Federal Reserve Bank of St. Louis

REVIEW

MAY/JUNE 2008 VOLUME 90, NUMBER 3, PART 2

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ISSN 0014-9187

II

Introduction

William T. Gavin
Review Editor-in-Chief

The Federal Reserve Bank of St. Louis has published its *Review* continuously since 1969, when it was first abstracted by the *Journal of Economic Literature* (JEL); it has maintained a bimonthly printing schedule for the past 20 years and was accepted into the Social Sciences Citation Index (SSCI) in 2005. In November 2006 we announced plans to build on this tradition by publishing a supplemental series of issues, a "Part II" of our *Review*. This is the inaugural issue.

This Part II series will include research from Federal Reserve System economists and ongoing visiting scholars that focuses on central bank policy, current events, and other economic topics. We intend to publish research for a wide audience (as we have been doing with the *Review* for decades). The most important criteria for articles are usefulness, accuracy, and readability.

Manuscripts submitted to the Part II series are peer-reviewed, and the series itself is directed by an editorial board of economists associated with the Federal Reserve System: Charles Carlstrom from the Federal Reserve Bank of Cleveland, Julie Hotchkiss from the Federal Reserve Bank of Atlanta, Marco Del Negro and Don Morgan from the Federal Reserve Bank of New York, John Rogers from the Division of International Finance at the Federal Reserve Board, and Steve Williamson, who is on the faculty at Washington University in St. Louis and is a regular visitor at the St. Louis Fed.

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Inertial Taylor Rules: The Benefit of Signaling Future Policy

Charles T. Carlstrom and Timothy S. Fuerst

This article traces the consequences of an energy shock on the economy under two different monetary policy rules: (i) a standard Taylor rule, where the Fed responds to inflation and the output gap, and (ii) a Taylor rule with inertia, where the Fed moves slowly to the rate predicted by the standard rule. The authors show that, with both sticky wages and sticky prices, the outcome of an inertial Taylor rule is superior to that of the standard rule, in the sense that inflation is lower and output is higher following an adverse energy shock. However, if prices alone are sticky, the results are less clear and the standard rule delivers substantially less inflation than the inertial rule in the short run. (JEL E52, E61)

Federal Reserve Bank of St. Louis *Review*, May/June 2008, *90*(3, Part 2), pp. 193-203.

Before exiting an expressway, a cautious driver always signals his intention by switching on his turn signal well in advance of turning because he understands that other drivers' behavior will be affected by what they anticipate he will do. This commonplace example may speak metaphorically to central bank policy: If market participants are forward looking, then it may be important for the central bank to signal future policy moves.

Starting in June 2004, the FOMC changed its language to indicate that existing policy accommodation would be removed at a "measured pace," strongly signaling the direction of future Fed policy. But why adjust partway by signaling future policy instead of going all the way more quickly? Likewise, why increase the funds rate 25 basis points at each of 10 policy meetings, instead of making five moves of 50 basis points, or, for that matter, one move of 250 basis points? What are the advantages of a measured pace?

One way to describe Fed policy is with a simple Taylor (1993) rule in which monetary policy responds to inflation and the output gap. Clearly, the Fed does not automatically adjust policy according to the prescriptions of the rule. Nevertheless, there is substantial empirical evidence that broad movements in the funds rate are well tracked by a simple Taylor rule. But this evidence also suggests that the Fed adjusts the funds rate much more slowly than the standard Taylor rule prescribes. That is, although funds rate movements are typically in the direction suggested by the rule, these movements are only partial; thus, it takes a series of policy moves to reach the level a standard Taylor rule suggests. This type of Taylor rule is said to be inertial because it changes slowly and today's funds rate depends on yesterday's funds rate.

One way to think about an inertial Taylor rule is that policy consists of both the funds rate today and the expected path of the funds rate. Without inertia, policy moves more immediately and does not indicate where the funds rate is

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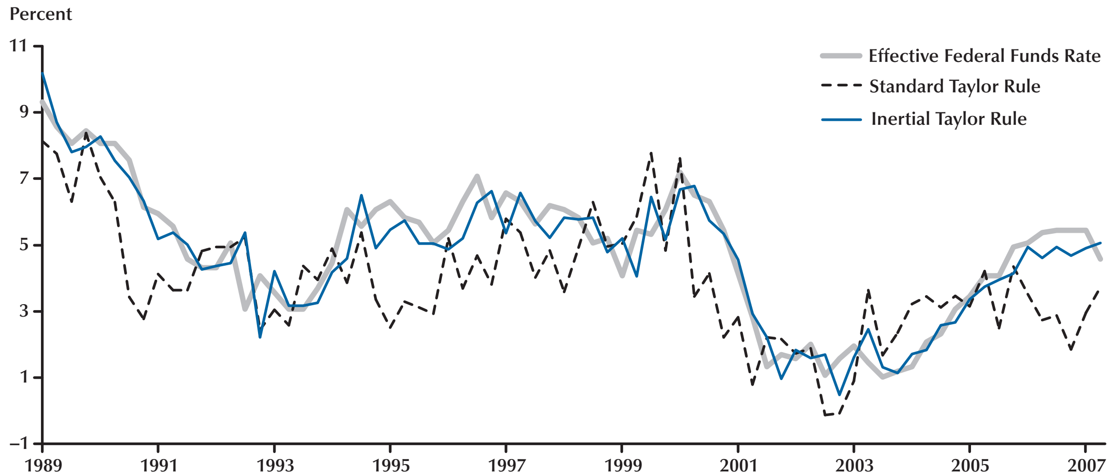
Figure 1

Inertial and Non-Inertial Taylor Rules



NOTE: The standard (non-inertial) Taylor rule is adapted from Taylor (1993). The effective federal funds rate is the rate on the last day of each quarter. The inertial (partial-adjustment) Taylor rule is the weighted average of last quarter's federal funds rate and the target Taylor rule. The exact form of both Taylor rules comes from Kozicki (1999).

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis; Bloomberg Financial Services; Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release H.15, "Selected Interest Rates"; and the Congressional Budget Office.

likely to head.[1] This article shows, in the context of a standard, quantitative, dynamic New Keynesian model, that it is beneficial for policy accommodation to be removed slowly instead of in one—or a few—large moves. That is, an inertial Taylor rule frequently delivers a better outcome than a non-inertial rule.

In particular, we trace the consequences of an energy shock on the economy under two different monetary policy rules: a standard Taylor rule, where the Fed responds to inflation and the output gap, and an inertial Taylor rule, where the Fed moves slowly to the rate predicted by the standard rule. We show that with both sticky wages and sticky prices, an inertial (partial-adjustment) Taylor rule's outcome is superior to that of a standard rule, in the sense that inflation is lower and output higher following an adverse energy shock. However, if prices alone are sticky, the results are less clear and the standard rule delivers substantially less inflation than the inertial rule in the short run.

THE TAYLOR RULE

The Taylor rule has had a big impact in both monetary policy circles and academic economic research. Figure 1 suggests why. The rule seems to track broad policy moves since 1987 very successfully, which seems remarkable because it is so simple: It is set according to only four components: The first is the Fed's long-term inflation target and the second is the "natural" or long-term real (inflation-adjusted) federal funds interest rate. The sum of these first two factors determines the long-run (nominal) federal funds rate, which amounted to 4 percent annually in Taylor's original rule. The two remaining factors, the current output gap and the four-quarter inflation rate, address the way policy should respond to changing circumstances in the short run.

[1] Of course, even with a non-inertial Taylor rule, one will anticipate future funds rate movements to the extent that future inflation and the output gap are forecasted.

The Taylor rule prescribes that the Fed "lean against the wind" when setting interest rates; that is, it should raise rates when current output surpasses potential. It prescribes a similar response to inflation—raise interest rates when the inflation rate over the past year exceeds its long-term target.

But mere leaning is not enough when it comes to inflation. Taylor cautioned that interest rates must rise by *more than* the increase in inflation. Given that nominal interest rates naturally increase one-for-one with movements in anticipated inflation (leaving the real rate unchanged), just increasing the funds rate one-for-one with increases in inflation is like treading water. Therefore, the Fed must increase the *real* funds rate in response to the rise in inflation to make any headway. This more-than-proportional response of the nominal funds rate to inflation, known as the *Taylor principle*, therefore prescribes that the real federal funds rate should be made greater than the natural rate of interest whenever inflation is above target.

In the simplest form of the rule, Taylor argued that the Fed should increase the real funds rate by half a percentage point for every percentage point that inflation is above target or output is above potential. This implies that the nominal funds rate should increase by 1.5 percent for every percentage point increase in inflation. (Likewise, the Fed should decrease the real funds rate by the same amount for deviations below either target or potential.) Thus, Taylor felt that monetary policy (in terms of the real funds rate) should respond equally (in terms of the real interest rate) to inflation and output deviations. But the exact weights are not crucial. Empirical evidence suggests that the Fed has responded to output gap deviations (at least since 1983) a little less than Taylor had assumed:

$$i_t^* = 2.32 + 1.44 * \left(\pi_t - \pi^*\right) + 0.15 * \text{output gap}_t .$$

Figure 1 plots this rule and shows that it remains below or above the actual funds rate for long periods. One reason for these long misses is that the FOMC does not change the funds rate as often or as dramatically as the standard Taylor rule suggests. Instead, the actual funds rate exhibits a lot of inertia, suggesting that an inertial Taylor rule might be a better fit. Here the Fed also looks at the past funds rate in setting its target. The inertial Taylor rule is given by

$$i_t^{PA} = 0.76 * i_{t-1} + 0.24 * i_t^* ,$$

where i_{t-1} is last quarter's funds rate (measured by the federal funds rate on the last day of the quarter) and i^* is the target rate (the rate suggested by the Taylor rule without inertia). Figure 1 also plots this inertial rule. The baseline rule without inertia is basically a longer-run target that provides guidance for where the funds rate will eventually end up. The data suggest that instead of moving to the target immediately, the Fed moves only 24 percent of the way there each quarter. Figure 1 clearly shows that this partial-adjustment Taylor rule tracks the actual funds rate very closely. Another way of thinking about the partial-adjustment formulation is that, instead of reacting to today's inflation and the output gap, the Federal Open Market Committee (FOMC) reacts to a weighted average of today's and all past inflation and output gaps.

The discussion that follows shows that, with sticky prices and sticky wages, a partial-adjustment Taylor rule delivers better inflation and output outcomes than the traditional Taylor rule. This is shown in the context of an oil shock that reduces output and increases inflation.

OIL PRICES AND MONETARY POLICY: A COMPUTABLE GENERAL-EQUILIBRIUM MODEL

To ascertain whether an inertial or non-inertial Taylor rule is better, we need a calibrated computable general-equilibrium model. Here we sketch the model used for our simulations; we describe it more fully in the appendix, along with our calibration of its parameters. Oil is an important input in manufacturing (and, perhaps to a lesser extent, in services). Oil price increases will therefore reduce output and (for a given monetary policy) increase prices. The rise in prices is not instantaneous, however; the evidence suggests that prices are sticky and adjust slowly and that wages are sticky as well. Both these forms of nominal stickiness imply that output will not respond efficiently and will differ from its first-best level (or potential). That is, if both prices and wages were perfectly flexible, the output gap would be zero.

A key issue in the analysis is, of course, the statement of monetary policy. For the benchmark simulation, we assume that policy is given by the standard (non-inertial) Taylor rule described in the previous section. For the inertial rule we use the partial-adjustment rate estimated by Kozicki (1999), where policy adjusts only 24 percent of the way to the rate predicted by the standard Taylor rule.

MODEL SIMULATIONS

Model simulations suggest that there may be an advantage in adjusting the funds rate slowly. Figure 2 answers these hypothetical questions: Holding everything else constant, how would inflation, interest rates, and output be expected to behave following a one-time 30 percent increase in oil prices? How would these variables behave if the Fed followed a non-inertial Taylor rule compared with an inertial Taylor rule? All variables are plotted as log deviations from trend. (For the funds rate and inflation, these are linear deviations from trend.)

With both rules, the oil shock tends to increase inflation. The standard Taylor rule suggests that policymakers raise the nominal interest rate to keep inflation from increasing even more. But with an inertial Taylor rule, this increase is smaller and spread out over time. Therefore, the difference between an inertial rule and non-inertial rule is that the latter increases rates less today with a promise of future increases.

This promise to increase rates in the future is extremely important. With the inertial rule, the nominal funds rate lags behind the rule without inertia and peaks at a much lower level as well. This promise of future rate increases keeps inflation lower than the non-inertial rule as well. Surprisingly, the funds rate with inertia is always lower than the non-inertial Taylor rule; yet inflation, too, is always lower. This is because the stance of monetary policy is not given by the nominal funds rate but by the real, inflation-adjusted funds rate. More precisely, the policy stance is given by how much the real, inflation-adjusted funds rate deviates from the Wicksellian interest rate (the real interest rate that would prevail in the economy if there were no price or wage stickiness or, equivalently, if the output gap were always equal to zero). By construction, therefore, the Wicksellian rate is the same for both the inertial and non-inertial rules.

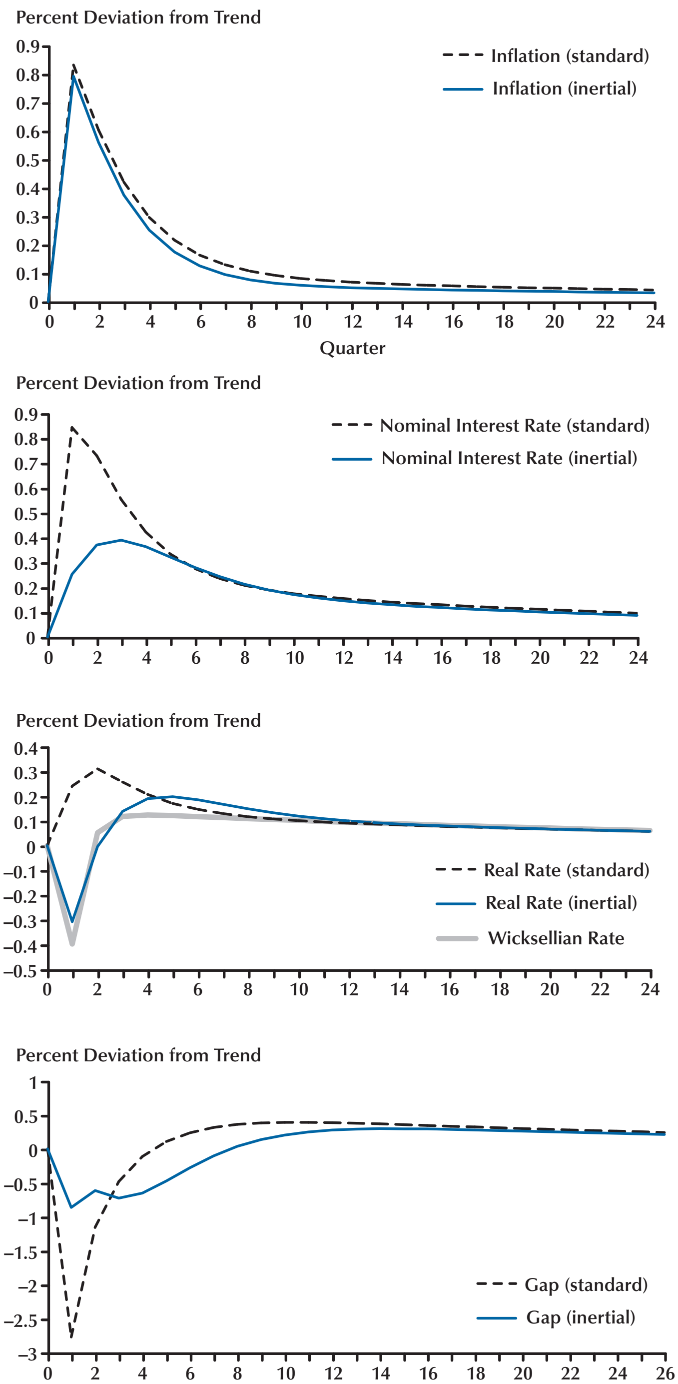
In the quarters immediately following an oil price increase, policy is much easier (the real rate is lower) for the inertial rule. However, this does not translate into more inflation today, because in later periods, policy is expected to be tighter for the inertial rule. A long period in the distant future, when policy is expected to be tighter, more than compensates (in terms of inflation outcomes) for the shorter period of time when policy was substantially easier. The true stance of monetary policy, therefore, is given not only by the real interest rate but also by the real rate's future path.

Although inversely related, the behavior of the output gap mirrors that of the real interest rate. In the beginning, the real interest rate is lower, making policy less restrictive for the inertial rule than it is for the non-inertial rule. Not surprisingly, during these periods, output and thus the output gap is higher for the inertial rules. In subsequent periods, things are reversed. The output gap is composed of two distortions, one arising from sticky prices and the other from sticky wages. The output gap from sticky prices is nearly identical for the two rules (although a little lower for the inertial rule). It is the gap arising from sticky wages that drives the difference between each rule's total output gap.

Inflation is a little lower in the inertial model because output and the output gap resulting from sticky prices are a little lower. Another way of thinking about inflation is that it is the present discounted value of all future marginal costs (the inverse of the markup). Current prices are determined by marginal cost, as it is today and is

Figure 2

Response to an Oil Shock (Sticky Prices and Sticky Wages)

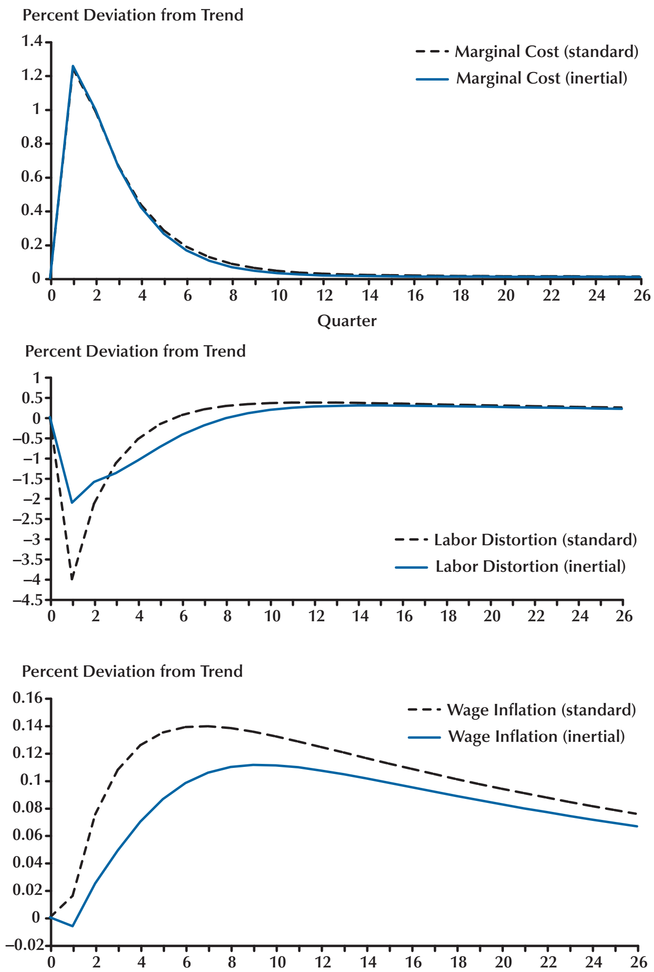


NOTE: Simulations are hypothetical responses to a 30 percent oil price shock, given that future oil prices behave as they have in the past.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis; U.S. Department of Labor, Bureau of Labor Statistics; Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release H.15, "Selected Interest Rates"; and author's calculations.

Figure 2, cont'd

Response to an Oil Shock (Sticky Prices and Sticky Wages)

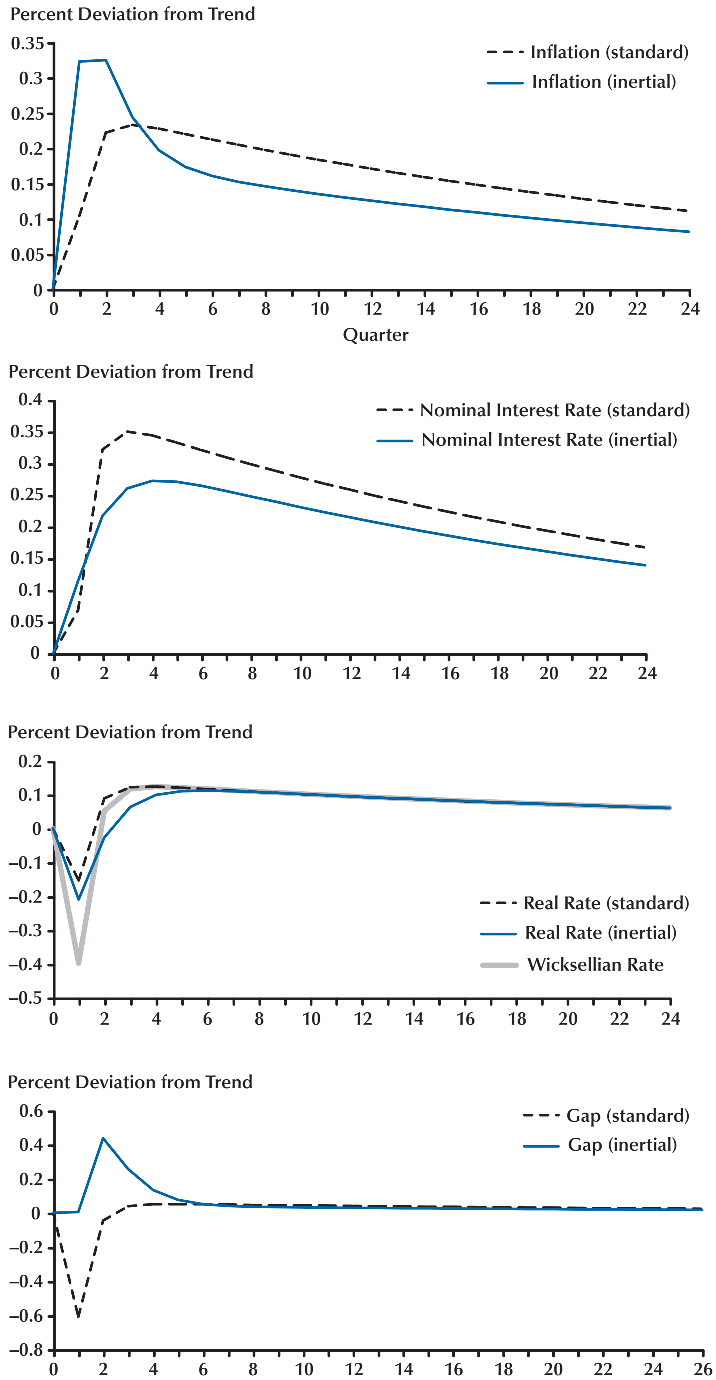


NOTE: Simulations are hypothetical responses to a 30 percent oil price shock, given that future oil prices behave as they have in the past.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis; U.S. Department of Labor, Bureau of Labor Statistics; Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release H.15, "Selected Interest Rates"; and author's calculations.

Figure 3

Response to an Oil Shock (Sticky Prices Only)



NOTE: Simulations are hypothetical responses to a 30 percent oil price shock, given that future oil prices behave as they have in the past.

SOURCE: U.S. Department of Commerce, Bureau of Economic Analysis; U.S. Department of Labor, Bureau of Labor Statistics; Board of Governors of the Federal Reserve System, Federal Reserve Statistical Release H.15, “Selected Interest Rates”; and author’s calculations.

expected to be in the future. A larger markup (lower marginal cost) means that output is further below its efficient level, a negative output gap.

Like marginal cost for sticky prices, the monopoly distortion in labor markets measures the difference between the household's marginal rate of substitution and the real wage. A value of unity would mean no distortion, whereas a smaller value would imply a larger distortion and thus less output. Analogous to inflation, wage inflation is the present discounted value of all these future deviations. This distortion is what drives the difference between the output gap measures for the inertial and non-inertial Taylor rule simulations. Nominal wage inflation driven by differences in real wage growth is always lower for the inertial model. This fact implies that, in a present discounted sense, output is further below potential than it is in the model without inertia.

The difference between the part of the output gap driven by sticky prices versus that driven by sticky wages suggests that sticky wages may be crucial to the result that the inertial model appears to deliver better outcomes. A model with only sticky prices bears this out. Figure 3 graphs the outcomes for the model with only sticky prices. Inflation was everywhere lower for the inertial Taylor rule in the model with both sticky prices and sticky wages. But with only sticky prices, inflation is initially much higher for the inertial Taylor rule and output is further above potential. Because of the large inflation jump, nominal interest rates in the first few quarters after the energy shock are just as high for the inertial rule as for the non-inertial rule.

The importance of inertial Taylor rules is reminiscent of the benefits of forward-looking language in FOMC policy statements. With forward-looking language, the Fed moves today and signals where they intend to move in the future. Likewise, by influencing expectations, monetary policy operates off of both short- and long-term rates. An inertial Taylor rule basically states where the Fed moves today and where they are expected to move in the future.

CONCLUSION

This paper has shown that in a standard model with sticky wages and sticky prices, a Taylor rule with inertia delivers better outcomes than the standard Taylor rule without inertia. This result, however, depends on the stickiness of wages relative to prices. Recent work by Christiano, Eichenbaum, and Evans (2005) suggests the importance of sticky wages in explaining business cycle fluctuations. This lends support to the notion that the Fed implicitly follows an inertial Taylor rule because it delivers lower interest rates and inflation without worsening output significantly. In fact, for the first several quarters following an oil price increase, output is also higher for the inertial rule.

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APPENDIX

THE MODEL

Apart from adding oil to the production technology, the underlying model is fairly standard. See Woodford (2003) and Walsh (2003) for details. The theoretical model described here consists of households and firms; we present the decision problems of each in turn.

Households

Households are infinitely lived, discounting the future at rate β. Their period-by-period utility function is given by

$$U\left(C_t, L_t, \frac{M_{t+1}}{P_t}\right) \equiv \frac{C_t^{1-\sigma}}{1-\sigma} - \frac{L_t^{1+\gamma}}{1+\gamma} + V\left(\frac{M_{t+1}}{P_t}\right),$$

where $\sigma > 0$, $\gamma > 0$, V is increasing and concave, C_t denotes consumption, L_t denotes labor, and M_{t+1}/P_t denotes real cash balances that can facilitate time-t transactions. The household begins period t with M_t cash balances and B_{t-1} one-period nominal bonds that pay R_{t-1} gross interest. With w_t denoting the real wage, P_t the price level, and X_t the time-t monetary injection, the household's intertemporal budget constraint is given by

$$P_t C_t + B_t + M_{t+1} \leq M_t + R_{t-1} B_{t-1} + P_t w_t L_t + X_t.$$

The household's portfolio choice is given by

$$\frac{V'\left(M_{t+1} / P_t\right)}{C_t^{-\sigma}} = \frac{R_t - 1}{R_t}$$

$$C_t^{-\sigma} = R_t \beta C_{t+1}^{-\sigma} / \pi_{t+1}.$$

Following Erceg, Henderson, and Levin (2000), we assume that households are monopolistic suppliers of labor and that nominal wages are adjusted as in Calvo (1983). In this case, labor-supply behavior is given by

$$C_t^{\sigma} L_t^{\gamma} = Zh_t W_t.$$

It is easy to see that the wage elasticity of labor demand in this model is $1/\gamma$. The variable Zh_t in this labor demand equation is the monopoly distortion because it measures the difference between the household's marginal rate of substitution and the real wage. In the case of perfectly flexible but monopolistic wages, $Zh_t = Zh$ is constant and less than unity. The smaller Zh is, the greater is the monopoly power. In the case of sticky nominal wages, Zh_t is variable and moves in response to the real and nominal shocks hitting the economy. Erceg, Henderson, and Levin (2000) demonstrate that in log deviations, *nominal* wage adjustment is given by

$$\pi_t^W = \lambda^W zh_t + \beta\pi_{t+1}^W,$$

where π_t^W is time-t net nominal wage growth and zh_t denotes the log deviation from the steady state.

Firms

The firms in the model utilize labor services, L_t, from households and energy, E_t, from external sources to produce the final good using the constant elasticity of substitution (CES) technology:

$$Y = f(L,E) \equiv \left[(1-a)L^{1-\rho} + aE^{1-\rho}\right]^{1/(1-\rho)}.$$

The real energy price is equal to p_t^e so that a firm's nominal profits are given by

$$profits = P_t\left(Y_t - w_t L_t - p_t^e E_t\right).$$

The firm is a monopolistic producer of these goods, implying that labor will be paid below its marginal product. Let Z_t denote marginal cost so that we have

$$w_t = Z_t f_L(t)$$
$$p_t^e = Z_t f_E(t).$$

The variable Z_t is the monopoly distortion as it measures how far the firm's marginal products differ from the real factor prices. In the case of perfectly flexible but monopolistic prices, $Z_t = Z$ is constant and less than unity. The smaller Z is, the greater is the monopoly power. In the case of sticky prices, Z_t is variable and moves in response to the real and nominal shocks hitting the economy. Yun (1996) demonstrates that in log deviations, *nominal* price adjustment is given by

$$\pi_t = \lambda z_t + \beta\pi_{t+1},$$

where π_t is time-t nominal price growth (as a deviation from steady-state nominal price growth) and lower case z_t denotes the log deviation from the steady state.

Equilibrium and Policy

There are four markets in this theoretical model: labor, goods, bonds, and money. The respective market-clearing conditions include $C_t = Y_t - p_t^e E_t$ and $B_t = 0$. The money market clears with the household holding the per capita money supply intertemporally.

Calibration

We set parameter values consistent with empirical estimates for a quarterly model. Preference parameters are given by $\beta = 0.99$ (implying a 4 percent annual steady-state real rate of return), $\sigma = 2$, and $\gamma = 3$. The latter values are consistent with microeconomic evidence of fairly inelastic savings and labor supply behavior. Because monetary policy is given by an interest rate targeting procedure, the nature of money's utility is irrelevant. Finally, we assume that prices and nominal wage levels can be adjusted on average every 2.9 quarters. Given the other preference parameters, this implies $\lambda = 0.19$ and $\lambda^w = 0.0146$. For the model with sticky prices only, $\lambda^w = 1{,}000$.

As for firms, the elasticity of substitution between oil and labor is equal to $1/\rho$. Consistent with empirical estimates, we set this elasticity to 0.59, or $\rho = 1.7$. (See Kim and Loungani, 1992.) The share parameter, a, is set to 0.02. This implies a share of energy in total output of 6 percent (consistent with its share in 1989).

The (logged) real price of oil is given by an exogenous AR(2) process:

$$p_t^e = a_1 p_{t-1}^e + a_2 p_{t-2}^e + \varepsilon_t.$$

Estimating this process yields $a_1 = 1.12$ and $a_2 = -15$.

Finally, recall that monetary policy in the baseline experiment is given by

$$R_t = (1-\rho) R_{ss} + \rho R_{t-1} + (1-\rho)\left(\tau \pi_t + \tau_g \text{output gap}_t\right),$$

where

$$\text{output gap}_t = \frac{(z_t + z h_t)}{(\gamma + \sigma)}.$$

Empirical evidence presented in Kozicki (1999) suggests that, since 1983, the coefficients in this monetary policy rule are $\tau = 1.44$ and $\tau_g = 0.14$. For the non-inertial Taylor rule, $\rho = 0$; whereas, for the inertial Taylor rule, $\rho = 0.76$.

II

Core Inflation: A Review of Some Conceptual Issues

Mark A. Wynne

This paper reviews various approaches to the measurement of core inflation that have been proposed over the years using the stochastic approach to index numbers as a unifying framework. It begins with a review of how the concept of core inflation is used by the world's major central banks, including some of the inflation-targeting central banks. The author provides a comprehensive review of many of the measures of core inflation that have been developed over the years and highlights some of the conceptual and practical problems associated with them. (JEL E31, C43)

Federal Reserve Bank of St. Louis *Review*, May/June 2008, *90*(3, Part 2), pp. 205-28.

The notion of core inflation has played an important role in the deliberations of monetary policymakers for the past 25 years. However, despite the central role of this concept, there is still no consensus on how best to go about measuring core inflation. The most elementary approach, and the one that is probably the most widely used, consists of simply excluding certain categories of prices from the overall inflation rate. This is the so-called "ex. food and energy" approach to core inflation measurement, and it reflects the origin of the concept of core inflation in the turbulent decade of the 1970s. More recently, however, there has been a number of attempts to put the measurement of core inflation on a more solid statistical and theoretical footing. The newer approaches have two key features in common: First, they adopt a more statistical rather than behavioral (e.g., cost of living) approach to the problem of price measurement. And second, they invoke an alternative, monetary concept of inflation, as opposed to the traditional microeconomic cost-of-living concept as the guiding theory.

In this paper I critically review various approaches to measuring core inflation by linking these approaches in a single theoretical framework, the so-called stochastic approach to index numbers. I evaluate the competing merits of the different approaches and argue that a common shortcoming is the absence of a well-formulated theory of what these measures of inflation are supposed to be capturing. The notion that they somehow better capture the "monetary" component of inflation, or the component of inflation that ought to be of primary concern to central bankers, is questionable.

THE CONCEPT OF CORE INFLATION

Implicit in all discussions of core inflation is the idea that this type of inflation is fundamentally different from changes in the cost of living. The theory of the cost-of-living index is by far the most well-developed and coherent framework for infla-

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tion measurement that currently exists: The basic theory takes as its point of departure the expenditure or cost function of a representative household at a given point in time. The change in the cost of living between some base period, 0, and some subsequent comparison period, 1, is then defined as the change in the minimum cost of attaining the reference utility level, *u*, between the two periods. This theory, appropriately elaborated, forms the framework for the design of the consumer price index (CPI) in the United States. However, the theory of the cost-of-living index is not the theoretical framework for the harmonized index of consumer prices (HICP) that is used to assess inflation developments in the euro area: At the time of this writing, there is no fully articulated theoretical framework for the HICP, although there is a relatively well-defined price concept, namely, "final household monetary consumption." By eschewing the use of the cost-of-living concept, Eurostat (the statistical office of the European Community) can legitimately motivate the exclusion of certain categories of prices from the HICP. The category that has attracted the most attention by its omission is the cost of owner-occupied housing. In the U.S. CPI, for example, the cost of owner-occupied housing is measured on a rental equivalent basis, which is appropriate given the cost-of-living concept that underlies the U.S. CPI. That is, what is priced each month is not the cost of purchasing a home for owner occupancy, but rather the cost of the flow of services consumed each month, which can be proxied by the rental rates on similar housing unites (see U.S. Department of Labor, Bureau of Labor Statistics, 1997). Since the rental equivalence cost of consuming housing services each month is not part of household monetary consumption, it is not priced as part of the HICP. However, the net acquisition costs of new dwellings are arguably part of such consumption, and Eurostat is at present investigating ways of including such costs in the HICP (see Commission of the European Communities, 1998).

One common measure of core inflation excludes the effects of changes in indirect taxes from the overall inflation rate. Donkers et al. (1983) discuss how this is done in a number of European countries. This type of measure is potentially of interest from a monetary policy perspective because, arguably, an acceleration in headline inflation that is in some sense attributable to an increase in indirect taxes ought not to be of concern to the central bank. Current practice, as reviewed by Donkers et al., is to employ various ad hoc methods to derive an estimate of the inflation rate net of indirect taxes. The exact methods employed differ from country to country. One approach is to (i) simply assume that all of the observed price change reflects the change in the tax and (ii) calculate an alternative CPI on the basis of this assumption.[1] The problem with this approach is that the implicit assumption about supply elasticities (perfectly elastic) is unlikely to be a good approximation of reality for many products. A more sophisticated approach might allow for the effects of a change in indirect tax rates on the structure of production prices, but the variant analyzed by Diewert and Bossons (1987) still requires restrictive assumptions about the invariance of the input-output structure of the economy to changes in indirect tax rates.

These calculations raise the question of what it is we want a core inflation statistic to measure. If the object we are pursuing is a true cost-of-living index, then it is not clear that we should be eliminating the effects of tax increases from our price measure. Furthermore, the reasoning above is only partial equilibrium. A proper treatment of the effects of indirect taxes on a measure of the price level would require a detailed general equilibrium analysis of the effects of the tax increase that would go well beyond current practice.[2] Diewert and Fox (1998) suggest a method for handling tax changes for the purposes of using inflation measures to make welfare comparisons.[3]

[1] For details see, for example, Diewert and Bossons (1987).

[2] Diewert (1997) notes that "there is no unambiguous, completely accurate method for removing all indirect commodity taxes...any attempt to do this will be a complex exercise in applied general-equilibrium modelling rather than in economic measurement. Moreover, the fact that the government has caused consumer prices to increase rather than some other economic phenomenon seems somewhat immaterial: In either case, households are facing higher prices, and we may want to measure this fact!" (Diewert, 1997, p. 134).

[3] See also Diewert and Bossons (1987).

Note also that in principle the distortionary effect of large infrequent changes in indirect taxes on the inflation signal may be adequately handled by some or all of the approaches reviewed below. Indirect tax changes that apply to some commodities but not others would be reflected in large price changes for the commodities in question. Limited-influence estimators of core inflation of the sort proposed by Bryan and Pike (1991) and Bryan and Cecchetti (1994) would omit these observations from the calculation of inflation. However, large changes in relative prices induced by changes in indirect taxes are arguably different from large changes that are due to other factors, such as supply or demand developments in the markets for specific goods or services. These other factors may be more difficult to identify than changes in indirect tax rates, and thus it may be more difficult to filter out their effects on the overall inflation rate.

The common point of departure for almost all analyses of core inflation is the idea that there is a well-defined concept of monetary inflation that ought to be of concern to monetary policymakers and that this type of inflation, being conceptually different from the cost of living, is not adequately captured by the standard price statistics.[4] Thus it is argued that central banks ought to target a price index whose rate of increase corresponds to the inflation that generates the costs that central banks are seeking to avoid by focusing on an inflation-control objective. Inflation is costly to society because it disrupts the coordination of economic activity and discourages the use of fiat money in market transactions. Although it is possible that some of the costs of inflation are captured by changes in the cost of living, some of them may require a much broader measure of market transactions. One conclusion from this line of reasoning is that, for the purposes of monetary policy, what is needed is not a microeconomic theory of the cost of living, but a macroeconomic theory of the cost of inflation. Thus we can interpret various measures of core inflation as attempts to better measure this more-appropriate measure of inflation for monetary policy purposes.

[4] See, for example, Howitt (1997).

But just how much guidance does the concept of monetary inflation provide when it comes to measurement? Consider a very standard money market equilibrium condition:

$$\frac{M^S}{P} = L(Y,R),$$

where M^S denotes the stock of money, P denotes the price level, $L(Y,R)$denotes the demand for money, which is assumed to be a function of real income, Y, and the interest rate, R. What is the effect of a supply shock (e.g., a hike in oil prices or tax rates) on the price level?[5] An adverse supply shock that lowers the level of output would, under standard assumptions about the nature of the demand for money, also lower the demand for real balances. Absent any action on the part of the central bank to alter the stock of money outstanding, M^S, the price level must rise to clear the market for real balances. Is this increase in the price level "monetary" inflation or not? It does not constitute monetary inflation in the sense that its proximate cause is something other than an action on the part of the central bank. It does constitute monetary inflation to the extent that, in principle, an appropriate response on the part of the central bank (cutting the stock of base money to match the decline in the demand for base money) could have prevented it from occurring. More generally, the inflation rate is determined by the rate of growth of the stock of money relative to the demand for it. The inflation rate is not uniquely determined by the monetary authorities, but by the monetary authorities and the private sector jointly.

Origin, History, and Definition of Core Inflation

Core inflation is a concept that has long lurked on the fringes of mainstream academic debate. Despite the frequency with which the term is used in policy discussions, it is rare that the term turns

[5] Bryan and Cecchetti (1994, p. 195) argue that "during periods of poor weather, for example, food prices may rise to reflect decreased supply, thereby producing transitory increases in the aggregate index. Because these price changes do not constitute underlying monetary inflation, the monetary authorities should avoid basing their decisions on them."

up in mainstream academic publications. This is perhaps surprising, given that the term has been around for quite some time. In a search of the JSTOR database, the first occurrence of the term "core inflation" is Schreder (1952).[6] Schreder used the term in the context of a discussion of the inflationary gap that the United States was believed to be facing in the early 1950s and wrote that "even those who tend to agree with the concept of a rough balance between supply and demand, point out that there is still a huge money supply—and that is the hard core of inflation.… our money supply (currency outside banks and adjusted private demand deposits) is well over three times the 1939 level; and over the longer term basic economic factors, including prices, do tend to move into line with money supply" (Schreder, 1952, p. 153). Schreder does not provide any further discussion of core inflation, and the context in which he uses the term makes it hard to link his use with contemporary usage. The next reference turned up is Sprinkel (1975), who uses the term in the context of a discussion of the short-term outlook for the U.S. economy. Sprinkel (1975) writes that "profligate economic policies explain the average annual inflation of the past 3 years, but recent price increases of 10-12 percent annually were about double the hard-core inflation" (p. 1). Later in the same paper he refers to "the basic inflation of 5-6 percent…" (p. 4), suggesting that what he has in mind is some concept of trend inflation. Tobin (1981, p. 38) uses the term in the context of a discussion of sacrifice ratios: "Two or three point-years of extra unemployment bring down the inertial core inflation by only one point." Tobin does not provide any further discussion of core inflation, but what he seems to have in mind is some notion of trend expected inflation.

It would appear, then, that Eckstein (1981, p. v) was the first to propose a formal definition of core inflation, as the "trend rate of increase of the price of aggregate supply." Eckstein postulated that measured inflation, π, could be broken down into three components: core inflation, π^c; demand inflation, π^d; and shock inflation, π^s:

$$\pi = \pi^c + \pi^d + \pi^s.$$

Core inflation is measured as a weighted average of the rate of increase in unit labor costs and the user cost of capital and is essentially the rate of growth of the supply price of output along the steady-state growth path with a constant-returns-to-scale Cobb-Douglas production technology and Hicks-neutral technological change. That is, core inflation is defined as steady state inflation. Eckstein notes that "the core rate reflects those price increases made necessary by increases in the trend costs of the inputs to production. The cost increases, in turn, are largely a function of underlying price expectations. These expectations are the results of previous experience, which, in turn, is created by the history of demand and shock inflation" (Eckstein, 1981, p. 8). Parkin (1984) in his review of Eckstein's book shows that Eckstein's definition of core inflation collapses to the steady-state growth rate of unit labor costs.[7] Parkin's critique of Eckstein is noteworthy in a number of respects. If core inflation is nothing more than trend or expected inflation, it raises the question of why we would want to estimate trend or expected inflation indirectly rather than looking at direct measures of both.

The *CPI Detailed Report* for January 1978 was the first to routinely include the CPI All Items less Energy and All Items less Food and Energy measures. These indices were first reported in the *CPI Detailed Report* for December 1975 (in Table B, "Changes in Wholesale and Consumer Price Indexes 1973-75"). Thereafter, they were reported every three months in a special table until their regular inclusion in 1978. Note that the *CPI Detailed Report* and the publications it replaced regularly reported a variety of other special indices (such as "all items less food," "all items less shelter," "all items less medical care," from

[6] The JSTOR search was conducted over the 18 journals in the economics and finance categories. The search turned up 57 items matching the search constraints, which were set to be as broad as possible and included articles, reviews, opinion pieces, and other items.

[7] By contrast, Blinder (1982) sees the growth rate of unit labor costs as a measure of core or underlying inflation that is distinct from Eckstein's) and is also equal to (the rationally expected or perfectly foreseen) expected inflation.

a 1968 report). The March 2001 issue of *Monthly Labor Review* reports no fewer than 15 "special" indices that could be classified as measures of core inflation in the CPI tables (such as "all items less food and energy," "all items less shelter," "all items less medical care," etc.). In September 1981, the *Monthly Labor Review* carried an article by David Callahan (Callahan, 1981) explaining the differences between six alternative measures of core or underlying inflation. The earliest Fed publication on core or underlying inflation is Scadding (1979).

The *Statistical Abstract of the United States* for 1951 is the first that I can find to publish a chart of core WPI inflation (specifically, wholesale prices for all commodities other than farm products) (Figure XIV, p. 278). The 1953 edition of the *Abstract* provides monthly data on wholesale prices for all commodities other than farm products and foods from 1926 (Table 334, p. 303). The 1960 edition of the *Abstract* reports annual data for the CPI All Items excluding Food and All Items excluding Shelter back to 1935 (Table 438, p. 336). The original source cited for the data is *Monthly Labor Review*.

ROLE OF THE CONCEPT OF CORE INFLATION IN MONETARY POLICY

The Federal Reserve System is unusual among central banks in that it does not espouse a formal strategy for monetary policy. Unlike, say, the European Central Bank, the Federal Reserve System is not charged with the maintenance of price stability as its primary objective. Rather, the Federal Reserve Act states

> The Board of Governors of the Federal Reserve System and the Federal Open Market Committee shall maintain long run growth of the monetary and credit aggregates commensurate with the economy's long run potential to increase production, so as to promote effectively the goals of maximum employment, stable prices, and moderate long-term interest rates. (Federal Reserve Act, 1-017)

As part of the Board's semiannual *Monetary Policy Report*, the Chairman of the FOMC reports on developments in the U.S. economy, including inflation, and also reports inflation outcomes and forecasts. The forecasts are those of the Governors and the Federal Reserve Bank presidents and had previously pertained to headline inflation—originally headline CPI inflation; then, from February 2000 through 2003, headline PCE inflation.[8] Starting with the July 2004 *Report*, the FOMC has reported projections of core ("ex. food and energy") PCE inflation. The analysis of recent developments also includes data for the core (excluding food and energy) CPI and PCE inflation rates. A number of authors have proposed that the United States adopt an inflation-targeting strategy for monetary policy similar to that pursued in a number of other countries. Bernanke et al. (1999) make such an argument and also suggest that the inflation target be defined in terms of some measure of core CPI inflation:

> Although the particular choice of the price index used in constructing the inflation target is perhaps not critical, we lean towards the use of a "core" CPI measure that excludes food, energy and other volatile items from the price index. The core CPI is likely to provide a better guide to monetary policy than other indices, since it measures the more persistent underlying inflation rather than transitory influences on the price level. Moreover, its use indicates to the public that the central bank will respond flexibly to inflationary shocks arising from supply shocks (such as sharp increases in the prices of oil or food). Use of a core CPI measure also helps the central bank to communicate to the public that not every shock that raises prices will lead to a permanent increase in inflation, and that short-term changes in inflation resulting from supply shocks will be treated differently from changes driven by aggregate demand. (Bernanke et al., 1999, pp. 321-22)

[8] In explaining the switch from the CPI to the PCE deflator, the FOMC noted that the PCE deflator was less susceptible to measurement error than the CPI because it uses an index formula that allows for commodity substitution in response to changes in relative prices, has more comprehensive coverage of expenditures than the CPI, and can be revised to take into account new information and improvements in measurement techniques. See Board of Governors of the Federal Reserve System (2000).

The Federal Reserve System also stands out among central banks in that it has published relatively little research on the merits of competing measures of core inflation. The Federal Reserve Bank of Cleveland is an exception in this regard: The limited-influence estimators of core inflation proposed by Bryan and Pike (1991) and Bryan and Cecchetti (1994) have been widely emulated by other central banks.[9]

The Maastricht Treaty (or Treaty on European Union [EU]) stipulates that "the primary objective of the ESCB shall be to maintain price stability" (Maastricht Treaty Article 105). The ECB subsequently quantified price stability as "a year-on-year increase in the Harmonised Index of Consumer Prices (HICP) for the euro area of below 2%" (ECB Press Release, October 13, 1998, "A stability-oriented monetary policy strategy for the ESCB"). Note that the ECB's communiqué on strategy contains no mention of core inflation. However, it does note that "the statement that 'price stability is to be maintained over the medium term' reflects the need for monetary policy to have a forward-looking, medium-term orientation. It also acknowledges the existence of short-term volatility in prices which cannot be controlled by monetary policy." Measures of core inflation are usually designed to eliminate some of this short-term volatility. However, the ECB does routinely report a variety of measures of core inflation in its *Monthly Bulletin*. In its first Bulletin, published in January 1999, it simply reported the rate of inflation for "non-energy industrial goods," which at that time accounted for about one third of the HICP. By December 2007, the ECB was routinely including additional core measures in its *Monthly Bulletin*, including traditional "ex. food and energy"–like measures.

The ECB has published a couple of working papers on core inflation—see Wynne (1999), Morana (2000), Vega and Wynne (2001), and Angelini, Henry, and Mestre (2001a,b)—but has not formally endorsed one measure over another. It is worth noting that each month the European statistical agency Eurostat publishes five measures of core along with the headline HICP inflation rate for the EU and the euro area (specifically, HICP All-items excluding Energy; HICP All-items excluding Energy, Food, Alcohol, and Tobacco; HICP All-items excluding Tobacco; HICP All-items excluding Energy and Seasonal Food; and HICP All-items excluding Energy and Unprocessed Food).

The Bank of Japan has tended to emphasize a core-like measure of inflation in its communications with the general public. The minutes of the Bank's Monetary Policy Board routinely refer to the year-on-year increase in the CPI excluding fresh food in the assessment of domestic price developments.[10] However, the Bank has made it clear that it interprets its mandate for price stability in terms of headline inflation: "In today's Monetary Policy Board Meeting…it was agreed that, by making use of the rate of year-on-year change in the consumer price index to describe the understanding of [price stability], an approximate range between zero and two percent was generally consistent with the distribution of each Board member's understanding of medium- to long-term price stability" (Bank of Japan, 2006).

Over the past decade and a half, inflation targeting has become increasingly popular as a framework for monetary policy. Inflation targeting as a strategy for monetary policy originated in New Zealand in 1990. The most recent Policy Targets Agreement (PTA) between the Reserve Bank of New Zealand (RBNZ) and the government adopted in May 2007 defines price stability as an annual rate of increase in the New Zealand all-groups CPI of between 1 and 3 percent over the medium term. However, the PTA also notes the following:

> For a variety of reasons, the actual annual rate of CPI inflation will vary around the medium-term trend of inflation, which is the focus of the policy target. Amongst these reasons, there is a

[9] The only other studies of alternative measures of core inflation by Fed economists are Scadding (1979), McElhattan (1982), Motley (1997) (which is a commentary on Bryan and Cecchetti, 1994), and Cogley (1998). Clark (2001), Rich and Steindel (2005), and Khettry and Mester (2006) are more recent evaluations of core inflation measures for the United States.

[10] Shiratsuka (2006) presents evidence that the CPI excluding fresh food and the 10 percent trimmed mean do a better job at tracking trend inflation and forecasting future headline inflation in Japan than other measures of core inflation.

> range of events whose impact would normally be temporary. Such events include, for example, shifts in the aggregate price level as a result of exceptional movements in the prices of commodities traded in world markets, changes in indirect taxes, significant government policy changes that directly affect prices, or a natural disaster affecting a major part of the economy… When disturbances of the kind described [above] arise, the Bank will respond consistent with meeting its medium-term target.

The first PTA (in 1990) specified a target range for inflation of 0 to 2 percent. The agreement noted that "the primary measure of prices used to calculate the inflation rate for the purpose of these targets should relate to the prices of goods and services currently consumed by households. Unfortunately, the All Groups Consumers Price Index (CPI) is not an entirely suitable measure of these prices since it also incorporates prices and servicing costs of investment-related expenditures, notably in the housing field" and directed that "the Bank is to prepare an alternative measure of consumer prices based on an internationally comparable approach, so as to provide a basis for assessing the impact of investment-related housing costs on the CPI" (Reserve Bank of New Zealand, 1990). Subsequent PTAs stated explicitly that the price stability target was defined in terms of the all-groups CPI, but continued to note that a variety of shocks could cause short-term deviations of the CPI from the target range. Invoking these clauses in the PTA, the RBNZ targeted a measure of underlying inflation it constructed itself by excluding credit services from the CPI (CPIX). In 1997, the target was redefined in terms of the CPIX published by Statistics New Zealand (RBNZ, 1997a,b) and the Bank discontinued its own series on underlying inflation. And as already noted in 1999, the target was once again specified in terms of the all-groups CPI after the introduction of a revised CPI in September 1999 that no longer included interest costs (which were usually the main source of differences between the headline inflation rate and the RBNZ's estimate of underlying inflation; see RBNZ, 1999). However, the 1999 PTA explicitly states that "the underlying trend in prices…is the proper focus of monetary policy." The RBNZ routinely publishes on its website statistics for CPI inflation and a number of core measures: CPI excluding Credit Services (CPIX) and Weighted Median CPI. The RBNZ has also published a number of working papers examining the properties of alternative measures of core inflation. See Roger (1995, 1997, and 1998) and, more recently, Giannone and Matheson (2006).

The Bank of Canada adopted inflation targeting in 1991. The target is defined in terms of the 12-month rate of change in the headline CPI. Under the most recent agreement between the government of Canada and the Bank of Canada (dated November 23, 2006), the target for inflation is set at 2 percent, with a "target range" of 1 to 3 percent, unchanged from the agreement reached in 2001. Note that, although the target is specified in terms of headline inflation, core inflation plays a key role in monetary policy deliberations. In documentation released in conjunction with the latest renewal of the inflation target, the Bank of Canada (2006, p. 7) noted that "measures of core inflation, along with indicators of capacity pressures, have been shown to be useful indicators of underlying inflation and, hence, or where total CPI inflation could be in the future. For this reason, core inflation provides a useful guide for the conduct of monetary policy." The latest headline and core CPI (CPIX) inflation statistics are prominently displayed on the first page of the Bank of Canada's website. The CPIX measure of core inflation excludes the eight most volatile components (fruits, vegetables, gasoline, fuel oil, natural gas, mortgage interest, inter-city transportation, and tobacco products) of the Canadian CPI. The CPIX measure also excludes the effects of changes in indirect taxes on the remaining components of the CPI. The Bank of Canada also tracks a different measure of core, the CPIW, which re-weights the components of the CPI using weights that are inversely proportional to the volatility of the component series.[11] Both measures of core inflation are also regularly featured in the Bank of Canada's *Monetary Policy Report*. The Bank of

[11] The construction of the CPIW series is explained in more detail in Hogan, Johnson, and Laflèche (2001) and Laflèche (1997). Bank of Canada (1991) explains the construction of the CPI net of tax effects.

Canada (2006) further clarified the use of its measure of core inflation in its deliberations: "It should be noted, however, that core inflation provides a useful guide to the extent that total CPI inflation is expected to converge to core inflation. If this were not expected to be the case, owing to anticipated persistent changes in the CPI components that are excluded from the core measure, *total CPI inflation would take precedence*" (Bank of Canada, 2006, p. 7, emphasis added).

The Bank of England has pursued inflation targeting since October 1992 and has published a quarterly *Inflation Report* since February 1993. The inflation target is set by the government and was originally defined in terms of a core-like measure of inflation, the retail price index excluding mortgage interest payments, or RPIX. The RPIX includes food and energy prices traditionally excluded from a measure of core. The Bank of England also routinely monitored a measure of retail price inflation that excludes, in addition to mortgage interest costs, the first-round effects of indirect taxes (i.e., the RPIY) and a measure of domestically generated inflation (i.e., the RPIX excluding import prices). Both were reported on a regular basis in the Bank of England's quarterly *Inflation Report*, along with a number of alternative measures of core inflation, including the median and the (15 percent) trimmed mean, and measures of domestically generated inflation (arguably interpretable as core inflation). Examples of the last of these include the HARP (*H*ousing-*A*djusted *R*etail *P*rices, an adjusted version of RPIX that replaces the Central Statistics Office/Office of National Statistics estimate of housing depreciation with an estimate of the user cost of housing calculated by the Bank of England), THARP (a similarly adjusted version of RPIY, introduced in the November 1994 *Inflation Report*), RPIX excluding export prices, unit labor costs, and unit labor costs based on trend productivity.[12] The trimmed mean and weighted median measures of Bryan and Cecchetti were first reported by the Bank of England in its May 1993 *Inflation Report*, while the Quah-Vahey measure (which was referred to as "output-neutral" inflation) was introduced in the August 1993 *Inflation Report*.[13] The Bank also occasionally publishes analyses of how various fiscal measures affect RPIX inflation. For example, in the May 2001 *Inflation Report* it reported estimates of the effects of increases in various taxes and duties prepared by the U.K. Office of National Statistics.[14] The Bank of England has also published a number of research papers explaining the construction and examining the properties of alternative measures of core inflation: Cutler (2001), Bakhshi and Yates (1999), Beaton and Fisher (1995), and Quah and Vahey (1995).[15]

However, in recent years, the Bank of England seems to have greatly downplayed the importance of core inflation in its deliberations or communications with the general public. Indeed, there has been no mention of the concept of core inflation in any of the Bank's *Inflation Reports* since November 2000. Bean (2006) makes the following observation: "The fact that the rise in oil prices is the flip side of the globalization shock to me renders highly suspect the practice of focussing on measures of core inflation that strip out energy prices while retaining the falling goods prices." The Bank's inflation target, which was originally defined in terms of the core-like RPIX, was redefined in terms of the headline CPI or HICP in 2003.

Sveriges Riksbank (the Bank of Sweden) adopted inflation targeting in 1993. The Bank of Sweden's inflation target is defined in terms of the headline rate of increase in the CPI (since 1995, 2 percent ± 1 percent). The Bank of Sweden routinely reports two measures of core inflation in

[12] Bank of England's first *Inflation Report* (February 1993) included a short discussion of the treatment of owner-occupied housing in the RPI and the construction of the HARP index.

[13] Interestingly enough, that seems to have been the one and only appearance of the Quah-Vahey measure in the Bank of England's *Inflation Report*. In a speech published in the subsequent (November 1993) issue of the Bank of England *Quarterly Bulletin*, the Deputy Governor noted that "all the senior people in the Bank believe that inflation's roots lie in excessive monetary expansion. We all believe that inflation is deeply damaging to the real economy of jobs and output and spending and growth."

[14] See Bank of England (2001, p. 42).

[15] Bank of England's first *Inflation Report* (February 1993) included a footnote mentioning the possibility of defining core inflation in terms of the component of observed inflation that is uncorrelated with output in the long run.

its regular *Inflation Report* (since 2007 renamed *Monetary Policy Report)*: UND1X, which is defined as the CPI excluding interest expenditure and direct effects of altered indirect taxes and subsidies; and UNDINHX, which is the CPI excluding interest expenditure, goods that are mainly imported, and direct effects of altered domestic indirect taxes and subsidies. Since 1999 the Riksbank has also reported a model-based measure of core inflation based on the research of Apel and Jansson (1999), which is explained at some length in *Inflation Report* (1999, pp. 51-52). Other research published by the Bank of Sweden on core inflation and its role in monetary policy includes Nessén and Söderström (2000) and Blix (1995). In their review of Swedish monetary policy over the period 1995-2005, Giavazzi and Mishkin (2007) recommended that the Bank's inflation target should be defined in terms of a price index that is not directly affected by the costs of owner-occupied housing, such as the UND1X measure, but this recommendation was rejected by the Executive Board.

The Reserve Bank of Australia also adopted inflation targeting as its strategy for monetary policy in 1993. The inflation target was originally specified in terms of the underlying rate of CPI inflation and as expressed as a range of 2 to 3 percent per annum. The most recent *Statement on the Conduct of Monetary Policy* issued in December 2007 stated that

> In pursuing the goal of medium-term price stability, both the Reserve Bank and the Government agree on the objective of keeping consumer price inflation between 2 and 3 percent, on average, over the cycle. This formulation allows for the natural short run variation in underlying inflation over the cycle while preserving a clearly identifiable benchmark performance over time. (Reserve Bank of Australia, 2007)

Note that the wording of this statement is somewhat different from that in the 1996 statement (Reserve Bank of Australia, 1996), which referred to the objective of keeping underlying inflation in the 2 to 3 percent range over the cycle, without specifying which measure of underlying inflation was to be used. In late 1998 the Reserve Bank of Australia announced that in the future the inflation target would be interpreted as referring to the headline CPI inflation rate rather than any measure of core (see Reserve Bank of Australia, 1998), and the switch from underlying to overall consumer price inflation was made in the 2003 statement. The reason for the change was improvements (changes) in the treatment of housing in the CPI as part of the regular periodic (five-year) review of the Australian CPI, specifically the switch from the use of mortgage interest costs to measure changes in the costs of owner-occupied housing to the treatment of owner-occupied housing on a net acquisitions basis. The Bank regularly publishes a number of measures of core inflation in its quarterly *Statement on Monetary Policy*, including the trimmed mean, the weighted median, the CPI excluding volatile items (which is the CPI excluding fruit and vegetables and automotive fuel), and market goods and services excluding volatile items. This last item excludes—in addition to the items already excluded from the CPI excluding volatile items—utilities, property rates and charges, health, other motoring charges, urban transport fares, postal, education, and child care categories. (See for example Table 11 in the May 2001 *Statement*.[16]) The Reserve Bank of Australia has also published in its *Bulletin* a number of articles explaining the computation of underlying inflation (Reserve Bank of Australia, 1994) and a number of research papers on alternative measures of core: Kearns (1998), Roberts (2005), and Brischetto and Richards (2006).

This brief review of current practice shows that central banks tend to differ in the importance they assign to the concept of core inflation. Insofar as a measure of core inflation plays a role in monetary policy, whether as a target or as a means of communicating with the general public, central banks invariably rely on traditional exclusion-type measures of core. A number of central banks also report some of the newer measures of core, especially variants of the limited influence measures advocated by Bryan and Cecchetti.

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16 See Australian Bureau of Statistics (2000).

THE BASIC FRAMEWORK

The stochastic approach to index numbers has (implicitly or explicitly) formed the basis of many recent attempts to improve upon existing core inflation measures. In the academic literature, this approach is exemplified by the papers by Clements and Izan (1981, 1987) as well as a book by Selvanathan and Prasada Rao (1994). The research of Bryan and Pike (1991), Bryan and Cecchetti (1993, 1994), and Cecchetti (1997) has brought this approach to inflation measurement to the attention of monetary policymakers in the United States, while the work of Quah and Vahey (1995), Blix (1995), and Fase and Folkertsma (1996) indicates that this alternative way of thinking about inflation is also influential among the national central banks in the EU. Diewert (1995) provides a critique of this literature from the perspective of the traditional economic approach to price measurement; some additional discussion is to be found in Wynne (1997).

The point of departure for all attempts to measure core inflation is the observation that the changes in the prices of individual goods and services between two periods contain a common component that constitutes core inflation and an idiosyncratic component that primarily reflects developments in local markets. The problem of core inflation measurement is then to isolate these two components of observed price changes. This idea is formalized by writing

$$\pi_{i,t} = \Pi_t + x_{i,t}.$$

This expression defines the rate of change of the price of an individual commodity, $\pi_{i,t} = \ln(p_{i,t}) - \ln(p_{i,t-1})$, as consisting of an aggregate inflation component, $\Pi_t \equiv \ln(P_t) - \ln(P_{t-1})$, and a relative price change component, $x_{i,t}$. The object we are interested in is P_t, the common component of all prices and what we might interpret as the purchasing power of money. Different approaches to the measurement of core inflation can be characterized by how they go about achieving identification.

The presumption in all of these approaches is that the "headline" rate, which is some weighted average of the individual price changes,

$$\sum_{i=1}^{N} w_{i,t}\pi_{i,t},$$

with weights chosen on the basis of expenditure shares, is a poor or second-best approximation to Π_t. What differentiates the various approaches to core inflation measurement is the information that is used to arrive at the core measure. One approach is to simply recombine the price changes of individual goods and services at each point in time to derive a core measure. This is the "ex. food & energy" approach and also the essence of the limited influence measures (such as the trimmed mean and weighted median) advocated by Bryan and Cecchetti. Alternatively, we might choose to ignore the information in the cross-section distribution of individual price changes and instead derive a measure of core inflation by smoothing current and previous headline inflation rates. Thus some have advocated constructing a measure of core inflation by taking a moving average of past inflation rates or applying a Hodrick-Prescott (1997) filter to headline rates. Between these two extremes is the dynamic factor index proposed by Bryan and Cecchetti (1993), which combines information on both the time-series and cross-section characteristics of individual price changes.

ESTIMATING CORE INFLATION USING ONLY CONTEMPORANEOUS PRICE DATA

There is some intuitive appeal to the idea that we can somehow isolate the monetary component of price changes by simply averaging the changes in the prices of individual goods and services. This approach to inflation measurement has a long history and was perhaps first fully articulated by Jevons (1865). Jevons argued for the use of the geometric mean of price changes in calculating inflation

> as it seems likely to give in the most accurate manner such general change in prices as is due to a change on the part of gold. For any change in gold will affect all prices in an equal ratio; and if other disturbing causes may be considered proportional to the ratio of change of price

> they produce in one or more commodities, then all the individual variations of prices will be correctly balanced off against each other in the geometric mean, and the true variation of the value of gold will be detected. (Jevons, 1865, p. 296)

If we interpret the relative price term, $x_{i,t}$, in the equation above as an error term that is normally distributed, with mean and variance given by $E(x_t) = 0, E(x_t x_t{}') = \sigma_t^2 I_N$, where $x_t = [x_{1,t}, x_{2,t}, \ldots x_{N,t}]'$, it is straightforward to show that the maximum likelihood estimator of the inflation rate, $\hat{\Pi}_t$, is given by a simple unweighted average of the rates of change of the individual price series[17]:

$$\hat{\Pi}_t = \frac{1}{N} \sum_{i=1}^{N} \pi_{i,t}.$$

Note that we identify core inflation in this model by defining it as the component of price changes that is orthogonal to relative price changes. By construction, the estimated relative price changes, $\hat{x}_{i,t}$, have the property

$$\sum_{i=1}^{N} \hat{x}_{i,t} = 0.$$

That is, the implied relative price changes average to zero.

Taking the exponential of both sides of the proposed measure of inflation, we obtain the geometric mean price index proposed by Jevons (1865) as a way of computing the change in the purchasing power of money over time:

$$\exp\left(\hat{\Pi}_t\right) = \prod_{i=1}^{N} \left(\frac{P_{i,t}}{P_{i,t-1}} \right)^{1/N}.$$

This measure of inflation has a number of appealing properties, not the least of which is the ease with which it can be calculated. Unlike a simple arithmetic mean of price relatives $(p_{i,t}/p_{i,t-1})$ (the so-called Carli index), this index satisfies the time reversal property.[18] Fase and Folkertsma (1996) argue for the use of simple averages of price changes to isolate core inflation in a structural vector autoregression (VAR) framework (discussed below). However, this measure of inflation also has a number of serious shortcomings, all of which ultimately relate to the strong assumptions made about the behavior of the relative price terms, $x_{i,t}$.

Note that so far nothing has been said about *which prices* to include in the calculations. The prices that are averaged to arrive at a measure of inflation could be just consumer prices, or could include the prices of all gross domestic product (GDP) transactions or the prices of all transactions (including intermediate transactions), or could even include the prices of assets. Fisher (1920) argued that when it comes to constructing a measure of the purchasing power of money, we ought to look at as many prices as possible:

> Perhaps the best and most practical scheme [for the construction of an index number] is that which has been used in the explanation of [the price level] *P* in our equation of exchange, an index number in which every article and service is weighted according to the value of it exchanged at base prices in the year whose level of prices it is desired to find. By this means, goods bought for immediate consumption are included in the weighting, as are also all durable capital goods exchanged during the period covered by the index number. What is repaid in contracts so measured is the same general purchasing power. This includes purchasing power over everything purchased and purchasable, including real estate, securities, labor, other services, such as the services rendered by corporations, and commodities. (Fisher, 1920, pp. 217-18)

It is interesting to note that the preamble to the European Council Regulation governing the calculation of the HICP, which will form the basis for assessing inflation developments in the euro area, notes that "it is recognised that inflation is a phenomenon manifesting itself in all forms of market transactions including capital purchases, government purchases, payments to labour as well as purchases by consumers" (European Commission, 1998). Once we have abandoned the cost of living as the guiding concept for inflation measurement

[17] See Diewert (1995).

[18] A price index is said to satisfy the time reversal property if, when we reverse the order of time, the recalculated index is simply the reciprocal of the previously calculated index.

for monetary policy purposes, there is no reason for confining our attention to changes in the prices of final consumer goods. Changes in the prices received by producers, changes in the prices of intermediate goods, and changes in the prices of existing assets all carry information about monetary inflation.

ARE ALL PRICES EQUALLY INFORMATIVE?

One possible problem with this approach to estimating inflation is that it treats all prices as being equally informative about inflation and thus equally important.[19] Arguably a more appropriate approach would be to weight the price changes of individual products in terms of their importance, somehow defined.[20] That is, an estimate of inflation of the form

$$\hat{\Pi}_t = \sum_{i=1}^{N} w_{i,t}\pi_{i,t}$$

(which assigns weights $w_{i,t}$ to the price changes of individual products in arriving at a measure of overall inflation) may be preferable. Diewert (1995) shows that, for this expression to be the maximum likelihood estimator of the inflation rate, we can retain our original assumption that the relative price changes have zero mean, but need to replace the variance assumption with

$$E\left(x_t x_t'\right) = \sigma_t^2 W_t^{-1},$$

where $W_t = \text{diag}[w_{1,t}, w_{2,t}, \ldots w_{N,t}]$. This assumption about the distribution of relative price changes was proposed by Clements and Izan (1981). They argued as follows: "If we think in terms of sampling of the individual prices to form ...[$\pi_{i,t}$]... for each commodity group, then it seems reasonable to postulate that the collection agency invests more resources in sampling the prices of those goods more important in the budget. This implies that ...[Var($x_{i,t}$)]... is inversely proportional to ...[$w_{i,t}$]" (Clements and Izan, 1981, p. 745). Later Clements and Izan (1987) provided a different justification for this assumption, arguing that the larger an item looms in the budget of consumers, the less scope there is for relative price changes in that item. Neither of these justifications is particularly appealing. However, the theory of the cost-of-living index provides an alternative rationale for weighting individual price changes by shares in consumer's budgets. A fixed-weight Laspeyres measure of the price level at date t with period 0 as the base period can be written as

$$P_t^L = \frac{\sum_{i=1}^{N} p_{i,t}q_{i,0}}{\sum_{i=1}^{N} p_{i,0}q_{i,0}} = \sum_{i=1}^{N} w_{i,0}\left(\frac{p_{i,t}}{p_{i,0}}\right) = \sum_{i=1}^{N} w_{i,0}p_{i,t},$$

where we set $p_{i,0} = 1, \forall i$. By log-differentiating this expression, we obtain

$$\frac{dP_t}{P_{t-1}} \equiv \Pi_t = \frac{1}{P_{t-1}}\sum_{i=1}^{N} w_{i,0}dp_{i,t} = \sum_{i=1}^{N} r_{i,t}\pi_{i,t}.$$

That is, the standard fixed-weight Laspeyres measure of inflation can be written as a weighted average of the rates of change of the prices of individual goods and services. However, note that the weights, $r_{i,t}$, are not the budget share weights of the base period, $w_{i,0}$. Rather, they are the "relative importances" of each product—that is, the base-period weight adjusted for the extent to which the price of the good in question has grown faster or slower than prices on average. Goods whose prices increase faster than average over time will have an increasing relative importance in a fixed-weight Laspeyres type price index. This is simply another way of expressing the well-

[19] Diewert (1997) sees this property of the Jevons index number as a "fatal flaw."

[20] The contrary view is taken by Bryan and Pike (1991), who write "the strength of the inflation signal in goods and services prices is not necessarily related to an item's share of the typical household budget. As a monetary phenomenon, inflation should influence the price of all goods and services equally. The inflationary signal in the price of a new pair of shoes is theoretically the same as that in the price of shoe leather or, for that matter, in the price of cows. There is no reason to expect movements in the price of one to be a clearer indicator of inflation than movements in the prices of others." Likewise Fase and Folkertsma (1996) note "weighting the price index means that some prices get to determine the general price level thus measured more than others. For an assessment of changes in purchasing power, weighting may certainly be useful but there is no clear reason to gauge inflation by way of weighting."

known tendency of fixed-weight Laspeyres measures to overstate the true rate of inflation as defined by the cost-of-living index.[21]

But why do we need to confine ourselves to looking to budget shares for weights? The use of budget shares as weights is best motivated by an appeal to the (a temporal) theory of the cost-of-living index. Yet, implicit in the notion of core inflation that ought to be of primary concern to monetary policymakers is the idea that such inflation is inherently different from inflation as measured by the cost-of-living index. Thus, the weighting scheme that is optimal for constructing a cost-of-living index may no longer be optimal for measuring inflation for the purposes of monetary policy.

A weighting scheme that might be more appropriate for monetary policy purposes would weight prices by the strength or quality of the inflation "signal" they provide. Indeed, this is the approach that implicitly underlies the "ex. food & energy" or "ex. indirect taxes" approaches to estimating core inflation that are used by many central banks and statistical agencies. In these approaches we attach zero weight to certain prices on the (unstated) grounds that they convey zero information about core inflation. Formally,

$$w_i = 0 \;\text{ if }\; \sigma_i^2 > \tilde{\sigma}^2,$$

where $\tilde{\sigma}^2$ is some "unacceptably high" level of variability in short-term price changes. It is worth noting that there is no justification for such a practice within the theory of the cost-of-living index; the rationale for excluding certain prices from an estimate of core inflation must lie elsewhere.

One scheme for weighting prices in terms of the quality of their inflation signal would be to set the weights as follows:

$$w_i = \frac{\frac{1}{\sigma_i^2}}{\sum_{i=1}^{N} \frac{1}{\sigma_i^2}}.$$

That is, choose weights for the various individual prices that are inversely proportional to the volatility of those prices. A weighting scheme along these lines has been investigated by Dow (1994), who termed the resulting measure of inflation a variance-weighted price index, and by Diewert (1995), who termed the resulting measure of inflation neo-Edgeworthian. Wynne (1997) reports the results of applying a scheme along these lines to U.S. CPI data. The advantage of employing a variance weighting scheme to calculate core inflation is that we do not discard potentially useful information about core inflation that may be contained in food and energy prices—or whatever categories are excluded. The "ex. food & energy" approach to estimating core inflation is further compromised by the need for a once-and-for-all judgment about what the least informative categories of prices are for estimating core inflation. A variance weighting scheme such as that noted above allows weights to change over time as the volatility of different categories of prices changes over time. The speed with which the weights will change in response to changes in volatility will be determined by the choice of the estimation "window" for the variances.

Yet another weighting scheme was proposed informally by Blinder (1997). Starting from a definition of core inflation as the persistent or durable component of inflation, Blinder suggests that when it comes to calculating core inflation, individual price changes should be weighted by their ability to forecast future inflation. Blinder argues that central bankers are a lot more concerned about future inflation than they are about past inflation; and, when we think about the measurement of core inflation as a signal extraction problem, future inflation is the object about which we are seeking information through current signals. Thus core inflation is defined in terms of its ability to predict future headline inflation. Smith (2007) is an attempt to implement this approach.[22]

SOME PROBLEMS

If we think about the problem of core inflation measurement in terms of an estimation problem,

[21] For further details, see Blinder (1980).

[22] However, note that Bryan and Cecchetti (1994) evaluate various measures of core inflation in terms of their ability to forecast future inflation.

we need to ask whether the distribution assumptions that underlie the estimation are borne out by the data. There are three important distributional assumptions that need to be looked at. The first is that individual price changes are normally distributed; the second is that individual price changes are independent of one another; and the third is that price changes are identically distributed.

The geometric mean of price relatives is the maximum likelihood estimator of core inflation under the assumption that individual price changes are normally distributed. But this assumption is not borne out by the data.

There is an extensive literature documenting the statistical properties of individual price changes, and it is clear that individual $\pi_{i,t}$ are typically not normally distributed. This fact was first noted by Bowley (1928) in a critique of Jevons and has subsequently been further documented by Vining and Elwertowski (1976), Ball and Mankiw (1995), Cassino (1995), Bryan and Cecchetti (1996), and Balke and Wynne (2000). There is evidence of significant skewness and kurtosis in the cross-section distribution of price changes. Skewness in the distribution of price changes may reflect the fact that changes in the money stock do not necessarily affect all prices at the same time,[23] or it may simply reflect skewness in the underlying shocks that causes relative prices to change.[24]

If the distribution of $\pi_{i,t}$ can be characterized in terms of a distribution with a finite number of moments, it may still be possible to estimate core inflation as the solution to a maximum likelihood problem. However, the resulting measure will probably be significantly more complicated than a simple geometric mean of price relatives.

A more constructive response to non-normality in the distribution of $\pi_{i,t}$ is to employ estimators that are robust to departures from normality. This is the approach advocated by Bryan and Pike (1991), Bryan and Cecchetti (1994, 1996), and Cecchetti (1997). Bryan and Pike argue for the use of the median of $\pi_{i,t}$ as an estimate of core inflation on the grounds that the median is a more robust measure of central tendency. Bryan and Cecchetti (1994) examine in more detail alternative approaches to estimating core inflation and conclude that, of the various measures they look at, the weighted median CPI performs best. More recently Bryan, Cecchetti, and Wiggins (1997) investigate the ability of various trimmed means of the cross-section distribution of price changes to track trend inflation. To compute the trimmed mean of the cross-section distribution of prices, start by ordering the sample (from largest to smallest price change, say). Then define the cumulative weight from 1 to *i* as

$$w_{i,t} = \sum_{j=1}^{i} w_{(j),t},$$

where $w_{(j),t}$ denotes the *sorted* *j*th weight. This allows us to define the index set

$$I_\alpha = \left\{ i : \alpha < W_{i,t} < 1-\alpha \right\}.$$

The α-percent trimmed mean inflation rate is then defined as

$$\bar{\Pi}_t^k(\alpha) = \frac{1}{1-2\alpha} \sum_{i \in I_\alpha} w_{(i),t} \pi_{(i),t}^k,$$

where $\pi_{(j),t}$ is the sorted *j*th price change. If $\alpha = 0$, we obtain the weighted sample mean. For $\alpha = 0.50$, we define $\bar{\Pi}_t^k(\alpha)$ as the weighted sample median.

A further objection to the use of the geometric mean is that changes in relative prices are not independent of each other. Thus if we continue to think about core inflation measurement as an estimation problem, the assumption that $E(x_t x_t') = \sigma_t^2 I_N$ needs to be replaced with the more realistic assumption $E(x_t x_t') = \sigma_t^2 \Omega$. In this case the core inflation rate can in principle be estimated as

$$\hat{\Pi}_t = \left(\iota_N' \Omega^{-1} \iota_N \right)^{-1} \iota_N' \Omega^{-1} \pi_t,$$

where ι_N is an $N \times 1$ vector of 1's. In practice, however, putting this approach into practice would require making strong assumptions about the

[23] Indeed, Ball and Mankiw (1995) argue that this property of the distribution of price changes is important evidence favoring sticky-price or menu-cost models of real-nominal interactions.

[24] Balke and Wynne (2000) propose this interpretation.

precise nature of the interaction between relative prices (i.e., specification of Ω); to date there do not appear to have been any attempts to construct estimates of core inflation along these lines.

A more fundamental objection to the use of the geometric mean is that it requires the systematic component of each price change to be the same, thereby precluding any long-term changes in relative prices. Casual empiricism suggests that this restriction is seriously at odds with reality. This criticism of the geometric mean of individual price changes as an estimate of inflation was first made by Keynes (1930).

Clements and Izan (1987) proposed a way around this problem. They start by writing

$$\pi_{i,t} = \Pi_t + x_{i,t} = \Pi_t + r_i + \varepsilon_{i,t},$$

where the relative price term, $x_{i,t}$, now contains a non-zero component, r_i, as well as a mean-zero stochastic component, $\varepsilon_{i,t}$. Assume

$$E\left(\varepsilon_t\right) = 0,\ E\left(\varepsilon_t \varepsilon_t'\right) = \sigma_t^2 W_t^{-1},$$

where $W_t = \text{diag}[w_{1,t}, w_{2,t}, \dots w_{N,t}]$. To identify Π_t and r_i, add the identifying assumption

$$\sum_{i=1}^{N} w_{i,t} r_i = 0.$$

The maximum likelihood estimator of the inflation rate is the same as in the basic model (i.e., a simple weighted average of the individual price changes), but now the expected change in the *i*th relative price is $E(\pi_{i,t} - \Pi_t) = r_i$. Although this model is an advance over the simple framework, it is not obvious that the assumption of *constant* (time invariant) rates of relative price changes is any more palatable than the assumption of *no systematic changes* in relative prices. For many products, their relative prices tend to follow a U-shaped pattern over their lifetimes: rapid relative price declines following the introduction of a product, relative price stability as the product reaches maturity, and relative price increases as the product is displaced by newer products before finally disappearing from the market.

COMBINING CONTEMPORANEOUS AND TIME-SERIES INFORMATION TO ESTIMATE CORE INFLATION

Perhaps a more serious shortcoming of these models is that they fail to take account of persistence in both individual price changes and the inflation rate. Some of the dynamic models that have been proposed in recent years seek to remedy this problem— and succeed to varying degrees. We will start by looking at the dynamic factor index (DFI) model proposed by Bryan and Cecchetti (1993) and Cecchetti (1997). This model is of interest for many reasons, not least of which is the fact that it is the only model that attempts to combine information on both the cross-section and time-series characteristics of individual price changes in deriving a core inflation measure.

The DFI model starts with the equation

$$\pi_t = \Pi_t + x_t,$$

where, as before, $\pi_t = [\pi_{1,t}, \pi_{2,t}, \dots, \pi_{N,t}]'$ and $x_t = [x_{1,t}, x_{2,t}, \dots, x_{N,t}]'$. Identification of the common inflation component in all price changes (core inflation) is accomplished by positing time-series processes for inflation and the relative price change components of individual price changes as follows:

$$\Psi(L)\Pi_t = \delta + \xi_t$$
$$\Theta(L)x_t = \eta_t,$$

where $\Psi(L)$ and $\Theta(L)$ are matrix polynomials in the lag operator L and ξ_t and η_t are scalar and vector i.i.d. processes, respectively. If $\Psi(L) = 1$ and $\Theta(L) = 1$, we obtain the static model discussed at length above. Another special case of this model where $\Psi(L) = 1 - \psi_1 L$ and $\Theta(L) = 1$ has been studied by Dow (1994). Bryan and Cecchetti (1993) and Cecchetti (1997) estimate versions of this model assuming that $\Psi(L) = 1 - \psi_1 L - \psi_2 L^2$ and $\Theta(L) = 1 - \theta_1 L - \theta_2 L^2$.

In the DFI model the common element in all price changes, Π_t, is identified by assuming that it is uncorrelated with the relative price disturbances at *all* leads and lags instead of just contemporaneously. This is clearly a much stronger identifying assumption than is used in the simple static factor models discussed above (where inflation is defined as the component of price changes that is uncorrelated with relative price changes contemporaneously). It is not clear what is obtained by employing this stronger assumption. The DFI model is also susceptible to the criticism that it allows for only constant trends in relative prices. But perhaps the biggest shortcoming of the DFI approach to measuring core inflation is that history changes each time a new observation is obtained and the model is reestimated. This problem is common to all measures of core inflation constructed using econometric procedures. While this is not usually ranked as a major concern in choosing and constructing a measure of core inflation, it is of great importance to a central bank that plans to use a core measure as an integral part of its communications with the general public about monetary policy decisions.

A recent paper by Reis and Watson (2007) uses a similar approach to identify what they call "pure inflation." They start with linear factor model

$$\pi_t = \Lambda F_t + x_t,$$

where, as before, $\pi_t = [\pi_{1,t}, \pi_{2,t}, \ldots, \pi_{N,t}]'$ and $x_t = [x_{1,t}, x_{2,t}, \ldots x_{N,t}]'$. The vector F_t has k elements or factors that capture the common sources of variation in individual prices, while the vector x_t captures the relative price variation in the prices of individual goods that is due to idiosyncratic sectoral events or measurement error. The aggregate component of price changes is further decomposed into an absolute-price component, denoted by the scalar a_t, and several relative price components, denoted by the k–1 element vector R_t:

$$\Lambda F_t = \iota_N a_t + \Gamma R_t,$$

where ι_N is an $N \times 1$ vector of 1's and Γ is an $N \times (k-1)$ matrix. Reis and Watson identity "pure inflation" as

$$\Pi_t = a_t - E\left\{a_t \middle| \left\{R_\tau\right\}_{\tau=1}^{T}\right\}.$$

That is, they define it as the common component in price changes that has an equiproportional effect on all prices and is uncorrelated with changes in relative prices at all dates. The "pure inflation" series thus identified (using quarterly data on the components of the personal consumption expenditures deflator) accounts for up to one-fifth of the overall variation in inflation in the United States.

DYNAMIC MODELS II: BRINGING SOME MONETARY THEORY TO BEAR ON THE DEFINITION OF CORE INFLATION

Core inflation as identified by the static and dynamic factor models above is essentially a statistical concept to which it is difficult to attach much economic meaning. Unlike the economic or cost-of-living approach to inflation measurement, no substantive economic theory is used to derive these estimates of core inflation. The motivation is usually some simple variant of the quantity theory of money, whereby a given change in the stock of base money is presumed to affect all prices equiproportionately (see previous quotation from Jevons). Thus, the best estimate of monetary inflation is whatever best estimates this average or common component in price changes. Bryan and Cecchetti (1994) do evaluate their measures of core inflation using basic propositions from monetary theory (core inflation should be caused by but not cause money growth, and core inflation should help to forecast future headline inflation). However these ex post evaluations of the performance of various proposed measures are not quite the same thing as using monetary theory to construct a measure of inflation. If there is a meaningful distinction between the cost of living and monetary inflation that is of concern to central bankers, then presumably we should be able to draw on monetary theory to help us measure this alternative concept of inflation.

This is the approach adopted by Quah and Vahey (1995), who adopt a more monetary-theoretic approach to the measurement of core inflation. They define core inflation as the component of measured inflation that has no impact on real output in the long run and motivate this definition on the basis of a vertical long-run

Phillips curve. Their measure is constructed by placing long-run restrictions on a bivariate VAR system for output and inflation. Quah and Vahey assume that both output and inflation have stochastic trends, but are not cointegrated. Thus they write their system in terms of output growth and the change in the inflation rate:

$$Z_t = \begin{bmatrix} \Delta Y_t \\ \Delta \Pi_t \end{bmatrix} = \sum_{j=0}^{\infty} D(j)\eta(t-j),$$

where $\eta = [\eta_1, \eta_2]'$ with the disturbances assumed to be pairwise orthogonal and $\mathrm{Var}(\eta) = 1$. Here Π_t denotes inflation at date t as measured by a conventional price index such as the CPI or the retail price index (RPI). Note that Quah and Vahey do not use any information on the cross-section distribution of individual price changes to construct their core inflation measure. The long-run output neutrality restriction is

$$\sum_{j=0}^{\infty} d_{11}(j) = 0.$$

The inflation process can be written

$$\Delta \Pi_t = \sum_{j=0}^{\infty} d_{21}(j)\eta_1(t-j) + \sum_{j=0}^{\infty} d_{22}(j)\eta_2(t-j).$$

Quah and Vahey's candidate measure of *changes* in core inflation is simply

$$\sum_{j=0}^{\infty} d_{21}(j)\eta_1(t-j).$$

The Quah and Vahey approach to measuring core inflation has also been implemented by Fase and Folkertsma (1996), Claus (1997), Jacquinot (1998), Gartner and Wehinger (1998), and Álvarez and Matea (1998). Fase and Folkertsma relate this measure of inflation to Carl Menger's concept of the inner value of money.[25] However, rather than measuring the inflation rate using the CPI, they take as their measure the *unweighted* average rate of change of the component series, calculated on the basis of 200 component price series for the Netherlands, arguing that "weighting may certainly be useful but there is no clear reason to gauge inflation [as a monetary phenomenon] by way of weighting." Fase and Folkertsma also calculate a core inflation measure for the EU by aggregating price and output data for Austria, Belgium, France, Germany, Italy, the Netherlands, Spain, Sweden, and the United Kingdom.

As noted, the theoretical justification for the Quah-Vahey approach is the presumption that the Phillips curve is vertical in the long run. Although this might appear to be a relatively innocuous assumption, on reflection it is clear that it is not without problems. If we accept that the Phillips curve is indeed vertical in the long run, we are essentially saying that *inflation* is neutral in its effects on the real economy.[26] It is not obvious that all monetary economists would accept this proposition—and still fewer central bankers charged with the pursuit of price stability. Even fully anticipated constant inflation can have real effects, as documented in the well-known study by Fischer and Modigliani (1978). More generally, insofar as inflation constitutes a tax on holdings of base money, changes in this tax rate may be expected to have implications for agents' decisions about how much money to hold, which will in turn have other real effects (except under limiting assumptions). Another way of thinking about this problem is in terms of the widely held view that the sole objective of monetary policy should be price stability.[27] If we accept that core inflation as measured by Quah and Vahey does in fact correspond to the component of inflation that is under the control of the monetary authority, and also that this component of inflation is in fact neutral with respect to output in the long run, it invites the question of why a central bank would

[25] Menger drew a distinction between the outer value ("äußerer Tauschwert") and the inner value ("innerer Tauschwert") of a commodity. The former is defined as the price of the commodity in equilibrium. The outer value of money is the purchasing power of money, i.e., the basket of goods that can be obtained for one unit of money. The outer value of money can thus be measured by an index such as the CPI. A change in the inner value of a commodity is a change that comes about because of a change in factors affecting that commodity alone. A change in the inner value of money is thus a price change that is due to monetary factors alone: a decline in the inner value of money will be reflected in an equiproportionate increase in all prices.

[26] The price level is superneutral.

[27] Although not universally: see, for example, Aiyagari (1990).

ever want to be concerned about price stability. After all, if all the central bank controls is the price level in the long run, and if the rate at which the price level increases has no implications for the level of real economic activity, then one inflation rate is just as good in welfare terms as another. There is no reason to prefer a steady-state inflation rate of 2 percent over one of, say, 20 percent. Price stability or zero inflation ought not to play any particular role in the setting of objectives for monetary policy. Of course, nobody seriously believes this. A more realistic assumption might be that the Phillips curve is not vertical in the long run, but rather upward sloping, from left to right, as proposed by Friedman (1977). Such an assumption would better capture the notion that steady-state or long-run inflation is indeed costly from society's perspective, but would probably be a lot more difficult to operationalize.

Blix (1995) also implements the Quah and Vahey model. However Blix's implementation of the model differs in important respects from Quah and Vahey's. To start with, the long-run identifying restriction is implemented in a common trends framework rather than a VAR. That is, the model estimated is

$$\begin{pmatrix} Y_t \\ P_t \end{pmatrix} = x_0 + \begin{pmatrix} \alpha_{11} & 0 \\ \alpha_{21} & \alpha_{22} \end{pmatrix} \begin{pmatrix} r_t \\ n_t \end{pmatrix} + \Phi(L) \begin{pmatrix} \varphi_{r,t} \\ \varphi_{n,t} \end{pmatrix},$$

with the growth terms given by the vector random walk process

$$\begin{pmatrix} r_t \\ n_t \end{pmatrix} = \mu + \begin{pmatrix} r_{t-1} \\ n_{t-1} \end{pmatrix} \begin{pmatrix} \varphi_{r,t} \\ \varphi_{n,t} \end{pmatrix}.$$

However, the most substantive difference between this specification and that of Quah and Vahey is the fact that the system is specified in terms of output and the *price level* rather than the inflation rate.[28] Arguably, the proposition that changes in the money stock (and by extension in the price level) are neutral in their effects on real economic activity is less controversial than the proposition that changes in the growth rate of the money stock (and by extension the inflation rate) are also neutral in the long run. The distinction is important. Estimating core inflation on the basis of posited neutrality of changes in the price level is surely a lot more appealing from a central banker's perspective than estimation based on the long-run neutrality of inflation.

Quah and Vahey express agnosticism about the exact determinants of underlying inflation. However, Blix extends the Quah and Vahey framework to make the role of money even more explicit by estimating the following extended system:

$$\begin{pmatrix} Y_t \\ P_t \\ M_t \end{pmatrix} = x_0 + \Xi_0 \begin{pmatrix} \alpha_{11} & 0 \\ \alpha_{21} & \alpha_{22} \end{pmatrix} \begin{pmatrix} r_t \\ n_t \end{pmatrix} + \Phi(L) \begin{pmatrix} \varphi_{r,t} \\ \varphi_{m,t} \\ \varphi_{p,t} \end{pmatrix}.$$

In addition, a cointegration restriction is imposed that requires that velocity (i.e., $Y_t + P_t - M_t$) is stationary. The restriction requires that

$$\Xi_0 = \begin{pmatrix} 1 & 0 \\ 0 & 1 \\ 1 & 1 \end{pmatrix}.$$

This extension thus brings further hypotheses about real and nominal interactions to bear on the estimation of core inflation. Blix reports that the measures of core inflation obtained in the basic and the extended forms of the Quah-Vahey model are quite similar. Unfortunately he does not provide details of the data used. Monetary theory tells us that, under a fiat monetary standard, the price level is ultimately determined by the stock of base money outstanding relative to the demand for it. Therefore, the appropriate measure of M in the system above is a measure of the base money stock. However, the assumption of stationary velocity of base money is probably at odds with the data for several, if not all, industrialized countries.

Blix's approach to estimating core inflation is more plausible in many respects than the original Quah-Vahey implementation; yet, it is still limited by the fundamental problem of what can be achieved by means of long-run restrictions

[28] As justification, Blix notes that "Dickey-Fuller tests suggest that the vector $\Delta x_t = (\Delta Y_t, \Delta P_t)'$ is stationary for all countries considered" including the United Kingdom. Quah and Vahey claim that "the standard tests confirm that measured *inflation* and output can be treated as I(1)" (emphasis added) using U.K. data. There is a puzzling inconsistency here.

when we have only a finite sample of data available. Faust and Leeper (1997) and Cooley and Dwyer (1998) explore this problem in some detail. The latter provide a series of compelling examples that demonstrate how sensitive inferences from structural VAR models are to seemingly innocuous auxiliary assumptions (about whether the data are trend stationary or difference stationary, the number of underlying shocks, etc.). So far there has been no attempt to evaluate the sensitivity of core inflation estimates from the structural VAR approach of Quah and Vahey to alternative auxiliary assumptions. This approach to core inflation estimation is also subject to the criticism levied against the DFI: that, because it is based on econometric estimates, history will change each time a new observation is added.

CONCLUDING OBSERVATIONS

This paper has reviewed various approaches to the measurement of core inflation. A common theme linking many of these approaches is that there is some concept of monetary inflation that is distinct from changes in the cost of living and that is a more appropriate target of monetary policy. From a traditional quantity theory perspective, this theme has motivated several authors to look at alternative estimates of the central tendency of the distribution of prices as the best estimate of core or monetary inflation. Other authors have used dynamic frameworks along with neutrality propositions from monetary theory to try to estimate core inflation. All of these approaches suffer from this fact: There is simply no agreed upon theory of money that can serve as a basis for inflation measurement that could plausibly replace the theory of the cost of living.

I have also addressed (somewhat tangentially) the question of how measures of core inflation ought to be evaluated. Many of the measures of core inflation that have been proposed in recent years eschew the theory of the cost-of-living index as the basis for measurement. This makes evaluation difficult. The theory of the cost-of-living index provides a coherent framework for the evaluation of measures of headline inflation such as the CPI or the HICP.[29] Essentially we deem a measure of headline inflation to be reliable by the degree to which it approximates the theoretical ideal. There is no theoretical ideal for a monetary measure of core inflation. Rather it is evaluated by its consistency with various loosely formulated propositions from monetary theory. Thus, a measure of core inflation that is designed to capture "monetary" inflation might be evaluated by the extent to which it is (Granger) caused by some measure of the money stock but does not (Granger) cause money. Or a measure might be evaluated by the degree to which it forecasts future inflation, which is an approach suggested by Blinder (1997). The problem with this is that we start to leave the area of economic measurement and enter the domain of formal theorizing and forecasting. It needs to be asked why we would want a measure of core inflation that forecasts future headline inflation. Surely the central bank would be more interested in forecasting future inflation (and would get better results) using multivariate rather than univariate approaches?

This review of various approaches to core inflation measurement also suggests a large number of questions for future research.

First and foremost, before choosing a measure of core inflation we need to specify what it is we want the measure for. Do we want a measure of core inflation to answer the question "What would the inflation rate have been if oil prices (or indirect taxes) had not increased last month?" If so, then *none* of the approaches reviewed above will help. This question can be answered only in the context of a full general equilibrium model of the economy. Furthermore, if the measure of inflation we are interested in is the cost of living, then it is not clear why we would ever want to exclude the effects of oil price increases or indirect taxes. Thus it must be the case that when measuring core inflation we have some other inflation concept in mind. Ideally, a central bank would be most interested in a measure of inflation that measured the rate of decline in the purchasing power of money. Unfortunately there is no well-

[29] Although, as noted earlier, the HICP uses household final monetary consumption rather than the cost of living as its price concept.

developed and generally agreed upon theory that can serve as a guide to constructing such a measure. Thus, in practical terms, we are left with the options of (i) constructing a core inflation measure so as to better track the trend inflation rate (somehow defined) in real time or (ii) forecast the future headline inflation rate, which in many circumstances may amount to the same thing.

The discussion above was highly critical of the various dynamic approaches to core inflation measurement, such as the DFI and the structural VAR approach of Quah and Vahey. I asserted that the major shortcoming of the DFI model is that history changes each time a new observation is added. It would be useful to know before dismissing this approach completely by how much history changes each time the model is reestimated. This should also be done for the other econometric-based measures of core inflation. If it turns out that the amount by which the addition of new information causes previous estimates of core inflation to change is trivial, this criticism might lose a lot of its force. There would also be some merit in further exploring the structural VAR approach of Quah and Vahey. The great merit of this approach is that it has some basis in monetary theory, but it makes sense only if it is operationalized on the basis of neutrality of money rather than superneutrality. Here what needs to be done (in addition to assessing the sensitivity of estimates to the addition of new information) is to see how sensitive the measures of core inflation are to violations of the auxiliary assumptions.

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Inflation Regimes and Inflation Expectations

Joseph E. Gagnon

This paper examines the formation of expectations about future inflation over long horizons. A key issue that agents must confront is the possibility that the economic policy framework—especially the monetary policy regime—could change at some future date. Agents are likely to base inferences about possible future regimes on experience over many years and decades past. This aspect of expectations formation may explain why inflation premiums in long-term bond yields are higher in countries with a long history of high inflation. (JEL E52, E61, G12)

Federal Reserve Bank of St. Louis *Review*, May/June 2008, *90*(3, Part 2), pp. 229-43.

"The further backward you look, the further forward you can see."
—Winston Churchill

Average inflation rates in industrial countries have fallen substantially since the 1980s. In several cases, countries that experienced higher inflation than the industrial-country average during the 1970s and 1980s achieved lower-than-average inflation in the 1990s. Bond yields in industrial countries have generally fallen by more than inflation rates, reflecting increased credibility of anti-inflationary policies. But the countries with the lowest inflation rates in recent years have not necessarily been those with the lowest bond yields. In particular, countries with a long history of higher inflation continue to have higher bond yields.

To provide concrete examples, Table 1 shows two bilateral comparisons: the United States versus Canada and Australia versus New Zealand. Average inflation was lower in Canada than in the United States in both the 1990s and the current decade. Indeed, Canadian inflation was lower than U.S. inflation in 13 of the 16 years since 1991. Despite this consistent record of lower inflation, the yield on 10-year government bonds in Canada was higher than comparable yields in the United States in both periods.[1] Similarly, the inflation rate was lower in New Zealand than in Australia for 14 of the past 16 years. New Zealand bond yields were slightly lower than Australian yields in the 1990s, but by less than the difference in inflation rates, and they have been higher than Australian yields in the current decade, despite continued lower inflation.

One explanation for these findings is that long-term inflation expectations depend on a long history of past inflation—more than just the past 5 or 10 years. Indeed, during the 1980s, inflation averaged 5.8 percent in Canada versus 4.6 percent in the United States and 10.2 percent in

[1] The higher Canadian bond yields in this decade are all the more surprising in light of the fiscal surplus in Canada and the fiscal deficit in the United States.

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Table 1

Average Inflation Rates and Bond Yields

	1981-90		1991-2000		2001-06	
	Inflation	Yield	Inflation	Yield	Inflation	Yield
United States	4.6	10.3	2.8	6.4	2.7	4.5
Canada	5.8	11.6	2.0	7.4	2.3	5.1
Australia	7.8	13.6	2.2	7.8	3.1	5.6
New Zealand	10.2	14.0	1.7	7.5	2.6	6.0

SOURCE: Consumer price inflation rates and long-term government bond yields were obtained from IMF *International Financial Statistics*.

New Zealand versus 7.8 percent in Australia. A similar pattern (not shown) also characterizes the 1970s. In each case, the country with lower recent inflation experienced higher inflation over a long period in the past. The effect of past inflation over a long horizon may also explain the higher bond yields in Australia and New Zealand versus the United States and Canada.[2]

More generally, there is evidence documented by Gagnon (1996) that nominal long-term interest rates are strongly correlated with both recent inflation and past inflation over a long horizon. This correlation holds both across countries and within countries over time. One explanation for this correlation is that long-term inflation expectations are influenced by a long history of past inflation.

This article develops a theoretical framework to explain these empirical findings. The basic idea is that at least since the collapse of the gold standard in the 1930s, the policy regimes of most central banks have periodically changed. Regime changes may be associated with changes in the central bank governor or political party in power, depending on the institutional independence of the central bank. Other factors may give rise to regime changes: Evolving theories about economic behavior may lead to new views on the optimal conduct of monetary policy. Or, extreme social or economic shocks may necessitate a persistent shift in monetary policy. However, in general, it is not useful to think of the regime changing with every shock. Instead, regimes are viewed as implicit or explicit rules governing the behavior of monetary policy in response to ordinary shocks.

One important outcome of different monetary regimes is different average inflation rates across regimes. When agents consider expected inflation over a long future horizon, they must factor-in the possibility that the current regime will not survive over the horizon in question. Recent inflation rates may provide a good forecast of future inflation rates if the current regime survives, but they may not provide a good forecast if the current regime is replaced. To factor-in the effect of a potential new regime, agents may base their forecasts on their experience of past monetary regimes over a long horizon.

For instance, in 1989 the Reserve Bank of New Zealand adopted a central target of 1 percent inflation, which was lower than the inflation rate in 39 of the previous 40 years. It is likely that any agent considering the possibility of a new inflation regime in the future would expect the new regime to have average inflation greater than 1 percent. Even if agents believed that the Reserve Bank would achieve its target of 1 percent inflation in the current regime, they would have to factor the possibility of a change to a higher-inflation regime into their expectations, thereby raising expected future inflation above 1 percent. The importance of regime changes for expecta-

[2] Another explanation for different nominal long-term interest rates is that real long-term interest rates may differ across countries. Market forces should arbitrage away such differences over time as long as capital and goods markets are open. Moreover, as discussed later, direct evidence on the inflation component of bond yields supports the conclusions of this paper.

tions of future inflation was borne out by subsequent political developments in New Zealand, which led to an increase in the center of the inflation target range from 1 percent to 1.5 percent and then to 2 percent.

In addition to explaining long-run inflation expectations in bond markets, a model with regime changes can explain the peculiar time-series properties of actual inflation over the postwar period. For most industrial countries, it is difficult to reject a unit root in the inflation rate. Yet, recent studies have found some evidence of weak mean reversion of inflation rates over long horizons. It is well known that structural breaks in an otherwise stationary series can induce apparent unit roots into the series. If inflation has undergone a small number of regime shifts in the postwar period, it would be difficult to reject a unit root. However, if the regime shifts themselves were around a constant average inflation rate, one would expect to find some evidence of mean reversion in inflation. Moreover, within relatively long-lasting regimes, it should be possible to reject a unit root, which may explain the apparent stationarity of inflation over certain subsamples.

Finally, the possibility of regime shifts leads to highly asymmetric distributions of future inflation rates. The asymmetric distribution of future inflation may explain the asymmetric distribution of survey responses on future inflation expectations. Moreover, the asymmetric distribution of future inflation may explain the frequently large discrepancies between surveys of inflation expectations and implied inflation expectations in bond yields. If survey respondents report the most likely outcome (the statistical mode) and bondholders care about the average outcome (the statistical mean), then the discrepancy between different measures of inflation expectations would be resolved.

LITERATURE REVIEW

Empirical Models of Inflation

Empirical analyses of the long-run properties of inflation rates have often occurred in the context of the real interest rate literature. See, for example, Rose (1988) and Mishkin (1992). Using data from the entire postwar period, one cannot reject a unit root in inflation for most industrial countries using standard augmented Dickey-Fuller tests. However, for many countries, one can reject nonstationarity of the inflation rate in certain subsamples.

Hassler and Wolters (1995) and Baillie, Chung, and Tieslau (1996) use the Phillips-Perron test and the KPSS test on postwar monthly inflation rates and reject both a unit root and stationarity for several countries. To reconcile these conflicting findings, they turn to models with "fractional integration" and find that they are strongly supported by the data. Fractional integration allows for slow mean reversion that does not decay as rapidly as the asymptotically exponential pattern associated with standard autoregressive moving-average models. This slow mean reversion is termed "long memory."

Other researchers have sought to explain the apparent nonstationarity of inflation as the result of regime shifts in the mean and variability of the inflation rate. Chapman and Ogaki (1993), Hostland (1995), Bai and Perron (1998), and Levin and Piger (2002) find significant evidence of regime shifts in inflation in several industrial countries, including the United States. Evans and Lewis (1995), Ricketts and Rose (1995), and Simon (1996) estimate Markov-switching models for inflation in the G-7 countries and Australia. At least two regimes are statistically significant in all countries except Germany.

Occasional shifts in the inflation regime are more economically interpretable than fractional integration. Moreover, if there are only a small number of regimes that cycle back and forth, or if the regime-generating process is stationary, simple models of inflation will appear to have long memory, which is consistent with the fractional integration literature.

Evidence from Bond Markets

Instead of modeling the inflation process, a more direct way to learn about long-run inflation expectations is to examine the inflation premiums in long-term bond markets. Fuhrer (1996) shows that the pure expectations theory of the term structure fits better when one allows structural breaks in the Fed reaction function, especially the implicit inflation target. Gagnon (1996) shows that the inflation premium in long-term interest rates is more closely correlated with a long backward average of inflation than a short backward average, implying that there is long memory in long-run inflation expectations and/or the inflation risk premium.

Focusing directly on countries that announced explicit inflation targets, Ammer and Freeman (1995) and Freeman and Willis (1995) provide evidence that announced inflation targets were not fully credible in the first few years after adoption, where credibility is defined as obtaining long-term inflation expectations equal to the official target for inflation. I present updated evidence on credibility of inflation policies in a later section of this paper.

MODELS OF INFLATION REGIMES

Complete Information

I begin with a model in which agents are fully informed. They know when a regime change has occurred. They know the inflation target of the current regime. They know the probability with which the current regime will end in the next period. And they know the probability distribution of the inflation target across future regimes. (I will relax some of these assumptions later.)

(1) $$\pi_t = \Pi_{t-1} + \varepsilon_t$$

(2) $$\Pi_t = (1-\theta_t)\Pi_{t-1} + \theta_t \eta_t$$

The inflation rate, π, in each period is given by the inflation target, Π, effective in the previous period plus a random error, ε. This lag reflects the conventional monetary transmission lag of roughly one year. The word "target" is used loosely to mean the expected inflation rate within a given regime. It does not necessarily imply that the central bank is officially or unofficially aiming for this inflation rate, only that this inflation rate is the expected average outcome of its policies. More generally, one might expect the variability and persistence of the temporary shock, ε, to be different across regimes. However, such an empirically realistic extension would add complexity to the model without altering the basic theoretical conclusion.

A regime shift ($\theta = 1$) occurs with probability q. With probability $1 - q$ there is no regime shift ($\theta = 0$). The probability of a regime shift in each period determines the average length of regimes. The expected length of a regime is $1/q$ periods. An empirically reasonable range for inflation regimes is between 2 and 20 years, implying a value of q between 0.05 and 0.5. New inflation targets, η, are drawn from a normal distribution with mean m and standard deviation κ.

This specification of the regime-shifting mechanism is silent on the forces that end existing regimes and give rise to new regimes. One interpretation is that different central bank governors have different objectives with regard to the level and variability of inflation and other economic variables. These differences are not fully observable prior to the appointment of a new governor. The term of each governor is random and depends on both personal factors and the struggle of partisan politics. Alternatively, inflation regimes may be seen as the outcome of broader social and political forces that are manifested in opinion polls, public debates, and election results. Still another possibility is that regime shifts are triggered by certain large and persistent shocks, such as energy supply shocks.

One important feature of the models developed in this paper is that the regime-generating process is stationary. In the broad global and historical context, this assumption is reasonable, because inflation rates tend to be bounded between a small negative and a large positive number. Hyperinflations are at most sporadic and not persistent, while hyperdeflations have never happened. However, within these bounds it is conceivable that the regime-generating process has drifted over time. Such a drift may be the result of demographic or technological forces that operate on a time scale much larger than that of monetary policy regimes. Or one may view the switch to fiat money standards this past century as the beginning of a new era in which central banks have had to learn about society's inflation preferences by trial and error. In such a world, one would expect the mean of inflation regimes to drift as central bank learning proceeds. In either case, inflation regimes would appear stationary over a sufficiently long time span, but may appear nonstationary in certain finite samples.

I begin this analysis by considering the formation of inflationary expectations in this model. Expected inflation over the next period is simply given by the current inflation target as shown in equation (3). Expected inflation in subsequent periods is a weighted average of the current inflation target and the expected value of future inflation targets, as shown by equations (4) and (5). The farther ahead one looks, the more likely there will be at least one regime shift and the greater the weight attached to the expected value of future inflation targets, μ.

$$E_t\ \pi_{t+1} = \Pi_t \tag{3}$$

$$E_t\ \pi_{t+2} = (1-q)\Pi_t + q\mu \tag{4}$$

$$E_t\ \pi_{t+1+i} = (1-q)^i\,\Pi_t + q\left(\sum_{j=1}^{i}(1-q)^{j-1}\right)\mu \quad i=1,\ldots,\infty \tag{5}$$

One important property of this model is that the probability density of future inflation is not symmetric if there is a possibility that a regime change may affect the inflation rate in the period in question. The probability density of inflation one period ahead is symmetric because any regime shift that may occur next period will not affect inflation until the following period. For one-period-ahead inflation, the probability density is simply the normal density with mean equal to the current inflation target and variance equal to that of the temporary shock (equation (6)). The notation $f_\varepsilon(x)$ refers to the probability density of the variable ε evaluated at the value x. For example, if $\sigma = 1$, $f_\varepsilon(0) = 0.4$ because ε has a standard normal distribution and the standard normal density at zero is 0.4.

$$f_{\pi_{t+1}}(x) = f_\varepsilon(x-\Pi_t) \tag{6}$$

$$f_{\pi_{t+2}}(x) = (1-q)f_\varepsilon(x-\Pi_t) + q\int_{-\infty}^{\infty} f_\eta(x-\varepsilon)f_\varepsilon(\varepsilon)d\varepsilon \tag{7}$$

$$f_{\pi_{t+1+i}}(x) = (1-q)^i f_\varepsilon(x-\Pi_t) + q\left(\sum_{j=1}^{i}(1-q)^{j-1}\right)\int_{-\infty}^{\infty} f_\eta(x-\varepsilon)f_\varepsilon(\varepsilon)d\varepsilon \quad i=1,\ldots,\infty \tag{8}$$

If we look two periods ahead, the probability density of inflation takes on a two-part form. The first term in equation (7) states that if the current regime survives next period (with probability $1-q$), the probability density of inflation two periods ahead is the same as for one period ahead. The second term in equation (7) states that if the current regime is replaced next period (with probability q), the probability density of inflation in subsequent periods is a convolution of two densities. The first density under the integral is the density of inflation targets across regimes, and the second density is the density of inflation rates within a regime.

If we look ahead $1 + i$ periods, the probability of remaining in the current regime declines to $(1-q)^i$ and the probability of moving to a new regime increases accordingly. It is possible that there may be one or more regime shifts over this horizon, but the probability density of future inflation is independent of the number of regime shifts that may occur.[3]

I now consider an example to illustrate the properties of this model. The parameters are adapted from the three-state Markov process estimates of Ricketts and Rose (1995; RR) for Canada over the period 1954-93. RR assume that inflation cycles among three different regimes, with mean inflation rates of 1.5, 4.5, and 9 percent.[4] Translating these estimates into the model

[3] This property would not hold true if there were dependence across regimes.

[4] RR allow different serial correlations and variances of inflation in different regimes. In the high-inflation regime they impose a unit root on the inflation rate, which is not rejected by the data. With a unit root the population mean is undefined, but the sample mean is 9 percent.

Figure 1

Model 1

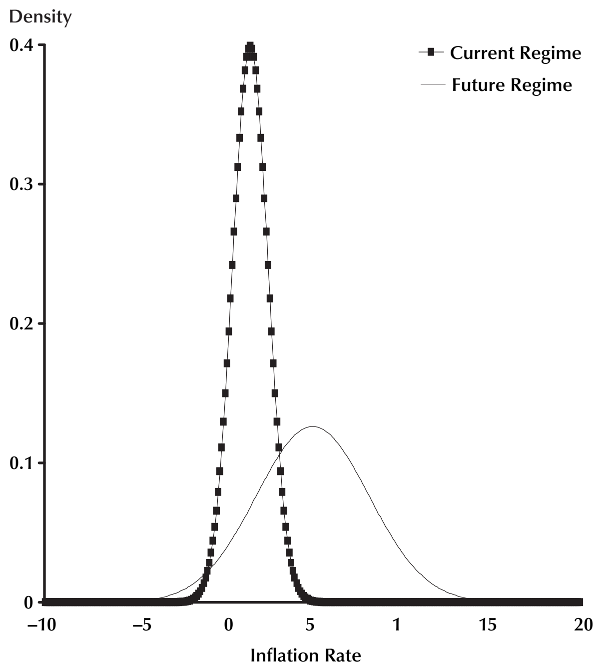
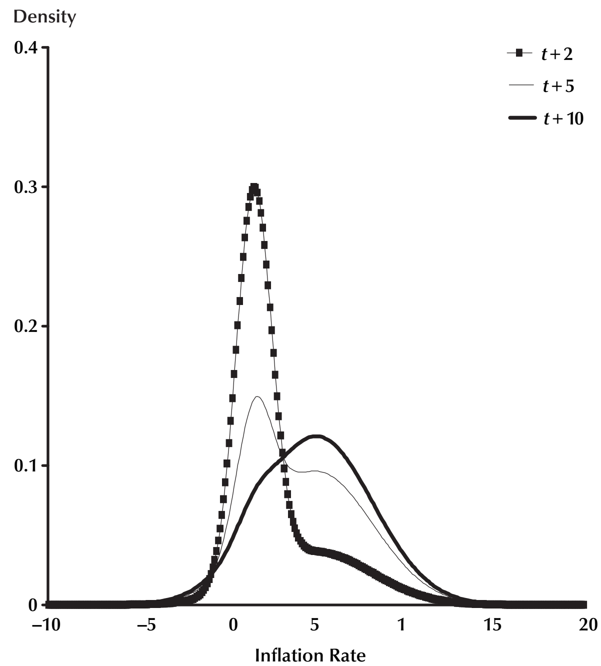


Figure 2

Model 1



of this section implies a mean inflation rate across regimes of 5 percent ($\mu = 5$) with a standard deviation of 3 percent ($\kappa = 3$). (The average inflation rate over this sample is also 5 percent.) The probability of entering a new regime is 30 percent per year ($q = 0.3$).[5] At the end of their sample, Canada was in the low-inflation regime ($\Pi = 1.5$). The standard deviation of inflation in the low-inflation regime is 1 percent, and this estimate is adopted for every regime in the model ($\sigma = 1$).

Figure 1 displays the probability densities of inflation under the current regime and under the assumption of a regime shift without any information on the inflation target in the new regime. Figure 2 displays the probability densities for inflation at different periods in the future. These densities are weighted averages of the two densities in Figure 1, with the weight on the regime-shift density increasing with the distance into the future. Clearly, the weighting of these two densities—each of which is symmetric—leads to a highly asymmetric density for future inflation over certain horizons.

Table 2 displays the mean, median, and mode of inflation from 1 to 10 periods ahead under Model 1. The asymmetry, as measured by the difference between the mean and the median, grows quickly and peaks in period $t + 3$ before declining slowly over longer horizons. In period $t + 10$ the density is quite close to the future regime density in Figure 1, which is symmetric. The density becomes bimodal in periods $t + 4$ through $t + 9$, with the second peak overtaking the first peak in period $t + 8$. Over the entire 10-year period, the average of the mean inflation rates is 3.9 percent, the average of the medians is 3.5 percent, and the average of the modes is 2.7 percent.

Learning about the Current Regime

Of the four informational assumptions described at the beginning of the previous sub-

[5] RR allow different probabilities of a regime shift, depending on the regime. For Canada, the probability of exiting a regime is close to 0.3 for each of the three regimes.

section, the most realistic are that agents know when there has been a regime change and that they know the probability of a regime change in any given period. Regime changes are likely to be associated with observable events such as a change in the party or individual in control of the central bank, an announcement by the central bank indicating that a new policy has been adopted, or a major economic or social shock such as a war. The probability of a regime change is given by the institutional structure of government and the randomness of individual career decisions and lifespans. It does not seem unreasonable to assume that agents understand this process well, or at least that their beliefs about it are not changing over time.

The first assumption that I relax is the assumption that agents know any new target inflation rate immediately. Instead, I assume that agents learn about the current regime by observing the inflation rates that occur. During the period in which a regime shift occurs, the best any agent can do is to expect future inflation to be equal to the mean across regimes, μ. (See equation (9).) The probability density is given by the convolution of the target density and the density of deviations from target, shown in equation (10).

$$E_t\pi_{t+i} = \mu \qquad i = 1,\ldots,\infty \tag{9}$$

$$f_{t,\pi_{t+i}}(x) = \int_{-\infty}^{\infty} f_\eta(x-\varepsilon)f_\varepsilon(\varepsilon)d\varepsilon \qquad i = 1,\ldots,\infty \tag{10}$$

In the following period, an inflation rate is observed. Assuming that there is no regime change, the optimal learning procedure is to use Bayes's rule to update the probability density of future inflation under the assumption that the current regime continues. The prior density is given by equation (10). Equation (12) displays Bayes's rule, which uses the prior density combined with observed information on inflation in the current regime to determine the conditional probability density of future inflation under the assumption that the current regime survives. Because inflation one period ahead is not affected by any future regime change, its expected value

Table 2

Asymmetric Distribution of Future Inflation Rates: Model 1

Π_t = 1.5, σ = 1, μ = 5, κ = 3, q = 0.3

Date	Mean	Median	Mode
t+1	1.5	1.5	1.5
t+2	2.5	1.9	1.5
t+3	3.3	2.4	1.6
t+4	3.8	3.1	1.6
t+5	4.2	3.6	1.7
t+6	4.4	4.1	1.8
t+7	4.6	4.5	2.0
t+8	4.7	4.6	5.0
t+9	4.8	4.7	5.0
t+10	4.9	4.8	5.0
Average	3.9	3.5	2.7

is given by the standard formula for the expectation of a continuously distributed random variable displayed in equation (11) using the density defined by equation (12).

$$E_{t+1}\pi_{t+2} = \int_{-\infty}^{\infty} x f_{t+1,\pi_{t+2}}(x)dx \tag{11}$$

$$f_{t+1,\pi_{t+2}}(x) = \frac{\int_{-\infty}^{\infty} f_\eta(x-\varepsilon)f_\varepsilon(\varepsilon)f_\varepsilon(\pi_{t+1}-x+\varepsilon)d\varepsilon}{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f_\eta(y-\varepsilon)f_\varepsilon(\varepsilon)f_\varepsilon(\pi_{t+1}-y+\varepsilon)d\varepsilon dy} \tag{12}$$

Once the current regime ends, the distribution of future inflation reverts to its prior distribution (equation (10)). Thus, the probability density of inflation more than one period ahead takes the compound form presented in equation (14). In all periods beyond t + 2, the probability density of inflation is equal to the probability of no regime change times the density for period t + 2 plus the probability of a regime change times the prior density of inflation under an unknown regime. The expected value of inflation in periods beyond t + 2 (equation (13)) takes a compound form parallel to equation (14). Note that the expected value of inflation under the prior density is μ, the average inflation target across regimes.

Figure 3

Model 2

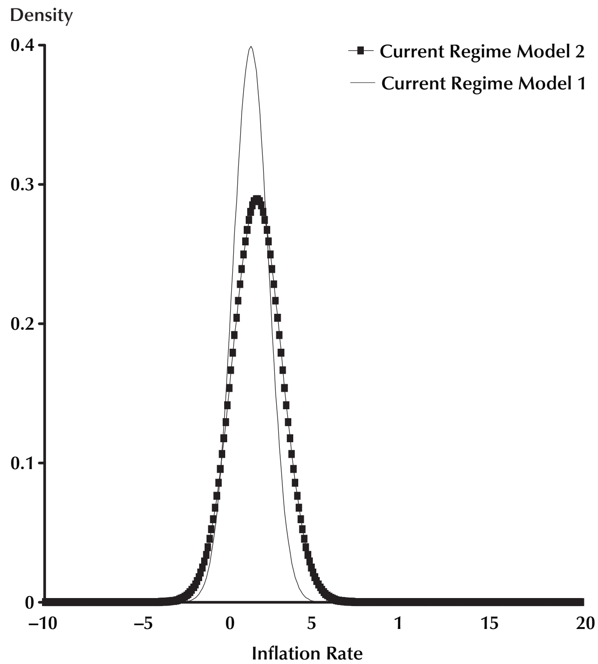
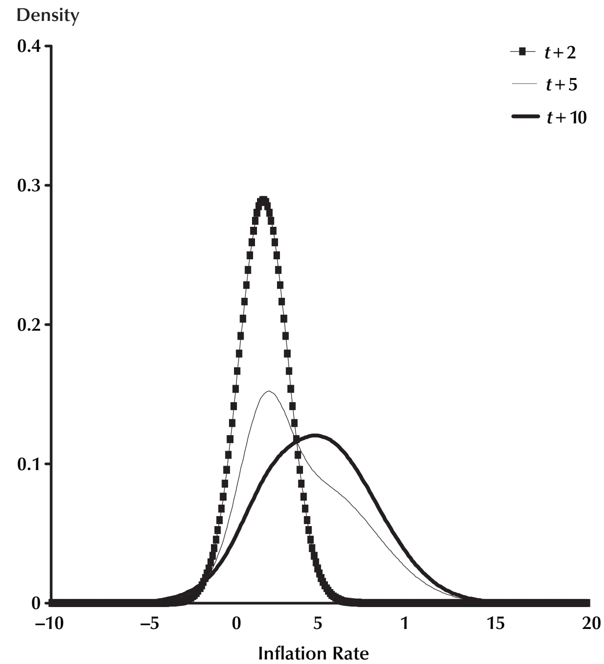


Figure 4

Model 2



$$E_{t+1}\pi_{t+2+i} = (1-q)^i E_{t+1}\pi_{t+2} + q\sum_{j=1}^{i}(1-q)^{j-1}\mu \quad i=1,\ldots,\infty \tag{13}$$

$$f_{t+1,\pi_{t+2+i}}(x) = (1-q)^i f_{t+1,\pi_{t+2}}(x) + q\sum_{j=1}^{i}(1-q)^{j-1} f_{t,\pi_{t+1}}(x) \quad i=1,\ldots,\infty \tag{14}$$

After observing inflation in period $t+2$, the conditional density of inflation in period $t+3$ is given by Bayes's rule using the prior density (equation (10)) and two pieces of information, π_{t+1} and π_{t+2}. (This density is not shown.) As more periods of inflation are observed without a regime shift, the influence of the prior density diminishes and the conditional density of inflation approaches that of the case in which the current regime target inflation rate is known.

I now consider an example to illustrate the properties of this model. As in the previous section, suppose that the mean inflation target across regimes is 5 percent, with a standard deviation of 3 percent, and that the probability of a new regime is 0.3 per period. Suppose that within a regime, the standard deviation of inflation around its target is 1 percent and the current inflation target is 1.5 percent. If a regime shift occurs in the current period, the conditional density of future inflation in every period is given simply by the density under the assumption of a future regime shift, as shown in Figure 1.

If a regime shift occurred last period and the regime survives in the current period, the distribution of next period's inflation depends on the current observation of inflation. If we assume that current inflation is 1.5 (the current inflation target), Figure 3 displays the probability density of inflation next period. For comparison, the density assuming complete knowledge of the current regime is also plotted. Note that the density with incomplete knowledge is more diffuse than that assuming complete knowledge. Figure 4 displays the probability densities for inflation at various periods in the future. These densities are weighted averages of the density in Figure 3 and the density assuming an unknown regime shift (shown in Figure 1). Once again, the weighting of these two densities—each of which is symmetric—leads to an asymmetric density for future inflation.

Table 3, which pertains to Model 2, displays the mean, median, and mode of inflation from 1 to 10 periods ahead, conditional on observing inflation in period $t + 1$ after a regime shift in period t. The growing asymmetry is readily apparent, but not as extreme as in the case of complete knowledge of the current regime.

Table 3

Asymmetric Distribution of Future Inflation Rates: Model 2

Π_t = 1.5, σ = 1, μ = 5, κ = 3, q = 0.3

Date	Mean	Median	Mode
t+2	1.8	1.8	1.8
t+3	2.8	2.3	1.9
t+4	3.5	2.8	2.0
t+5	3.9	3.3	2.2
t+6	4.2	3.8	2.4
t+7	4.5	4.2	2.7
t+8	4.6	4.4	3.6
t+9	4.7	4.6	4.6
t+10	4.8	4.7	4.8
t+11	4.9	4.8	4.9
Average	4.0	3.7	3.1

Learning about Future Regimes

The other assumption that I relax is the assumption that agents know the distribution of target inflation rates across future regimes. To simplify the analysis, I return to the assumption that agents know the current and past inflation targets.

In this model, agents must estimate the mean and standard deviation of inflation targets across regimes using data on past regimes. Each time a new regime occurs, agents update their estimates of the mean and standard deviation. Expected inflation in the next period is simply the current inflation target, shown in equation (15). Expected inflation more than one period ahead is a weighted average of the current inflation target and the average of current and past inflation targets. (See equation (16).) Because inflation regimes typically last for more than one period, the second term in equation (16) is an average computed using the first year of each regime, denoted by the set $\{R_N\}$, which contains N elements, where N is the number of regimes. By the law of large numbers, when N is large, the right-hand side of equation (16) approaches equality with the right-hand sides of equations (2) and (3). In other words, when there have been many regimes in the past, agents can estimate the true mean of future inflation targets quite accurately.

$$E_t\ \pi_{t+1} = \Pi_t \tag{15}$$

$$E_t\ \pi_{t+1+i} = (1-q)^i\,\Pi_t + q\left(\sum_{j=1}^{i}(1-q)^j\right)\left(\sum_{k\in R_N}\frac{\Pi_k}{N}\right) \quad i = 1,\ldots,\infty \tag{16}$$

The probability density of inflation one period ahead is given by equation (17), which is identical to equation (6). The probability densities of inflation more than one period ahead are given by equation (18), under the assumption of a diffuse prior distribution on the mean and standard deviation of inflation targets across regimes.

$$f_{\pi_{t+1}}(x) = f_\varepsilon(x-\Pi_t) \tag{17}$$

(18)

$$f_{\pi_{t+1+i}}(x) = (1-q)^i f_\varepsilon(x-\Pi_t) + q\sum_{j=1}^{i}(1-q)^{j-1}\frac{\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f_\varepsilon(\varepsilon) f_\eta(x-\varepsilon) f_\eta(\Pi_1)\cdots f_\eta(\Pi_N)\,d\mu\, d\kappa\, d\varepsilon}{\left(\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f_\eta(\Pi_1)\cdots f_\eta(\Pi_N)\,d\mu\, d\kappa\right)}$$

$$i = 1,\ldots,\infty$$

Figure 5

Model 3

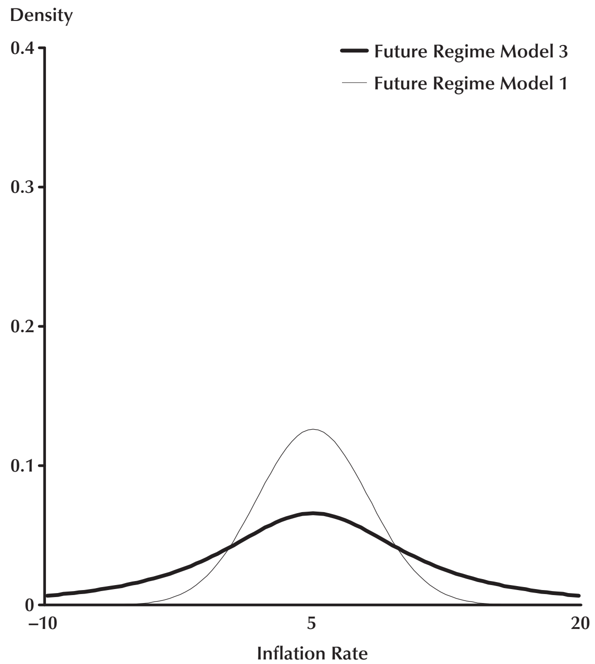
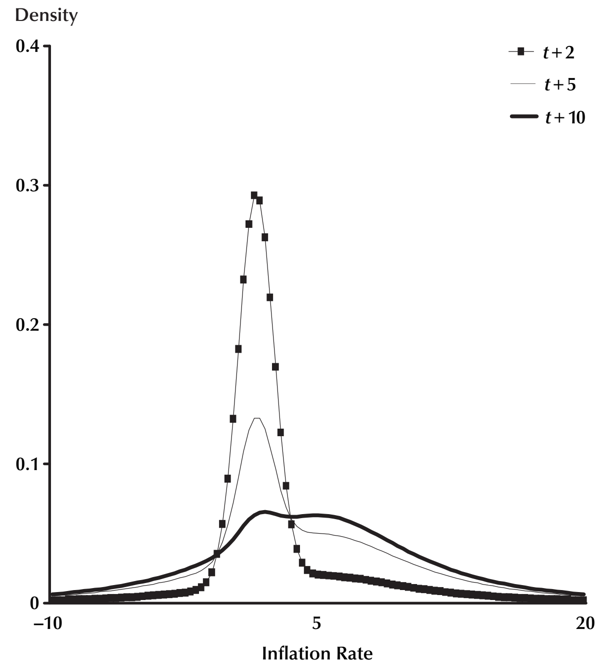


Figure 6

Model 3



As the number of past regimes increases, this density approaches those of equations (7) and (8) and we return to the case of complete knowledge about the distribution of future inflation targets.

To illustrate the properties of this model, I need to specify values of current and past inflation targets. To continue with the flavor of past examples, I choose past inflation targets of 4.5 percent and 9 percent and a current inflation target of 1.5 percent. The average of these targets is 5 percent and the standard deviation is 3 percent. Thus, these outcomes are consistent with the earlier assumption of $\mu = 5$ and $\kappa = 3$. Figure 5 displays the density of future inflation under the assumption that there is a regime shift—that is, the ratio of the triple integral to the double integral in equation (18). For comparison, Figure 5 also displays the density of future inflation after a regime shift under the assumption of complete knowledge of the distribution of inflation targets, which was originally displayed in Figure 1. It is not surprising that the density without knowledge is more diffuse than the density with knowledge. Both densities are symmetric around the same mean, however, as a result of the choice of observed inflation targets with the same mean as the true distribution.

Figure 6 displays the densities of inflation in three specific future periods. Once again, the densities are asymmetric whenever there is a positive probability that a regime shift may affect inflation in the period in question. Table 4, which pertains to Model 3, displays the mean, median, and mode of inflation in various future periods under the assumption that agents do not know the parameters of the distribution of future inflation targets and must infer them from observed inflation targets. The means and medians are identical to those displayed in Table 1 because the average of current and past inflation is assumed to be equal to the true mean of inflation targets across regimes. The only difference between Model 3 and Model 1 is that the density of inflation after a regime change is much more diffuse. This diffuseness affects the mode of future inflation because the secondary peak at 5 percent inflation is much lower than in Model 1. This diffuseness has no effect on the mean or median of future inflation.

Finally, I consider the effect of a new regime on the mean of future inflation in the case of learning about the distribution of inflation targets. Suppose that a new regime occurs in the example above with an inflation target of 1.5 percent. In other words, suppose that a new central bank governor chose to continue the previous inflation target of 1.5 percent. The effect of this new regime depends on the number of previously observed regimes. If there were only three previous regimes, the average of current and past inflation targets drops from 5 percent to 4.1 percent. If there were ten previous regimes, which is the number of regimes estimated for Canada by RR, the average of current and past regimes declines by much less, from 5 percent to 4.7 percent. In other words, the effect of a given inflation regime on agents' expectations for future regimes is smaller when agents have experienced more changes in regimes in the past. Of course, it is possible that agents could draw inferences from regime changes that occurred before they were born—which might imply a very large number of past regimes—but in reality it is likely that trends in political systems and in financial technology may cause agents to heavily discount the relevance of regimes in the distant past.

Table 4

Asymmetric Distribution of Future Inflation Rates: Model 3

Π_R = {4.5, 9, 1.5}, Π_t = 1.5, σ = 1, q = 0.3

Date	Mean	Median	Mode
t+1	1.5	1.5	1.5
t+2	2.5	1.9	1.5
t+3	3.3	2.4	1.5
t+4	3.8	3.1	1.6
t+5	4.2	3.6	1.7
t+6	4.4	4.1	1.7
t+7	4.6	4.4	1.7
t+8	4.7	4.6	1.8
t+9	4.8	4.7	1.9
t+10	4.9	4.8	2.0
Average	3.9	3.5	1.6

EMPIRICAL SUPPORT

Estimation and testing of the models in the previous section pose a serious econometric challenge that is beyond the scope of this paper. Instead, I show that artificial data generated by the basic model of this paper behave in a manner similar to observed inflation and that this model may explain certain puzzling properties of the observed data. In addition, I show that the model developed here may be able to explain puzzling features of the evidence on long-run inflation expectations.

Despite the fact that this model does not incorporate any serial correlation of inflation within a regime, nor any serial correlation across regimes, it is capable of explaining much of the observed serial correlation of inflation. Over the sample period examined by RR, 1954-93, the Canadian CPI inflation rate has an estimated dominant autoregressive root of about 0.85, and augmented Dickey-Fuller (ADF) tests cannot reject a unit root at any significance level. Monte Carlo data generated by Model 1 with the parameters in Table 1 for the same number of observations yield a median dominant autoregressive root of about 0.5; and ADF tests reject a unit root at the 5 percent level only about 45 percent of the time. If the model is extended to include an autoregressive lag on inflation of 0.7 (the mean of the within-regime autoregressive parameters estimated by RR) and new Monte Carlo data are generated, the median dominant root increases to 0.82 and the power of the 5 percent ADF test drops to 15 percent. For comparison, data generated by a simple autoregression with no regime shifts and a lag coefficient of 0.7 yield a median estimated dominant root of 0.66 and the power of the 5 percent ADF test is 40 percent.

In addition to explaining the near unit-root behavior of inflation over long horizons, a model with regime shifts can also explain the apparent stationarity of inflation over certain shorter horizons. Simply put, inflation is stationary within regimes; therefore, one ought to be able to reject nonstationarity in a regime that is sufficiently long-lasting. For example, ADF tests on quarterly U.S. inflation reject a unit root between 1954 and 1966 and also between 1984 and 1996. RR find that regimes of this length are plausible for the United States; using U.S. data, they estimate a probability of only 10 percent per year of a regime shift ($q = 0.10$). Levin and Piger (2002) show that there is strong evidence of shifts in average inflation in many industrial countries and that allowing for such breaks leads to estimates of low persistence in inflation in most countries.

The asymmetric distribution of future inflation in these models of regime shifts may explain the asymmetric distribution of survey responses on future inflation expectations. Carlson (1975) and Lahiri and Teigland (1987) present evidence that the distribution of 1-year-ahead inflation expectations across survey respondents is usually asymmetrically distributed. Moreover, the direction of the skewness is identical to that predicted by a regime-shift model for the true distribution of future inflation.[6] When inflation is higher than its historical average, expectations are skewed negatively. When inflation is lower than its historical average, expectations are skewed positively.

A more direct measure of the asymmetry of the distribution for future inflation is captured by the Survey of Professional Forecasters, which asks forecasters to provide a probability density for next year's inflation rate in the United States.[7] Based on these densities, one can calculate the mean, median, and mode of future inflation for each forecaster.[8] Between 1992:Q1 and 2008:Q1, the average of the forecast means was 2.50 percent; the average of the forecast medians was 2.45, and the average of the forecast modes was 2.43.[9] The differences between the average mean, median, and mode are not statistically significant. Nevertheless, they do follow the qualitative pattern one would expect if recent inflation is below its long-run average and agents are factoring in at least a small probability of a change in monetary policy regime. Moreover, this survey does not ask for the probability density of inflation beyond the next year. As we have seen, the impact of potential future regime changes on the probability distribution of inflation is greater for longer-term forecasts.

Finally, the asymmetric distribution of future inflation may explain the tendency for inflation compensation in bond yields to be larger than both the official inflation targets of central banks and surveys of long-run expected inflation from professional forecasters. The first column of Table 5 lists the inflation target or the center of the target range for countries that have announced a numeric goal for inflation. The second column lists average inflation expectations over the next 10 years from the October 8, 2007, *Consensus Forecasts* survey.[10] The third column lists inflation compensation implied by the difference between 10-year nominal and inflation-indexed bond yields as of the same date.[11] In every case but New Zealand, the survey response for long-run inflation is within 0.1 percent of the announced target. This result may reflect a relatively low perceived probability of a regime shift, leading to a forecast mode equal to the tar-

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6 I am unaware of any research on how the distribution of a variable affects the distribution across individual forecasts of that variable. Nevertheless, these results are suggestive.

7 The Survey is conducted by the Federal Reserve Bank of Philadelphia; www.philadelphiafed.org/econ/spf/. Forecasters are asked to assign probabilities of inflation occurring in each of 10 buckets. The bucket widths are 1 percentage point, except for the bottom and top buckets, which are open-ended. I assigned a mid-point for the open-ended buckets equal to 1 percentage point away from the mid-point of the adjacent bucket. The probabilities attached to the open-ended buckets were very low. The Bank of England has asked a similar question in its Survey of External Forecasters since 1996, but its survey has fewer and more frequently changing density buckets.

8 The mean is calculated as the probability of each bucket times the midpoint of that bucket summed over all buckets. The median is calculated by interpolating between the midpoints of the two buckets that have cumulative density on either side of 0.50. The mode is calculated as the average of the midpoints of the three buckets with highest probability weighted by their respective probabilities.

9 Similar results were obtained for earlier years, but there were fewer buckets and the ranges changed over time, making the estimates much less precise.

10 See www.consensusforecasts.com.

11 Bond data were obtained from Bloomberg.

get in the current regime. Interestingly, the sole exception, New Zealand, is also the only one of these countries to have experienced an announced change in the inflation target since an inflation goal was first publicly adopted. In every case but Japan, the inflation compensation in bond yields is greater than the policy target and, by extension, inflation compensation in bond yields is greater than inflation expectations in surveys.[12] If survey respondents report the modal outcome and bondholders care about the average outcome, then the discrepancy between different measures of inflation expectations would be resolved.[13,14]

INTERPRETATIONS AND EXTENSIONS

The basic point of this paper is a stark one: Monetary regimes with inflation targets that are quite different from the average inflation rate across previous regimes may never be seen as fully credible over the long term by financial markets. Here I define credibility to be equality between the announced inflation target and the mean of the distribution of future inflation. This lack of credibility is not necessarily due to slow learning by private agents or to a lack of resolve on the part of the central bank. Even when agents understand and believe in the central bank's target inflation rate, they must attach some probability to a change in the regime. For example, the central bank governor may die or resign or the government may change the institutional framework of monetary policy. There is no way to guarantee that these things will not happen.

The key to credibility over the long term is the expected value of inflation under the next regime. This paper considers two approaches to modeling expectations of inflation under the next regime. In the first approach, it is assumed that agents know the constant mean inflation rate across regimes. If the current regime's inflation target is equal to this long-run inflation mean, then policy is credible in the long run. If the current regime's inflation target is far from the long-run inflation mean, then policy is not credible and policy will never become fully credible no matter how long the current regime lasts or how often similar regimes arise. In the second approach, agents update their expectations about inflation in the next regime based on inflation in the current and previous regimes. Under this approach, a sequence of low (or high) inflation regimes would change agents' expectations of inflation

Table 5

10-Year Inflation Expectations (October 2007)

	Policy	Survey	Bond
Australia	2.5	2.6	3.6
Canada*	2.0	2.0	2.4
Euro Area†	1.8	1.9	2.3
Japan	1.0	1.0	0.4
New Zealand	2.0	2.5	2.5
Sweden	2.0	1.9	2.5
U.K.‡	2.0	2.0	3.2
U.S.	N/A	2.2	2.4

NOTE: *For Canada, bond measure is for 14-year maturity. †For the Euro Area, policy goal is inflation "close to but below 2 percent." ‡For the U.K., policy and survey refer to consumer prices whereas bonds are indexed to retail prices.

[12] In the United Kingdom, inflation compensation in indexed bonds is tied to the retail price index. Retail price inflation has averaged about 0.5 percent higher than consumer price inflation, but, even after adjusting for this difference, inflation compensation in bond yields exceeds inflation expectations from surveys.

[13] The professional forecasters surveyed in *Consensus Forecasts* presumably are judged by clients on the accuracy of their forecasts. I thank Jeff Dominitz for pointing out that forecasters should report the mean of future inflation if the penalty for forecast errors is proportional to the squared error. They should report something between the mean and the mode if the penalty is proportional to the absolute error. They should report the mode if the penalty is constant for all errors greater than a given magnitude and zero otherwise. In practice, forecasters communicate more to their clients than a simple point forecast. It is common to talk of the forecast being the most likely scenario with unequal upside and downside risks, which would imply a forecast that is closer to the mode than the mean. Boero, Smith, and Wallis (forthcoming) show that point forecasts of inflation in the United Kingdom since 1996 typically lie below the mean of the inflation densities supplied by the same forecasters.

[14] Two other factors to consider are inflation risk premiums and liquidity premiums. Aversion to inflation risk may account for some of the inflation compensation in nominal bond yields. But the lower liquidity of indexed bonds is an offsetting factor because it tends to push up yields on indexed bonds relative to yields on nominal bonds.

in the next regime. However, as demonstrated in a simple example, significant changes in long-run inflation expectations may still require a great deal of time.

One plausible extension of these models is to consider learning on the part of the central bank. For example, one may argue that the high inflation of the 1970s was a mistake, that central banks have learned their lessons, and that the public understands that this episode will not recur. Under this hypothesis, agents ought to place more weight on recent inflation rates when forming expectations about inflation in the next regime; in this case, long-run credibility would be easier to obtain than in the basic models. Nevertheless, as long as agents place some positive weight on past inflation targets in forming expectations about future inflation targets, the credibility problem will remain.

Another extension of the model would be to consider variation over time in the probability of a regime shift. One way to increase the long-run credibility of the current inflation target is to take steps to reduce the probability of a regime shift. Recent attempts in many countries to increase the independence of the central bank may be interpreted as reducing the probability of a regime shift and thus strengthening credibility. Nevertheless, it is not possible to guarantee that any regime will last forever.

Although the hypothesis of central bank learning seems plausible and many central banks have achieved greater independence in recent years, I would like to conclude the paper by noting several caveats. First, the recent recurrence of inflation in some countries that have a long history of inflation (such as Argentina and Venezuela) argues for caution about the idea that a bad experience with inflation inoculates a country against future inflation. At the very least, one should keep in mind that lessons learned may become lessons forgotten. Second, even if central banks have learned their lessons well and permanently, the public may be skeptical and the time needed to convince the public may be measured in decades rather than years. Third, even if one does discount the possibility of a return to double-digit inflation, it is harder to justify ignoring the possibility of a return to moderate inflation rates of around 5 percent or so. In light of the fact that no one is recommending a regime with negative inflation rates, an inflation target that is very close to zero can never be credible in the long run, as long as there is some possibility of a return to positive inflation.

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Inflation and the Size of Government

Song Han and Casey B. Mulligan

It is commonly supposed in public and academic discourse that inflation and big government are related. The authors show that economic theory delivers such a prediction only in special cases. As an empirical matter, inflation is significantly positively related to the size of government mainly when periods of war and peace are compared. The authors find a weak positive peacetime time-series correlation between inflation and the size of government and a negative cross-country correlation of inflation with non-defense spending. (JEL E52, E61, E63)

Federal Reserve Bank of St. Louis *Review*, May/June 2008, *90*(3, Part 2), pp. 245-67.

Traditionally, economic reasoning has been used to explain the reactions of consumers and firms to government policies. There is now growing appreciation that economic reasoning can explain government behavior as well. Can such reasoning explain which countries inflate and when? Alesina and Summers (1993), Cukierman (1992), and many others have recently begun to try to make such predictions.

Although we have relatively little to add to the literature on positive theories of inflation, we believe that one correlation in particular is especially relevant for such theories: the correlation between inflation and the size of government. With much being said in the literature on the theory of inflation, it is important to see how the theoretical predictions match the empirical evidence. Such evidence is provided in this paper. We study, from a public-finance perspective, how inflation varies across countries and over time in response to the changes in the size of government.

In particular, we first discuss how the quantity of government spending fits into the normative theories of inflation and public finance both in static models and in the steady states of dynamic models. These normative theories—following Barro (1979), Judd (1989), and others—might also be used as positive theories of long-run inflation. The lessons we learn from these studies are that, on the one hand, the conventional optimal tax considerations have suggested that the optimal inflation tax should increase with government spending (e.g., Mankiw, 1987, Veigh, 1989, and Poterba and Rotemberg, 1990); on the other hand, it has also been shown that, when money is a certain type of "intermediate good," it is not necessarily optimal for bigger governments to inflate more (e.g., Kimbrough, 1986, Woodford, 1990, and Correia and Teles, 1996).

We also review the dynamic stochastic theories of public finance in which governments optimally inflate and deflate in response to surprises caused by government spending shocks and economic conditions. These models emphasize the unanticipated portion of government spending and seem particularly applicable to times of war

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(e.g., Barro and Gordon, 1983a, and Lucas and Stokey, 1983).

Our empirical analysis makes three contributions to the literature. First, we use three dimensions of data—cross-country, time-series, and wartime—to study how inflation responds to government spending, whereas previous studies mainly looked at cross-country evidence (e.g., Campillo and Miron, 1997, and Click, 1998). The cross-country analysis is most suitable to study the long-run relation between inflation and the size of government—or, in other words, how inflation responds to permanent changes in the size of government. To study how inflation responds to temporary changes in the size of government, time-series analysis is more appropriate. The wartime analysis provides evidence of what happens to inflation when the temporary changes in government spending are large. In particular, we study the behavior of inflation during suspensions of convertibility in the classical gold-standard periods and in the paper-standard periods.

Second, we study how inflation responds to the changes in not only total government spending but also its components, defense and non-defense spending. Distinguishing between defense and non-defense spending is necessary because most of the large temporary changes in the size of government are due to changes in defense spending in wartime, whereas other increases in the size of government are mainly due to the secular increases in non-defense spending. Also, changes in defense spending are more likely to be exogenous than changes in non-defense spending (Becker and Mulligan, 2003). Hence the effects of defense spending on inflation may be different from those of non-defense spending. The previous studies on this topic, such as Campillo and Miron (1997) and Click (1998), did not study how inflation is related to the components of government spending.

Third, we use an instrumental variable (IV) method to mitigate the potential bias caused by the endogeneity of government size and non-defense spending in the ordinary least-squares (OLS) regressions.[1] The IV we use is the ratio of Social Security spending to output, because, although the *ratio* of Social Security spending to output is correlated with the ratio of non-Social Security non-defense government spending to output, it is unlikely to be correlated with inflation directly. This independence arises because most countries rely exclusively on payroll taxes to finance Social Security spending.[2] We will discuss more about the appropriateness of the instrument in the third section. Previous studies did not attempt to correct the possible endogeneity problems in their OLS regressions.

The next section reviews the existing theories of inflation. The third section presents evidence from 80 countries showing that there is little cross-country correlation between inflation and the size of government. Defense spending is slightly positively correlated and non-defense spending slightly negatively correlated with inflation. Thus, although we explicitly recognize that seigniorage enters the government budget constraint, we suggest that the emphasis of Sargent (1982) and others on "inflation as a fiscal phenomenon" is not very useful for predicting inflation across countries. These results are also contrary to previous studies, such as those by Grilli, Masciandaro, and Tabellini (1991) and Campillo and Miron (1997), that found a positive correlation between inflation and the size of government.

The fourth section studies U.S. and U.K. time-series data on inflation and government spending. We show that inflation and the size of government have both trended upward while the temporary increases in government spending during wartime have also been positively correlated with inflation. The fifth section takes a closer look at wartime inflation during suspensions of convertibility in the classical gold-standard and the paper-standard

[1] There are several possibilities of why government spending may be endogenous. For example, governments may want to reduce spending or their deficit to reduce inflation. Cukierman (1992) and Becker and Mulligan (1997) also suggest that government spending may respond to inflation and not the other way around (which is discussed in the next session). Finally, governments with limited means for taxing their citizens cannot spend very much and must rely relatively heavily on seigniorage for the little revenue that they do spend.

[2] In some countries, such as the United States, Social Security payments are indexed to the changes in the cost of living. However, the *ratio* of Social Security spending to output may not necessarily change with the cost of living because of the high correlation between the changes in the cost of living and the changes in the gross domestic product (GDP) price deflator.

periods. We show that inflation rises above normal at the beginning of wars, whereas inflation falls below normal at the conclusion of wars except in countries that are defeated.

THEORY

In this section, we review the normative theories of inflation in public finance that relate inflation to the size of government. The review also provides a guide to our empirical specifications.

Inflation in the Static Theory of Public Finance

It has been argued by Barro (1979), Judd (1989), and others that the normative theory of public finance can also serve as a positive theory of government policy. Although a literal application of the normative theory absurdly suggests that economies are run by "benevolent social planners," Becker (1983 and 1985), Wittman (1995), and others have shown that in more realistic political models of government decisionmaking, policies reflect efficiency considerations in the long run. For example, Becker's (1983, p. 386) proposition 4 states that "competition among pressure groups favors efficient methods of taxation." Thus we first turn to the normative theory of public finance to obtain a prediction for the relationship between inflation and the size of government.

Following Ramsey (1927), Phelps (1973) argues that, because seigniorage is a source of government revenue, the marginal deadweight loss of inflation should be equated to the marginal deadweight loss of other taxes. Presumably the marginal deadweight loss of other taxes is greater when the government must raise more revenue. So, assuming the relevant portion of the seigniorage Laffer curve is upward sloping, larger governments should have higher inflation rates, more seigniorage, and a greater marginal deadweight loss from inflation.

However, it has been argued by Kimbrough (1986), Woodford (1990), and others that Ramsey's (1927) formulation does not directly apply to the inflation tax because the inflation tax affects the marginal deadweight loss of other taxes. With some configurations of tastes and technologies, the marginal deadweight loss of inflation and that of other taxes can never be equated because a higher inflation rate sufficiently increases the marginal deadweight loss of other taxes such that the Ramsey-optimal "inflation tax rate" is zero.[3] In many models, an optimal inflation tax rate of zero—often referred to as the "Friedman rule," due to Milton Friedman's (1969) advocacy of such a policy—corresponds to a zero nominal interest rate and an inflation rate equal to zero minus the real interest rate.

Because inflation and nominal interest rates in nearly every country and every year since 1945 have been positive, the Friedman rule can hardly serve as a positive theory of inflation. But can the basic logic of the models of Kimbrough (1986), Woodford (1990), and others deliver a prediction for the relationship between inflation and the size of government? If the reason for deviating from the Friedman rule has to do with reasons of politics or equity, then these models are not up to the task. But, as Woodford (1990), Faig (1988), and others have pointed out, the Ramsey-optimal inflation tax rate is positive for some of these models. Unfortunately, these models are still pretty ambiguous about the relationship between inflation and the size of government. To see this, consider the model of Mulligan and Sala-i-Martin (1997), which they show to be a generalized version of many of the models that have appeared in the literature. In the spirit of the inventory models of demand for money, money reduces the transaction costs, or "shopping time," of purchasing consumption goods rather than entering the consumer's utility function. Utility is therefore defined only over consumption and leisure, $u(c,l)$, a function that is assumed to have the usual properties. Shopping time v is a function of two variables: the amount of transactions and the real money stock held by the consumer. The quantity of transactions is assumed to be equal to c plus a fraction λ of consumption tax revenues, τc: This allows for the possibility

[3] See also Chari, Christiano, and Kehoe (1996), Correia and Teles (1996, 1999), and de Costa and Werning (2007) for situations in which the Friedman rule is optimal. Mulligan and Sala-i-Martin (1997) review the literature and discuss the economics of these results.

that not all taxes have to be paid with money or that the "velocity" of money used to pay taxes is greater than the velocity of other money. Mulligan and Sala-i-Martin define the indirect utility function, $V(\tau,R)$, according to

$$V(\tau,R) \equiv \max_{c,l,m} u(c,l)$$

subject to

$$Rm + (1+\tau)c \leq T - l - v([1+\lambda\tau]c, m),$$

where R is the nominal interest rate and T is the time endowment. The Ramsey problem is

$$\max_{\tau,R} V(\tau,R) \;\; s.t. \;\; \tau c(\tau,R) + Rm(\tau,R) \geq g,$$

where g is government spending (taken as given in the Ramsey problem) and $c(\tau,R)$ and $m(\tau,R)$ are "demand functions" from the consumer's optimization program.

Within the above framework, Mulligan and Sala-i-Martin showed that how R and g are related depends crucially on the functional forms of the indirect utility function, V, and the transaction function, v. In particular, their proposition 10 states the following:

> If the shopping time function $v(x,m)$ is homogeneous of degree one and the Laffer conditions hold,[4] then the Ramsey optimal inflation tax depends only on the monetary parameters (the fraction of taxes paid with money, λ, and the shape of the shopping time function $v(\cdot)$). (Mulligan and Sala-i-Martin, 1997, p. 704)

That is, although the Ramsey-optimal inflation tax is not necessarily zero, it is independent of the size of government in the special case described by the proposition. Thus we cannot say for sure whether static optimal tax considerations predict a positive relationship between inflation and the size of government. However, Mulligan and Sala-i-Martin's (1997) calibration of the monetary parameters from micro and macro empirical studies of consumer behavior suggest that, when the Laffer conditions hold, the Ramsey-optimal inflation tax is quite small and quantitatively insensitive to the size of government.

The Laffer conditions may not hold in some countries. If the maximum amount of revenue that can be raised from the non-inflation taxes (the top of the "non-inflation tax Laffer curve") is less than the required revenue, g, then inflation tax revenue must increase in response to increases in g. Assuming that the top of the inflation Laffer curve has not yet been reached, then more g means higher inflation. One empirically relevant example may be countries without effective personal income tax systems. These may be the best cases for Sargent's (1982) and others' emphasis on inflation as a fiscal phenomenon.

Inflation as State-Contingent Debt Manager

Lucas and Stokey (1983), Judd (1989), and others have argued that an optimal tax policy involves the use of "state-contingent debt." Citizens buy contingent claims on the government, which pay off extraordinarily well when government revenues (spending) are above (below) expectations and poorly when government revenues (spending) are below (above) expectations. Judd (1989) argues that nominal government liabilities and nominal provisions in the tax code serve this state-contingent debt function, with monetary policy adjusting the price level appropriately to achieve the right pattern of payoffs for the state-contingent debt. Thus, inflation is above normal upon the receipt of "bad news" about the government's fiscal situation and below normal upon receipt of "good news." One empirical counterpart to good and bad news is the beginning and end of wars—inflation should be high during the war and prices should jump down at the conclusion of the war.[5]

Inflation as Evidence of a Commitment Problem

Alesina and Tabellini (1987), Barro and Gordon (1983a,b), and others have argued that

4 That is, the relevant portion of the seigniorage Laffer curve is upward sloping.

5 The exact timing of wartime inflation depends on expectations about the duration and cost of the war and how those expectations change over time. The end of a war is, of course, "bad news" to the defeated country, especially when large reparations are expected.

inflation is evidence of a government that cannot make credible promises. Such governments, optimally inflate to enjoy the short-run benefits of price-level surprises. Depending on which types of agents are best represented in the government (e.g., creditors or debtors), either surprise inflation or surprise deflation can provide short-run gains for the government, but it is commonly assumed in the literature that surprise inflation is desirable. In this case, governments inflate more in the absence of commitment. Barro and Gordon derived a formula for the inflation rate chosen by the discretionary government: It is an increasing function of the "full commitment" inflation rate and an increasing function of the benefits of surprise inflation.[6] In particular, they pointed out that the benefits of surprise inflation include temporary increases in output and decreases in real values of government debts.

If the size of government is uncorrelated with a government's ability to make commitments and with the benefits of surprise inflation, then, because the discretionary inflation rate is an increasing function of the "full commitment" inflation rate, the Barro and Gordon model inherits the predictions of the static public finance model for the relationship between inflation and the size of government. Relatively little is known about a government's ability to make commitments or the benefits of surprise inflation, so we can say little about the correlation between inflation and the size of government in the general case. However, Alesina and Summers (1993) have suggested that governments make commitments by creating an independent central bank. Inflation should therefore be negatively related to central bank independence, and, holding constant independence and the benefits of surprise inflation, inflation should vary with the size of government and other variables as suggested by the static theory of inflation and public finance.

The Size of Government as a Response to Efficient Taxes

Cukierman (1992) and Becker and Mulligan (2003) argue that the size of the government responds to the efficiency of taxes. A country without access to efficient taxes (perhaps for technological reasons or because those harmed by efficient taxes are politically powerful) will have a smaller government and rely relatively heavily on inefficient taxes (such as inflation) for revenue. Thus, inflation and the size of government can be negatively correlated.

If we further accept the auxiliary hypothesis of Becker and Mulligan (2003) that defense spending is "exogenous" while non-defense spending is "endogenous" (i.e., more sensitive to the efficiency of taxes), then we also expect defense spending to be positively correlated with inflation and non-defense spending to be negatively correlated with inflation.

Because the theory here suggests that government spending, especially non-defense spending, responds to inflation instead of the other way around, the OLS regressions of inflation on government size may be biased. We will discuss how we use instrumental variable (IV) methods to correct the potential bias.

CROSS-COUNTRY EVIDENCE

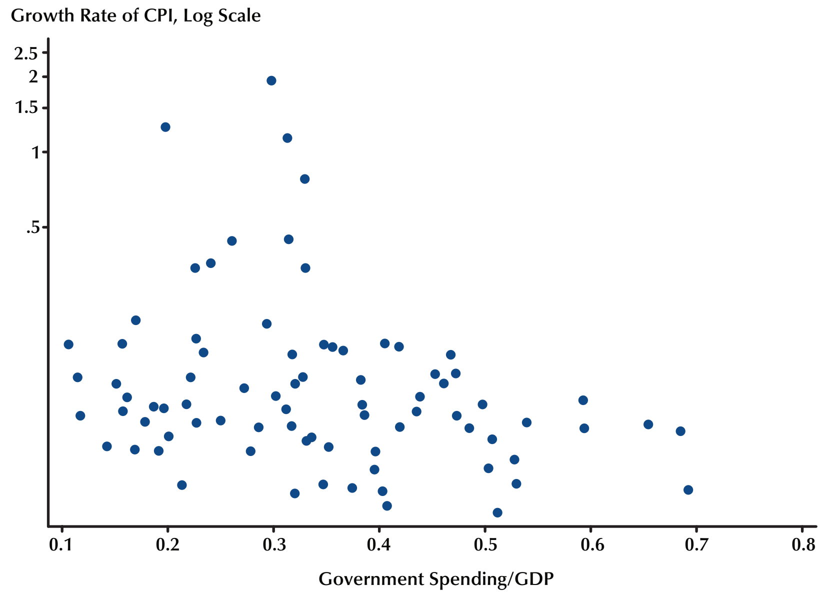
The cross-country analysis provides evidence on the long-run or steady-state relation between inflation and the size of government. Our sample consists of 80 countries during the period 1973-90. Inflation is measured by the average growth rates of the consumer price index (CPI) and M1, and the size of government is measured by the average of the ratios of general government spending to GDP.[7] Only countries with at least four consecutive years of observations in the period 1973-90 are included in our sample. Figure 1 is

[6] The Barro-Gordon discretionary government minimizes $a(\pi-\pi^*)^2/2-b(\pi-\pi^e)$, taking π^e as given. π is actual inflation (chosen by the government), π^e is expected inflation, and π^* is the "static" or "full commitment" optimal inflation. Because expectations are formed with full knowledge of the government's objective, the equilibrium inflation rate under a discretionary government is $\pi^e = \pi = b/a + \pi^*$. Thus, given b/a, π varies directly with π^*. Also, π increases as the benefit of surprise inflation, b, increases.

[7] Data on general government expenditure, defense spending, and GDP are from the International Monetary Fund (IMF) *Government Finance Statistics Yearbooks* (various years) and supplemented with the United Nations *National Accounts Statistics: Main Aggregates and Detailed Tables* (various issues). Data on CPI and M1 are from the IMF *Statistics Yearbook* (various years).

Figure 1

Inflation and Government Size, 1973 to 1990



a scatter diagram displaying the relationship between inflation and the size of government. The vertical axis measures the average growth rate of CPI, and the horizontal axis measures total government spending as a fraction of GDP. Note that, although the growth rate of CPI is measured as the log difference, we display this log difference on a log scale in the figures. We do so because inflation rates for a few countries are an order of magnitude larger than the inflation rates of most countries. Figure 2 is a scatter diagram with the average annual growth rates of CPI replaced by the average annual growth rates of M1 (again on a log scale).

Contrary to the conventional view, the figures show a negative relationship between inflation and the size of government. This negative correlation is confirmed in our regressions. Table 1 shows the regression results using the growth rate of CPI as the measure of inflation. (The results using the growth rate of M1 are similar, but are not shown.) The first four regressions (columns 1 through 4) use the whole sample, whereas the last four regressions (columns 5 through 8) exclude six countries that experienced hyperinflation during the sample period.[8] The OLS regressions of inflation on government size (columns 1 and 5) show significant negative coefficients.

As discussed in the previous section, other variables such as defense spending may affect the relationship between inflation and the size of government. In the next set of OLS regressions (columns 2 and 6), we divide total government spending into defense and non-defense spending (all as fractions of GDP). The results indicate that inflation is positively but statistically insignificantly correlated with defense spending, but negatively and statistically significantly correlated with non-defense spending. These coefficients suggest that the observed negative relationship

[8] There is no consensus on the definition of hyperinflation. The six countries we exclude are those countries that adopted dramatic policies, including changing their currencies to fight against inflation during 1973-90: Argentina, Bolivia, Brazil, Chile, Nicaragua, and Uruguay. The static theory of inflation and public finance suggests one reason for separating the "hyperinflation" countries from the rest—hyperinflation countries may be those that are not on the upward-sloping portion of their non-inflation tax Laffer curves. Another reason is that those countries appear to be outliers on Figures 1 and 2.

Figure 2

Growth Rate of M1 and Government Size, 1973 to 1990

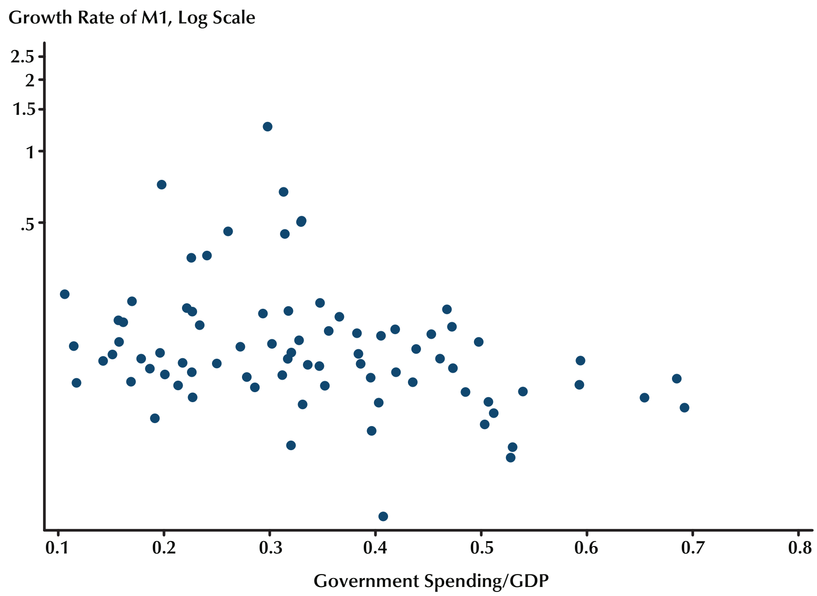


Table 1

Cross-Country Inflation Regressions, 1973-90 Averages
Dependent variable = log (average annual CPI growth rate)

	All countries				Excluding countries that experienced hyperinflation			
Independent variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Government spending/GDP	–1.49		–1.84		–1.04		–1.90	
	(0.61)		(0.93)		(0.41)		(0.63)	
Non-defense spending/GDP		–1.57		–1.82		–1.14		–1.89
		(0.63)		(0.94)		(0.41)		(0.62)
Defense spending/GDP		0.99		0.98		1.98		1.96
		(3.43)		(3.43)		(2.27)		(2.32)
Regression method	OLS	OLS	IV	IV	OLS	OLS	IV	IV
Number of countries	80	80	80	80	74	74	74	74
R^2	0.07	0.08	0.07	0.08	0.08	0.11	0.13	0.14

NOTE: Figures in parentheses are standard errors. The instrumental variable in the IV regressions is the average of the ratio of Social Security spending to GDP in 1973-90.

between inflation and government size shown in Figures 1 and 2 is driven mostly by the negative relation between inflation and non-defense spending. The results also suggest that the conventional view on the link between inflation and government size may be true only when defense spending represents a very important share of total government spending, for example, during wartime. But from cross-country regressions we cannot tell whether the temporary nature of wartime is important for the relationship between inflation and the size of government, as is suggested by the "inflation as a state-contingent debt manager" model. This issue is better analyzed with the time-series data, as presented in the next section.

The coefficients of the OLS regressions may be biased because, as discussed in the previous section, government spending, especially non-defense spending, may respond to inflation and hence be endogenous. We use the ratio of Social Security spending to GDP as an IV for government size and non-defense spending. The ratio of Social Security spending to GDP is a reasonable IV because, first, it is correlated with government size and especially non-defense spending other than Social Security spending. In the cross-country data, the correlation between Social Security spending and non-Social Security non-defense spending (both as a fraction of GDP) is 0.44. (See also discussions on the correlation by, e.g., Mulligan and Sala-i-Martin, 1999 and 2004.) Second, because most countries rely exclusively on payroll taxes to finance Social Security spending,[9] there is no need for a government to use the inflation tax to finance it. We note that in some countries, such as the United States, Social Security payments are indexed to the changes in the cost of living. However, because the changes in the cost of living and the changes in the GDP price deflator are highly correlated, the *ratio* of Social Security spending to output may not necessarily change with the cost of living. In other words, inflation is unlikely to be correlated directly with the ratio of Social Security spending to GDP.

The IV estimates using the whole sample (columns 3 and 4) are similar to the OLS estimates. The results using the sample that excludes the hyperinflation countries (columns 7 and 8) are similar to those using the whole sample, except that the magnitudes of the effects of defense spending on inflation are stronger, although still statistically insignificant.

We now include in our inflation regressions other factors that are correlated with government: central bank independence, the budget deficit, and the output level. First, it is often believed that, because price stability is a chief goal of central banks, a more independent central bank leads to lower inflation rates (see, e.g., Cukierman, 1992). We use two measures of central bank independence taken from Cukierman (1992). The first one is a ranking of central bank legal independence in the 1980s, and the second is the turnover rate of central bank governors during the period 1950-89.

Government debt or deficit can also be a potential determinant of the inflation tax. Because the inflation tax can be used as a direct way to generate seigniorage or reduce the real value of outstanding government debts, governments with larger nominal government debts would be inclined to inflate more (e.g., Barro and Gordon, 1983a, and Cukierman, Edwards, and Tabellini, 1992). When determining inflation in the "steady state" of a dynamic model or the static model, however, only the *initial* debt-to-GDP ratio matters. This is because, given the initial debt level, governments optimally choose the amount of debts and inflation over time (Cukierman, Edwards, and Tabellini, 1992). So what we are really interested in is a reduced-form relation with the initial debt-to-GDP ratio as one of the exogenous variables. Based on this, we add the initial debt-to-GDP ratio to our regressions.[10] The debt used is defined as total public debts minus that held by monetary authorities. The data used to calculate the ratios are from 1973 or the year with nonmissing observations closest to 1973.

[9] The cross-country correlation between Social Security spending and payroll taxes is high (about 0.87 in our sample). The high propensity to finance Social Security out of payroll taxes is itself evidence that the inflation tax is not a substantial source of revenue.

[10] We also conducted experiments with an average deficit-to-GDP ratio in the sample period, instead of initial debt-to-GDP ratio. The regression results with this alternative measure (not shown here) are similar.

Table 2

Cross-Country Inflation Regressions, 1973-90 Averages with Measures of Central Bank Independence
Dependent variable = log (average annual CPI growth rate)

	All countries				Excluding countries that experienced hyperinflation			
Independent variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Government spending/GDP				0.74				1.02
				(0.83)				(0.85)
Non-defense spending/GDP	–1.76	–0.15	0.80		–1.38	–0.82	0.17	
	(0.81)	(0.74)	(0.85)		(0.62)	(0.78)	(0.86)	
Defense spending/GDP	–2.33	–2.95	–3.48		–2.82	–3.10	–4.05	
	(7.48)	(6.07)	(6.14)		(5.92)	(5.97)	(5.68)	
CB legal independence in 1980s		–0.06	0.06	0.07		–0.21	–0.09	–0.08
		(0.81)	(0.78)	(0.78)		(0.81)	(0.75)	(0.75)
CB governor turnover rate, 1950-89		3.17	3.03	3.01		1.25	0.79	0.75
		(0.67)	(0.64)	(0.64)		(1.05)	(1.00)	(0.99)
Public debt/GDP, 1973			–0.21	–0.31			–0.19	–0.27
			(0.56)	(0.53)			(0.66)	(0.65)
Average log (real GDP per capita)			–0.29	–0.28			–0.34	–0.33
			(0.13)	(0.12)			(0.12)	(0.12)
Number of countries	43	43	43	43	40	40	40	40
R^2	0.11	0.44	0.51	0.51	0.12	0.21	0.33	0.31

NOTE: CB is central bank. Figures in parentheses are standard errors. All regressions are OLS.

The third variable we add to our regressions is real GDP per capita (in logs). It has been suggested that a country's wealth is a good indicator of the efficiency of the non-inflation taxes (e.g., Cukierman, Edwards, and Tabellini, 1992, and Click, 1998). Also, much has been written on whether there is any relationship between inflation and output in the long run. If inflation is related to output, it may induce spurious effects on the relation between inflation and government size because the latter is defined as the ratio of government spending to GDP. So including real GDP per capita can also reduce these possible effects.

The results of the OLS and IV estimations with the above additional variables are shown in Tables 2 and 3, respectively. As in Table 1, we show two sets of regressions: one using the whole sample (columns 1 through 4 in Table 2 and 1 through 6 in Table 3) and another excluding countries that experienced hyperinflation during the period 1973-90 (columns 5 through 8 in Table 2 and 7 through 12 in Table 3).[11] Because indices of central bank independence are available only for about half of the countries, the sample size is reduced substantially. Comparing the OLS regressions (columns 1 and 5 in Table 2 and 1 and 7 in Table 3 with columns 2 and 6 in Table 1), it appears that the smaller sample size changes the signs of the estimated relation between inflation and defense spending from positive to negative, although they are still statistically insignificant. But the smaller sample size seems to have no qualitative effects on the estimated relation between inflation and non-defense spending. For non-defense spending, the coefficients are

[11] The countries excluded are Argentina, Chile, and Uruguay.

Table 3

Cross-Country Inflation IV Regressions, 1973-90 Averages with Measures of Central Bank Independence
Dependent variable = log (average annual CPI growth rate)

	All countries						Excluding countries that experienced hyperinflation					
Independent variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Government spending/GDP						–0.40						–1.41
						(2.18)						(2.33)
Non-defense spending/GDP	–2.14	0.80	–2.90	–1.20	–0.40		–1.47	–0.13	–2.61	–2.97	–1.41	
	(0.93)	(1.01)	(1.50)	(1.59)	(2.22)		(0.71)	(1.04)	(1.17)	(2.06)	(2.36)	
Defense spending/GDP	–3.53	–1.62	–4.36	–2.81	–2.84		–2.43	–2.88	–3.67	–4.16	–4.19	
	(8.08)	(6.89)	(8.26)	(6.89)	(7.32)		(6.20)	(6.31)	(6.53)	(7.01)	(6.83)	
CB legal independence in 1980s		0.04		–0.08	0.02	0.04		–0.07		–0.32	–0.08	–0.06
		(0.88)		(0.89)	(0.90)	(0.88)		(0.83)		(0.92)	(0.85)	(0.83)
CB governor turnover rate, 1950-89		3.15		2.69	2.77	2.79		0.46		–0.67	–0.34	–0.33
		(0.75)		(0.99)	(0.98)	(0.97)		(1.19)		(1.92)	(1.79)	(1.77)
Public debt/GDP, 1973		–0.25			–0.06	–0.12		–0.43			–0.11	–0.17
		(0.63)			(0.71)	(0.68)		(0.74)			(0.92)	(0.89)
Average log (real GDP per capita)		–0.22			–0.14	–0.13		–0.33			–0.25	–0.25
		(0.17)			(0.22)	(0.22)		(0.16)			(0.20)	(0.19)
Regression method	OLS	OLS	IV	IV	IV	IV	OLS	OLS	IV	IV	IV	IV
Number of countries	37	37	37	37	37	37	34	34	34	34	34	34
R^2	0.13	0.51	0.12	0.44	0.48	0.48	0.12	0.52	0.05	0.02	0.23	0.22

NOTE: CB is central bank. Figures in parentheses are standard errors. The instrumental variable in the IV regressions is the average of the ratios of Social Security spending to GDP in 1973-90.

still negative and significant. The same observation can be made when comparing the IV regressions (columns 3 and 9 in Table 3 with columns 4 and 8 in Table 1). With other variables included in the regressions, the OLS and IV regressions using both samples show that inflation is still negatively related to non-defense spending, but the effects become statistically insignificant. The relation between inflation and defense spending is also negative and statistically insignificant.

Other findings are as follows: First, the effects of central bank legal independence on inflation are very weak (in terms of *t*-statistics) and change signs from one regression to another. With the whole sample, both the OLS and IV estimations show that inflation is significantly positively related to the turnover rate of central bank governors. With the three hyperinflation countries excluded, the relation is positive in the OLS regressions and negative in the IV regressions and none of them is statistically significant. This suggests that, first, independence written on paper means little if central bank governors can be easily removed in reality; second, in determining inflation, central bank independence matters only in countries that have experienced hyperinflation. Those countries are presumably those that are not on the upward-sloping portion of their non-inflation tax Laffer curves.

Second, all regressions show that inflation is weakly negatively related to initial debt-to-GDP ratios. If we think of redemption of initial debt as part of total government spending, the negative relation seems consistent with the relation between inflation and non-defense spending. We also find that inflation is negatively related to real GDP per capital (in logs) in all regressions. This relation is significant except in the IV regressions: The negative relations suggest that countries with efficient tax systems tend to rely less on inflation to finance a given amount of government spending.

In summary, the cross-country exercises show that, first, the correlation between inflation and government size is negative but weak.[12] The negative correlation is driven mainly by the negative relation between inflation and non-defense spending. Second, with the whole sample of 80 countries, inflation is significantly positively related to defense spending. So, when defense spending is an important fraction of total government spending, the conventional view that inflation is positively related to government size holds. When we include only those countries for which central bank independence data are available, inflation is shown weakly negatively related to defense spending. Our analysis strongly suggests that the switch of signs of the estimates is caused mainly by sample attrition. Finally, the regressions also suggest that inflation may be indeed negatively related to central bank independence, especially for countries that have experienced hyperinflation. Also, inflation is shown to be weakly negatively related to the initial debt-to-GDP ratio and more strongly negatively related to real GDP per capita.

TIME-SERIES EVIDENCE

The above cross-country analysis is suitable for studying the relation between inflation and government size in the steady state of a dynamic model or in a static model, which tells us how inflation responds to long-run or permanent changes in government spending. To find out how governments inflate and deflate in response to temporary changes in government spending, we have to turn to time-series data. We study this issue using U.S. and U.K. time-series data.

The United States

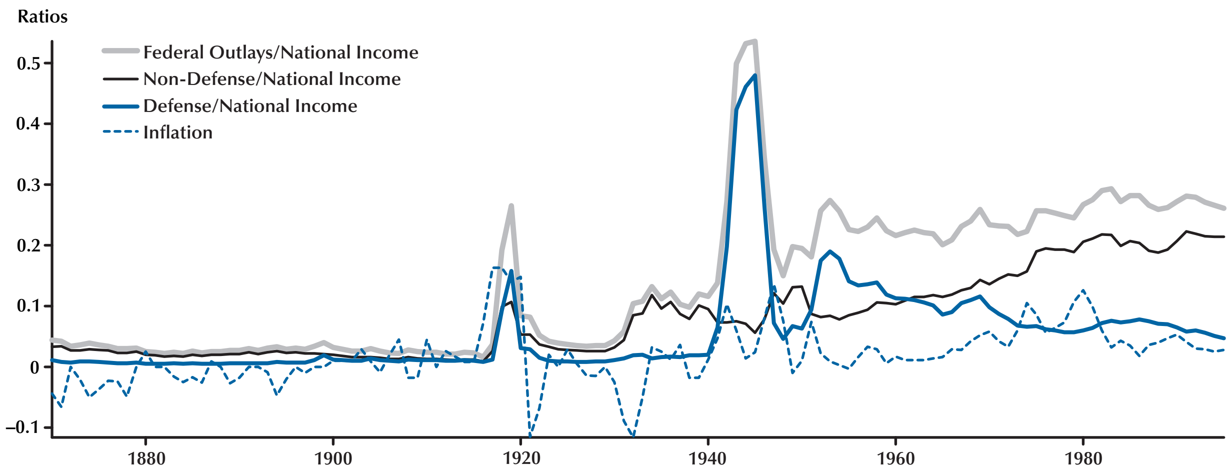
For the United States, government size is defined as the ratio of federal government outlays to national income.[13] We use growth rates of CPI and M2 as measures of the inflation tax. The data,

[12] Although the inflation tax rate and the size of government do not display a strong positive relationship across countries, other tax rates are correlated with the size of government. For example, regressions with the personal income tax rate show that some tax rates are positively correlated with government size (results not reported here). See also Click (1998).

[13] We use national income instead of gross national product (GNP) because we do not have data on GNP for the earlier years. The evidence using GNP (not shown here) is similar to that using national income for the periods when we have data on both variables.

Figure 3

Inflation and Government Size and Its Components: United States, 1870-1995



plotted in Figure 3, are annual time series for the period 1870-1995.[14]

The figure shows that roughly before 1930, federal government outlays as a fraction of national income (solid gray line) is small and stable, except during the large temporary increase during World War I. Since 1930, there has been a secular upward trend in government spending driven mainly by non-defense spending (thin black line). The large temporary increases in government spending, however, were driven mainly by defense spending (solid blue line), as shown by the spikes for World War II, the Korean War, and the Vietnam War. Defense spending seems to return to its steady state in the late 1970s, although the steady state seems higher than that in the prewar period. From the figure, it is not clear how inflation (dashed blue line) is related to government spending, except that inflation during wartime is usually higher than the normal levels.

The regression results are shown in Table 4. Regressions in panel A use the growth rate of CPI as the dependent variable, whereas those in panel B use the growth rate of M2. In addition to government spending, we also include the ratio of government debt in year t–1 to national income in year t in our regressions. The first four columns in both panels are OLS regressions using data for the entire sample period 1870-1995. All OLS regressions are estimated by assuming that the error terms follow AR(1) processes. The results show that the growth rate of CPI is positively related to non-defense spending but negatively related to defense spending. Because of price controls during wartime (e.g., World War II), however, the growth rate of CPI may not be a good measure of the inflation tax. Instead, the growth rate of the money supply may be a more reliable measure to test the public finance theory of inflation in the time-series context. The regressions shown in the first four columns of panel B indicate that the growth rate of M2 is weakly negatively related to non-defense spending and strongly positively related to defense spending and government size.

In the rest of the regressions in Table 4, we use data from only 1936-95. There are two reasons for considering the short sample period. First, before 1933, the United States was in the classical gold-standard period. With the gold standard, governments have only limited ways to generate revenue through the inflation tax. Hence, to test

[14] The data are from the *Historical Statistics of the United States, 1790-1970* (Dodd, 1973) and the *Economic Report of the President* (various years).

Table 4

Time-Series Regressions of Inflation in the United States, 1870-1995 and 1936-95

Independent variables	1870-1995 (OLS)				1936-95 (OLS)				1936-95 (IV)			
A. Dependent variable: growth rate of CPI												
Government spending/GNP	0.06	–0.03			–0.16	–0.16			0.72	0.47		
	(0.05)	(0.07)			(0.07)	(0.07)			(0.70)	(0.34)		
Non-defense spending/GNP			0.25	0.14			–0.19	–0.18			0.21	0.22
			(0.11)	(0.13)			(0.20)	(0.21)			(0.10)	(0.11)
Defense spending/GNP			–0.02	–0.07			–0.16	–0.16			0.04	0.04
			(0.07)	(0.08)			(0.07)	(0.07)			(0.05)	(0.05)
Debt[*t*–1]/GNP[*t*]		0.06		0.05		0.02		0.02		–0.02		0.00
		(0.03)		(0.03)		(0.03)		(0.03)		(0.02)		(0.02)
R^2	0.01	0.04	0.04	0.06	0.09	0.10	0.09	0.10	0.02	0.04	0.13	0.10
Adjusted DW statistic	1.77	1.74	1.78	1.74	1.49	1.49	1.49	1.49				
B. Dependent variable: growth rate of M2												
Government spending/GNP	0.14	0.18			0.32	0.31			–0.36	–0.60		
	(0.06)	(0.06)			(0.07)	(0.06)			(0.67)	(0.57)		
Non-defense spending/GNP			–0.05	–0.00			0.27	0.09			0.13	–0.07
			(0.10)	(0.11)			(0.15)	(0.11)			(0.10)	(0.08)
Defense spending/GNP			0.25	0.28			0.32	0.32			0.29	0.30
			(0.07)	(0.08)			(0.07)	(0.06)			(0.05)	(0.04)
Debt [*t*–1]/GNP[*t*]		–0.02		–0.02		–0.03		–0.05		–0.02		–0.06
		(0.02)		(0.02)		(0.02)		(0.02)		(0.04)		(0.01)
R^2	0.05	0.06	0.09	0.10	0.30	0.33	0.31	0.42	0.01	0.04	0.39	0.57
Adjusted DW statistic	1.82	1.83	1.82	1.81	1.91	1.90	1.90	1.80				

NOTE: DW is Durbin-Watson. Figures in parentheses are standard errors.

the public finance theory of inflation, the appropriate economic system should be the paper standard. We will discuss this issue further in the fifth section. Second, as in the cross-country analysis, we would like to use Social Security spending (as a ratio of national income) as an IV for government spending (especially non-defense spending) to mitigate the potential bias caused by the endogeneity problem. But the Social Security program started only in the late 1930s.

The IV regressions for the period 1936-95 are shown in the last four columns of Table 4. To show the differences between OLS and IV regressions, in the middle four columns we reproduce the OLS regressions for the period. These results show that the growth rate of CPI is negatively related to both non-defense and defense spending as well as government size. The signs all change and become positive in the IV regressions. However, as discussed above, because of price controls during World War II, those coefficients may be downward-biased estimates of the relation between the inflation tax and government size. The results in panel B show that, for the period 1936-95, the growth rate of M2 is positively related to both non-defense and defense spending in both the OLS and IV regressions. Moreover, the coefficients for defense spending are all statistically significant while those for non-defense spending are not significant.

It is also interesting to note that the growth rate of M2 is shown to be positively related to government size in all OLS regressions in panel B. But the signs all change and become negative in the IV regressions. It is important to note that Social Security spending is a better IV for non-defense spending than for government size. The correlation between Social Security spending and non-defense spending is 0.80, while the correlation between Social Security spending and government size is only 0.15. So the IV results for non-defense spending are more reliable than those for government size.

Finally, the growth rate of M2 is weakly negatively related to the lagged debt-to-national income ratios, as we have seen in the cross-country analysis.

In summary, the evidence based on the U.S. time-series data shows that inflation is strongly positively related to government size and the relation is driven mainly by the strong positive relation between inflation and defense spending. The relation between inflation and non-defense spending is ambiguous and statistically weak.

The United Kingdom

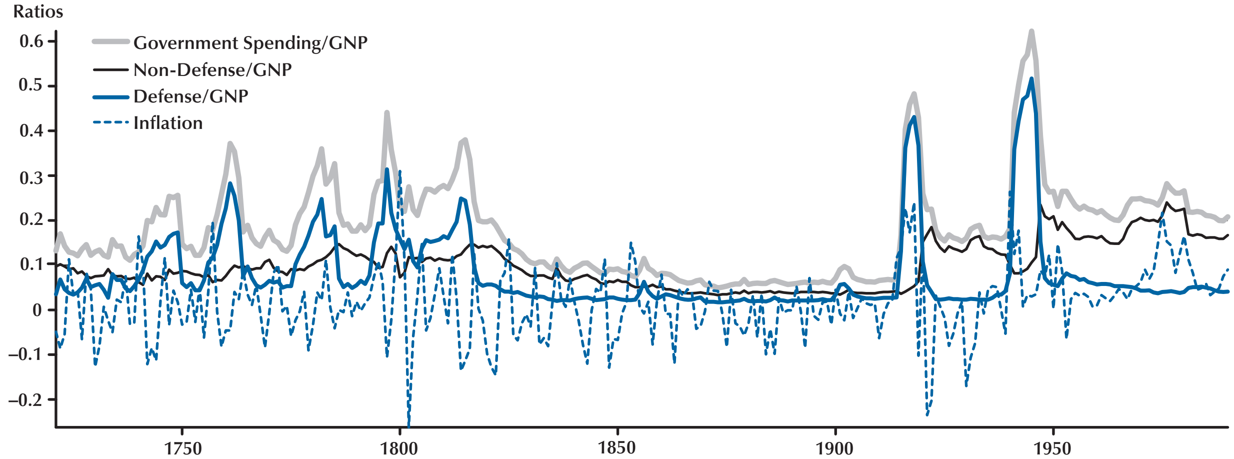
We now turn to the U.K. time series for the period 1721-1990. We measure government size by total central government spending as a fraction of GNP. We also compute the ratios of defense and non-defense spending to GNP. Inflation is measured by growth rates of CPI and M1.[15] The time series are plotted in Figure 4. The first noticeable feature of the figure is that the spikes for the size of government (solid gray line) are mainly due to the sharp increases in defense spending (solid blue line). The United Kingdom fought several wars during the sample period, resulting in unusually large temporary increases in defense spending (as a fraction of GNP).

As with the U.S. time series, the U.K. time series show a secular upward trend in government spending (as a fraction of GNP) after World War II and the trend seems to be associated mainly with the increases in the size of non-defense spending (thin black line). On the other hand, the fractions for defense spending are about the same in the entire sample period, except during the wars. Finally, as with the United States, it is not clear how U.K. inflation (dashed blue line) is related

[15] The data on price levels are from McCusker (1992). The data used to calculate the growth rate of money for the period 1720-1921 are bank notes of the Bank of England from Mitchell (1988, pp. 655-70) and since 1922 are M1 from Mitchell (1988, pp. 674, and 1998, pp. 813-23). The data on central government spending for the period 1700-1801 are net public expenditures from Mitchell (1988, pp. 578-80), for 1801-1980 are gross public expenditures from Mitchell (1988, pp. 587-95), and for 1981-90 are central government expenditures from the United Nations (1985, 1994). The data on defense spending for the period 1700-1980 are from Mitchell (1988, pp. 578-80, 587-95), which combine the spending for the army, ordinances, naval and air forces, special expeditions, and votes of credits. For the period after 1980, the data on defense spending are from the United Nations (1985, 1994). The data on GNP for the period 1830-1980 are from Mitchell (1988, pp. 831-36) and for 1980-90 are from the United Nations (1985, 1994). For the period 1700-1830, Deane (1967, pp. 78, 282) provides estimates on the 10-year growth rate of real GNP. To obtain estimates within a decade, we interpolate this series according to the average annual growth rate of GNP in a decade.

Figure 4

Inflation and Government Size and Its Components: United Kingdom, 1721-1990



to government spending, except that inflation during wartime is usually higher than the normal levels. This is especially true in the paper-standard period, which is further discussed in the next section.

The time-series regressions using the growth rates of CPI (panel A) and M1 (panel B) as dependent variables are shown in Table 5. As in the analysis of the U.S. time series, we consider regressions using both the entire sample period and the paper-standard period 1932-90. All regressions are OLS and assume that the error terms are AR(1) processes.

The results are similar to what we obtain using the U.S. time series. First, with the entire sample period, the growth rates of both CPI and M1 are positively related to government size as well as defense and non-defense spending. In particular, the relation is statistically significant for the growth rate of M1. Second, for the paper-standard period, the growth rates of both CPI and M1 are positively related to defense spending, but ambiguously related to non-defense spending. The relation between the growth rate of CPI and the size of government is also not clear.

We also find that, as in the U.S. time series and cross-country analysis, the growth rates of both CPI and M1 are negatively related to the debt-to-GNP ratio. The main difference is that for the U.K. time series the relations are statistically significant in all regressions

In summary, as in the U.S. time-series analysis, we find that inflation is positively related to government size, which is driven mainly by the positive relation between inflation and defense spending. The relation between inflation and non-defense spending is ambiguous and statistically weak.

WARTIME INFLATION AND SUSPENSION OF CONVERTIBILITY

In the previous section, we provided a statistical analysis of the effects of the stochastic changes in the size of government on inflation. In this section, we look specifically into the behavior of inflation during periods when large and temporary changes in the size of government are induced by war.

In British and American history, temporarily high levels of government spending—especially defense spending associated with major wars—were often financed by public debts that were

Table 5

Time-Series Regressions of Inflation in the United Kingdom, 1721-1990 and 1932-90

Independent variables	1721-1990				1932-90			
A. Dependent variable: growth rate of CPI								
Government spending/GNP	0.10 (0.06)	0.21 (0.06)			–0.10 (0.12)	0.08 (0.10)		
Non-defense spending/GNP			0.18 (0.13)	0.33 (0.12)			0.37 (0.31)	0.38 (0.30)
Defense spending/GNP			0.07 (0.07)	0.17 (0.07)			0.04 (0.10)	0.11 (0.10)
Debt[t–1]/GNP[t]		–0.03 (0.01)		–0.03 (0.01)		–0.04 (0.02)		–0.03 (0.02)
R^2	0.01	0.06	0.01	0.06	0.01	0.07	0.03	0.09
Adjusted DW statistic	1.95	1.94	1.95	1.93	2.38	2.04	2.06	2.12
B. Dependent variable: growth rate of M1								
Government spending/GNP	0.27 (0.06)	0.39 (0.07)			0.13 (0.18)	0.32 (0.17)		
Non-defense spending/GNP			0.39 (0.13)	0.56 (0.13)			–0.08 (0.60)	–0.12 (0.49)
Defense spending/GNP			0.22 (0.07)	0.34 (0.08)			0.10 (0.19)	0.29 (0.16)
Debt[t–1]/GNP[t]		–0.04 (0.01)		–0.04 (0.01)		–0.09 (0.03)		–0.09 (0.03)
R^2	0.06	0.11	0.07	0.12	0.01	0.14	0.01	0.16
Adjusted DW statistic	1.97	2.10	1.98	2.11	2.08	1.99	2.08	1.98

NOTE: DW is Durbin-Watson. All regressions are OLS. Figures in parentheses are standard errors.

nominally denominated in their own currencies. Because of these nominal provisions, the theory of Lucas and Stokey (1983), Judd (1989), and others suggests that inflation serves as a state-contingent manager to adjust the real returns on the public debt. In particular, inflation would rise on the arrival of "bad" news—the start of a war—and fall on the arrival of "good" news—the end of a war. This reduces the real returns on the public debt during a war but raises the real returns when a war is over. This high expected real rate of return after a war induces people to buy government debt at reasonable prices and generates the necessary revenues for fighting a war. Moreover, the theory also suggests that, from the viewpoint of optimal taxation, inflation can be desirable in the event of temporary increases in government spending because ex post inflation serves as a tax on a stock variable—money holding—as a kind of "capital levy." In both arguments, through the adjustment of inflation, government achieves a certain degree of smoothness of total taxes across different states and reduces the distortion of taxation.

The presumptions of the previously mentioned state-contingent theory are that the government has the ability to adjust inflation contingent

Table 6

Inflation and Money Growth Rates During Suspensions of Convertibility in the Classical Gold-Standard Periods in the United Kingdom and United States

		Inflation			Money growth rate*		
Episodes	Number of periods	Mean (standard deviation)	Minimum	Peak	Mean (standard deviation)	Minimum	Peak
United Kingdom: 1717-1931							
1797-1821 (paper pound)	25	0.00 (0.12)	–0.26	0.31	0.03 (0.08)	–0.08	0.20
1797-1802 (French Revolutionary War)	6	0.02 (0.20)	–0.26	0.31	0.08 (0.09)	–0.04	0.20
1803-15 (Napoleonic War)	13	0.01 (0.09)	–0.14	0.15	0.04 (0.07)	–0.06	0.18
1914-25	12	0.04 (0.16)	–0.23	0.24	0.10 (0.14)	–0.06	0.35
1914-19 (World War I)	6	0.13 (0.12)	–0.10	0.24	0.17 (0.13)	0.05	0.35
Non-suspension periods	178	0.00 (0.06)	–0.17	0.20	0.01 (0.10)	–0.41	0.41
United States: 1792-1933							
1862-79	18	0.01 (0.09)	–0.07	0.22	0.04 (0.05)	–0.05	0.12
1862-65 (American Civil War)	4	0.15 (0.09)	0.04	0.22	N/A	N/A	N/A
Non-suspension periods	124	0.00 (0.06)	–0.17	0.18	0.05 (0.06)	–0.12	0.17

NOTE: *For the United Kingdom, the money growth rate is the growth rate of M1; data are available only since 1721. For the United States, the money growth rate is the growth rate of M2; data are available only since 1868.

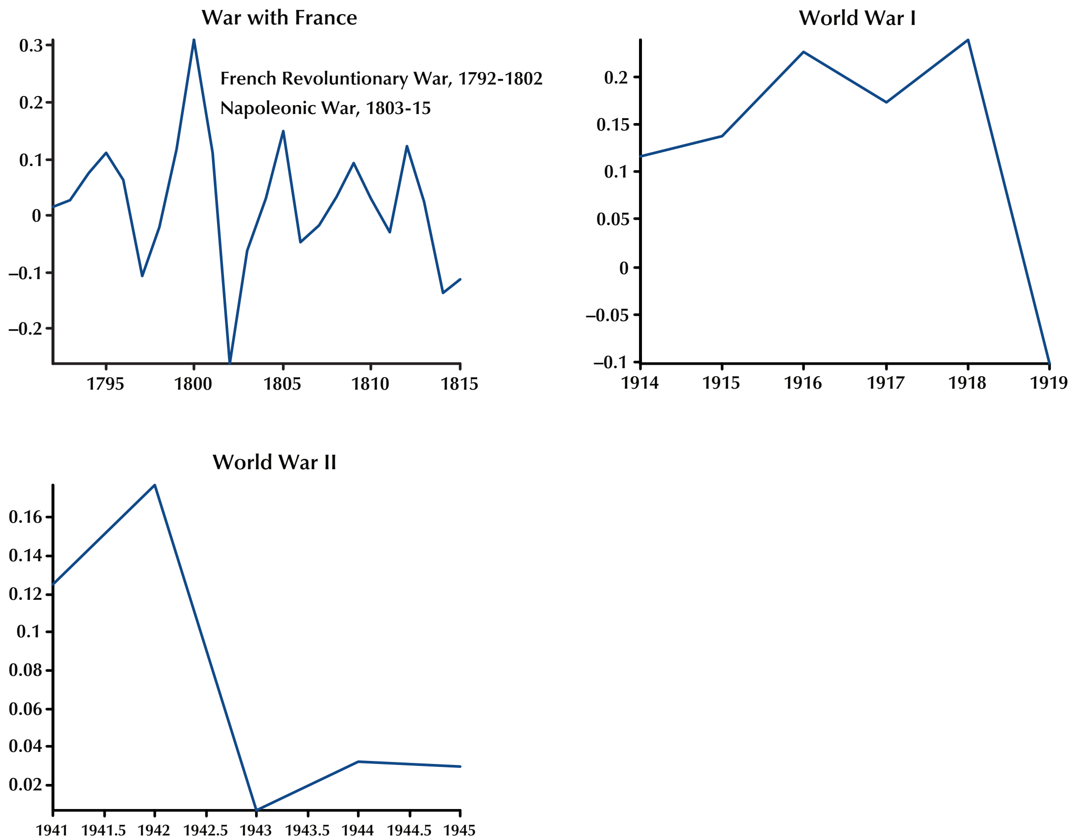
on the event of a war and that the government should also show the public that it commits to such a contingent policy. In the classical gold standard system, suspension of convertibility (and/or lowering of conversion ratios) serves as a tool to effectively raise inflation at the start of a war because it allows the government to print paper money to generate more seigniorage. Inflation in turn also reduces the real value of government's debt payments during the war. At the same time, resumption of convertibility shows government commitment to the state-contingent policy (Bordo and Kydland, 1996). Hence, the state-contingent theory of inflation implies that inflation is high at the beginning and during suspensions of convertibility and low when convertibility resumes.

There are two episodes of suspension of convertibility in the United Kingdom in the U.K. classical gold-standard period (1717-1931): 1797-1821, because of the war with France (1793-1815); and 1914-1925, because of World War I. In the United States, there is one episode of suspension of convertibility in the U.S. classical gold-standard period (1792-1933): 1862-79, because of the Civil War (1862-65). In Table 6, we compare inflation and money growth during these episodes of suspension with those during the non-suspension gold-standard periods.

On average, as Table 6 shows, inflation and the money growth rate are higher in the suspension than the non-suspension periods. For example, in the United Kingdom, the average inflation is essentially 0 and the M1 growth rate is 0.01 in the non-suspension periods, whereas the average inflation ranges from 0.01 to 0.13 and the average M1 growth rate from 0.03 to 0.17 in the two wartime suspension periods. The same pattern also exists in the U.S. episode. Note that, because in all cases convertibility did not resume until several years after a war ended, the inflation and money growth rates had to be much lower at the end of each suspension period in order to reach the low inflation in the non-suspension periods.

Figure 5

Wartime Inflation During Suspensions of Convertibility in the Classical Gold Standard Period and in the Paper Standard Period: United Kingdom, 1721-1990



To see this, we plot time series for U.K. (top two panels of Figure 5) and U.S. (top left panel of Figure 6) inflation during these episodes.

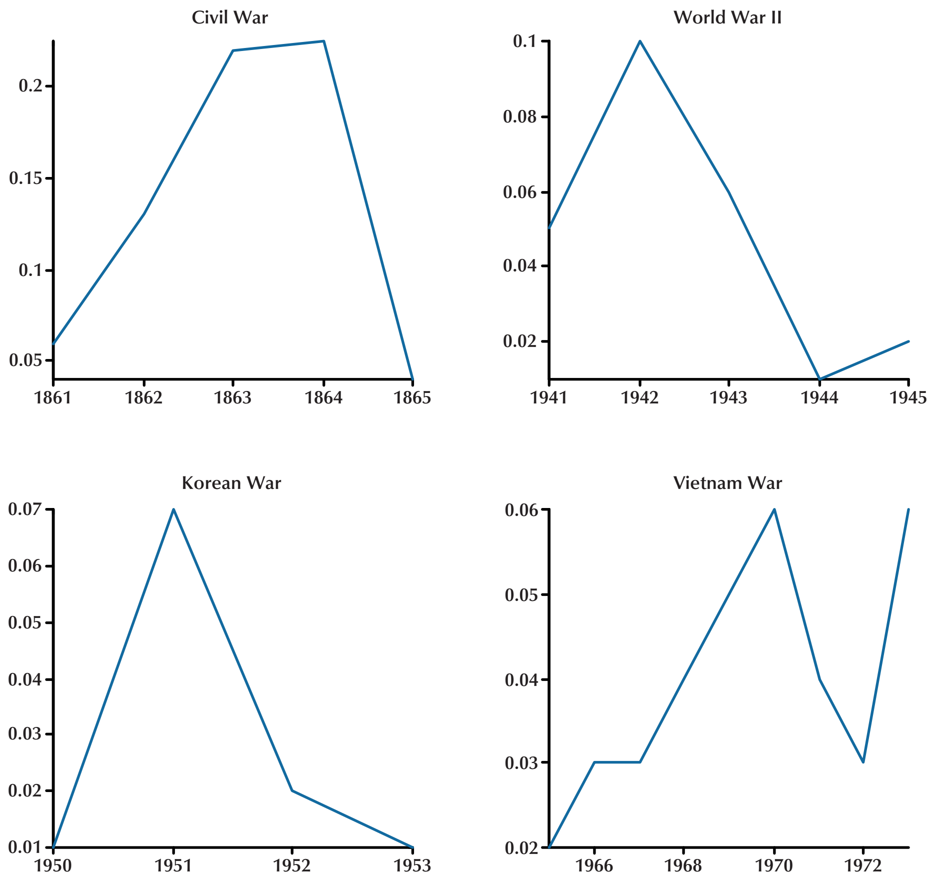
As we can see, inflation even started to fall at the end of each war. U.K. inflation during World War I[16] and U.S. inflation during the Civil War are high at the beginning of the wars, reach peaks during the wars, and are low or become negative at the end of or immediately after the wars. U.K. inflation seems to behave differently during the war with France (1793-1815), which has two phases: the French Revolutionary War (1792-1802) and the Napoleonic War (1803-15). The first trough of inflation matches the end of the French Revolutionary War, in which Britain was a winner. After a brief truce, war begins again in 1803; inflation rises above the normal level again then falls at the end of the war.

In short, the above analysis shows that, in the classical gold-standard periods, suspension and resumption of convertibility serve as a state-contingent manager to adjust (i) inflation and (ii) the real returns on government debts during periods in which there is a temporary need for increased revenues. As a result, inflation is high at the beginning of the wars and suspension of

[16] Inflation in both the United Kingdom and the United States did not decline until a couple of years after the end of World War I. However, although official fighting in World War I ended on November 11, 1918, when the armistice was declared, the peace itself was not established until the Treaty of Versailles was signed on June 28, 1919, and it did not go into effect until January 10, 1920.

Figure 6

Wartime Inflation During Suspensions of Convertibility in the Classical Gold Standard Period and in the Paper Standard Period: United States, 1792-1995



convertibility and low at the end of the wars and the resumption of convertibility.

The above observations on inflation during the suspension of convertibility in the classical gold-standard periods also hold for wars after the classical gold-standard periods. Table 7 shows the summary statistics of inflation during wars since 1933. The time series for inflation during these times of war are plotted in Figure 5 for the United Kingdom (lower panel) and Figure 6 for the United States (top-right and lower panels). In all cases except the Vietnam War (1965-73),[17] inflation is high at the beginning, reaches a peak in the middle, and is low at the conclusion of a war. This supports the theory that inflation is above normal on the receipt of "bad news" of government fiscal situations—the start of a war—and below normal upon the receipt of "good news"—the end of war.

For the United States, inflation rose at the end of the Vietnam War. Note that the Vietnam War is one of the few wars since U.S. independence

[17] For both the United Kingdom and the United States, inflation remained at high levels after Word War II. Grossman (1990) argues that the continuing high inflation after World War II can be explained by the changes in factors increasing the power of debtors relative to that of creditors in the political process and the large demands on national resources for huge postwar reconstruction and maintenance of a nuclear arsenal.

Table 7

Inflation and Money Growth Rates During Wars in the Post-Classical Gold-Standard Periods in the United Kingdom and United States

		Inflation			Money growth rate*		
Episodes	Number of periods	Mean (standard deviation)	Minimum	Peak	Mean (standard deviation)	Minimum	Peak
United Kingdom: 1932-90							
1941-45 (World War II)	5	0.07 (0.07)	0.00	0.17	0.15 (0.03)	0.12	0.21
Non-war periods	54	0.06 (0.06)	–0.07	0.26	0.08 (0.11)	–0.06	0.80
United States: 1834-95							
1941-45 (World War II)	5	0.05 (0.03)	0.01	0.10	0.15 (0.04)	0.10	0.21
1950-53 (Korean War)	4	0.03 (0.03)	0.01	0.07	0.05 (0.01)	0.03	0.06
1965-73 (Vietnam War)	9	0.04 (0.01)	0.02	0.06	0.08 (0.03)	0.04	0.13
Non-suspension periods	44	0.04 (0.04)	–0.02	0.14	0.06 (0.03)	–0.00	0.13

NOTE: *For the United Kingdom, the money growth rate is the growth rate of M1; for the United States, it is the growth rate of M2.

that did not end in an unmistakable American victory. This suggests that ending a war alone is not always good news for a government's fiscal situation. For a defeated country, its government has to face tougher challenges, both economically and politically, to raise necessary revenues using only non-inflation taxes to meet the needs of post-war reconstructions, debt repayments, and, possibly, large war reparations. This provides more incentives for the government to rely on inflation as a revenue source. These episodes and the high inflations in the defeated countries[18] after the two World Wars suggest that inflation responds strongly to the nature of how a war ends and the ability of a government to meet its future fiscal obligations.

SUMMARY

In this paper we review the implications of existing theories on the relationship between inflation and the size of government and study how the theoretical predictions match empirical evidence. We find that the strongest empirical relationship between inflation and the size of government arises from wartime. Inflation was fairly high during several British and American wars and often negative after wars. We also find that permanently high non-defense government spending—as observed across countries—seems to be weakly negatively related to inflation while defense spending is somewhat more strongly positively related. Also there has been a slight secular increase in inflation with the size of government over time, which we cannot account for with defense spending.

The static or steady-state Ramsey theory thus fails to predict the magnitude of the inflation tax. Not only is the theory ambiguous about the sign of the relationship between inflation and the size of government, it also fails to explain why wars are the best predictors of inflation and why the composition of government spending is correlated with inflation.

To the extent that wars are surprises, a dynamic stochastic Ramsey theory (such as Lucas and Stokey, 1983) does explain the strong correlation between inflation and temporary wartime government spending, although perhaps not the

[18] During Word War II, the Nazi government in Germany imposed strict prices to keep inflation low. After its defeat in 1945, currency reform was carried out. As a result, there was no high inflation in Germany. Other defeated countries such as Japan and Italy experienced high inflation after the war.

relationship with more permanent defense spending.

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