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Frederic S. Mishkin

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Frederic S. Mishkin

Member
Board of Governors of the Federal Reserve System

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Over the past three decades, we have seen a remarkable change in the performance of monetary policy. By the end of the 1970s, inflation had risen to very high levels, with many countries in the Organisation for Economic Co-operation and Development (OECD) experiencing double-digit inflation rates (figure 1). Most OECD countries today have inflation rates around the 2 percent level, which is consistent with what most economists see as price stability, and the volatility of inflation has also fallen dramatically (figure 2). One concern might be that the low and stable levels of inflation might have been achieved at the expense of higher volatility in output, but that is not what has occurred. Output volatility has also declined in most OECD countries (figure 3). The improved performance of monetary policy has been associated with advances in the science of monetary policy, that is, a set of principles that have been developed from rigorous theory and empirical work that have come to guide the thinking of monetary policy practitioners.

In this paper, I will review the progress that the science of monetary policy has made over recent decades. In my view, this progress has significantly expanded the degree to which the practice of monetary policy reflects the application of a core set of "scientific" principles. Does this progress mean that, as Keynes put it, monetary policy will become as boring as dentistry--i.e., that policy will be reduced to the routine application of core principles, much like filling cavities?[1] I will argue that there remains, and will likely always remain, elements of art in the conduct of monetary policy; in other words, substantial judgment will always be needed to achieve desirable outcomes on both the inflation and employment fronts.

[1] Given that my wife was a dentist, I have to say that Keynes may have been unfair to dentists. I am sure that many of them find their work very exciting.

I.

Advances in the Science of Monetary Policy in Recent Decades

Over the last five decades, monetary economists have developed a set of basic scientific principles, derived from theory and empirical evidence, that now guide thinking at almost all central banks and explain much of the success in the conduct of monetary policy. I will outline my views on the key principles and how they were developed over the last fifty or so years. The principles are: 1) inflation is always and everywhere a monetary phenomenon; 2) price stability has important benefits; 3) there is no long-run tradeoff between unemployment and inflation; 4) expectations play a crucial role in the determination of inflation and in the transmission of monetary policy to the macroeconomy; 5) real interest rates need to rise with higher inflation, i.e., the Taylor Principle; 6) monetary policy is subject to the time-inconsistency problem; 7) central bank independence helps improve the efficiency of monetary policy; 8) commitment to a strong nominal anchor is central to producing good monetary policy outcomes; and 9) financial frictions play an important role in business cycles. I will examine each principle in turn.

1. Inflation is Always and Everywhere a Monetary Phenomenon

By the 1950s and 1960s, the majority of macroeconomists had converged on a consensus view of macroeconomic fluctuations that downplayed the role of monetary factors. Much of this consensus reflected the aftermath of the Great Depression and Keynes' seminal *The General Theory of Employment, Interest, and Prices*, which emphasized shortfalls in aggregate demand as the source of the Great Depression and the role of fiscal factors as possible remedies. In contrast, research by Milton Friedman and others in what became known as the "monetarist" tradition (Friedman and Meiselman, 1963; Friedman and Schwartz, 1963a,b) attributed much of the economic malaise of the Depression to poor monetary policy decisions and more generally argued that the growth in the money supply was a key determinant of aggregate economic activity and, particularly, inflation. Over time, this research, as well as Friedman's predictions that expansionary monetary policy in the 1960s would lead to high inflation and high interest rates (Friedman, 1968), had a major impact on the economics profession, with almost all economists eventually coming to agree with the Friedman's famous adage, "Inflation is always and everywhere a monetary phenomenon" (Friedman 1963, p. 17), as long as inflation is referring to a sustained increase in the price level (e.g., Mishkin, 2007a).

General agreement with Friedman's adage did not mean that all economists subscribed to the view that the money growth was the most informative piece of information about inflation, but rather that the ultimate source of inflation was overly expansionary monetary policy. In particular, an important imprint of this line of thought was that central bankers came to recognize that keeping inflation under control was their responsibility.[2]

[2] Furthermore, monetarist research led Keynesian economists--for example Franco Modigliani--to search for transmission mechanisms linking monetary policy to output and inflation (Mishkin, 2007a, chapter 23).

2. The Benefits of Price Stability

With the rise of inflation in the 1960s and 1970s, economists, and also the public and politicians, began to discuss the high costs of inflation (for example, see the surveys in Fischer, 1993; and Anderson and Gruen, 1995). High inflation undermines the role of money as a medium of exchange by acting as a tax on cash holdings. On top of this, a high-inflation environment leads to overinvestment in the financial sector, which expands to help individuals and businesses escape some of the costs of inflation (English, 1996). Inflation leads to uncertainty about relative prices and the future price level, making it harder for firms and individuals to make appropriate decisions, thereby decreasing economic efficiency (Lucas, 1972; Briault, 1995). The interaction of the tax system and inflation also increases distortions that adversely affect economic activity (Feldstein, 1997). Unanticipated inflation causes redistributions of wealth, and, to the extent that high inflation tends to be associated with volatile inflation, these distortions may boost the costs of borrowing. Finally, some households undoubtedly do not fully understand the implications of a general trend in prices--that is, they may suffer from nominal illusion--making financial planning more difficult.[3] The total effect of these distortions became more fully appreciated over the course of the 1970s, and the recognition

[3] Of course, economic theory implies that inflation can be either too high or too low. The discussion has emphasized costs associated with high inflation. But there are also potentially important costs associated with rates of inflation that are very low. For example, Akerlof, Dickens, and Perry (1996) suggest that downward nominal wage rigidity could result in severe difficulties for economic performance at some times when inflation is too low. Other research has shown that the zero lower bound on nominal interest rates can lower economic efficiency if inflation is too low (e.g., Reifschneider and Williams, 2000). Eggertsson and Woodford (2003) discuss strategies to address the zero-lower-bound problem.

of the high costs of inflation led to the view that low and stable inflation can increase the level of resources productively employed in the economy.[4, 5]

3. No Long-Run Tradeoff Between Unemployment and Inflation

A paper published in 1960 by Paul Samuelson and Robert Solow argued that work by A.W. Phillips (1958), which became known as the Phillips curve, suggested that there was a long-run tradeoff between unemployment and inflation and that this tradeoff should be exploited. Under this view, the policymaker would have to choose between two competing goals--inflation and unemployment--and decide how high an inflation rate he or she would be willing to accept to attain a lower unemployment rate. Indeed, Samuelson and Solow even mentioned that a nonperfectionist goal of a 3 percent unemployment rate could be achieved at what they considered to be a not-too-high inflation rate of 4 percent to 5 percent per year. This thinking was influential, and probably contributed to monetary and fiscal policy activism aimed at bringing the economy to levels of employment that, with hindsight, were not sustainable. Indeed, the economic record from the late 1960s through the 1970s was not a happy one: Inflation accelerated, with the inflation rate in the United States and other industrialized countries eventually climbing above 10 percent in the 1970s, leading to what has been dubbed "The Great Inflation."

[4] A further possibility is that low inflation may even help increase the rate of economic growth. While time-series studies of individual countries and cross-national comparisons of growth rates were not in total agreement (Anderson and Gruen, 1995), the consensus grew that inflation is detrimental to economic growth, particularly when inflation rates are high.

[5] The deleterious effects of inflation on economic efficiency implies that the level of sustainable employment is probably lower at higher rates of inflation. Thus, the goals of price stability and high employment are likely to be complementary, rather than competing, and so there is no policy tradeoff between the goals of price stability and maximum sustainable employment, the so-called dual mandate that the Federal Reserve has been given by Congress (Mishkin, 2007b).

The tradeoff suggested by Samuelson and Solow was hotly contested by Milton Friedman (1968) and Edmund Phelps (1968), who independently argued that there was no long-run tradeoff between unemployment and the inflation rate: Rather, the economy would gravitate to some natural rate of unemployment in the long run no matter what the rate of inflation was. In other words, the long-run Phillips curve would be vertical, and attempts to lower unemployment below the natural rate would result only in higher inflation. The Friedman-Phelps natural rate hypothesis was immediately influential and fairly quickly began to be incorporated in formal econometric models.

Given the probable role that the attempt to exploit a long-run Phillips curve tradeoff had in the 'Great Inflation," central bankers have been well served by adopting the natural rate, or no-long-run-tradeoff, view. Of course, the earlier discussion of the benefits of price stability suggests a long-run tradeoff--but not of the Phillips curve type. Rather, low inflation likely contributes to improved efficiency and hence higher employment in the long run.

4. The Crucial Role of Expectations

A key aspect of the Friedman-Phelps natural rate hypothesis was that sustained inflation may initially confuse firms and households, but in the long run sustained inflation would not boost employment because *expectations* of inflation would adjust to any sustained rate of increase in prices. Starting in the early 1970s, the rational expectations revolution, launched in a series of papers by Robert Lucas (1972, 1973, and 1976), took this reasoning a step further and demonstrated that the public and the markets' expectations of policy actions have important

effects on almost every sector of the economy.[6] The theory of rational expectations emphasized that economic agents should be driven by optimizing behavior, and therefore their expectations of future variables should be optimal forecasts (the best guess of the future) using all available information. Because the optimizing behavior posited by rational expectations indicates that expectations should respond immediately to new information, rational expectations suggests that the long run might be quite short, so that attempting to lower unemployment below the natural rate could lead to higher inflation very quickly.

A fundamental insight of the rational expectations revolution is that expectations about future monetary policy have an important impact on the evolution of economic activity. As a result, the systematic component of policymakers' actions--i.e., the component that can be anticipated--plays a crucial role in the conduct of monetary policy. Indeed, the management of expectations about future policy has become a central element of monetary theory, as emphasized in the recent synthesis of Michael Woodford (2003).[7] And this insight has far-reaching implications, for example, with regard to the types of systematic behavior by policymakers that are likely to be conducive to macroeconomic stability and growth.[8]

5. The Taylor Principle

[6] The 1976 Lucas paper was already very influential in 1973, when it was first presented at the Carnegie-Rochester Conference. Note that although Muth (1961) introduced the idea of rational expectations more than ten years earlier, his work went largely unnoticed until resurrected by Lucas.

[7] Indeed, one implication of rational expectations in a world of flexible wages and prices was the policy ineffectiveness proposition, which indicated that if monetary policy was anticipated, it would have no real effect on output; only unanticipated monetary policy could have a significant impact. Although evidence for the policy ineffectiveness proposition turned out to be weak (Barro, 1977; Mishkin, 1982a,b, 1983), the rational expectation revolution's point that monetary policy's impact on the economy is substantially influenced by whether it is anticipated or not has become widely accepted.

[8] Of course, the recognition that management of expectations is a central element in monetary policymaking raises to the forefront the credibility of monetary policy authorities to do what they say they will do. It does not diminish, however, the importance of actions by the monetary authorities because "actions speak louder than words": Monetary authorities will be believed only if they take the actions consistent with how they want expectations to be managed.

The recognition that economic outcomes depend on expectations of monetary policy suggests that policy evaluation requires the comparison of economic performance under different monetary policy rules.[9] One type of rule that has received enormous attention in the literature is the Taylor rule (Taylor, 1993a), which describes monetary policy as setting an overnight bank rate (federal funds rate in the United States) in response to the deviation of inflation from its desired level or target (the inflation gap) and the deviation of output from its natural rate level (the output gap).[10] Taylor (1993a) emphasized that a rule of this type had desirable properties and in particular would stabilize inflation only if the coefficient on the inflation gap exceeded unity. This conclusion came to be known as the "Taylor principle" (Woodford, 2001) and can be described most simply by saying that stabilizing monetary policy must raise the nominal interest rate by more than the rise in inflation. In other words, inflation will remain under control only if real interest rates rise in response to a rise in inflation. Although, the Taylor principle now seems pretty obvious, estimates of Taylor rules, such as those by Clarida, Gali, and Gertler (1998), indicate that during the late 1960s and 1970s many central banks, including the Federal Reserve, violated the Taylor principle, resulting in the "Great Inflation" that so many countries experienced during this period.[11] Indeed, as inflation rose in the United States, real interest rates fell.[12]

[9] Although Lucas (1976) was a critique of the then-current practice of using econometric models to evaluate specific policy actions, it leads to the conclusion that monetary policy analysis should involve the comparison of economic performance arising from different rules.

[10] Variants of the Taylor rule also allow for interest rate smoothing, as in Taylor (1999).

[11] In contrast, Orphanides (2003) argues that the Federal Reserve did abide by the Taylor principle but pursued overly expansionary policies during this period because of large and persistent misperceptions of the level of potential output and the natural unemployment rate.

[12] E.g., the estimates in Mishkin (1981, 1992).

6. The Time-Inconsistency Problem

Another important development in the science of monetary policy that emanated from the rational expectations revolutions was the discovery of the importance of the time-inconsistency problem in papers by Kydland and Prescott (1977), Calvo (1978), and Barro and Gordon (1983). The time-inconsistency problem can arise if monetary policy conducted on a discretionary, day-by-day basis leads to worse long-run outcomes than could be achieved by committing to a policy rule. In particular, policymakers may find it tempting to exploit a short-run Phillips curve tradeoff between inflation and employment; but private agents, cognizant of this temptation, will adjust expectations to anticipate the expansionary policy, so that it will result only in higher inflation with no short-run increase in employment In other words, without a commitment mechanism, monetary policy makers may find themselves unable to *consistently* follow an optimal plan over *time;* the optimal plan can be *time-inconsistent* and so will soon be abandoned. The notion of time-inconsistency has led to a number of important insights regarding central bank behavior--such as the importance of reputation (formalized in the concept of *reputational equilibria*) and institutional design.

7. Central Bank Independence

Indeed, the potential problem of time-inconsistency has led to a great deal of research that examines the importance of institutional features that can give central bankers the commitment mechanisms they need to pursue low inflation. Perhaps the most significant has been research showing that central bank independence, at least along some dimensions, is likely

very important to maintaining low inflation. Allowing central banks to be instrument independent, i.e., to control the setting of monetary policy instruments, can help insulate them from short-run pressures to exploit the Phillips-curve tradeoff between employment and inflation and thus avoid the time-inconsistency problem.[13]

Evidence supports the conjecture that macroeconomic performance is improved when central banks are more independent. When central banks in industrialized countries are ranked from least legally independent to most legally independent, the inflation performance is found to be the best for countries with the most independent central banks (Alesina and Summers, 1993; Cukierman, 1993; Fischer, 1994; and the surveys in Forder, 2000, and Cukierman, 2006).

A particularly interesting example occurred with the granting of instrument independence to the Bank of England in May of 1997 (Mishkin and Posen, 1997; Bernanke and others, 1999); before that date, the Chancellor of the Exchequer (the finance minister) set the monetary policy instrument, not the Bank of England. As figure 4 illustrates, during 1995-96 the U.K. retail inflation rate (RPIX) was fairly close to 3 percent, but the spread between nominal and indexed bond yields--referred to as 10-year breakeven inflation--was substantially higher, in the range of 4 percent to 5 percent, reflecting investors' inflation expectations as well as compensation for perceived inflation risk at a 10-year horizon. Notably, breakeven inflation declined markedly on the day that the government announced the Bank of England's independence and has remained substantially lower ever since. This case study provides a striking example of the benefits of instrument independence.

[13] For an example of how the time-inconsistency problem can be modeled as resulting from political pressure, see Mishkin and Westelius (forthcoming). Instrument independence also insulates the central bank from the myopia that can be a feature of the political process. Instrument independence thus makes it more likely that the central bank will be forward looking and adequately allow for the long lags from monetary policy actions to inflation in setting their policy instruments.

Although there is a strong case for instrument independence, the same is not true for goal independence, the ability of the central bank to set its own goals for monetary policy.[14] In a democracy, the public exercises control over government actions, and policymakers are accountable, which requires that the goals of monetary policy be set by the elected government. Although basic democratic principles argue for the government setting the goals of monetary policy, the question of whether it should set goals for the short-run or intermediate-run is more controversial. For example, an arrangement in which the government set a short-run inflation or exchange rate target that was changed every month or every quarter could easily lead to a serious time-inconsistency problem in which short-run objectives would dominate. In practice, however, this problem does not appear to be severe because, for example, in many countries in which the government sets the annual inflation target, the target is rarely changed once price stability is achieved. Even though, in theory, governments could manipulate monetary policy goals to pursue short-run objectives, they usually do not if the goal-setting process is highly transparent.

However, the length of the lags from monetary policy to inflation is a technical issue that the central bank is well placed to determine. Thus, for example, deciding how long it should take for inflation to return to a long-run goal necessarily requires judgment and expertise regarding the nature of the inflation process and its interaction with real activity. That need for judgment and expertise argues for having the central bank set medium-term goals because the speed with which it can achieve them depends on the lags of monetary policy. Whether the central bank or the government should set medium-term inflation targets is therefore an open question.

8. Commitment to a Nominal Anchor

[14] The distinction between goal and instrument independence was first made by Debelle and Fischer (1994) and Fischer (1994).

The inability of monetary policy to boost employment in the long run, the importance of expectations, the benefits of price stability, and the time-inconsistency problem are the reasons that commitment to a nominal anchor--i.e., stabilization of a nominal variable such as the inflation rate, the money supply, or an exchange rate--is crucial to successful monetary policy outcomes.

An institutional commitment to price stability via establishing a nominal anchor provides a counterbalance to the time-inconsistency problem because it makes it clear that the central bank must focus on the long-run and thus resist the temptation to pursue short-run expansionary policies that are inconsistent with the nominal anchor. Commitment to a nominal anchor can also encourage the government to be more fiscally responsible, which also supports price stability. For example, persistent fiscal imbalances have, in the absence of a strong nominal anchor, led some governments, particularly in less-developed economies, to resort to the so-called inflation tax--the issuing/printing of money to pay for goods and services that leads to more inflation and is thus inconsistent with price stability.

Commitment to a nominal anchor also leads to policy actions that promote price stability, which helps promote economic efficiency and growth. The commitment to a nominal anchor helps stabilize inflation expectations, which reduce the likelihood of "inflation scares," in which expected inflation and interest rates shoot up (Goodfriend, 1993). Inflation scares lead to bad economic outcomes because the rise in inflation expectations leads not only to higher actual inflation but also to monetary policy tightening to get inflation back under control that often results in large declines in economic activity. Commitment to a nominal anchor is therefore a crucial element in the successful management of expectations; and it is a key feature of recent

theory on optimal monetary policy, referred to as the new-neoclassical (or new-Keynesian) synthesis (Goodfriend and King, 1997; Clarida, Gali, and Gertler, 1999; Woodford, 2003). A successful commitment to a nominal anchor has been found to produce not only more-stable inflation but lower volatility of output fluctuations (Fatás, Mihov, and Rose, 2007; Mishkin and Schmidt-Hebbel, 2002, 2007).

9. Financial Frictions and the Business Cycle

Research that outlined how asymmetric information could impede the efficient functioning of the financial system (Akerlof, 1970; Myers and Majluf, 1984; and Greenwald, Stiglitz, and Weiss, 1984) suggests an important link between business cycle fluctuations and financial frictions. When shocks to the financial system increase information asymmetry so that financial frictions increase dramatically, financial instability results, and the financial system is no longer able to channel funds to those with productive investment opportunities, with the result that the economy can experience a severe economic downturn (Mishkin, 1997). The rediscovery of Irving Fisher's (1933) paper on the Great Depression led to the recognition that financial instability played a central role in the collapse of economic activity during that period (Mishkin, 1978; Bernanke, 1983; and the survey in Calomiris, 1993), and it has spawned a large literature on the role of financial frictions in business cycle fluctuations (e.g., Bernanke and Gertler, 1999, 2001; Bernanke, Gertler, and Gilchrist, 1999; Kashyap and Stein, 1994). Indeed, it is now well

understood that the most severe business cycle downturns are always associated with financial instability, not only in advanced countries but also in emerging-market countries (Mishkin, 1991, 1996). Minimizing output fluctuations thus requires that monetary policy factors in the impact of financial frictions on economic activity.

II.

Advances in the Applied Science of Monetary Policy

Scientific principles are all well and good, but they have to be applied in a practical way to produce good policies. The scientific principles from physics or biology provide important guidance for real-world projects, but it is with the applied fields of engineering and medicine that we build bridges and cure patients. Within economics, it is also important to delineate the use of scientific principles in policymaking, as this type of categorization helps us understand where progress has been made and where further progress is most needed. I will categorize the applied science of monetary policy as those aspects that involve systematic, or algorithmic, methods such as the development of econometric models. Other, more judgmental aspects of policymaking are what I will call the "art" of policymaking.

So, how have the basic scientific principles outlined above been used algorithmically? I focus particularly on the U.S. examples because they are the ones I am most familiar with given

my experience as an American central banker, but similar developments have occurred elsewhere.

Early Keynesian econometric models of the macroeconomy did not give monetary policy a prominent role (for example, Tinbergen, 1939; Adelman and Adelman, 1959; Klein, 1968). In contrast, the policy-oriented models developed in the 1960s--such as the MIT-Penn-SSRC (MPS) model, developed by Franco Modigliani and collaborators and used as the workhorse model for policy analysis at the Federal Reserve until 1996--incorporated a very important role for monetary policy, broadly similar to the main channels of the monetary policy transmission mechanism that are embedded in the current generation of models.[15]
In this sense, the notion that inflation is a monetary phenomenon has been embedded in formal models for several decades.

Very early versions of the MPS model did display a long-run tradeoff between unemployment and inflation, as the principle that there should be no long-run tradeoff took some time to be accepted (e.g., Gramlich, 2004). By the early 1970s, the principle of no long-run tradeoff was fully ensconced in the MPS model by the adoption of an accelerationist Phillips curve (Pierce and Enzler, 1974; Brayton and others, 1997). The recognition in their models that lower unemployment could not be bought by accepting higher inflation was a factor driving central banks to adopt anti-inflationary policies by the 1980s.

Although accelerationist Phillips curves became standard in macroeconometric models used at central banks like the MPS model through the 1970s, expectational elements were still largely missing. The next generation of models emphasized the importance of expectations. For example, the staff at the Board of Governors of the Federal Reserve System developed their

[15] Brayton and Mauskopf (1985) describe the MPS model. As pointed out by Gramlich (2004), the researchers at the Federal Reserve were instrumental in the building of this model and it might more accurately be described as the Fed-MIT model or the Fed-MIT-Penn model.

next-generation model, FRB/US (Brayton and Tinsley, 1995; Reifschneider, Stockton, and Wilcox, 1997; Reifschneider, Tetlow, and Williams, 1999), to incorporate the importance of expectations in the determination of real activity and inflation. The FRB/US model, and similar models developed at other central banks such as the Bank of Canada's QPM model (Coletti and others, 1996) and the Reserve Bank of New Zealand's FPS model (Hunt, Rose, and Scott, 2000) were an outgrowth of the rational expectations revolution, and they allowed expectations to be derived under many different assumptions, including rational expectations. Policy simulations to help guide monetary policy decisions, such as those that are shown to the Federal Open Market Committee (FOMC), explicitly emphasize assumptions about future expectations and how they are formed. Policymakers have thus come to recognize that their decisions about policy involve not only the current policy setting but also how they may be thinking about future policy settings.

The focus on optimizing economic agents coming out of the rational expectations revolution has led to modeling efforts at central banks that not only make use of rational expectations, but that are also grounded on sounder microfoundations. Specifically, these models build on two recent literatures, real business cycle theory (e.g., Prescott, 1986) and new-Keynesian theory (e.g., Mankiw and Romer, 1991). In contrast to older Keynesian macro modeling, new-Keynesian theory provides microfoundations for Keynesian concepts such as nominal rigidities, the non-neutrality of money, and the inefficiency of business cycle fluctuations by deriving them from optimizing behavior. The real business cycle approach makes use of stochastic general equilibrium growth models with representative, optimizing agents. The resulting new class of models, in which new-Keynesian features such as nominal rigidities and monopolistic competition are added to the frictionless real business models, have

become known as dynamic stochastic general equilibrium (DSGE) models. Simple versions of such models have already provided a framework in which to think about key aspects of monetary policy design--insights perhaps best illustrated in the Woodford (2003) discussion of policy issues in the now-textbook, three-equation new-Keynesian model. Larger, more empirically-motivated DSGE models are now in their early stages of development and are beginning to be used for policy analysis at central banks (e.g., at the European Central Bank, Smets and Wouters, 2003, and Coenen, McAdam, and Straub, 2007; and at the Federal Reserve Board, Erceg, Guerrieri, and Gust, 2006, and Edge, Kiley, and Laforte, 2007).

There are two very important implications from policy analysis with DSGE models, as emphasized by Gali and Gertler (forthcoming): First, "monetary transmission depends critically on private sector expectations of the future path of the central bank's policy instrument." Second, "the natural (flexible price equilibrium) values of both output and the real interest rate provide important reference points for monetary policy--and may fluctuate considerably." I can attest that both of these propositions indeed are now featured in the Bluebook (the staff's main document for analyzing policy options for the FOMC) .

The basic logic of the Taylor principle--that is, raising nominal interest rates more than one-for-one in response to an increase in inflation--was developed in conjunction with the analysis of Taylor's multicountry model and other macroeconometric models (Taylor, 1993a,b; Bryant, Hooper, and Mann, 1993). However, although the Taylor principle is a necessary condition for good monetary policy outcomes, it is not sufficient. Central bankers require knowledge about how much difference the Taylor principle makes to monetary policy outcomes. They also require an understanding of how much greater than one the response of nominal interest rates should be to increases in inflation and also need to know how the policy

rate should respond to other variables. Studying the performance of different rules in macroeconometric models has become a major enterprise at central banks, and the conclusion is that the Taylor principle is indeed very important. Analysis of policy rules in macroeconometric models that are not fully based on optimizing agents has been very extensive (e.g., Bryant, Hooper, and Mann, 1993; Levin, Wieland, and Williams, 1999), and we are now seeing similar analysis using DSGE models (e.g., Levin and others, 2006; Schmitt-Grohé and Uribe, 2006).

The second principle, and the sixth through the eighth principles -- which emphasize the benefits of price stability and the importance of the time-inconsistency problem, central bank independence and a commitment to a nominal anchor -- have important applications to the design of monetary policy institutions.

The argument that independent central banks perform better and are better able to resist the pressures for overly expansionary monetary policy arising from the time-inconsistency problem has led to a remarkable trend toward increasing central bank independence. Before the 1990s, only a few central banks were highly independent, most notably the Bundesbank, the Swiss National Bank, and, to a somewhat lesser extent, the Federal Reserve. Now almost all central banks in advanced countries and many in emerging-market countries have central banks with a level of independence on par with or exceeding that of the Federal Reserve. In the 1990s, greater independence was granted to central banks in such diverse countries as Japan, New Zealand, South Korea, Sweden, the United Kingdom, and those in the euro zone.

The increasing recognition of the time-inconsistency problem and the role of a nominal anchor in producing better economic outcomes has been an important impetus behind increasing central banks' commitments to nominal anchors. One resulting dramatic development in recent years has been a new monetary policy strategy, inflation targeting--the public announcement of

medium-term numerical targets for inflation with commitment and accountability to achieve this target, along with increased transparency of the monetary policy strategy through communication with the public (Bernanke and Mishkin, 1997). There has been a remarkable trend toward inflation targeting, which was adopted first by New Zealand in March 1990, and has since been adopted by an additional 23 countries (Rose, 2006). The evidence, is in general quite favorable to inflation targeting, although countries that have adopted inflation targeting have not improved their monetary policy performance beyond that of nontargeters in industrial countries that have had successful monetary policy (e.g., Bernanke and others, 1999; Mishkin and Schmidt-Hebbel, 2002, 2007; Rose, 2006). And, in contrast to other monetary policy regimes, no country with its own currency that has adopted inflation targeting has been forced to abandon it.[16]

The scientific principle that financial frictions matter to economic fluctuations has led to increased attention at central banks to concerns about financial stability. Many central banks now publish so-called *Financial Stability* reports, which examine vulnerabilities to the financial system that could have negative consequences for economic activity in the future. Other central banks are involved in prudential regulation and supervision of the financial system to reduce excessive risk-taking that could lead to financial instability. Central banks also have designed their lending facilities to improve their ability to function as a lender of last resort, so they can provide liquidity quickly to the financial system in case of financial disruptions.

III.

The Art of Monetary Policy

[16] Spain and Finland gave up inflation targeting when they entered the euro zone.

I have argued that there have been major advances in the science of monetary policy in recent years, both in terms of basic scientific principles and applications of these principles to the real world of monetary policymaking. Monetary policy has indeed become more of a science. There are, however, serious limitations to the science of monetary policy. Thus, as former vice-chairman of the Federal Reserve Board, Alan Blinder (1998, p.17), has emphasized, "central banking in practice is as much art as science." By "art," I mean the use of judgment--judgment that is informed by economic theory and data but in a manner that is less explicitly tied to formal models or algorithms.

There are several reasons why judgment will always be an important element in the conduct of monetary policy. First, models are able to make use of only a small fraction of the potentially valuable information that tells us about the complexity of the economy. For example, there are very high frequency data--monthly, weekly, and daily--that are not incorporated into macroeconometric models, which are usually estimated on quarterly data. These high-frequency data can often be very informative about the near-term dynamics of the economy and are used judgmentally by central-bank forecasters (e.g., Reifschneider, Stockton, and Wilcox, 1997).

Second, information that can be very useful in forecasting the economy or deciding whether a particular model makes sense is often anecdotal and is thus not easily quantifiable. The Federal Reserve makes extensive use of anecdotal information in producing its forecasts. The staff at the Board and the Federal Reserve Banks monitor a huge amount of anecdotal information, and such information is discussed extensively in the publicly released Beige Book, which reports information from contacts in the Federal Reserve Districts, and by the participants in FOMC meetings.

Third, although monetary policy makers make extensive use of models in both forecasting and evaluating different policies, they are never sure that one model is the correct one. Active, and sometimes bitter, debates about which modeling approaches are the right ones are ongoing in macroeconomics, and there often is not a consensus on the best model. As a result, central banks must express some degree of humility regarding their knowledge of the structural relationships that determine activity and prices. This humility is readily apparent in the practice at central banks, which involves looking at many different models--structural, reduced-form, general equilibrium and partial equilibrium, and continually using judgment to decide which models are most informative.

Fourth, the economy does not stand still but, rather, changes over time. Economic relationships are thus unlikely to remain stable, and it is not always clear how these relationships are changing.[17] Therefore, policymakers must sometimes put less weight on econometrically estimated equations and instead make informed guesses about how the economy will evolve.

Fifth, as part of managing expectations, monetary policy makers communicate with economic agents who are not automatons but instead process information in complex ways. Subtle changes can make a big difference in the effectiveness of communication strategies--i.e., details matter--and judgment is therefore always an important element of good communication.[18]

Although, for the reasons outlined above, judgment will always be a necessary element of monetary policy, good decisions require that judgment be disciplined--not too ad hoc--and be well informed by the science of monetary policy. As Blinder (1998, p. 17), has put it, "Nonetheless, while practicing this dark art, I have always found the science quite useful." Here

[17] The housing channel is one example in which the monetary transmission mechanism has changed substantially and is likely to continue to do so over time, e.g., Bernanke (2007) and Mishkin (2007c).

[18] Because subtle details matter, there is an important rationale for the use of case studies to research best practice in central bank communication strategies and this is why I have been drawn to case-study research (Bernanke and Mishkin, 1992; Bernanke and others, 1999; Mishkin, 1999).

I will discuss two recent episodes in the United States--the financial-headwinds period in the early 1990s and the new-economy, productivity burst of the late 1990s--to illustrate how judgment informed by science was able to produce good economic outcomes.

Financial Headwinds in the Early 1990s

The last scientific principle discussed in the paper's first section emphasizes the link between financial frictions and the business cycle, but it is unfortunately quite hard to model the role of these frictions in a general equilibrium, macroeconometric model. The late 1980s saw a boom and then a major bust in the commercial real estate market leading to huge loan losses that caused a substantial fall in capital at depository institutions (banks). At the same time, regulators were raising bank capital requirements to ensure compliance with the Basel Accord. The resulting capital shortfalls meant that banks had to either raise new capital or restrict their asset growth by cutting back on lending. Because of their weak condition, banks could not raise much new capital, so they chose the latter course. The resulting slowdown in the growth of credit was unprecedented in the post-World War II era (Reifschneider, Stockton, and Wilcox, 1997). Because banks have informational advantages in making certain loans (e.g., Mishkin, 2007a), many bank-dependent borrowers could no longer get access to financing and thus had to cut back on their spending.

Although the large-scale macromodel then in use at the Federal Reserve Board did not explicitly have financial frictions in its equations, officials at the Federal Reserve were aware that these frictions could be very important and were concerned that they might be playing a critical role at that juncture. In part reflecting this concern, many Fed economists were actively

engaged in research on the impact of bank credit on economic activity. This research, together with anecdotal reports that businesses were finding themselves credit constrained and survey information indicating that bank credit standards were being tightened, gave rise to the view among Federal Reserve policymakers that the capital crunch at banks was noticeably constraining credit flows and hence spending by households and firms. Indeed, Federal Reserve Chairman Alan Greenspan (1992) suggested that financial conditions in the early-1990s was holding back activity like a "50-mile per hour headwind," and in that period the FOMC reduced the federal funds rate to levels well below that suggested by the Taylor rule (e.g., Rudebusch, 2006). Indeed, the recovery from the 1990-91 recession was very slow, and the Fed kept the federal funds rate at 3 percent (which, with an inflation rate of around 3 percent, implied a real rate of zero) until February of 1994--a very accommodative policy stance. The Fed's expansionary policy stance at the time has in hindsight been judged as very successful, with the economy finally recovering and inflation remaining contained.

The New-Economy, Productivity Burst of the late 1990s

By the beginning of 1997, the unemployment rate had declined to 5.3 percent, and the Board staff was forecasting that the unemployment rate would fall to 5 percent--an outcome that followed by midyear. The forecast of a 5 percent unemployment rate was well below most estimates of the NAIRU (nonaccelerating inflation rate of unemployment). As a result, the staff forecast was for a rise in inflation (Svensson and Tetlow, 2005). The staff forecast and the recommendation in the February Bluebook suggested that a period of monetary policy tightening would be needed to "forestall a continuous rise in core inflation" (Federal Reserve Board, 1997,

p. 7). Although the FOMC did raise the federal funds rate in March 1997, it desisted from raising rates further; in fact, the FOMC reduced the federal funds rate in the fall of 1998 after the episode involving the Long-Term Capital Management hedge fund and the Russian-bond meltdown. Despite an unemployment rate continually below estimates of the NAIRU, the outcome was not the acceleration that the Board staff's models predicted (Svensson and Tetlow, 2005; Tetlow and Ironside, 2006) but instead a decline in the inflation rate.

Why did the FOMC hold off and not raise rates in the face of economic growth that was forecasted to be far in excess of potential growth--a decision that, ex post, appears to have resulted in desirable outcomes for inflation and employment? The answer is that Fed Chairman Greenspan guessed correctly that something unusual was going on with productivity. For example, he was hearing from businesspeople that new information technologies were transforming their businesses, making it easier for them to raise productivity. He was also a big fan of the historical work by Paul David (1990), which suggested that new technological innovations often took years to produce accelerations in productivity in the overall economy (Meyer, 2004). Chairman Greenspan was led to the conclusion that the trend in productivity growth was accelerating, a conclusion that the Board staff's forecast did not come to fully accept until late 1999 (Svensson and Tetlow, 2005). Moreover, he appeared to be convinced that the acceleration in productivity would cap inflationary pressures, implying that inflation would not accelerate even with rapid economic growth. His view prevailed in the FOMC (Meyer, 2004).[19]

The types of information used to foresee the effects of a productivity acceleration are inherently difficult to incorporate into formal models. This is obvious with respect to the anecdotes I have mentioned. But even the systematic data available at the time required the use

[19] Chairman Greenspan's successful use of judgment during this period is one reason why he was dubbed the "maestro" by Woodward (2000).

of judgment. For example, part of the story of the late 1990s reflected the different signals being sent by real-time measures of gross domestic product and gross domestic income--or at least the component of the latter produced by nonfinancial corporations, which is perhaps better measured (Corrado and Slifman, 1999) and provided some advance signal of the productivity acceleration. Of course, these two measures--GDP and GDI--are the same in our formal models, and only a judgmental filtering of the information content in each can be useful in real time.

Good judgment benefits not only from a good feel for the data and the successful processing of anecdotal information but also from the use of scientific models, and the late-1990s episode is no exception. At the July 1997 FOMC meeting, the Board staff presented simulations using the FRB/US model examining what would happen if productivity were to accelerate (Meyer, 2004; Tetlow and Ironside, 2006). Their simulations produced several results that were consistent with what seemed to be happening. An acceleration of productivity would raise profits and the value of equities, which would boost aggregate demand because higher stock values would stimulate business investment and boost consumer spending through wealth effects. The acceleration in productivity would also be disinflationary and could therefore explain why inflation would fall despite a declining unemployment rate. An unexpected rise in productivity growth would not be immediately reflected in higher wage rates, so unit labor costs (wages adjusted for productivity growth) would fall, leading to a decline in inflation. Another way of looking at this is through the NAIRU framework. For a given rate of unemployment, an unexpected acceleration in productivity would produce an inflation rate lower than it otherwise would be, so that the NAIRU at which the unemployment rate would not lead to an acceleration of inflation would decline. As events unfolded in line with these simulation results, the FOMC

became more convinced that a productivity boom was under way and that there was less need for a monetary tightening.

The two episodes discussed here illustrate several points about the art of central banking. First, monetary policy is more likely to produce better outcomes when central bankers recognize the limitations of their formal models. However, judgment cannot be undisciplined. The accuracy of judgment is likely to be enhanced when it is informed by the science of monetary policy, either through use of model simulations or applications of basic scientific principles.

IV.

Further Advances to Make Monetary Policy More of a Science

Although art will always be a feature of monetary policy, the science of monetary policy will keep advancing, making monetary policy more of a science. In this section I will briefly discuss where I think future advances in the science of monetary policy are likely to be made.

The push to build sound microfoundations into general equilibrium macroeconometric models is ongoing as the expanding literature on DSGE models indicates (survey in Gali and Gertler, forthcoming; and the discussions of model enhancements in Erceg, Gust, and Guerrieri, 2006, and in Edge, Kiley, and Laforte, 2007). However, these DSGE models are only now starting to be brought to the data and are not nearly as rich in their coverage of features of the economy as are older, more-Keynesian models such as FRB/US.[20] Models like FRB/US do have elements that are more ad hoc, but at the current juncture central bankers see them as more

[20] To be fair, models like FRB/US do have much in common with DSGE models in that many of their equations, but not all, are built on solid microfoundations.

realistic. Building macroeconometric models thoroughly grounded on solid microfoundations, but with treatment of more sectors of the economy, will be one of the main challenges for the science of monetary policy in the future.

Nominal rigidities are central to understanding quantitatively the impact of monetary policy on the economy. The canonical DSGE model makes use of a simple new-Keynesian Phillips curve framework because it makes the model very tractable.[21] This framework is highly stylized, however, and does not allow for endogenous changes in how often contracts are renegotiated. Furthermore, there may be other reasons why prices are not reset too often, such as rational inattention.[22] Better explanations--and more empirical validation--regarding the source of nominal rigidities may lead to important advances in the science of monetary policy.[23]

Tractability has led to models based on microfoundations, such as DSGE models, to rely on representative agents, which is a serious drawback. I have a strong sense that what drives many macroeconomic phenomena that are particularly interesting is heterogeneity of economic agents. Building heterogeneous agents into macroeconometric models will by no means be easy, but it has the potential to make these models much more realistic. Furthermore, it may allow us to understand the link between aggregate economic fluctuations and income distribution, a hot topic in political circles. Heterogeneity of economic agents is also crucial to understanding labor market frictions. In some DSGE models, all fluctuations in employment are from variation in hours per worker, and yet in the real world, changes in unemployment are a more important source of employment fluctuations. Bringing the search and matching literature more directly

[21] These models often use the Calvo (1983) staggering construct or the quadratic adjustment costs of Rotemberg (1982); these specifications yield identical Phillips curve specifications.
[22] Mankiw and Reis (2002) introduce this type of model; Kiley (2007) compares the ability of this type of model to improve upon the fit of more familiar sticky-price models.
[23] Microeconomic studies have begun to make interesting progress (e.g., Bils and Klenow, 2004; Nakamura and Steinsson, 2006).

into microfounded macroeconometric models will make them more realistic and also allow better welfare comparisons of different monetary policies.

Although, as discussed above, monetary policy makers understand the importance of financial frictions to the business cycle, general equilibrium macroeconometric models, for the most part, ignore financial market imperfections. Research has begun to incorporate financial market imperfections into quantitative dynamic general equilibrium models (e.g., Bernanke, Gertler, and Gilchrist, 1999), and some of this research has even begun to estimate these types of DSGE models (e.g., Christiano, Motto, and Rostagno, 2007). But we need to know a lot more about the how to *scientifically* incorporate financial frictions into policy deliberations. For the time being, the role for art is this area is very important.

The new field of behavioral economics, which makes use of concepts from other social sciences such as anthropology, sociology, and, particularly, psychology, suggests that economic agents may not always be the rational, optimizing agents we assume in our models. Embedding behavioral economics into macro models can make a major difference in the way these models work (Akerlof, 2007). How important are deviations from rationality to our views on the monetary transmission mechanism, and what are welfare-enhancing monetary policies? How can systematic deviations from rationality be modeled in a serious way and built into macroeconometric models? Answers to these questions may further enhance the realism of macroeconometric models used for policy purposes.

One of the rationales for the use of judgment (art) in the conduct of monetary policy is that the economy is not stationary, but rather is changing all the time. This means that economic agents are continually learning about the state of the economy, so the rational expectations assumption that depends on stationarity to derive expectations often may not be valid. Research

on the how agents learn and its implications for business cycles is an active area of research (Bullard and Mitra, 2002; Evans and Honkapohja, 2003) that should have major payoff in helping us to better understand the impact of monetary policy on the economy.

Another rationale for keeping art in monetary policymaking is that we can never be sure what is the right model of the economy. As I mentioned earlier, this argues for humility at central banks. It also argues for advances in scientific techniques to think about which monetary policies are more robust in producing good economic outcomes. Research in this area is also very active. One approach examines parametric uncertainties in which methods are examined to ensure that a prescribed policy works well in an entire class of models (e.g., Levin, Wieland, and Williams, 1999). Nonparametric approaches look at designing policies that protect against model misspecifications that cannot be measured (e.g., Hansen and Sargent, forthcoming; Tetlow and von zur Muehlen, 2001).

The list of areas here that will advance the science of monetary policy is necessarily incomplete. Some of the most important advances in economic science are often very hard to predict.

V.

Concluding Remarks

The science of monetary policy has come a long way over the past fifty years, and I would argue that its advances are an important reason for the policy successes that so many countries have been experiencing in recent years. Monetary policy will however never become as boring as dentistry. Monetary policy will always have elements of art as well as science.

(That is good news because it will keep life interesting for monetary economists like me.) However, the advances in the science of monetary policy that I have described here suggest that monetary policy will become more of a science over time. Furthermore, even though art will always be a key element in the conduct of monetary policy, the more it is informed by good science, the more successful monetary policy will be.

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Figure 1: Headline Inflation

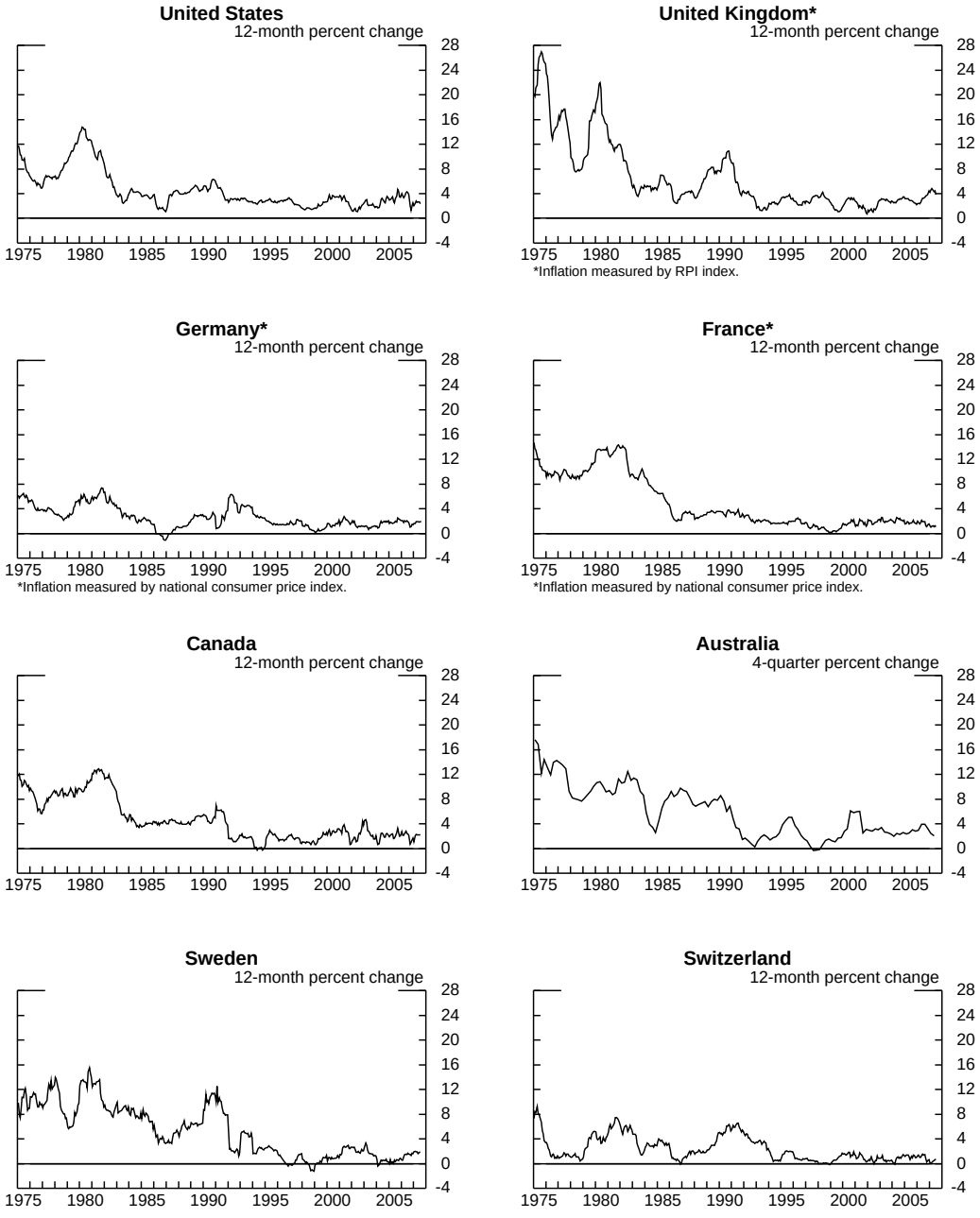


Figure 2: Standard Deviation of Headline Inflation

(5-year window)

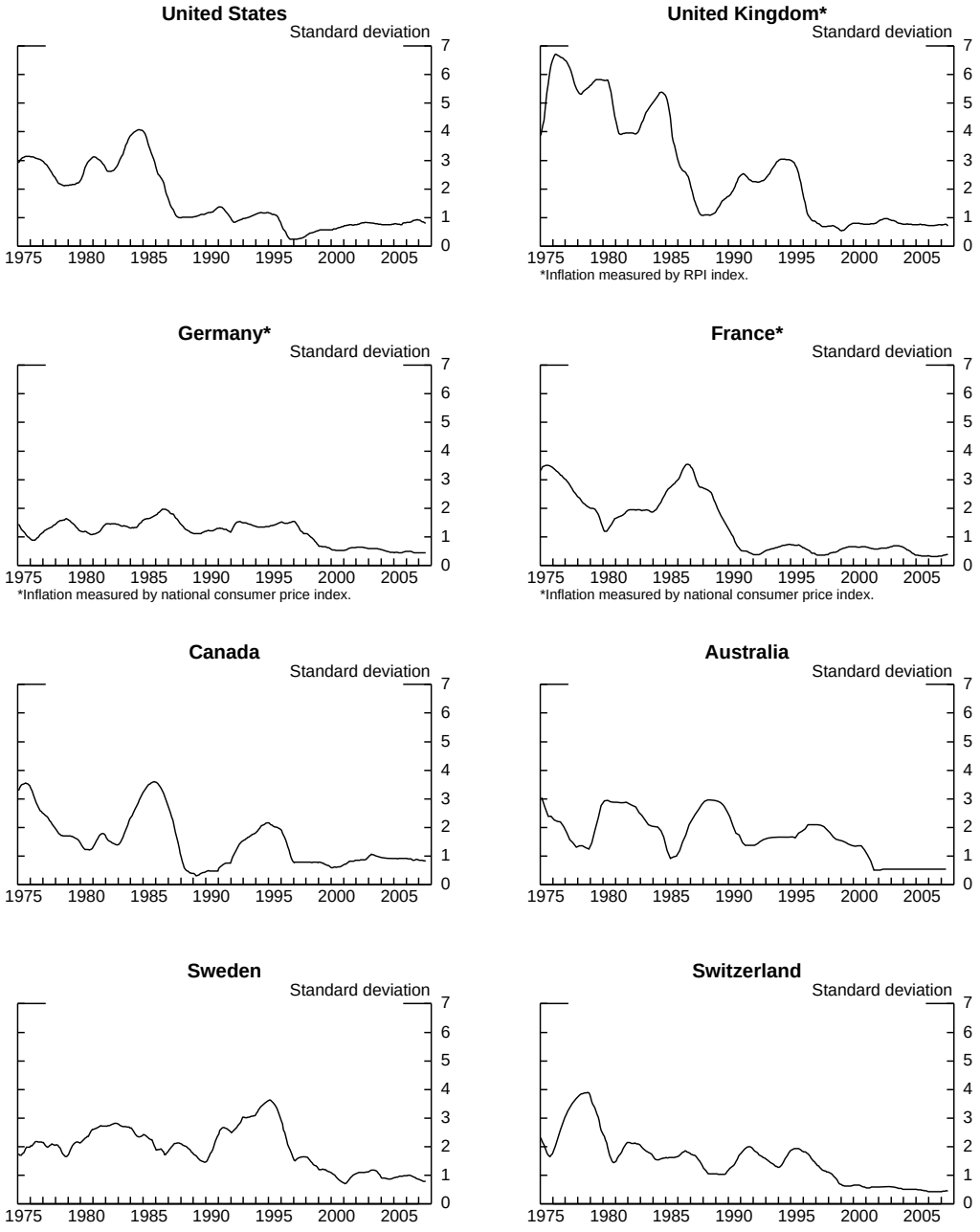


Figure 3: Standard Deviation of Output Growth

(5-year window)

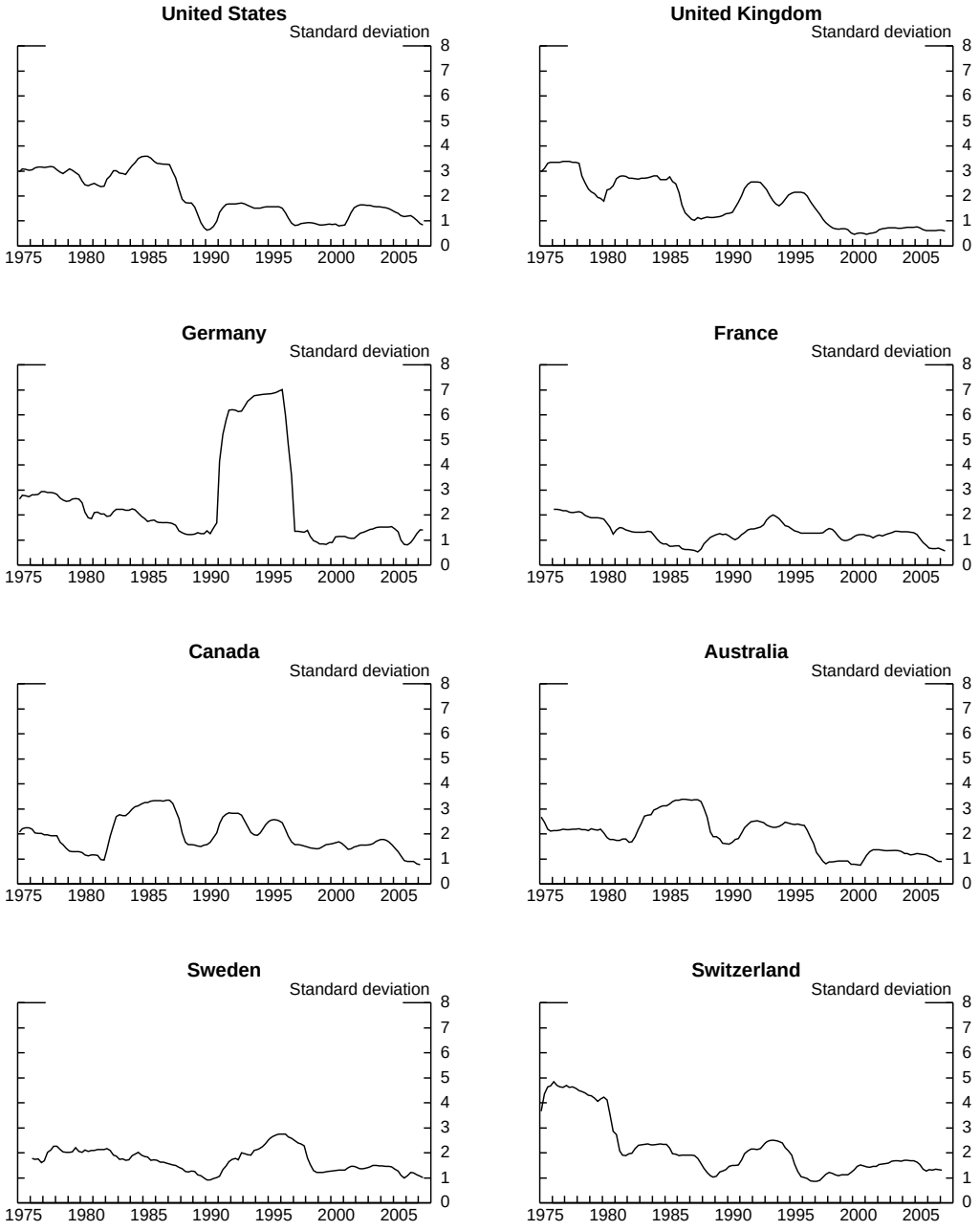
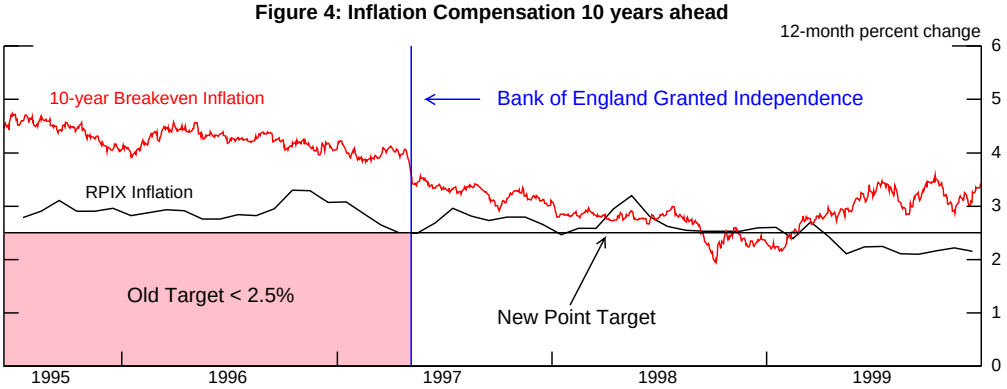


Figure 4: Inflation Compensation 10 years ahead



Note: RPIX series is not seasonally adjusted; breakeven inflation uses a real bond indexed to RPI inflation.