviations after 1985 averaged to zero. Central bank policy rates for each country were used as the interest rates. The inflation rates are from the headline CPIs for Germany and Japan and the RPI for the United Kingdom. The output gaps for each country were taken from the *OECD Economic Outlook* database. We examine each of these policy-reaction functions over the period starting in the late 1960s and extending through the early 1990s.

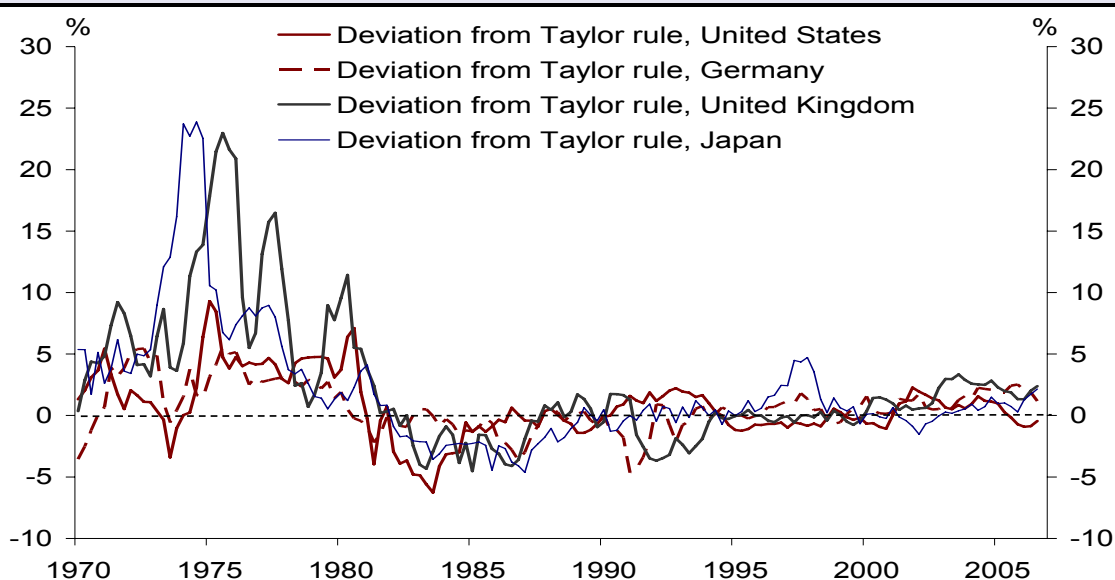
In estimating the Taylor-rule rates for these three countries, data limitations compelled us to use current, rather than real-time, data. Because the U.S. results reported in the previous section were not very sensitive to this choice, this limitation seems unlikely to affect our qualitative conclusions. We gauge the evolution of the inflation process in each of these countries using the smoothed estimates of  $\tau$  and  $\sigma_\varepsilon$  based on the GDP deflators. For comparison, we also include

<sup>24</sup> As we noted above, the levels of the output gap may have been viewed at the time as higher than official estimates suggested, so that the policy rate deviations may be understated.

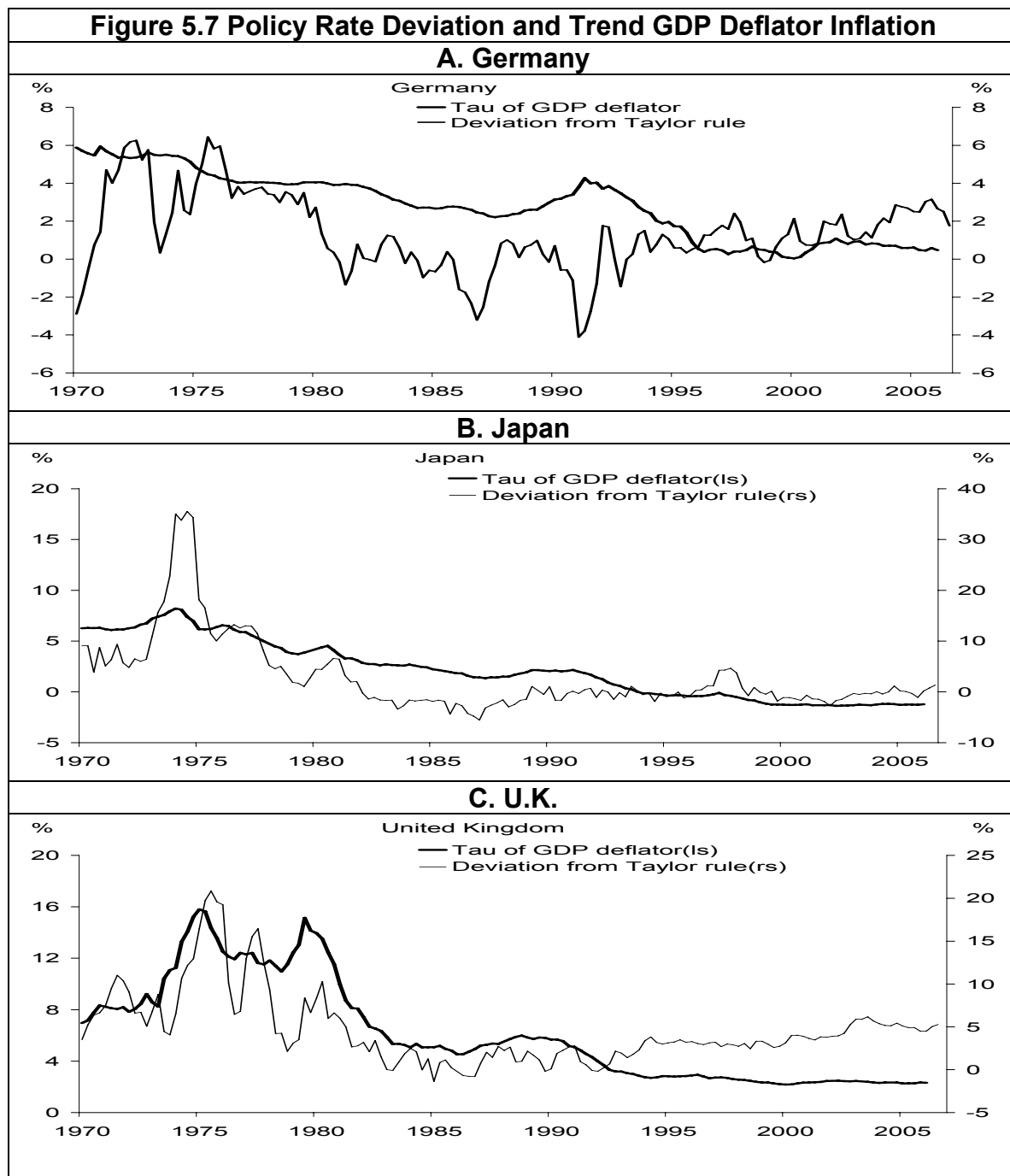
comparable results for the United States (again using current data for the Taylor rule and smoothed estimates of the GDP deflator trend and the standard deviation of its innovation).

Deviations of policy-controlled interest rates from those implied by the various Taylor rules are plotted in Figure 5.6. The patterns of the policy rate deviations are qualitatively similar to the U.S. pattern: The deviations generally were much larger and more positive during the 1970s and more negative during the 1980s than they have been more recently. However, there are significant quantitative differences across countries, with the 1970s deviations in Japan and the United Kingdom much larger (more accommodative) than in the United States, and the deviation in Germany somewhat smaller.

**Figure 5.6 Policy Rate Deviations Across Countries**



Following our earlier procedure, we plotted for each country estimates of the policy rate deviations together with estimates of the behavior of trend inflation (based on the GDP deflator). Figure 5.7, which is analogous to Figure 5.4 for the United States, reports the results for Germany, Japan and the United Kingdom.



For Germany (Panel A of Figure 5.7), the relationship between policy rate deviations from the Taylor rule and  $\tau$  is loose, although higher trend inflation generally is correlated with accommodative deviations from the policy rule. In both Japan and the United Kingdom (Panels B and C of Figures 5.7), the relationships are much tighter. In both of these countries, the shifts in policy regime were fairly dramatic and largely coincided with changes in the inflation dynamics.

**Table 5.2. Average and average absolute deviations from Taylor rules**

	1970-84		1985-06	
	Mean	Mean Absolute	Mean	Mean Absolute
<b>Germany</b>	1.56	2.25	0.00	1.12
<b>Japan</b>	5.01	5.90	0.00	1.23
<b>U.K.</b>	6.00	6.83	0.00	1.45
<b>U.S.</b>	1.79	3.54	0.00	1.10

*Source:* Computed from the data plotted in Figure 5.6. Note that the means after 1985 are zero by construction.

Table 5.2 summarizes the shifts in policy regime across countries. Splitting the sample period after 1985, we find that deviations from the policy rule were substantially greater during the earlier sub-period than during the recent one (where the mean deviations were zero by construction). As our visual inspection of the data suggested, policy rate deviations are considerably larger for Japan and the United Kingdom than for the United States, partly reflecting the relatively high coefficients on inflation gaps in the Taylor rules for those countries. In the case of Germany, the shift between the two sub-periods is less pronounced. This pattern is consistent with the general perception that the Bundesbank (and its successor, the European Central Bank) pursued a more consistent anti-inflationary policy and achieved a relatively stable pattern of trend inflation over the full period.<sup>25</sup>

Summing up the international comparisons, three of the four countries exhibit a qualitatively similar pattern in which deviations from a simple policy rule during the 1970s and early 1980s are consistent with the timing of the increases and declines in trend inflation (and its volatility). The peak in the inflation trend and the undershooting of interest rates relative to those implied by a Taylor rule generally occurred around the mid-1970s. There also is some evidence that increases in deviations from policy rules (in an accommodative direction) accompanied increases in trend inflation in the early 1970s. Judging from Figure 5.7, policy rate deviations in the early 1980s appeared negative (or sub-average) in the three non-U.S. economies, indicating the same sort of shift in the direction of policy restraint as occurred in the United States during that period.

## 5.5 Discussion

Our policy rule investigation suggests that shifts in monetary policy regimes were central to the large movements in the trend of inflation (and in the volatility of its innovation) over the past four decades, not just in the United States, but also other countries. During the latter 1960s and 1970s, central banks were less responsive to inflation shocks (and possibly more responsive to growth shocks) – or they pursued higher inflation targets -- than has been the case after 1985. Consistent with the judgments of many analysts cited in section 2, we believe that this earlier, accommodative pattern led to the Great Inflation. While misestimates of the U.S. economy's

<sup>25</sup> The constant term in the Taylor rule for the US was reduced from 2.0 to 1.75 to move the mean deviation for 1985-06 to zero. This makes the US result for the earlier period look much the same as Germany's, but recall the deviation for the US was substantially negative over the first half of the 1980s, and generally more positive than Germany's during the 1970s.

deviation from potential may have contributed to excess accommodation, they do *not* appear sufficient to account for the scale and duration of the Great Inflation, in contrast to the Orphanides hypothesis.

During the early 1980s, central banks responded forcefully to inflation shocks or overshoots. As many authors have suggested, this shift led to the Inflation Stabilization. Absent changes in the ability of the central banks to pre-commit, these restrictive policy shifts do not appear consistent with the “expectations trap” hypothesis. In the United States, the availability of useful real-time evidence on the economy’s deviation from potential raises doubt that policy learning alone could account for the long delay in sustainably reducing policy accommodation after the Great Inflation began. Other factors, including changing political influences or a (possibly related) shift in policymaker preferences, may have contributed.

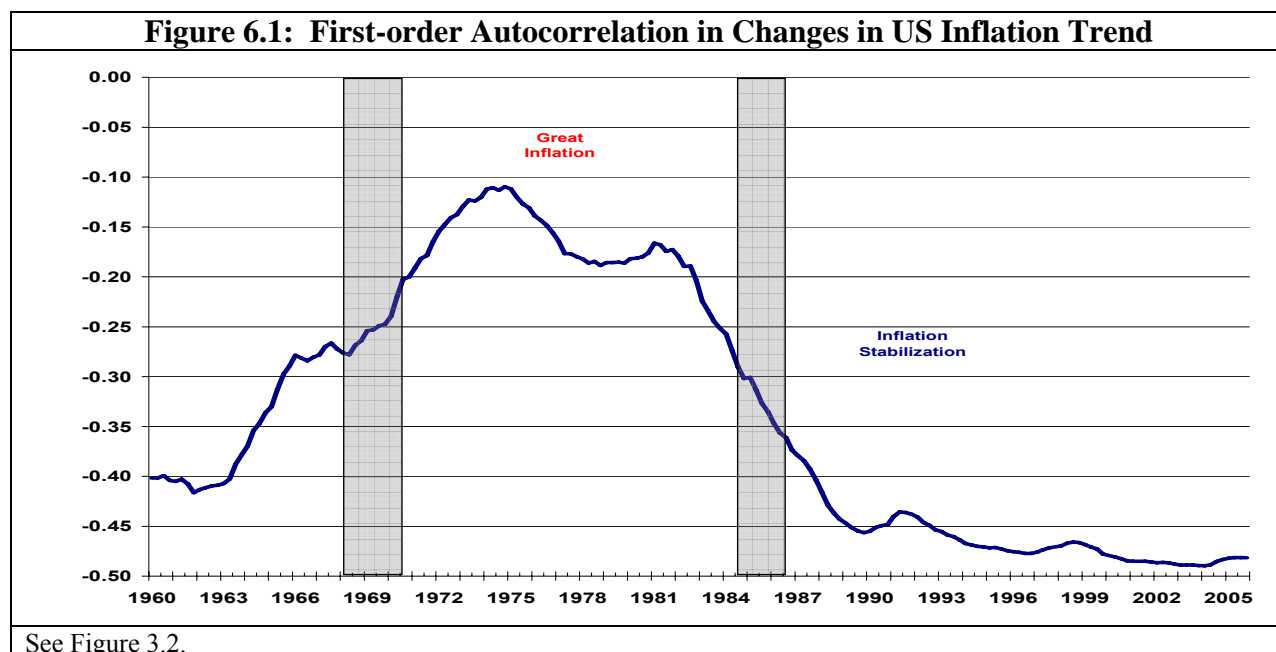
## 6. A Small Structural Model of Inflation Dynamics

In previous sections, we documented changes in the time-series properties of the inflation process in the United States and other G-7 economies, and focused on the central role of monetary policy in accounting for these changes. In this section, we seek to examine whether the inflation dynamics implied by a workhorse macroeconomic model are capable of matching what we document earlier.

Closely following Roberts (2006), we examine a three-equation structural model that links inflation, real activity, and policy-controlled interest rates. The three equations include a Phillips Curve, a dynamic IS curve, and a monetary policy reaction function. Together, these allow us to characterize the dynamic properties of inflation and analyze whether (and under what conditions) this model portrayal can reproduce the changes that occurred in the historical record.

Preceding studies tend to focus on the persistence of inflation, often measured as a sum of autoregressive coefficients or the largest root of the lag polynomial of inflation (for example, Fuhrer (2006), or Rudd and Whelan (2006)). Our exercise differs from earlier work in that we seek to relate the model to more fundamental changes in the inflation process. Recall from Section 3.2 that the UC-SV model implies that the first-order autocorrelation of the change in inflation,  $\rho_{\Delta\pi}$ , varies over time and is uniformly negative.

Figure 6.1 reproduces the implied estimates of  $\rho_{\Delta\pi}$  for the United States. The plot has a very distinctive pattern, rising as high as  $-0.11$  during the Great Inflation, before falling close to the  $-0.50$  minimum during the Inflation Stabilization. Mechanically, we know that this variation arises from time variation in the volatility of the inflation trend: As  $\sigma_\varepsilon$  rose and then fell,  $\rho_{\Delta\pi}$  went with it.





Can we link changes in the parameterization of a simple macroeconomic model with these observed changes in the inflation process? To see, we specify a simple three-equation model, then solve the model for a given set of parameters, and finally compute the model's implied first-order autocorrelation of changes in inflation,  $\rho_{\Delta\pi}$ . By doing this for a wide range of parameter values we are able to characterize the changes that might be the source of the variation that we observe.

## 6.1 Specifying a formal framework

We begin by discussing the pivotal relation in our investigation: the relation between inflation, its past and future values, and real economic activity. This relation, the New Keynesian Phillips curve (NKPC), has been the object of a spirited debate. Substantial disagreement centers on two aspects of the NKPC: (i) the appropriate measure of real economic activity (traditional output gaps or a measure of real marginal cost such as the labor share) and (ii) the extent to which forward-looking behavior matters for inflation, as the common micro-founded argument suggests, or whether backward-looking specifications are more important, as traditional econometric models assume.

We will largely side-step the first argument. We cannot bypass the second concern, because the degree to which inflation is forward-looking or backward-looking appears to be the key means of linking the simple model with the observed changes in the inflation process that are our focus. To highlight this, we specify a standard hybrid NKPC with both backward- and forward-looking elements:

$$\pi_t = \omega \cdot E_t \pi_{t+1} + (1 - \omega) \cdot \pi_{t-1} + \gamma \cdot x_t + \varepsilon_t^{PC} . \quad (6.1)$$

In equation (6.1)  $\pi_t$  is inflation in period  $t$ ,  $\omega$  is the weight on expected inflation,  $x_t$  is the measure of real economic activity, and  $\varepsilon_t^{PC}$  is a disturbance to the inflation process, often interpreted as a supply shock, such as a sudden change in energy prices.

In the NKPC, economic activity is the forcing variable for inflation. As in a standard IS curve, real activity is determined by the level of the real interest rates. And, analogous to the supply-side of the model, we allow for a forward-looking term (again as suggested by theory) and a backward-looking term. The result is:

$$x_t = (1 - \phi) \cdot E_t x_{t+1} + \phi \cdot x_{t-1} - \psi \cdot (r_{t-2} - r^*) + \varepsilon_t^{IS} , \quad (6.2)$$

where  $x_t$  is the output gap;  $r_t$  is the real interest rate;  $r^*$  is the equilibrium real interest rate that is assumed to be a constant; and  $\varepsilon_t^{IS}$  is a disturbance to activity, often interpreted as a demand shock such as a shift due to fiscal policy. Following Roberts (2006), we assume that the real interest rate enters with a two-period lag. As he discusses, this is consistent with the existence of planning lags in production that cause interest rate changes to affect aggregate activity only after some time has passed.

Finally, the model is closed with a determination of the interest rate (nominal, in this case, with the real interest rate given by the Fisher relation). The nominal rate is determined by a Taylor rule where, following Clarida, Galí, and Gertler (1999), we allow for lagged persistence in the policy rate  $i_t$ :

$$i_t = \theta \cdot i_{t-1} + (1 - \theta) \cdot \{r^* + \pi_t + \alpha \cdot x_t + \beta \cdot [\pi_t - \pi_t^*]\} + (1 - \theta)\alpha \varepsilon_t^{MP}. \quad (6.3)$$

Here the central bank's inflation target is  $\pi_t^*$ . Following Orphanides et al. (2000), we interpret the error term  $\varepsilon_t^{MP}$  as measurement error in the output gap. That is, policymakers react to the *observed* output gap  $\tilde{x}_t$ , but the *true* gap  $x_t$  is what appears in (6.3). The error is then  $\varepsilon_t^{MP} = (\tilde{x}_t - x_t)$ . Using data on output gap mismeasurement, Orphanides et al. (2000) find that  $\varepsilon_t^{MP}$  is well approximated by an AR(1). That is,  $\varepsilon_t^{MP} = \delta \varepsilon_{t-1}^{MP} + v_t$ .

Finally, and again following Roberts (2006), we allow the target to drift, reflecting the work of Leigh (2005) and others who find evidence of time variation in the Fed's inflation target. If we allow the target to follow the process:

$$\pi_t^* = \mu \cdot \pi_{t-1}^* + (1 - \mu) \cdot \pi_{t-1}, \quad (6.4)$$

then we can nest the case of a perfectly credible inflation targeter with  $\mu=1$ .

While the time-series properties of the model are complex, two characteristics deserve highlighting: (1) So long as the inflation target changes over time ( $\mu \neq 1$ ), inflation itself will be nonstationary, and (2) the change in inflation has autoregressive and moving-average components.

## 6.2 Parameters describing the economy

We now turn to a description of the parameters we use to calibrate this simple model economy. Some of these parameters are fairly uncontroversial, while others are open to a wide range of disagreement.

The parameter governing the Phillips Curve weight on forward-looking inflation behavior  $\omega$  is the subject of much debate. Some researchers (Galí, Gertler, Lopez-Salido (2005), Sbordone (2003), Rabanal and Rubio (2004)) estimate a value close to 0.75. Others (Rudd and Whelan (2005), Linde (2004), Fuhrer (2006)) argue that the coefficient should be closer to 0.25. In practice, many analysts chose to split the difference and adopt the 0.5 rule of thumb from Fuhrer and Moore (1994). While we use this value in our baseline setting, we also examine the implications of varying the relative weight on the forward- and backward-looking components in the Phillips Curve.

For the slope of the Phillips curve,  $\gamma$ , we use 0.03, a value that would appear to be in the middle of the range of estimates in the literature.<sup>26</sup> The values for the IS-curve parameters are the subject of comparatively little debate. We follow Roberts (2006) and set the weight on forward-looking output,  $\phi$ , equal to 0.5, and the sensitivity of the output gap to the real interest rate,  $\psi$ , equal to 0.1.

Turning to the monetary policy reaction function, we fix the partial adjustment coefficient governing the persistence of the nominal interest rates,  $\theta$ , equal to the commonly estimated value of 0.7. In the baseline analysis, we set the weights on the output and inflation gaps equal to the levels that Taylor originally suggested,  $\alpha=1$  and  $\beta=0.5$ . Since the weight on the inflation gap,  $\beta$ , is thought to have risen when Paul Volcker became Chairman of the Federal Reserve Board in 1979, we also investigate the consequence of changes in this parameter.<sup>27</sup>

The evolution of the implied inflation target is governed by  $\mu$ . There are two reasons that we set this to the relatively high value of 0.99, one economic and the other technical. First, a high value for  $\mu$  suggests a plausibly slow evolution of the inflation target. Second, for many reasonable settings of the other model parameters a large value of  $\mu$  is needed if we are to obtain a unique solution.

In choosing the values of parameters governing the innovation process, we largely follow Roberts and assume the two structural shocks to be white noise with the standard deviations of the Phillips curve ( $\varepsilon_t^{PC}$ ) and IS shocks ( $\varepsilon_t^{IS}$ ) to 0.17 and 0.55, respectively. The ratio of these shocks, the quantity that Fuhrer (2006) emphasizes, equals approximately 0.3, which lies in the middle of the range of estimated values. Finally, we assume that the policy shock  $\varepsilon_t^{MP}$  has an innovation  $v_t$  with standard deviation 1.0 and an autoregressive parameter  $\delta$  equal to 0.9. Consequently, at the benchmark values of the parameters, the scaled shock in the monetary policy reaction function (6.3) – namely,  $(1-\theta)\alpha\varepsilon_t^{MP}$  – has a standard deviation equal to 0.69, or just below that of the IS shock.

### 6.3 Solving the Model

We proceed to solve the model and compute various properties of the first-difference of inflation,  $\Delta\pi$ . To do this, we start by solving out the forward-looking components of the model and writing the change in inflation as a linear function of the current and lagged values of the three shocks: the Phillips-curve shock  $\varepsilon_t^{PC}$ , the IS shock  $\varepsilon_t^{IS}$ , and the innovation to the monetary policy shock,  $v_t$ .<sup>28</sup> That is, we compute the vector-moving-average representation of the change in inflation

$$\Delta\pi_t = A_1(L)\varepsilon_t^{PC} + A_2(L)\varepsilon_t^{IS} + A_3(L)v_t, \quad (6.5)$$

<sup>26</sup> A recent paper by Li (2006) suggests that  $\gamma$  is much smaller, reporting values closer to 0.001.

<sup>27</sup> See Clarida, Galí, and Gertler (2000).

<sup>28</sup> For a description on how to solve models of this sort, see King and Watson (1998 and 2002).

where the  $A(L)$ 's are lag polynomials with coefficients that depend on the parameters of the model. From the solution (6.5), we proceed to calculate the first-order autocorrelation of the change in inflation,  $\rho_{\Delta\pi}$ , and then compare this result with the values that we report in Figure 6.1. We also parse the variance and autocovariances of  $\Delta\pi_t$  into the three possible sources. This decomposition reveals which of the shocks is responsible for the properties of  $\Delta\pi_t$ .

Table 6.1 presents results for these model-implied properties. Starting with the benchmark calibration in the upper left of the table, we note three regularities. First and most important, the first-order autocorrelation is *positive* and very large. Second, the decomposition of the variance and autocovariances of  $\Delta\pi_t$  indicates that the IS shock plays virtually no role in the volatility and dynamics of inflation. Third, the Phillips curve shock is the only ingredient in the model that is capable of generating negative serial correlation in the change in inflation. However, at the benchmark settings, this negative contribution of  $\varepsilon_t^{PC}$  to  $\rho_{\Delta\pi}$  is insufficient to overcome the large positive contribution from the monetary policy shock  $v_t$ .

There is a useful intuition for the result that the IS and Monetary Policy shocks lead to inflation changes that are positively autocorrelated, while Phillips Curve shocks have the opposite effect. The first two of these,  $\varepsilon_t^{IS}$  and  $v_t$ , are demand shocks that move inflation and the output gap in the same direction, while  $\varepsilon_t^{PC}$  is a supply shock that moves them in opposite directions. To see what happens following a shock, consider the consequences of a positive IS shock. The impact is to drive inflation up – a positive change ( $\Delta\pi > 0$ ) – and to raise the output gap, creating a positive output gap ( $x_t > 0$ ). The positive output gap subsequently drives inflation up further. So, a demand shock leads to a positive change that is followed by *another* positive change. That is the result which we see in the columns of the table 6.1 for the IS and the Monetary Policy Shocks:  $E(\Delta\pi_t \Delta\pi_{t-1})$  is positive.

Now, consider a negative Phillips Curve shock. Here, the impact is to move inflation up and the output gap down. With a negative output gap, the subsequent inflation move is down. So, the supply shock causes inflation to rise and then to fall, the pattern that we see in the columns labeled Phillips Curve in Table 6.1.

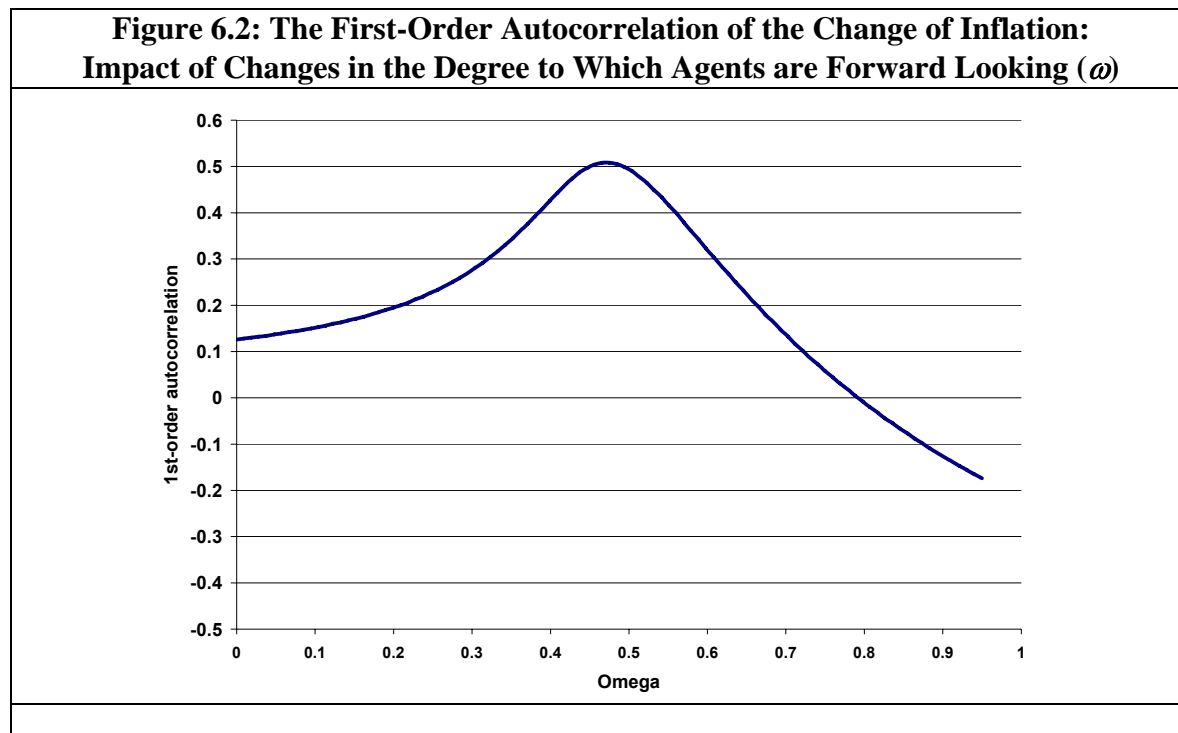
Looking at the table as a whole, we see that matching the large negative estimates of  $\rho_{\Delta\pi}$  reported in Section 3 requires a large value for  $\omega$ , the Phillips curve parameter associated with the degree to which agents are forward looking. This finding does *not* depend on the value of  $\gamma$ , the slope of the Phillips curve; on  $\beta$ , the policymaker's reaction to the inflation gap; or on  $\sigma_v$ , the standard deviation of the shock to the monetary policy reaction function. Importantly, neither a flattening of the Phillips curve, shown in the third panel of table 6.1, nor a more aggressive response of policymakers to a deviation of inflation from its target (seen in the fourth panel), can account for the inflation dynamics that we document in Section 3. By contrast, when we set  $\omega = 0.95$ , the value in the right half of Table 6.1,  $\rho_{\Delta\pi}$  becomes negative and large (in absolute value). The intuition for this pattern is as follows: When agents are forward looking, they know that demand shocks will be countered quickly by policy actions, eliminating the persistence of inflation changes. When IS and Monetary Policy shocks are unimportant, Phillips Curve shocks dominate, prompting inflation changes to be negatively autocorrelated.

While increasing  $\omega$  alone can allow us to match the first-order autocorrelation of inflation during the Great Inflation, when  $\rho_{\Delta\pi}$  was around -0.2, it cannot mimic the  $\rho_{\Delta\pi}$  values (of around -0.5) observed during the Inflation Stabilization. Looking at the table, we see that this outcome requires an additional adjustment to the model calibration. The simplest alteration is to reduce the variance of the monetary policy shock,  $v_t$ . The second panel of results in Table 6.1 are for a case in which  $\sigma_v = 0.1$ , one-tenth of its benchmark value. Together with  $\omega=0.95$ , this yields the result that we seek:  $\rho_{\Delta\pi} = -0.46$ .

<b>Table 6.1: Model-Implied Properties of the First Difference of Inflation</b>										
<b><math>\omega= 0.50</math></b>						<b><math>\omega= 0.95</math></b>				
<b>Decomposition of Variance and Autocovariances in its Sources</b>						<b>Decomposition of Variance and Autocovariances in its Sources</b>				
<b>Lag</b>	<b>Phillips Curve</b>	<b>IS Curve</b>	<b>Mon. Policy</b>	<b>Total</b>	<b><math>\rho_{\Delta\pi}</math></b>	<b>Phillips Curve</b>	<b>IS Curve</b>	<b>Mon. Policy</b>	<b>Total</b>	<b><math>\rho_{\Delta\pi}</math></b>
<b>Benchmark</b>										
<b>0</b>	0.0958	0.0083	0.1542	0.2582		0.0593	0.0023	0.0725	0.1341	
<b>1</b>	-0.0047	0.0043	0.1278	0.1274	0.49	-0.0283	-0.0002	0.0051	-0.0234	-0.17
<b>2</b>	-0.0058	0.0009	0.0946	0.0897	0.35	-0.0016	-0.0004	-0.0003	-0.0022	-0.02
<b>3</b>	-0.0068	-0.0014	0.0587	0.0504	0.20	-0.0001	-0.0003	-0.0024	-0.0028	-0.02
<b>4</b>	-0.0073	-0.0027	0.0251	0.0151	0.06	0.0000	-0.0002	-0.0036	-0.0038	-0.03
<b><math>\sigma_v=0.1</math></b>										
<b>0</b>	0.0958	0.0083	0.0015	0.1056		0.0593	0.0023	0.0007	0.0623	
<b>1</b>	-0.0047	0.0043	0.0013	0.0009	0.01	-0.0283	-0.0002	0.0001	-0.0284	-0.46
<b>2</b>	-0.0058	0.0009	0.0009	-0.0039	-0.04	-0.0016	-0.0004	0.0000	-0.0019	-0.03
<b>3</b>	-0.0068	-0.0014	0.0006	-0.0077	-0.07	-0.0001	-0.0003	0.0000	-0.0005	-0.01
<b>4</b>	-0.0073	-0.0027	0.0003	-0.0097	-0.09	0.0000	-0.0002	0.0000	-0.0002	0.00
<b><math>\gamma= 0.01, \mu=0.995^*</math></b>										
<b>0</b>	0.1024	0.0009	0.0353	0.1386		0.0604	0.0003	0.0093	0.0700	
<b>1</b>	-0.0036	0.0005	0.0306	0.0274	0.20	-0.0287	0.0000	0.0007	-0.0280	-0.40
<b>2</b>	-0.0041	0.0001	0.0250	0.0210	0.15	-0.0015	0.0000	0.0000	-0.0015	-0.02
<b>3</b>	-0.0045	-0.0001	0.0191	0.0144	0.10	-0.0001	0.0000	-0.0002	-0.0003	0.00
<b>4</b>	-0.0047	-0.0003	0.0133	0.0083	0.06	0.0000	0.0000	-0.0004	-0.0004	-0.01
<b><math>\beta=1.0</math></b>										
<b>0</b>	0.0906	0.0078	0.0712	0.1696		0.0587	0.0023	0.0548	0.1158	
<b>1</b>	-0.0060	0.0039	0.0583	0.0563	0.33	-0.0280	-0.0002	0.0038	-0.0244	-0.21
<b>2</b>	-0.0072	0.0007	0.0418	0.0353	0.21	-0.0016	-0.0004	-0.0002	-0.0022	-0.02
<b>3</b>	-0.0080	-0.0015	0.0239	0.0145	0.09	-0.0001	-0.0003	-0.0018	-0.0022	-0.02
<b>4</b>	-0.0079	-0.0026	0.0074	-0.0031	-0.02	0.0001	-0.0002	-0.0028	-0.0029	-0.03
Benchmark parameter settings are $\gamma=0.03, \phi=0.5, \psi=0.1, \rho=0.7, \alpha=1.0, \beta=0.5, \mu=0.99, \delta=0.9, \sigma_{\varepsilon^{PC}}=0.17, \sigma_{\varepsilon^{IS}}=0.5, \sigma_v=1.0$ .										
* The model does not have a unique solution for a lower value of $\mu$ .										

To get a better sense of what the model can and cannot produce, we performed a series of more detailed experiments that focus on the first-order autocorrelation of the change in inflation. We first varied  $\omega$  over its entire range from zero to one. The results of this exercise are plotted in Figure 6.2, which shows  $\rho_{\Delta\pi}$  on the vertical axis against  $\omega$  on the horizontal axis. The results are

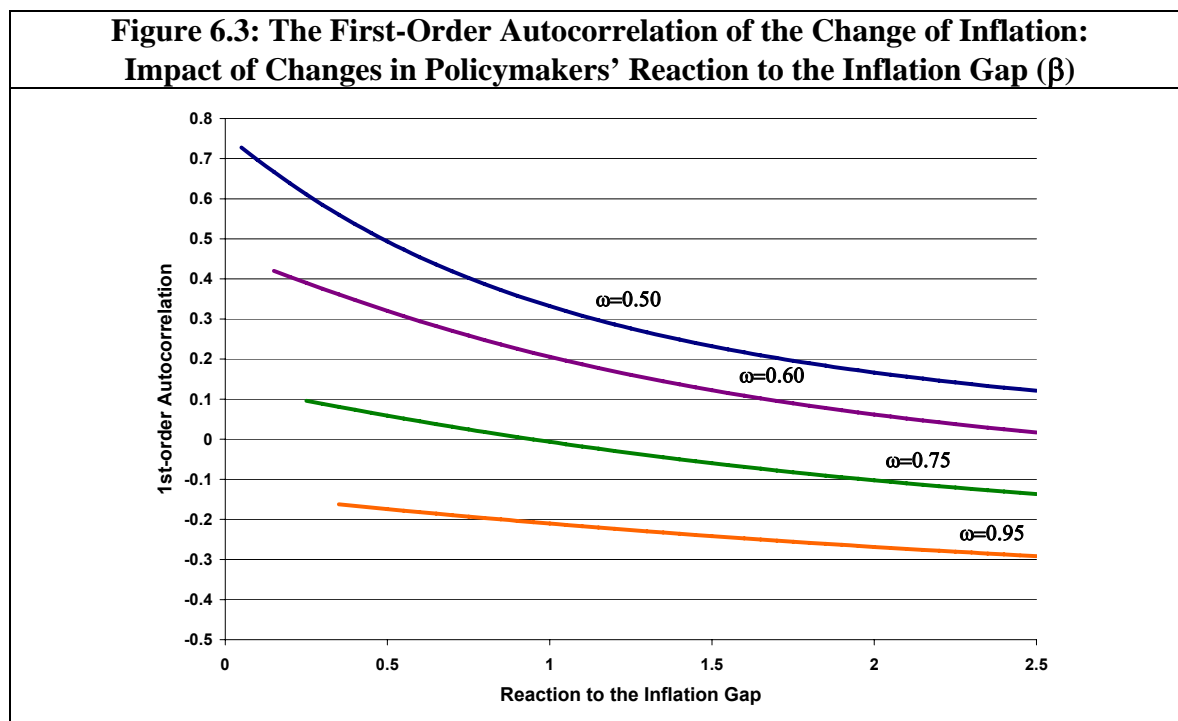
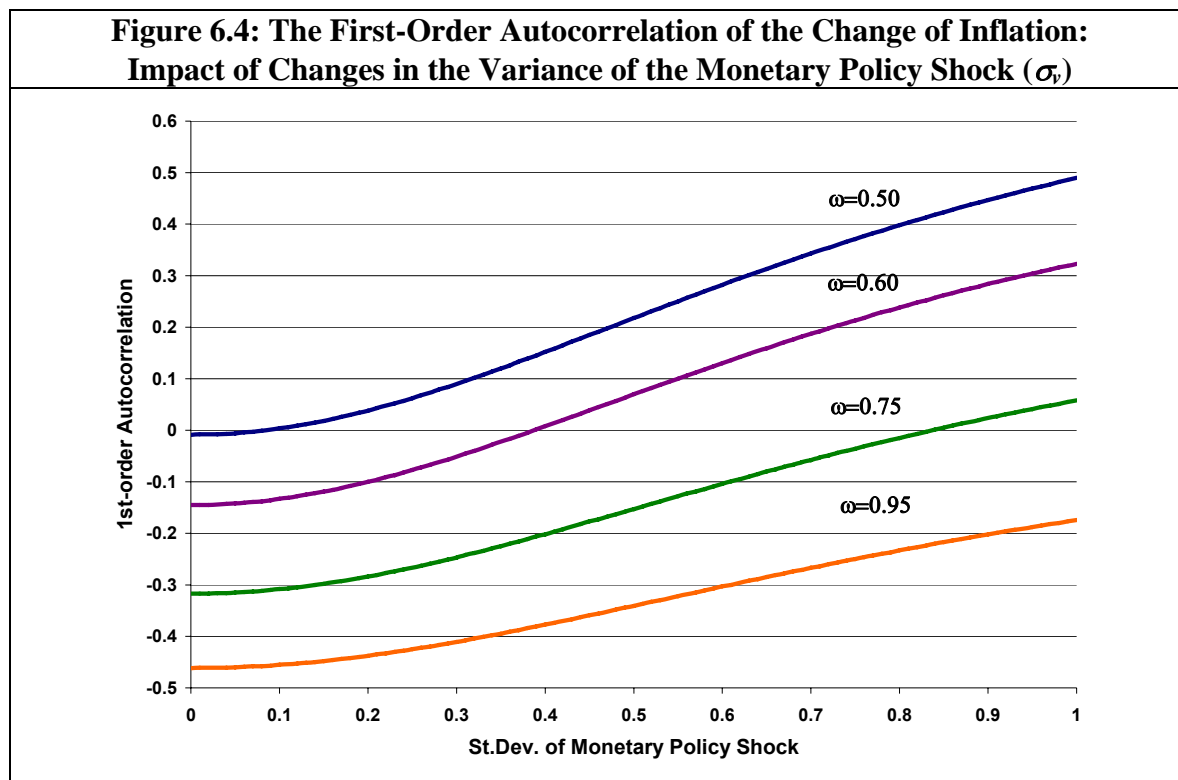
striking: For any value of  $\omega$  below 0.8,  $\rho_{\Delta\pi}$  is positive. Moreover,  $\rho_{\Delta\pi}$  peaks at 0.51 when  $\omega=0.475$ , near its benchmark setting.



The results in Table 6.1 suggest looking more closely at the relationship between the autocorrelation of changes in inflation and the volatility of the monetary policy shock. Figure 6.3 reports the results of a series of experiments that vary  $\sigma_v$  from zero to one, for different values of  $\omega$ . This figure makes it clear that obtaining low values of  $\rho_{\Delta\pi}$  requires both a high  $\omega$  and a low  $\sigma_v$ . In fact, in order to produce a first-order autocorrelation of inflation changes that is below -0.4,  $\omega$  must exceed 0.85. We also note that there is a relationship between  $\sigma_v$  and the coefficient on the output gap in the policy rule,  $\alpha$ . Lower values of  $\alpha$  have an impact that is similar to, but not identical to, reductions in the volatility of the shocks in the rule. For example, with  $\omega=0.95$ , reducing  $\alpha$  from 1.0 to 0 (with all other parameters set at their benchmark values), lowers  $\rho_{\Delta\pi}$  from -0.17 to around -0.31, which is similar to what happens when you cut  $\sigma_v$  from its benchmark value of 1.0 to 0.58.

Finally, we examine the consequences of a change in  $\beta$ , which reflects how aggressively policymakers react to a deviation of inflation from their objective. Figure 6.4 plots the impact of varying  $\beta$  across a wide range from 0.05 to 2.5. For each value of  $\omega$ , we report results for the region of the parameter space over which the model has a unique solution. The results suggest that an increase in  $\beta$  cannot be the primary source of the decline in  $\rho_{\Delta\pi}$ . Once again, the only way for the model to generate inflation changes that have a large negative autocorrelation is for  $\omega$  to be large.<sup>29</sup>

<sup>29</sup> Increasing  $\mu$  to 0.999 does not affect these results.



## 6.4 Discussion

In this section, we examined the ability of a simple three-equation New Keynesian model to replicate the properties of U.S. inflation documented in Section 3. We summarize our findings as following:

- Standard parameterizations of the model are incapable of reproducing the observed negative first-order autocorrelation of the change of inflation ( $\rho_{\Delta\pi}$ ), which ranges as high as -0.15 during the Great Inflation, and is now very nearly -0.50.
- Demand-side (IS and Monetary Policy) shocks create *positive* autocovariances in inflation changes, while Phillips Curve (supply) shocks create *negative* autocovariances. Consequently, the latter must dominate the former if the simple model is to mimic fundamental properties of U.S. inflation.
- Increases in policymakers' responsiveness to inflation deviations from their target ( $\beta$ ) and decreases of the slope of the Phillips curve (the structural response of inflation to the output gap,  $\alpha$ ) have only a very modest impact on  $\rho_{\Delta\pi}$ .
- For supply-side shocks to dominate – as is needed to replicate inflation's observed properties in this model – the model requires both that: (1) agents be very forward looking, so that the weight on expected future inflation in the Phillips curve is well in excess of the benchmark value of one half; *and* (2) shocks to the monetary policy reaction function be relatively small.



## 7. Inflation Expectations and the Inflation Trend

We now turn to several separate, but related, questions: What do inflation expectations tell us about future movements in the inflation trend? If we see increases in inflation expectations, are we at risk of seeing future rises in inflation itself? If so, by how much? Conversely, if the inflation trend rises, how do expectations react? The availability of long time series for inflation expectations limits our analysis of these questions to the U.S. case.

To examine the first question, we estimate the following simple forecasting regression:

$$\tau_{t/t} - \tau_{t-4/t-4} = \beta_0 + \beta_1(\pi_{t-4}^e - \tau_{t-4/t-4}) + u_t, \quad (7.1)$$

where  $\tau_{t/t}$  is the U.S. core consumer price index (one-sided filtered) estimate of  $\tau$  at time  $t$  given information available at  $t$ ;  $\pi^e$  is a candidate indicator for inflation expectations; and  $u$  is an error term. Because changes in  $\tau$  are constructed to be white noise, there is no need to include lags of  $\Delta\tau$  on the right-hand-side of the regression. This parsimony allows us to interpret  $\beta_1$  in two ways. First, it is a measure of the sensitivity of changes in the inflation trend four quarters ahead to deviations of expectations from the inflation trend today. Second, a simple test for whether  $\beta_1=0$  also is a test of Granger causality.

We estimate equation (7.1) from around 1980 in most cases to 3Q 2006 using four different measures of inflation expectations: (1) the Federal Reserve Board staff model's (FRB-US) measure of long-term inflation expectations (FRB)<sup>30</sup>, (2) the Federal Reserve Bank of Philadelphia's survey of professional long-run (10-year) inflation forecasts (SPF); (3) the Michigan one-year-ahead survey (UM1); and (4) the Michigan 5- to 10-year inflation expectations survey (UM5). The results are reported in Table 7.1. The specific sample period used in each case is shown at the bottom. The FRB measure is available over a longer history than the other three, and it is linked to the SPF measure after 1980.

Focusing on columns (1), (3), (5), and (7), we note three patterns. First, the estimated coefficients on  $(\pi_{t-4}^e - \tau_{t-4/t-4})$  are fairly large, about 0.5 for the FRB, 0.7 for the SPF, and over 0.8 for the 1-year and 5- to 10-year Michigan data. Second, in all four cases, the coefficients are significantly different from zero with implied t-ratios greater than 3 (robust standard errors are shown). Finally, for most of these regressions, the  $\bar{R}^2$  values are fairly high, on the order of 0.5 or more.

<sup>30</sup> The FRB series is the same as the SPF survey back to 1990, the same as the Hoey survey precursor to the SPF series during the 1908s, and was a series generated by the FRB model staff prior to 1980.

**Table 7.1 Using Expected Inflation to Forecast Changes in  $\tau$** Sample: Maximum for each  $\pi^e$ 

		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
		FRB	FRB	SPF	SPF	UM1	UM1	UM5	UM5
Intercept ( $\beta_0$ )	$\beta_0$	0.38 (0.22)	0.55 (0.32)	-0.32 (0.13)	-0.31 (0.25)	0.16 (0.20)	1.22 (0.34)	-0.61 (0.07)	-0.59 (0.20)
$(\pi_{t-4}^e - \tau_{t-4/t-4})$	$\beta_1$	0.47 (0.14)	0.50 (0.14)	0.72 (0.20)	0.71 (0.21)	0.84 (0.18)	1.36 (0.11)	0.92 (0.07)	0.92 (0.10)
$B_t$	$\beta_2$		-0.46 (0.33)		-0.09 (0.28)		-1.54 (0.35)		-0.08 (0.22)
$B_t(\pi_{t-4}^e - \tau_{t-4/t-4})$	$\beta_3$		0.41 (0.21)		0.20 (0.27)		-0.71 (0.15)		0.09 (0.16)
Chow Test P-Value	$H_0: \beta_2 = \beta_3 = 0$		0.04		0.75		0.00		0.72
$\bar{R}^2$		0.17	0.17	0.46	0.45	0.36	0.52	0.78	0.78
Sample Size		1Q 1963- 3Q 2006		4Q 1980- 3Q 2006		1Q 1979- 3Q 2006		1Q 1982- 3Q 2006	

Estimates of text equations (7.1) and (7.2). "B" is a dummy variable which takes on the value 1 beginning in 1Q 1994. Robust standard errors, computed with the Newey-West procedure using 4 lags, are shown in parentheses.

To understand these results, consider what would happen if the current inflation trend and expected inflation were equal at 2.5. Now imagine that the Michigan 5-10 year median survey rises by 0.5 percent. The results in column (7) tell us that we should raise our estimate of the inflation trend four quarters ahead by 0.45 percentage points to 2.95%. By comparison, the core CPI trend is only about half as sensitive to the FRB measure, while its sensitivity to the other two expectations measures lies between these two extremes.<sup>31</sup>

To assess robustness, we ask whether there has been a substantive change in the nature of the relationship between inflation expectations and future changes in the inflation trend. Specifically, we examine whether there was a break in the relationship in 1Q 1994, which is close to the mid-sample for three of the series. We implemented the test by running the following regression:

$$\tau_{t/t} - \tau_{t-4/t-4} = \beta_0 + \beta_1(\pi_{t-4}^e - \tau_{t-4/t-4}) + \beta_2 B_t + \beta_3 B_t \times (\pi_{t-4}^e - \tau_{t-4/t-4}) + u_t, \quad (7.2)$$

where  $B_t = 1$  for  $t \geq 1Q 1994$ .

The results for these break tests are reported in the even-numbered columns of Table 7.1. Tests for a structural break – namely, that the coefficients on the two terms including "B" in (7.2) are simultaneously zero – produce p-values of zero for the FRB and UM1 suggesting a break in the relationship.<sup>32</sup> But the SPF and UM5 results show high Chow test p-values, failing to reject the

<sup>31</sup> Like all of the results in this report, these regressions that they are based on quarterly data. This means that we should interpret a change in the expectations variable as a sustained three month change.

<sup>32</sup> A test for an earlier 1985 break in the FRB regression, not shown here, also rejected the null hypothesis of no break.

null hypothesis of stability. A closer look at the FRB and UM1 results suggests that the overall sensitivity of the inflation trend to movements in expectations has *increased* over time. For example, the results in column (2) indicate that a one-percentage-point change in the FRB measure would result in a 0.5-percentage-point increase in  $\tau$  *prior* to 1994. *After* 1994, that same change in the FRB measure is associated with a 0.91 percentage-point rise in  $\tau$  (i.e., the sum of the coefficient estimates for  $\beta_1$  and  $\beta_3$ ).

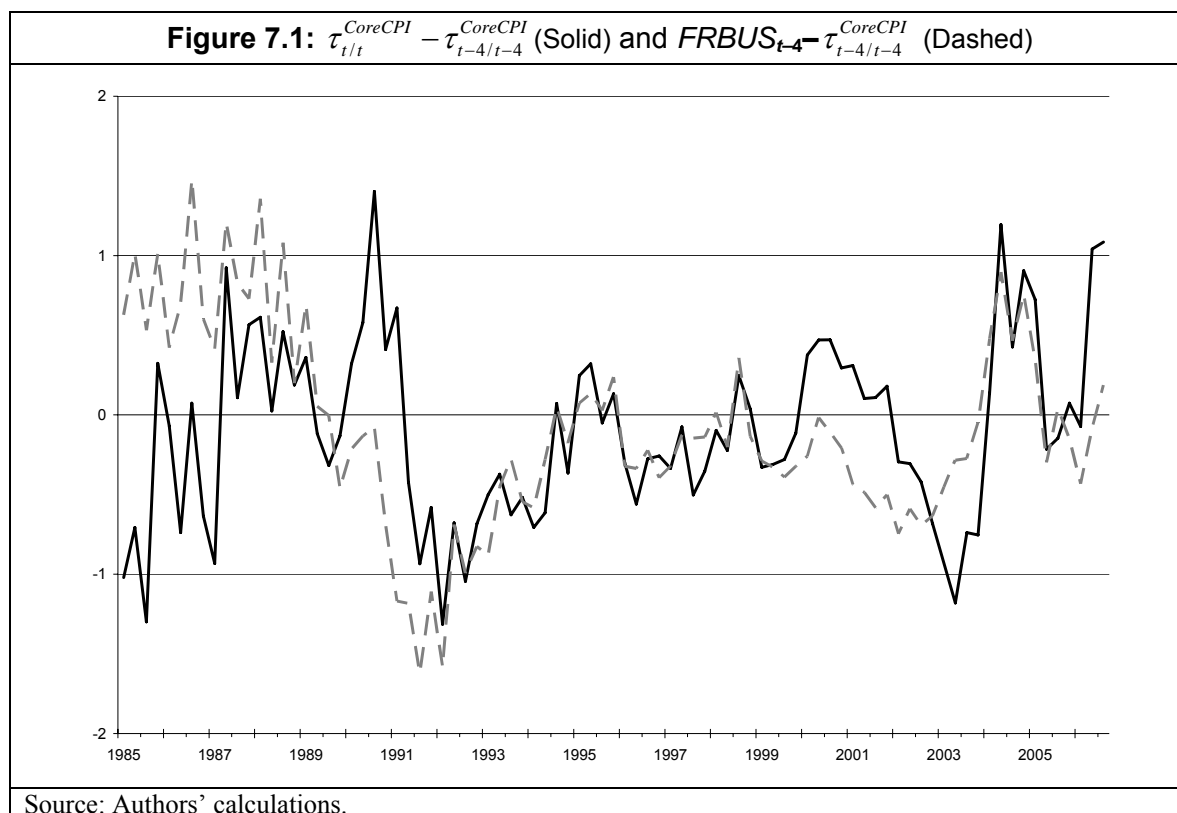
		(1)	(2)	(3)	(4)
		SPF	UM1	UM5	TIPS <sup>1</sup>
<i>Intercept</i> ( $\beta_0$ )	$\beta_0$	-0.30 (0.17)	-0.36 (0.11)	-0.76 (0.19)	0.07 (0.19)
$(\pi_{t-4}^e - \tau_{t-4/t-4})$	$\beta_1$	0.90 (0.16)	0.68 (0.14)	1.10 (0.16)	-0.22 (0.16)
$\bar{R}^2$		0.37	0.43	0.47	0.03

Estimates of text equation (7.1). Sample is 1999 to 2006. Robust standard errors, computed with the Newey-West procedure using 4 lags, are shown in parentheses.  
<sup>1</sup>For TIPS, the sample is 2Q 2001 to 3Q 2006.

For each expectations measure, we also estimated simple versions of the equation over an abbreviated sample period beginning in 1999. All four measures of inflation expectations were statistically significant in explaining movements in  $\tau$ , but the limited amount of data (there are roughly 8 non-overlapping observations) make it difficult to draw meaningful inference from these results (see Table 7.2). Notably, the 10-year TIPS breakeven measure that became available during this period was *not* found to be statistically significant.<sup>33</sup>

Collectively, this evidence indicates that changes in survey measures of inflation expectations serve as a useful early warning signal of an impending change in the inflation trend. Figure 7.1 highlights why equation 7.1 works reasonably well. The solid black line is the left-hand-side variable in the regression – the four-quarter change in the filtered estimate of the inflation trend ( $\tau_{t/t} - \tau_{t-4/t-4}$ ). The dashed gray line is the right hand side of the regression using the FRB measure, showing the deviation of expected inflation from the estimated trend, ( $\pi_{t-4}^e - \tau_{t-4/t-4}$ ). When the timing of the series is shifted to match the regression, they appear closely matched, especially beginning around 1991.

<sup>33</sup> The FRB series was dropped from this exercise, since it is essentially identical to the SPF over this brief sample.



What about making inferences in the opposite direction? What happens to inflation expectations when the inflation trend changes? To answer this question, we examine the following regression:

$$\pi_t^e - \pi_{t-4}^e = \beta_0 + \beta_\pi(L) \Delta \pi_{t-4}^e + \beta_{EC} (\tau_{t-4} - \pi_{t-4}^e) + \beta_{\Delta\tau}(L) \Delta \tau_{t-4}, \quad (7.3)$$

where  $\beta_\pi(L)$  and  $\beta_{\Delta\tau}(L)$  are each 4<sup>th</sup> order lag polynomials. Unlike the inflation trend,  $\tau$ , which is constructed to be a random walk, inflation expectations measures tend to be serially correlated. For this reason, equation (7.3) includes lags in the change in inflation expectations,  $\pi_{t-4}^e$ , as well as lags in the changes in the inflation trend,  $\Delta \tau_{t-4}$ .

To examine if  $\tau$  contains information about  $\pi_t^e$ , we test whether  $\beta_{EC}$  and the elements of  $\beta_{\Delta\tau}(L)$  are simultaneously zero. The p-values for this test range from less than 0.05 for the FRB and UM5 measures, to 0.06 for the UM1 and 0.56 for the SPF. The implication is that, most survey measures of expectations respond when the inflation trend rises.

We conclude that: (1) Signals from several survey measures of U.S. inflation expectations anticipate future movements in the U.S. inflation trend; and (2) when the inflation trend changes, survey measures of expectations are likely to follow. These results support the importance that policymakers attach to monitoring inflation expectations, not just as a gauge of their inflation-

fighting credibility but also, importantly, as an indicator of future movements in the inflation trend.

The first of these two conclusions differs from the assessment in an earlier draft of this report. In that draft, we presented results from regressions (of  $\tau_t$  onto lags of  $\tau_t$  and lags of  $\pi_t^e$ ) in which the null hypothesis that the coefficients on lags of  $\pi_t^e$  were equal to zero could *not* be rejected for many measures of inflation expectations in post-1985 samples. Put differently, the null hypothesis of “no Granger Causality” from  $\pi_t^e$  to  $\tau_t$  could not be rejected. The draft’s conclusion, that there is no statistically significant evidence that inflation expectations help forecast trend inflation in the recent sample period, prompted the following criticism: Because the regressors (inflation expectations) have had relatively low variation recently, the coefficients in the regression were difficult to estimate, so the econometric tests had low statistical power.

This concern about the power of the test led us to replace the Granger-causality regressions, which require estimation of a large number of coefficients, with the parsimonious specification in equation (7.1). This tightly parameterized model focuses specifically on one-year ahead forecasts and imposes the restrictions that, under the null hypothesis,  $\tau_t$  is a martingale and that  $\pi_t^e$  and  $\tau_t$  are cointegrated. The resulting regressions reveal that  $\pi_t^e$  does help predict future values of  $\tau_t$ , a result that is consistent with the pseudo-out-of-sample forecasting comparisons presented in Ang, Bekeart and Wei (2007).

## 8. Conclusions

The inflation history of the G-7 countries underscores the value of securing a monetary policy regime aimed at price stability. The achievement of relatively low and stable inflation for nearly two decades is widely shared, and the timing has been substantially synchronized across countries.

This common international pattern – in which the level and volatility of the inflation trend rose and fell at roughly the same time, with revealing exceptions – guided us in assessing possible triggers for the excessive monetary policy accommodation associated with the Great Inflation. Relatively few cost-push candidates satisfy both the timing and geographic-breadth requirements needed to explain the start of the Great Inflation. Oft-touted oil-and-commodity price shocks do not fit this bill, although they may have contributed to later policy errors that propagated the episode.

While all of the G-7 countries have experienced a fall in the volatility of real growth, they did so at different times. This contrast with the synchronization of the Inflation Stabilization leads us to conclude that, while central bank policy almost surely drove the latter, other factors (in addition to improved monetary policy) probably contributed significantly to the Great Moderation of output growth.

We present evidence that several prominent mono-causal explanations for the lengthy period of misguided monetary policy – aka the Great Inflation – fall short. First, miscalibrations of the economy's capacity or comparable miscalibrations appear too small to account for the scale and duration of the Great Inflation. While they only use data that was available to contemporary policymakers, our measures of simple policy feedback drivers – such as the output gap or the unemployment gap – are simply not so different from current measures, despite historical data revisions. Similar considerations cast doubt on the simplest policy learning models. Since the Great Inflation lasted about 15 years in the United States, why would it take policymakers so long to revise key judgments about excess capacity, equilibrium unemployment, or the long-run slope of the Phillips curve, when inflation routinely exceeded policy forecasts in the period and means to improve estimates of the economy's deviation from potential were available?

Second, explanations relying on the evolution of policymaker understanding of the economy must be squared with the different paths followed in Germany and, to a lesser extent, Japan. The estimated volatility of trend inflation in these countries highlights them as important outliers. Both examples show that a credible, anti-inflationary central bank could keep inflation relatively low and steady, or end a large inflation, even in the face of the common shocks that confronted the G-7. Both examples raise the question why many policymakers and economists in other G-7 countries at times viewed demand management as likely to be ineffective (or prohibitively costly) in ending the Great Inflation, and chose to rely on nonmonetary mechanisms, such as wage and price controls. Finally, both examples highlight the importance of strong political support for stable prices, including a willingness to tolerate painful episodes of unemployment.

Third, the G-7 Inflation Stabilization appears inconsistent with an “expectations trap” model. Neither the theoretical advances nor the improved policy frameworks of the past 20 years were

necessary to end the Great Inflation. The end occurred at a time when economic theorists had begun to argue that time-inconsistency considerations and the inability to make credible commitments would result in a persistent inflation bias in monetary policy. Neither Taylor's rule nor Taylor's principle had been proposed. No central bank had or planned an inflation target. There was no major change in the legal mandate of G-7 banks (except for the Humphrey-Hawkins Act, which did not encourage greater policy restraint). As Blinder (1998) has suggested in the U.S. case, G-7 central bankers followed the Nike motto: They just did it.

Taken as a whole, our analysis indicates that multiple causes, probably including changing policy preferences or political influences (or both), contributed to the duration and scale of the Great Inflation. Eventually, inflation eventually proved so damaging that – even in the face of overestimated sacrifice ratios – central bankers acted to disinflate and then to keep inflation low. The analysis leaves open an important question about the factors that account for the synchronization of policy shifts which ended the Great Inflation.

Since macroeconomic models based on the New Keynesian Phillips Curve (NKPC) have become part of the standard policy evaluation toolkit in the major central banks, we examine the ability of a simple NKPC model to mimic a robust property of estimated G-7 inflation dynamics: the negative serial correlation of inflation changes that intensified after the Inflation Stabilization. To replicate this pattern, the NKPC model requires that: (1) agents be very forward looking; (2) monetary policy shocks have low variance throughout the period; *and* (3) both of these properties became more pronounced during the past 20 years. However, these key characteristics, forward-looking agents and small monetary policy shocks, are at odds with the standard calibration of such models. Perhaps a future specification of the model will resolve this inconsistency with the data.

Finally, we find that several survey measures of inflation expectations help to forecast the estimated trend of U.S. core CPI inflation. This result is consistent with the assessment of Ang, Bekaert and Wei (2007), who find that out-of-sample inflation forecasts which use survey measures of inflation expectations outperform other forecasts. We also find that changes in the estimated inflation trend lead to changes in inflation expectations. These results suggest that policymakers are correct to view a rise of survey inflation expectations as a threat to price stability. Conversely, a rise of inflation that is not accompanied by a rise of inflation expectations is less likely to persist.

Overall, our results should temper any temptation on the part of monetary policymakers to exploit the low persistence of inflation that has prevailed over the past decade. Our statistical model mimics the widely-touted drop of persistence since the Great Inflation, but there is nothing structural about this result: It simply reflects the reduced share of noise that is allocated statistically to the innovation in the trend volatility. Moreover, our policy regime analysis suggests that the current low persistence of inflation is itself a result of the rule-like policy behavior that has predominated since the 1980s.

If the credibility dividend of the low-inflation era were to foster policy complacency in the face of unpleasant inflation news – or if perceptions of political interference in policy-setting were to arise – then the volatility of trend inflation could rebound. Furthermore, if sacrifice ratios have

risen, as many observers suggest they may have, risk management considerations should sway policymakers from potentially costly experimentation when inflation begins to rise.

When inflation does rise or fall unexpectedly, how much of the surprise should policymakers assume to be part of the new trend? The UC-SV model provides a straightforward answer: less than 4% today compared with more than 75% 30 years ago.<sup>34</sup> Like the short-run Phillips curve, however, this model result cannot be exploited. If the monetary policy regime were relaxed, we expect that the estimated influence of inflation news on the trend would rise.

While this paper makes no effort to assess the potential benefits of inflation targeting in the United States, we hope that it provides a useful benchmark by describing the low-inflation standard that already has been achieved. Presumably, the costs of a specific targeting scheme – in the form of reduced policy flexibility – should be assessed against the potential benefits of preserving or improving upon this low-inflation standard.

With regard to future research, our results point in several directions. First, building on the analysis of global common factors in inflation, in the spirit of recent work by Mojon and Ciccarelli (2005), it would be useful to determine the extent to which these factors relate to the permanent or transitory components of inflation. Presumably, policymakers should care much more about the former. Second, a multivariate version of our statistical model could help in understanding the drivers of inflation's trend volatility. Third, exploring the various influences on survey measures of inflation expectations that lead the estimated inflation trend could help identify key policy risks. Over time, increased availability of survey data also should allow an extension of this analysis to other economies.

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<sup>34</sup> This calculation, based on smoothed estimates of the GDP deflator, reflects the share of inflation news that the model currently attributes to the trend volatility and is the ratio  $[\sigma_{\varepsilon}^2 / (\sigma_{\varepsilon}^2 + 2\sigma_{\eta}^2)]$ .



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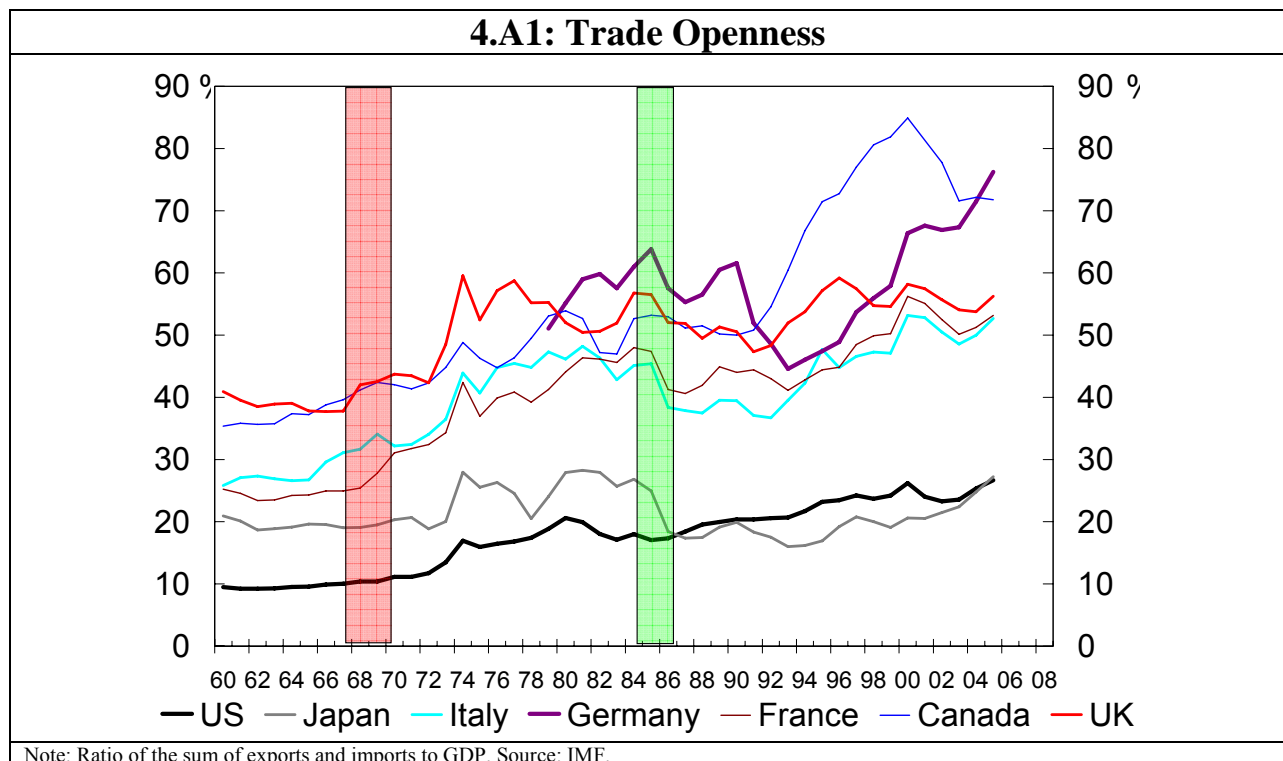
## Appendices

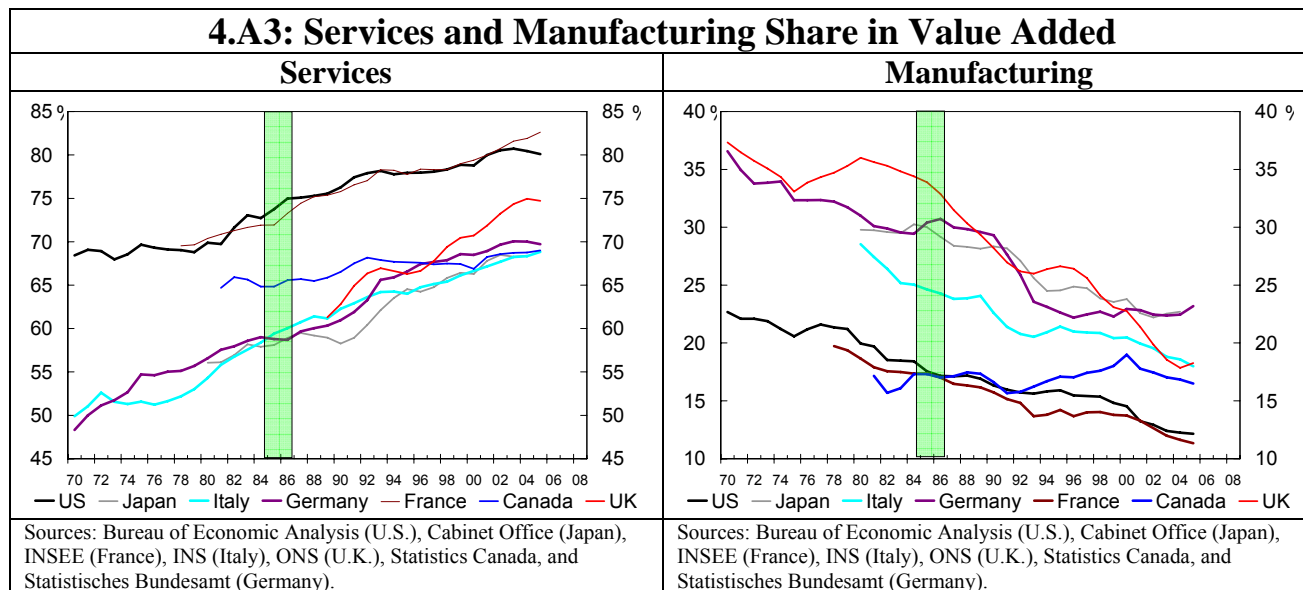
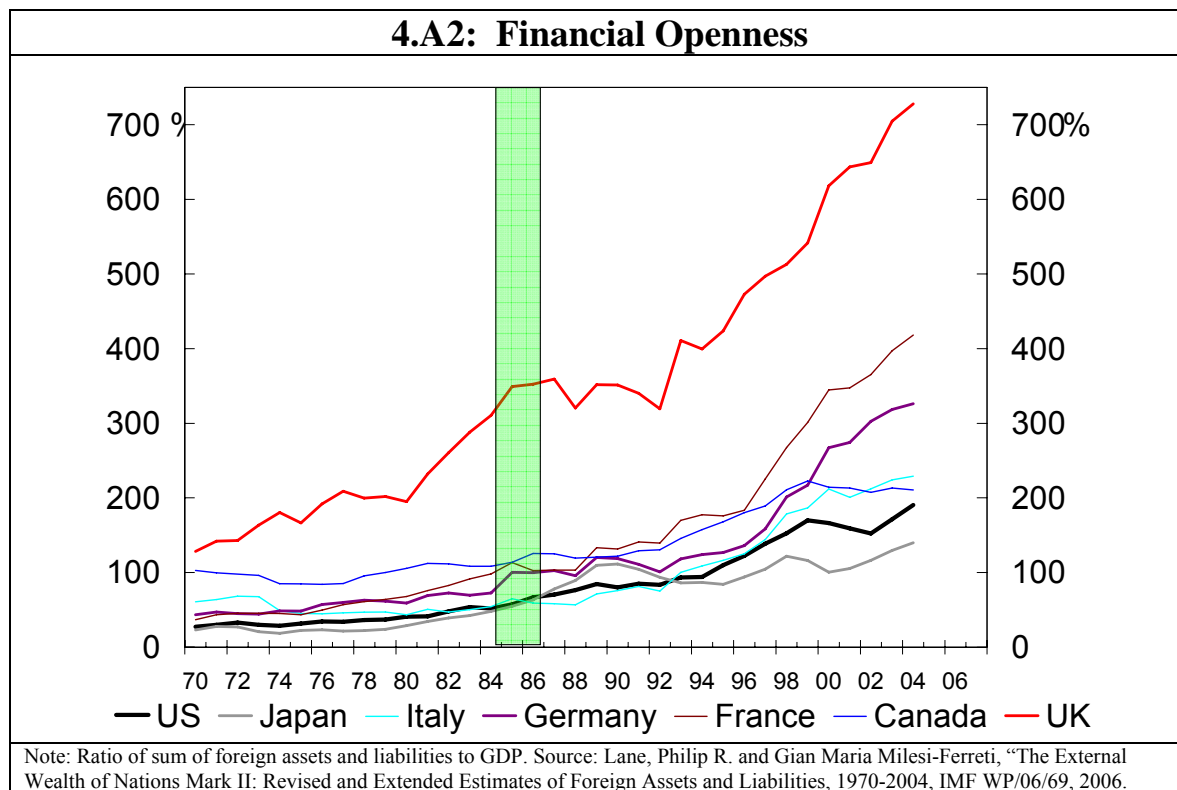
### Section 4

The following figures relate to the concepts listed in Table 4.1 and discussed in the surrounding text. For reference, the table is reproduced here:

<b>Table 4.1 Candidate Influences</b>	
<p><b><u>A. Stable Trends</u></b>                      Trade Openness (4.A1)                      Financial Openness (4.A2)                      Unionization Rates (Table 4.3)                      Services Share in Value Added (4.A3)                      Manufacturing Share in Value Added (4.A4)</p>	<p><b><u>B. Other Developments</u></b>                      Oil Shocks – Hamilton Filter (4.B1)                      Oil and Commodity Prices (4.B2)                      U.S. Fiscal Stance (4.B3)                      Exchange Rate Regime                      Labor Share (Pct. Dev. from Avg., 4.B4)                      Strike Days Lost (4.B5)                      Trend Productivity (4.B6)                      Unemployment Rate (Mov. Avg., 4.B7)                      Output Gap (Mov. Avg., 4.B8)                      U.S. 10 Yr. Yield and Volatility (4.B9)                      U.S. Inf. Expectations &amp; Volatility (4.B10)</p>
<p>Notations in parentheses refer to the figures in the appendices A and B. For example, (A1) is Appendix A, Figure A1.</p>	

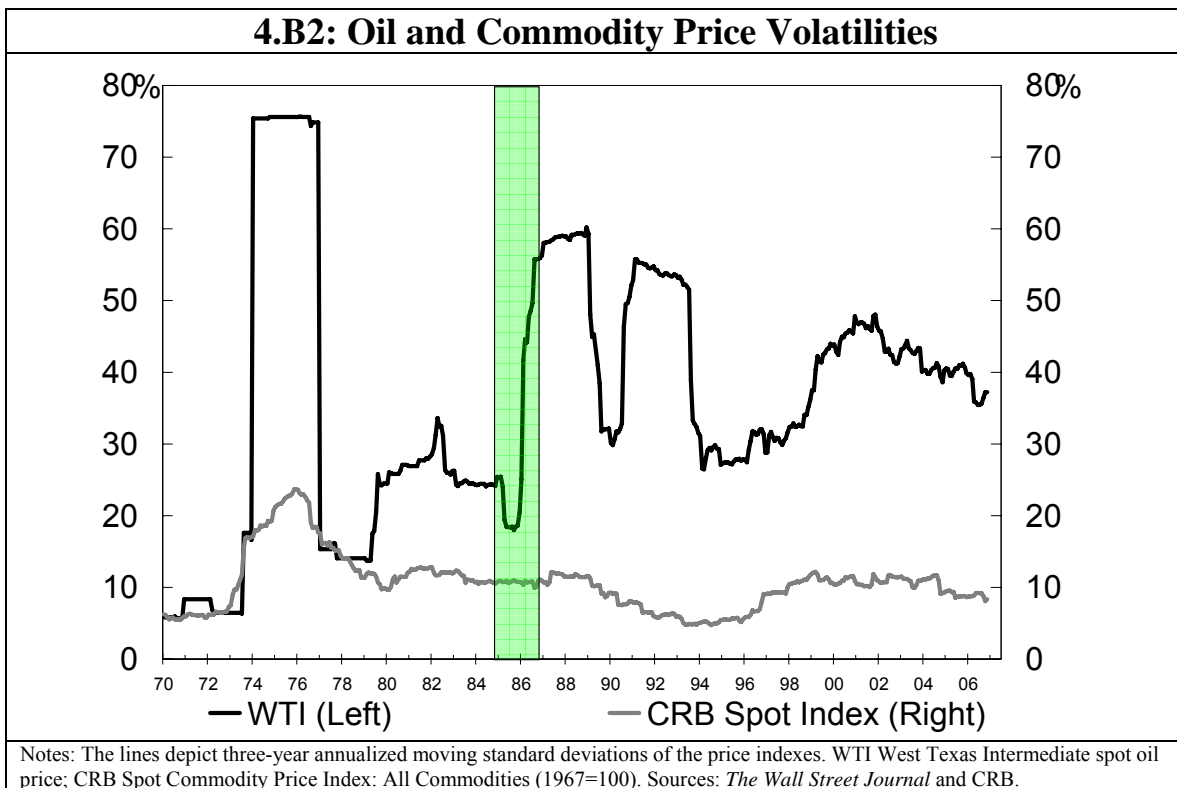
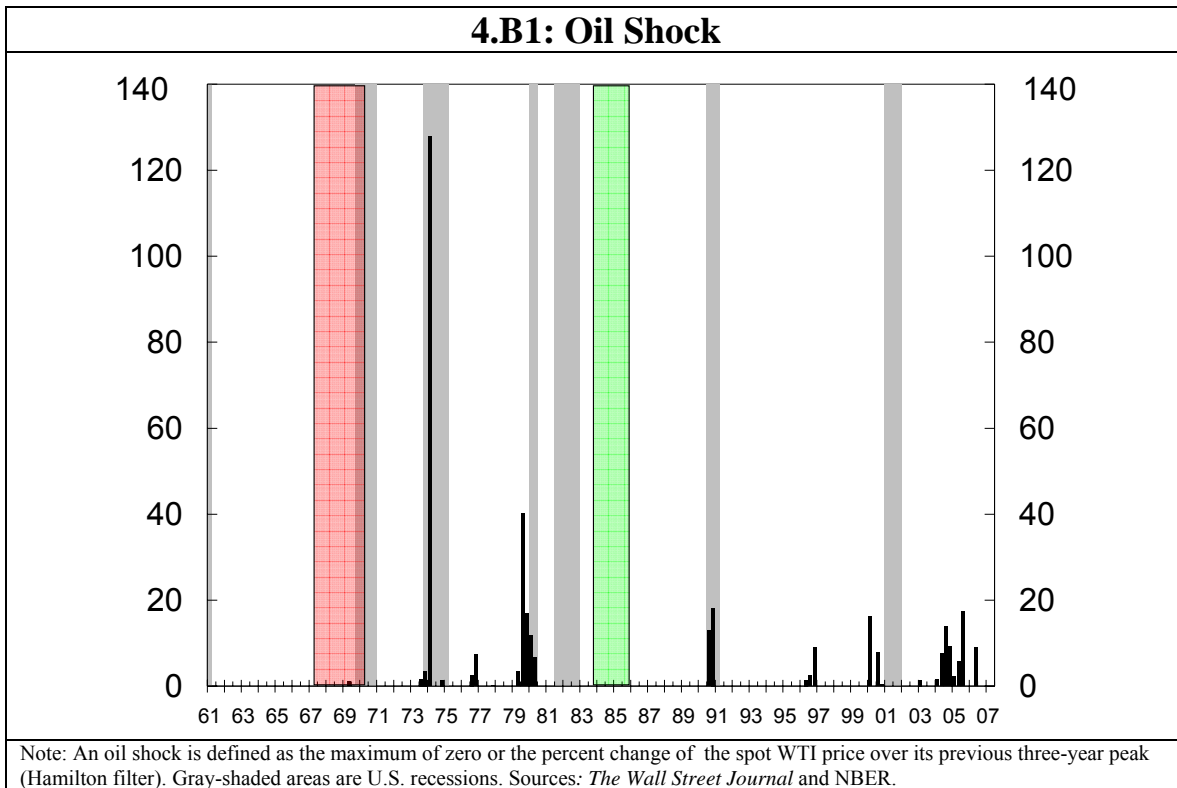
#### A. Stable Trends



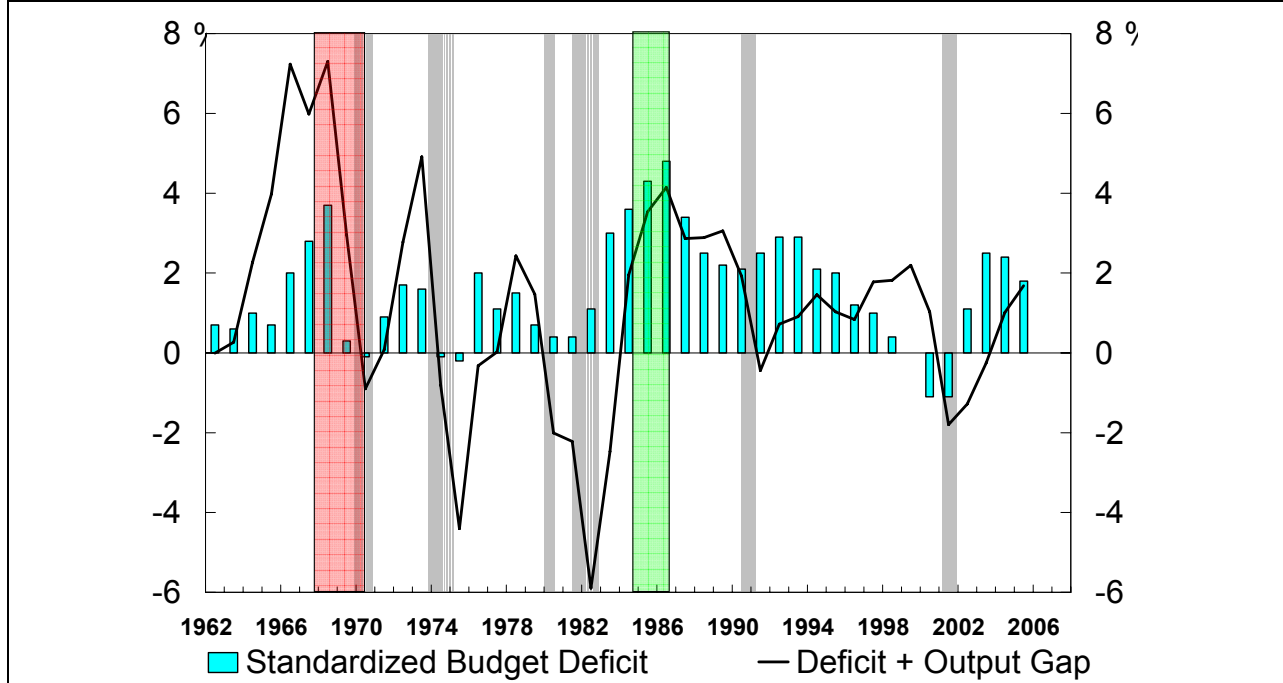




**B: Other Developments**

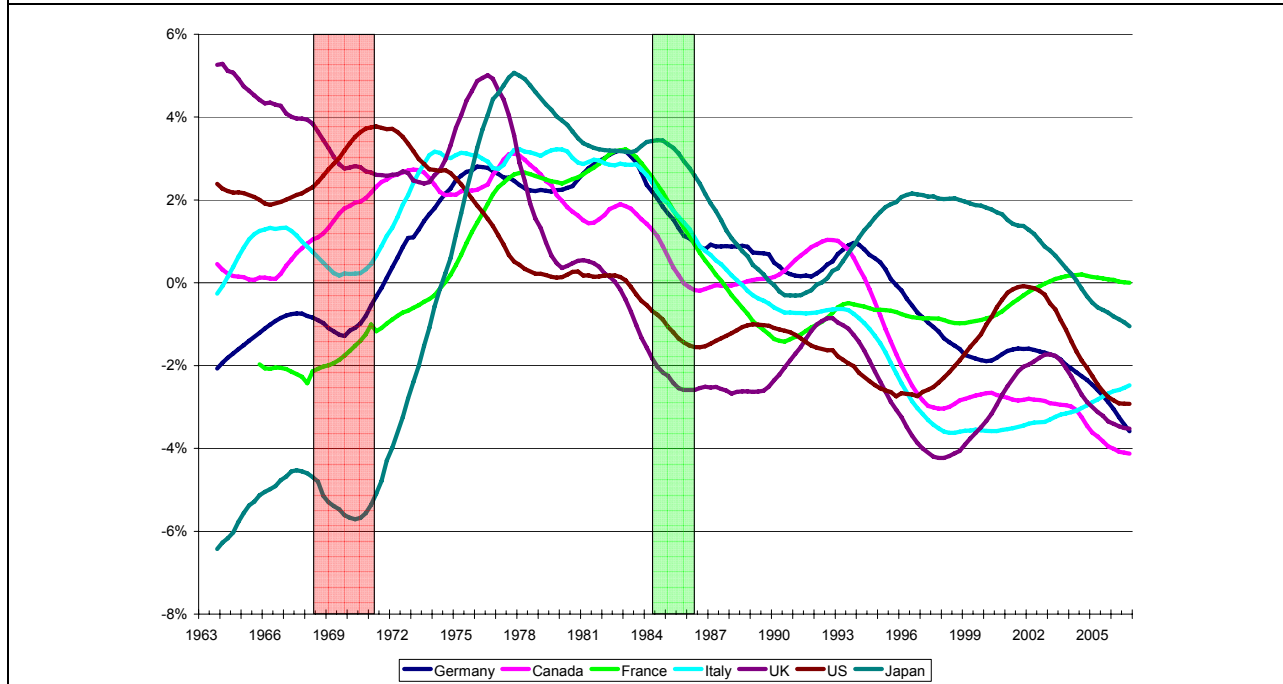


### 4.B3: U.S. Budget Deficit and Output Gap

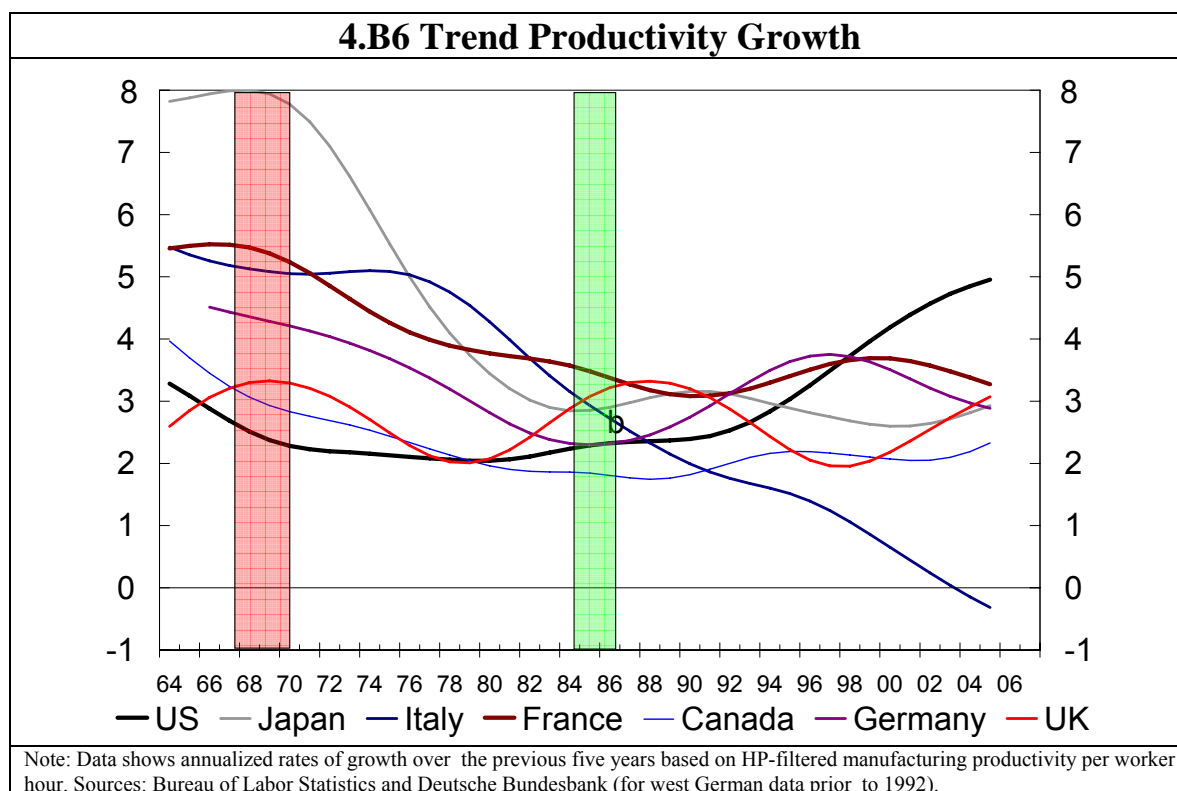
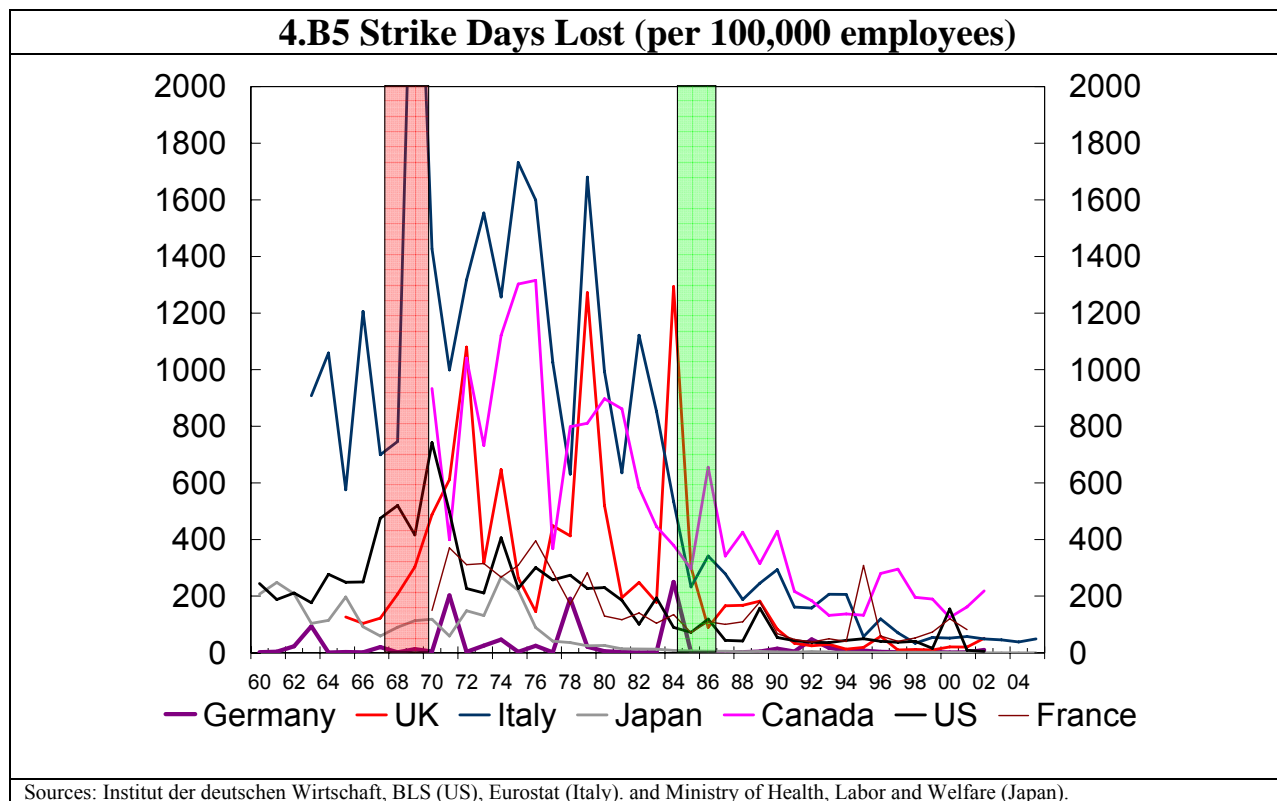


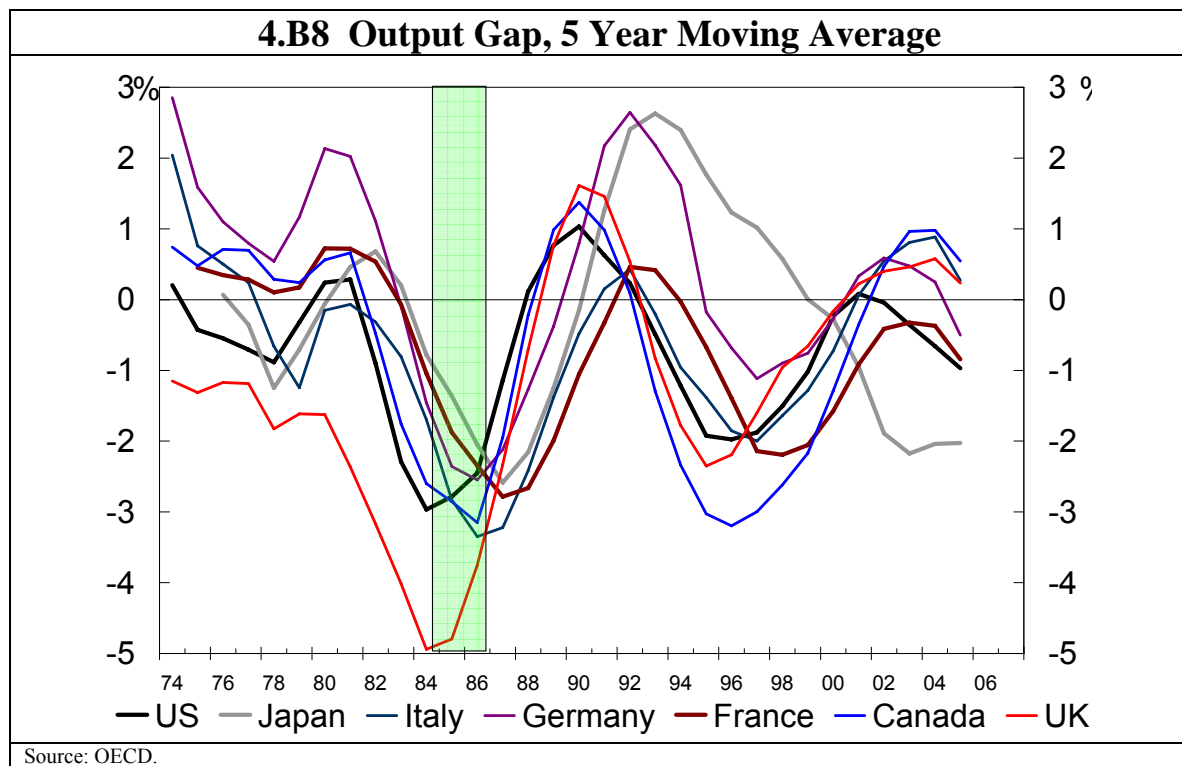
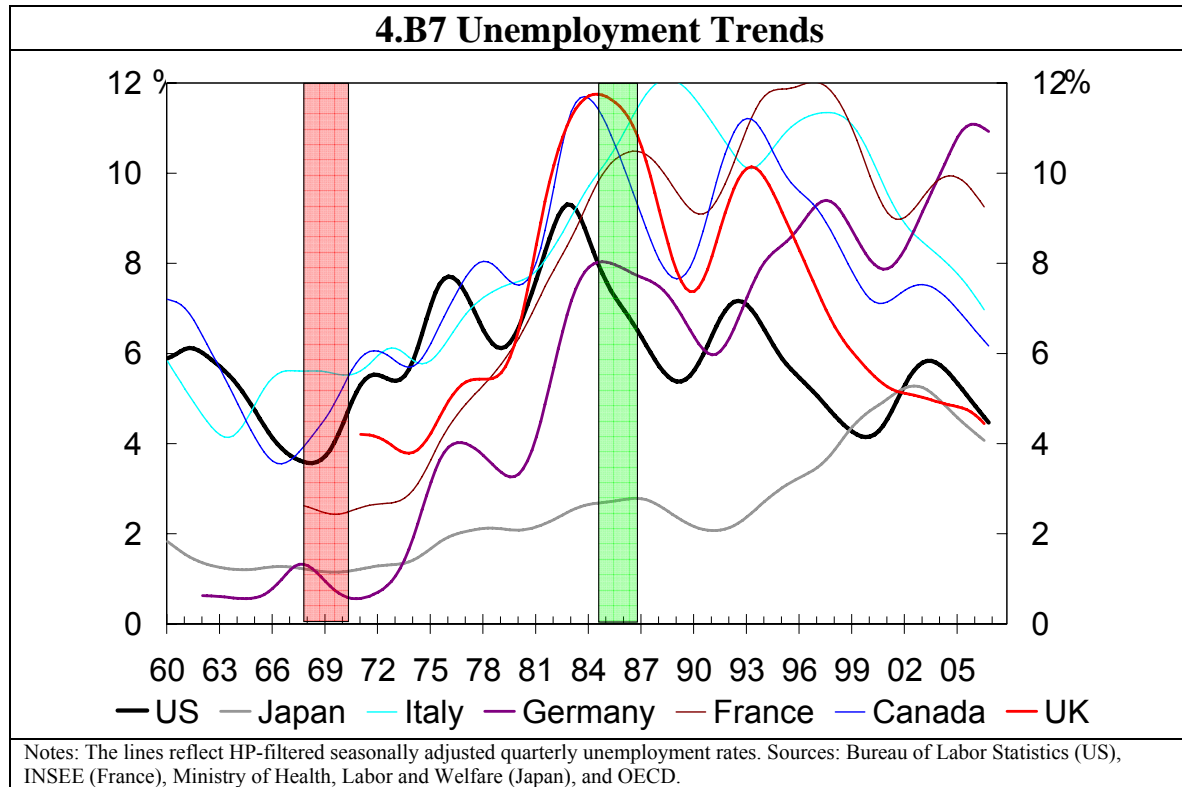
Note: Standardized budget deficit is the CBO cyclically adjusted measure of the U.S. federal budget deficit.  
Source: CBO.

### 4.B4 Labor's Share in GDP

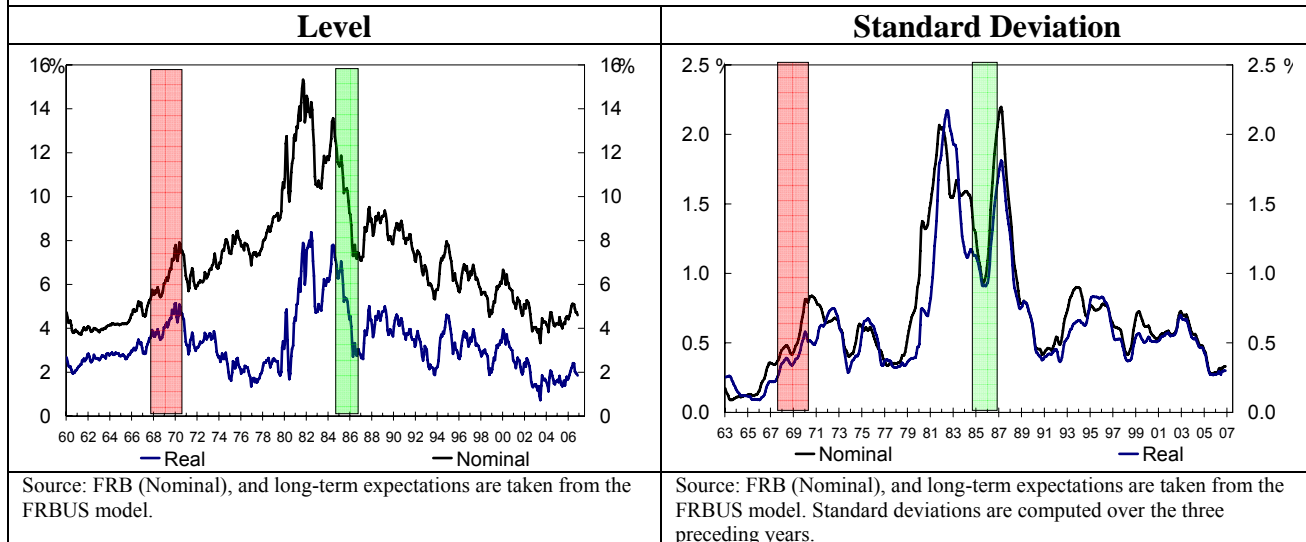


Note: Figure shows three-year smoothed percent deviations of labor shares from the period average. Source: OECD data on wages and GDP.





### 4.B9: U.S. 10 Year Yields: Nominal and Real



### 4.B10: U.S. Expected Long-Term Inflation

