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The role of the natural rate of interest in monetary policy

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Abstract

This paper examines the role of the natural rate of interest in the conduct of monetary policy. The natural rate figures prominently in many theories of the business cycle and of inflation fluctuations, and therefore has the potential to play a key role in monetary policy given the current mandates of many central banks. However, the presence of financial imperfections and measurement uncertainty draw into question whether estimates of the natural rate can be reliable indicators of excess demand pressures. Natural rate-based theories may, nonetheless, provide useful guidance in the formulation of desirable monetary policies.

Contents

1. Introduction[1]

This paper is a critical assessment of the role of the natural rate of interest in the conduct of monetary policy.[2] The natural rate of interest – and 'natural rate' theories more generally – has occupied a central place in both the macroeconomics literature and in practical discussions of policy making for over a century now, dating back to the seminal work of Wicksell (1896), through to Friedman (1968), and to more recent studies of monetary policy, for example, as typified by Woodford (2003). Broadly put, the natural rate of interest (hereafter, natural rate) can be defined to be the equilibrium real interest rate consistent with price stability.[3]

The natural rate has received increasing attention in recent years in both academic and policy making circles. In the academic literature, the resurgence of interest in the natural rate is largely due to the significant progress that has been made in developing dynamic general equilibrium models with nominal rigidities based on the optimising behaviour of the private sector. In this class of models, known as New Keynesian models or the Neo-Wicksellian framework, the natural rate plays a key role in output and inflation fluctuations. In these models, the natural rate is more precisely defined to be the equilibrium short-term real interest rate in an economy without nominal frictions; and it is generally assumed that the central bank's inflation target is zero.

In monetary policy making, the search for reliable indicators to guide the conduct of policy continues to be an ongoing process. Despite the success of many central banks at achieving low and stable inflation over the past two decades, a reliable tool kit of indicators of inflationary pressures and other underlying economic imbalances has remained elusive. In the light of the key role that the natural rate plays, explicitly or implicitly, in theories of the transmission mechanism subscribed to by many central banks, estimates of the natural rate could prove useful to policy makers. Moreover, since most central banks formulate monetary policy by setting a target for a short-term nominal interest rate (typically an overnight money market rate), the natural rate provides a convenient benchmark that policy rates can be measured against directly.

Indeed, it is easy to see why the natural rate can play a key role in monetary policy given the current mandates of many central banks. Among the main goals of monetary policy are price stability and output stabilisation. One way to interpret these objectives is that the best way monetary policy can contribute to economic welfare is to minimise the effects of nominal distortions in the economy; in turn, this is best achieved by stabilising inflation and the output gap. The natural rate, as the equilibrium real interest rate under price stability, can therefore provide a guide to a central bank in setting its policy interest rate target. In New Keynesian models, economies in the presence of price stability roughly behave like economies without nominal imperfections. Thus, by setting its target short-term nominal interest rate equal to the natural rate plus a (low positive or zero) target rate of inflation, a central bank is essentially trying to mimic the ideal conditions of an economy without nominal rigidities.

However, despite the obvious potential role the natural rate could play in the conduct of monetary policy, the fact that it cannot be observed draws into question its practical usefulness. Our purpose here is to assess how the natural rate might be employed in the daily conduct of monetary policy. As such, our focus is on the main policy issues, rather than on assessing the fundamental economic factors that determine the natural rate.

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1 Correspondence: 4002 Basel, Switzerland; e-mail: jeffery.amato@bis.org. This paper is a revised and extended version of a paper that previously circulated under the title, "Wicksell, New Keynesian Models and the Natural Rate of Interest". The author gratefully acknowledges helpful discussions with Andy Filardo and David Laidler, and comments from Claudio Borio, Thomas Laubach, Hyun Shin and seminar participants at the BIS and the Banco de Espana. All remaining errors are mine alone. The views expressed herein are those of the author and do not necessarily reflect those of the Bank for International Settlements

2 Some authors have used the term "neutral rate" to describe basically the same concept. We consider the two terms to be interchangeable.

3 A weaker definition would equate the natural rate with the real interest rate under an *arbitrary* inflation target of the authorities. However, this would lead to an almost tautological role for the natural rate in monetary policy, as in this case the natural rate would be the real interest rate that the central bank was aiming to achieve regardless of any particular inflation objective. Alternative definitions of the natural rate also appear in the literature. The next section presents and discusses some well-known formulations.

To set the stage and for purposes of clarity, in the first part of the paper we layout several definitions of the natural rate and discuss its role in the monetary transmission mechanism. We mainly emphasise the New Keynesian version and the recent batch of New Keynesian models.[4] The main common element in these models is that the difference between the actual short-term ex ante real interest rate and the natural rate – known as the real rate gap – is a principal source of aggregate demand-driven imbalances. Comparisons are drawn to earlier treatments of the natural rate as well, particularly the work of Wicksell (1898, 1906, 1907) and his natural rate-based theory of inflation determination.

In the second part of the paper we then turn to a discussion of some practical issues central banks face in incorporating the natural rate into the conduct of monetary policy, specifically, how the natural rate might influence decisions on interest rate policy. An appendix assesses some difficulties involved in estimating long-run movements in the natural rate.

The main conclusions we draw are:

- The importance of the natural rate for monetary policy is intrinsically tied to the objectives of policy. Under the current mandates of central banks to achieve price stability and output gap stabilisation, the natural rate is, in principle, one of the key benchmark indicators for monetary policy.
- One of the main contributions of the recent New Keynesian literature is the provision of a more precise (quantitative) definition of the natural rate, including various conditions under which the natural rate is implicitly and equivalently defined.
- Financial imperfections likely affect both the value of the natural rate as well as its role in output and inflation determination. To date, little is known about the impact and importance of these types of frictions.
- Uncertainty over an operational definition of the natural rate, however, draws into question its usefulness as an explicit indicator for monetary policy making. Even if policy makers have a natural rate-based view of the economy, other variables, notably aggregate price inflation, may be a sufficient guide to central banks in setting interest rates.

2. Origins and definitions

The natural rate concept arguably came to prominence in the work of Knut Wicksell (1898). Indeed, the natural rate has played a key role in monetary economics at different times over the past couple of centuries, although there have been substantial periods when it has not figured prominently in mainstream economic thought.[5] For instance, in the period leading up to Wicksell's writings, the quantity theory of money was the dominant intellectual paradigm, in large part due to Alfred Marshall. Wicksell was also an advocate of the quantity theory. In fact, his work on the natural rate, and the associated 'cumulative process' theory of inflation (see section 3), was largely motivated out of a desire to provide a more rigorous foundation of the link between money growth and inflation, which he felt was lacking in expositions of the quantity theory at the time. Wicksell drew upon the natural rate concept and the interest rate gap as a means to provide a more consistent theory of inflation determination.

Subsequently, the natural rate figured in theories of the business cycle that were developed during the inter-war period. In particular, Wicksell's interest rate gap had a strong influence on Austrian, Swedish and English economists. Later, Friedman's (1968) 'natural rate of unemployment' is to be seen as a direct analogue of Wicksell's natural rate of interest.

[4] Amongst the many recent contributions are Woodford (1999, 2003), Rotemberg and Woodford (1997, 1999), Erceg, Henderson and Levin (2000), Amato and Laubach (2003a, 2003b, 2004), Giannoni (2000), Giannoni and Woodford (2001), Neiss and Nelson (2001) and Smets and Wouters (2001).

[5] See Laidler (1999) and Leijonhufvud (1981) for extensive treatments of the historical role of the natural rate in macroeconomic thought.

The notion of the natural rate has evolved over time. Wicksell described the natural rate in several ways. Specifically, he defined the natural rate as (1) the rate of interest that equates saving with investment; (2) the marginal productivity of capital; and (3) the rate of interest that is consistent with aggregate price stability. Wicksell did not explicitly link these definitions together, though it can be inferred from his writings that he believed they are mutually consistent. It is worth highlighting three properties that Wicksell attributed to the natural rate. First is the notion that the natural rate is consistent with *equilibrium*. Second is that the natural rate is a characteristic of the economy in the long run. Third is the assumption that, in general, the natural rate would not be fixed at a given value, but instead would fluctuate mainly according to changes in technology that affect the productivity of capital. These definitions (and properties) of the natural rate were largely adopted by later generations of economists. For instance, economists during the inter-war period followed Wicksell in emphasising the property of the natural rate as the interest rate that equilibrates savings and investment. Friedman (1968) and Phelps (1968) emphasised the long run property of the natural rate of unemployment.

More recently, the natural rate of interest has reemerged to take a central role in theories of output and inflation determination in the literature on dynamic general equilibrium New Keynesian models. Woodford (1997) has referred to this group of models as “Neo-Wicksellian” frameworks. New Keynesian models can be distinguished by the presence of sticky prices, in what is otherwise largely a real business cycle model. The natural rate is defined to be the equilibrium real interest rate that would obtain in a ficticious replica of the economy in which nominal adjustment is complete. Moreover, it is generally presumed that agents form rational expectations, so that the natural rate can be defined further as the real interest rate obtained in a flexible-price rational expectations equilibrium. For example, it could be the real interest rate in a traditional competitive real business cycle model (eg Kydland and Prescott (1982)) or in a model with imperfect competition (eg Rotemberg and Woodford (1995)), where prices adjust fully each period to their desired level.

It is worth emphasising three general properties of the natural rate under this definition. First, it is a *one-period* interest rate. Second, it is an equilibrium real interest rate, where equilibrium is defined *period by period*. Third, it is subject to *variation* at both short and long horizons. For instance, even the long-run equilibrium real interest rate could vary over time with structural changes in the economy. To be clear, the natural rate is *not* defined to be a long-term real interest rate; it is a short-term rate, defined period-by-period, and with a long-run central tendency that can also (slowly) shift over time.

Furthermore, the New Keynesian definition can be seen as a synthesis of Wicksell’s definitions. Because the natural rate is the interest rate realised in general equilibrium, it is implicitly the rate consistent with savings equal to investment (in a closed economy). Moreover, firms will choose a level of investment such that the (possibly adjusted) marginal productivity of capital is equated with the real interest rate. Finally, while the existing New Keynesian literature has not imposed the further condition that the central bank’s inflation objective be equal to zero – and hence the natural rate would necessarily coincide with period-by-period price stability – most studies assume that the inflation target and steady-state inflation are zero.

Indeed, one notable difference of the New Keynesian natural rate from its predecessors is its property as an equilibrium rate consistent with period-by-period price stability. Wicksell, Friedman and others treated the natural rate as the real interest rate that the economy tends toward in the long run. In this sense, the New Keynesian natural rate is a more complete description of the economy under price stability than its forerunners, as it dictates what level of the real interest rate is consistent with stable prices on an ongoing basis.

In any given general equilibrium model, it is possible to derive an exact formula for the natural rate. One of the contributions of the New Keynesian paradigm is the possibility to obtain explicit expressions for the natural rate as a function of the primitive factors underlying the economy. The recipe for finding the natural rate is simply to solve for the equilibrium real interest rate that would obtain in the model economy when prices are assumed to be perfectly flexible; in other words, when output is equal to the natural rate of output. The various first-order conditions that must hold in equilibrium under the optimising behaviour of households and firms pin down the natural rate.

The natural rate is determined by various economic factors, such as households’ rate of time preference and their willingness to substitute consumption across time; the marginal productivity of capital, in particular, the level of the capital stock; and shocks that affect households’ savings decisions, such as innovations to total factor productivity and exogenous changes in government spending. Real rigidities in the economy affect equilibrium outcomes even when prices are fully flexible; therefore, real rigidities have a direct influence on the natural rate of interest. For instance, if investment goods are not completely transferable across firms (i.e. investment is partially irreversible), then the equilibrium real interest rate will be different than if investment goods were perfect substitutes.

It is instructive to consider the effects of shocks on the natural rate. For example, an expected increase in total factor productivity tends to raise the natural rate. When productivity growth is expected to increase, households expect to have more income in the future and hence desire to consume more today. In equilibrium, the real interest rate must rise to induce households to save more given the current level of production. If the implied ex ante interest rate in the market does not rise by enough, then there will be excess demand pressure and the output gap will rise.[6]

The dependence of the natural rate on variables that describe the current state of the economy (eg the capital stock) creates a subtle distinction in alternative applications of the New Keynesian definition, which can have important implications for monetary policy. In particular, the natural rate is not necessarily independent of the types of nominal rigidities that exist in the economy or government policies.

The issue at stake here is that the natural rate, as described so far, can be defined in one of two ways. The first is as the real interest rate in an economy where there is the (imagined) absence of nominal rigidities at the present time and in the future, *taking as given the current values of all state variables, notably the capital stock*. The second is as the real interest rate in an economy where nominal rigidities have been eliminated at all times – past, present and future.[7] In the former case, the fact that, for example, prices and wages were sticky in the past, implies that the current capital stock is likely to be different than it would have been if prices and wages had been fully flexible, a condition imposed in the latter definition. Under the former definition, the natural rate is *not* independent of the types of nominal rigidities in the economy and the history of monetary policy – a dichotomy between real and nominal rigidities, in terms of their influence on the natural rate, does not exist. For instance, a monetary policy that makes inflation more inertial can add considerable persistence to the effects of shocks on saving and investment, and in the process change the nature of capital stock adjustment and the dynamic path of the natural rate along with it. So far, there appears to be no consensus favouring one approach over the other in defining the natural rate.

Finally, it is worth emphasising that exogenous sticky prices are not crucial for the existence of a link between the real rate gap and inflation. Other frictions that prevent prices, wages, etc, from adjusting fully to their desired levels in the absence of such frictions are sufficient to create a link between real rate gaps, the output gap and price level changes. For example, if firms can change prices every period but they have imperfect information on the economy, then prices are unlikely to adjust fully to shocks. Examples of models with this feature include Mankiw and Reis (2000) and Amato and Shin (2003).[8]

3. Real rate gaps and the policy transmission mechanism

3.1 Conventional channels

In New Keynesian models, incomplete nominal adjustment is responsible for generating real rate gaps. In this sub-section, we briefly describe the main mechanism of how real rate gaps affect the

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6 By contrast, an expected increase in exogenous demand expenditures (eg an upward shift in exogenous government spending) tends to lower the natural rate. For government spending to take a larger share of output in the future, households must be enticed to consume relaticely more today than they would have otherwise desired. This change in consumption behaviour is brought about in equilibrium by having a lower real interest rate. However, if the actual ex ante real rate does not decline, then households will consume too little today. This is a situation of excess supply and downward pressure on inflation.

7 See Woodford (2003) and Neiss and Nelson (2001) for further discussion.

8 See also Leijonhufvud (1980), who makes the distinction between models with “spanner-in-the-works malfunctions” (i.e. sticky prices) and models of incomplete information.

output gap and inflation in these models. We also compare certain features of these models with Wicksell's cumulative process in an effort to draw out further lessons for monetary policy.

The typical New Keynesian model has firms engaged in monopolistic competition and prices are assumed to be sticky. Output is demand determined and suppliers meet the demand for their product at the prices they post. Thus, markets clear each period, resulting in period-by-period equilibrium. Households and firms are assumed to act optimally, which means that their choices will depend, at least in part, on their expectations of the future. In particular, consumption and investment decisions cause aggregate output to be affected by the private sector's expectations of future market interest rates and future values of the natural rate. If current and expected real rate gaps are zero, then output will be equal to the natural rate of output, the output gap will be zero and inflation will not be affected by demand pressures.[9]

In one sense, the Neo-Wicksellian framework laid out by Woodford, and developed by him and others, is exactly what its name implies: a modern version of the basic mechanism described by Wicksell, in which real interest rate gaps are at the core of welfare-reducing business cycle fluctuations.[10] Yet, there are some differences between Wicksell's 'cumulative process' theory of price level determination and New Keynesian models, which are of potential importance for monetary policy makers. It should be noted, however, that in drawing comparisons between Wicksell's theory and the more recent literature, it is important to keep in mind that, in contrast to New Keynesian models that are mainly geared towards understanding business cycle fluctuations, Wicksell envisaged real rate gaps as causing secular changes in the price level.

According to Wicksell's cumulative process theory, changes in the price level are caused by non-zero real rate gaps, just as in New Keynesian models.[11] In a monetary economy, Wicksell posited that if the loan and deposit rates set by banks were below the natural rate, then there would be excess demand for funds by firms to finance investment projects.[12] Consequently, the creation of liquidity by banks to absorb excess demand in the market for loanable funds would ultimately create excess money balances in the holdings of households. In an effort to spend the excess cash, prices begin to be driven upwards. The process of general price inflation ceases when, and only when, the market rate is brought into equality with the natural rate. Basically, to re-establish reserves at the desired level, banks increase deposit rates to attract savings and, consequently, raise loan rates as well.[13]

The key role played by money in Wicksell's natural rate-based theory of inflation determination differs markedly from the bulk of the New Keynesian literature. As pointed out by Humphrey (1997), the cumulative process is squarely in the tradition of the quantity theory of money. He suggests that the cumulative process was "nothing less than a full-scale extension of the [quantity] theory to account for the influence of bank deposits on the price level" (Humphrey, 1997, p 82). Prices rise due to increases in the supply of money, which come about from loan-led deposit creation by banks to finance excess desired investment. Even though it is the real rate gap that "gets the ball rolling", price increases do not occur, and would not occur, without the expansion of deposits by banks. The pivot in the system is stable real money demand. As soon as the money supply changes, households attempt to change their cash holdings; price movements occur entirely through real balance effects.

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9 Even in this case, however, inflation could change as firms change prices in response to inefficient supply shocks (eg variation in the degree of market power by firms). Clarida, Gali and Gertler (1999) discuss the implications of these types of shocks for monetary policy, which they call "cost push" shocks.

10 Hayek also adopted a Wicksellian version of the natural rate (the real interest rate consistent with equilibrium between savings and investment), although the policy implications that he drew regarding the existence of real rate gaps were quite different from Wicksell's own. The central feature of Hayek's theory was that discrepancies between the market and natural rates would lead to distortions in consumer and investor behaviour, and consequently between the relative price of consumption and investment goods.

11 See Humphrey (1992) for an algebraic representation of Wicksell's model of the cumulative process.

12 In analysing the effects of interest rate gaps on inflation, Wicksell assumes that the economy is in a state of full employment.

13 While banks play a crucial role in Wicksell's main story, one could imagine that it is the central bank that is determining the market rate of interest in this framework, by injecting and withdrawing liquidity to manipulate the rates offered at commercial banks. Alternatively, Wicksell also offers the example of a pure credit economy in which commercial banks do not exist and a single institution (the central bank) grants credits, which it discounts according to the rate of interest it sets.

By contrast, money typically has a passive role in New Keynesian models. In particular, assumptions about the velocity of circulation are usually not specified, and knowledge of the path of the money supply is unnecessary to determine inflation and output. One reason this assumption is typically made in New Keynesian models is because of a lack of evidence to be found on a significant real balance effect in many industrial countries in recent decades (eg see Ireland (2001)).[14] The implications for monetary policy are that, under the cumulative process, monetary aggregates should be a good indicator of imbalances arising from real rate gaps, whereas according to standard New Keynesian models, changes in the monetary aggregates might bear no relationship to real rate gaps.

Two other potentially important differences between the cumulative process and New Keynesian models are the time dimension and the notion of equilibrium. First, Wicksell makes no explicit mention of which rigidities prevent prices from rising instantaneously; presumably he had in mind the slow adjustment of expectations. By contrast, current and expected future real rate gaps can open and close on a quarterly basis in New Keynesian models. This means that monetary policy can have a strong influence on output and inflation over relatively short horizons. Second, the cumulative process is a theory of inflation rooted in disequilibrium in the market for loanable funds. Policies that aid coordination in this market, such as communications by the central bank, might improve welfare. By contrast, equilibrium is reached each period in New Keynesian models.

3.2 Implications of financial market imperfections

In most general equilibrium models, including New Keynesian models, it is generally assumed that financial markets are complete; finance has no real effects. In reality, markets are not complete and financial imperfections can have an impact on both the measure of the natural rate and the effects of real rate gaps on output, inflation and other macroeconomic variables.

To the extent that financial frictions are nominal in nature, they might have a limited effect on the natural rate; recall that the natural rate is defined to be the equilibrium real interest rate in an economy without nominal frictions. Nonetheless, nominal financial frictions are likely to influence investment spending, and hence the capital stock and the marginal productivity of capital; the natural rate will adjust accordingly. Financial frictions that are real in nature would almost certainly impact on the natural rate, just as the composition of the natural rate is affected by the presence of habit formation in consumption or irreversibilities in investment. The presence of, say, both nominal and real financial frictions will affect the link between the natural rate and other variables in the economy.

There are essentially four ways that imperfections in the financial sector can affect the natural rate and the link between real rate gaps to the economy. The first is through risk premia or credit rationing due to the existence of asymmetric information (eg the costly state verification model of Bernanke et al. (1999)). The second is through other forms of contractual imperfections, such as incomplete indexation. The third is through expectational errors on the part of financial market participants. A fourth is from agency problems within the financial sector itself (eg short horizons of portfolio managers).

Consider first the implications of risk premia. In reality, most spending decisions are not based on short-term interest rates; longer-term lending rates are what influence investment and durable consumption purchases. Thus, it is the deviation of the actual long-term interest rate from the "long-term natural rate" that is the key variable affecting the output gap and inflation. In turn, the long-term natural rate is essentially the sum of discounted expected future (short-term) natural rates. To the extent that longer-term market lending rates deviate from the sum of discounted expected future short-term riskfree rates, due to the existence of risk premia, there will be a wedge between real rate gaps and their effect on private sector behaviour. This contrasts with the feature of the standard New Keynesian model that real rate gaps are a sufficient statistic for demand imbalances. Policy makers must also take account of how risk premia vary with changes in both policy rates and the factors that affect the short-term natural rate.

As a second example, consider the impact of expectational errors by market participants. If agents are either too optimistic or too pessimistic about the state of the economy, then this will be reflected in the

[14] Andres et al (2004) provide contrasting evidence on the importance of the real balance effect.

prices of financial assets, in particular, lending rates to firms and consumers. Erroneous expectations will drive a wedge between actual market rates and the natural rate. According to Wicksell, errors in judgement in the banking sector were the main source of discrepancies between deposit and lending rates and the natural rate. In his view of a monetary economy, errors on the downside (i.e. interest rates that were too low) were corrected only gradually over time, as households adjusted their holdings of real balances in the light of general price increases and began to command higher deposit rates. However, it should be noted that the private sector's expectations are also a key factor in determining the natural rate as well, so it is not clear what the implications are for the *real rate gap* deriving from expectational errors.

4. Interest rate policy

As discussed in the Introduction, the natural rate is an obvious potential indicator for monetary policy. In more specific terms, how should the natural rate figure in the conduct of monetary policy?

According to most natural rate theories, the central bank should move the policy rate one-for-one with changes in the natural rate and, on average, nominal policy rates should equal the sum of the long-run natural rate and the central bank's (explicit or implicit) inflation target. However, since the natural rate is partly based on the expectations of the private sector regarding the likely near-term evolution of productivity growth, government spending, etc., as well as the evolution of monetary policy itself, central banks run the risk of engendering self-fulfilling expectations, and hence unstable equilibrium outcomes, if interest rate policy is not conditioned by observable variables in addition to the natural rate. In other words, policy makers must respond to inflation developments and possibly other variables in order to achieve their objectives of price stability and output gap stabilisation.

Before turning to a discussion of more complex "reaction functions" for the central bank, it is worthwhile to assess whether simple measures of the real rate gap have been good indicators of aggregate price changes. Table 1 reports correlations between inflation and two measures of the *cumulative* real rate gap at various leads and lags. The first rate gap measure (left-side of the table) is constructed as the difference between the normalised ex post real interest rate and normalised real GDP growth, where the latter is used as a proxy for the short-term natural rate. The second real rate gap is the difference between the ex post real rate and the estimate of the long-run real rate based on a latent variable model, where the latter series are the solid lines shown in Figure A2 (see the Appendix). Whether the real rate gap should lead or lag inflation depends upon how forward looking private sector agents are in their decision making. If current spending decisions are largely based on expectations of future interest rates (roughly speaking, current long-term interest rates), and firms' pricing decisions are largely based on their expectations of future excess demand, then *current* inflation should be negatively correlated with cumulated *future* real rate gaps. If, on the other hand, the private sector is mostly backward looking, or it is tightly constrained by past outcomes, then *current* inflation should be negatively correlated with *past* real rate gaps.

The correlations reported in Table 1 are fairly small and mostly *positive*. If natural rate theories of inflation determination are accurate, then these results suggest that the measures of the natural rate used in the calculations do not accurately capture movements in the true natural rate. Alternatively, the natural rate theories could be wrong. Yet another explanation is that the presence of inefficient supply shocks or external shocks will affect estimates of unconditional correlations. To the extent that these shocks have a large influence on inflation in reality, the correlation between real rate gaps and inflation will be weakened and the sign could even be reversed.

Many authors have recognised that the natural rate is inherently unobservable and would be difficult to measure in practice. In New Keynesian models, as well as in earlier natural rate theories, price level changes are directly associated with the presence of positive or negative real rate gaps. This has led to suggestions that inflation itself might serve as a good proxy variable for the real rate gap. Other variables, such as the output gap, should also be good indicators of real rate gap movements. This has led to a large recent literature on interest rate rules, which has grown in parallel to the development of New Keynesian models.[15] The most famous example is the Taylor (1993) rule, which has the central bank set its policy interest rate in response to deviations of inflation from an inflation target, the output gap and an estimate of the long-run natural rate of interest. Of course, the proposition that a central bank should follow such a rule as a means of eliminating real interest rate gaps has a long history dating back to Wicksell. As noted by Humphrey (1992), Wicksell suggested that the central bank could follow one of two different rules to contain the cumulative process. The first has the central bank changing interest rates in response to inflation rising above or below the (zero) target level ("inflation rule"). The second requires the central bank to change interest rates in response to deviations of the price level from a (constant) target path ("price-level rule"). In 1995, Fuhrer and Moore (1995) argued that monetary policy makers had been roughly following Wicksell's inflation rule for some time. The proliferation of inflation targeting regimes since then is but one piece of evidence that continues to support this claim. In addition, there is now a voluminous literature on estimating central bank reaction functions providing evidence that central banks have indeed controlled policy rates in this manner (see, amongst many others, Judd and Rudebusch (1998), Amato and Laubach (1999) and Gerlach and Schnabel (2000)).

On a theoretical level, while some studies have found it important for the central bank to respond to output fluctuations in addition to inflation (eg many of the contributions in Taylor (1999)), Woodford (2003) has argued that, since the natural rate of output is unobservable, it may be preferable for the central bank to follow a rule specified in terms of observable variables only. In fact, some authors have shown that interest rate rules specified solely in terms of inflation are a good approximation to optimal monetary policy in various spin-offs of the basic New Keynesian model (see, e.g., Amato and Laubach (2003b, 2004), Giannoni (2000) and Giannoni and Woodford (2001)). The general conclusion to be reached from this past research is that inflation is close to being a *sufficient statistic* for monetary policy even in natural rate-based theories of monetary policy.

However, there are some caveats. First, even in simple feedback rules referencing inflation, policy makers are formally required to have knowledge of the long-run natural rate, as it, along with the central bank's inflation target, serve to anchor the long-run level of the policy rate. Uncertainty about the level of the long-run natural rate may be more important than uncertainty about the desired sensitivites of policy to inflation and output fluctuations. Some evidence on this is given in Figure 1, which plots the implied value of the policy rate in the United States, United Kingdom and Germany/euro area under a benchmark specification of the Taylor rule. The columns show the sensitivities of the policy rate to changes in the long-run natural rate (left column), the feedback coefficient on inflation (center, labelled "alpha") and the feedback coefficient on detrended output (right, labelled "beta"). At each date, the value of the long-run natural rate is varied across the range of the one-standard-deviation confidence intervals reported in Figure A4. The ranges of the other parameters are based on the findings of previous studies on what are likely to be optimal values for these coefficients. Based on these plots, the bottom line is that uncertainty over the long-run natural rate can have a much bigger impact on the desired level of the policy rate compared to uncertainty over the feedback responses to inflation and output (which, in turn, reflect uncertainty about the transmission mechanism).

Second, the conclusion that eliminating real rate gaps is equivalent to achieving price stability, and hence that inflation is a sufficient statistic of real rate gap movements, rests on several assumptions that do not hold in reality. Here we highlight three issues that may be particularly important from a practical perspective: nominal wage stickiness, the source of nominal rigidities and financial imperfections.

The conclusion that central banks should move interest rates in response to changes in the aggregate price level or price inflation rests on the assumption that stickiness in goods and services prices is the main root cause of incomplete nominal adjustment. However, in economies with other significant nominal rigidities, notably wage stickiness, the central bank presumably should respond to movements in the observable variables associated with those rigidities as well. It is arguable that nominal wage stickiness is as prevalent in industrial economies as nominal price stickiness, if not more so. In this case, Erceg et al (2001) show that it is desirable for monetary policy to respond to both price inflation *and* wage inflation. Amato and Laubach (2003a) provide macroeconomic evidence on the importance

[15] These rules are also known as central bank reaction functions or feedback rules.

of nominal wage stickiness in the United States and assess its implications for the role of wage inflation in simple interest rate rules.

The fundamental source of nominal rigidities, and not just the decision variables affected, might also matter for the efficiency of inflation as an indicator of excess aggregate demand. As noted by Amato and Shin (2003), if imperfect information is the root cause of price stickiness, rather than some other exogenous rigidity, then the information content of inflation may be impaired. This occurs in the same model of monopolistic competition that underlies most New Keynesian models due to the presence of strategic complementarities in the price setting behaviour of firms. Since all firms lack perfect information on the state of the economy, each firm tries to second-guess what other firms know about current economic conditions. This leads to more inertial aggregate price changes than would otherwise be optimal, and, importantly, a wedge between changes in the real rate gap and inflation.

Finally, as was noted in the previous section, the existence of financial market imperfections implies that there might not be a clean link between the real rate gap and the funding costs of households and firms to undertake spending. In the financial accelerator model of Bernanke et al. (1999), shocks have an amplified and persistent effect on investment spending due to countercyclical movements in risk premia. This suggests that credit spreads or the growth in credit aggregates may provide valuable information on the margin beyond what can be inferred from aggregate price movements alone. Furthermore, as mentioned above, abnormal growth in the monetary aggregates should be a good indicator of changes in the real rate gap under Wicksell's cumulative process.

Furthermore, as mentioned above, one major contribution of New Keynesian models and associated real business cycle models is that the first-order conditions resulting from the optimising behaviour of agents gives a set of conditions that implicitly describe the evolution of the natural rate. That is, these models produce specific formulae that can be used to compute the natural rate *and* there exist multiple equations (i.e. more than one) within any given model that contain information about the natural rate. For instance, the natural rate can be inferred from the household's Euler equation for optimal consumption, and it can also be inferred from the Euler equation of firm's derived from optimal investment behaviour. Of course, in equilibrium all of these conditions are supposed to hold and, presumably, will pin-down a unique value for the natural rate. In practice, however, these conditions may be violated to varying degrees. In is in this sense that Borio et al. (2002) have argued that relying upon various observable indicators linked to agents' optimal decision rules might, in practice, be a more robust way to proxy for the real rate gap.

5. Conclusions

This paper has been an assessment of the role of the natural rate of interest in monetary policy. The natural rate has figured prominently in the academic literature for many decades, and, in particular, the focus has shifted towards it again with the recent development of New Keynesian models. Given the current mandates of most central banks, we have argued that the natural rate automatically assumes a central role in monetary policy, whether explicitly or implicitly. There is unlikely to be one formulation of the natural rate that would satisfy the tastes of all policy makers. In practice, a range of measures would need to be estimated on the basis of various alternative considerations. However, we have also argued that it may not be neccesary for central banks to obtain estimates of the natural rate even in cases where monetary policy is viewed through the lens of a natural rate-based theory of output and inflation determination. Headline consumer price inflation might be a sufficiently good proxy of real interest rate gaps. One notable area requiring further research is the impact of financial imperfections on the natural rate and, consequently, how this might affect the role of the natural rate in the conduct of monetary policy.

Appendix: Estimates of the long-run natural rate of interest

Estimates of the long-run natural rate – defined as the (time-varying) mean of the natural rate – are used in the calculations underlying Table 1 and Figure 1. This appendix briefly describes the methodology used for obtaining these estimates and highlights the potential sensitivity of the results. The reader is referred to Amato (2004) for further details.

To begin, Figure A1 plots time series of ex ante and ex post short-term real interest rates in the United States, United Kingdom and Germany (euro area after 1999).[16] A few properties of the series are worth highlighting, First, it does not appear to matter, except during a few brief periods, whether ex ante or ex post real rates are used to draw inferences about cyclical and trend movements. Second, short-term real interest rates (ex ante or ex post) were very volatile throughout the sample period. To the extent that monetary policy was attempting to track movements in the natural rate, this suggests that the natural rate itself also varied considerably over this period. Third, trend shifts in real interest rates are evident.

Evidence on this last point is provided in Figure A2, which plots estimates of the long-run natural rate from three different methods. The estimates are taken from Amato (2004). The solid and dashed lines in each panel of the figure are constructed only using data on ex post short-term real interest rates. The solid lines are estimated from a time-varying parameter (TVP) model, while the dashed lines are constructed using the Hodrick-Prescott (HP) filter. The dash-dotted lines are estimates of the long-run natural rate constructed from estimates of the trend in consumption growth using a TVP model. The rationale for using an estimate of trend consumption growth in estimating the long-run natural rate is that the short-term riskfree real interest rate should be directly related to mean consumption growth, given the optimal savings decisions of households over the long run.

It is evident from the graph that the choice of estimation procedure can matter. The HP trend shows much larger swings in the mean of the natural rate compared to the TVP estimates. In turn, the TVP model that also incorporates data on the trend in consumption growth is smoother than the univariate TVP model of real interest rates. This latter finding relfects the fact that consumption growth evolves more smoothly over time and its movements provide valuable marginal information to pinning-down the trend in real interest rates.

Figure A3 shows the relationship between the trends in real interest rates and consumption growth, and further highlights the difficulties in assessing movements in the long-run natural rate. This figure plots the univariate TVP estimate of the long-run real rate from Figure A2 against a TVP estimate of trend consumption growth. As noted above, standard consumption and asset pricing theory predicts that real rates should be an affine function of consumption growth, therefore, the two series are normalised by their sample mean and standard deviation in order to compare them. It is evident from the graph that trend consumption growth is less volatile. More importantly, however, it sometimes moves in the *opposite* direction of the trend in ex post real interest rates, particularly in the United States. Taken at face value, the fact that the series do not closely track one another suggests that either: (a) factors other than consumption growth have a significant influence on the natural rate over the long run; or, (b) there have been large trend changes in the preferences of households (see Amato (2004) for further discussion of this point). Either way, policy makers are left with the difficulty of identifying and evaluating other sources of movements in the natural rate.

Another perspective on the uncertainty surrounding estimates of the long-run natural rate is provided in Figure A4. The shaded regions are one-standard-error confidence bands around the time series of univariate TVP estimates from Figure A2 (solid lines) and the dashed lines are the actual values of the ex post real interest rate. While there are periods where the ex post real rate clearly falls outside of the confidence bands, there have been many occasions, including most of the period dating back to 1995 in the United States and United Kingdom, where the ex post real rate is within the range of plausible estimates of the long-run natural rate. This means that policy makers would have been uncertain whether policy was too tight or easy relative to a long-run neutral level, much less where it stood relative to the short-run natural rate.

[16] Proxies for expected inflation are constructed from a vector autoregression in the calculation of ex ante real rates.

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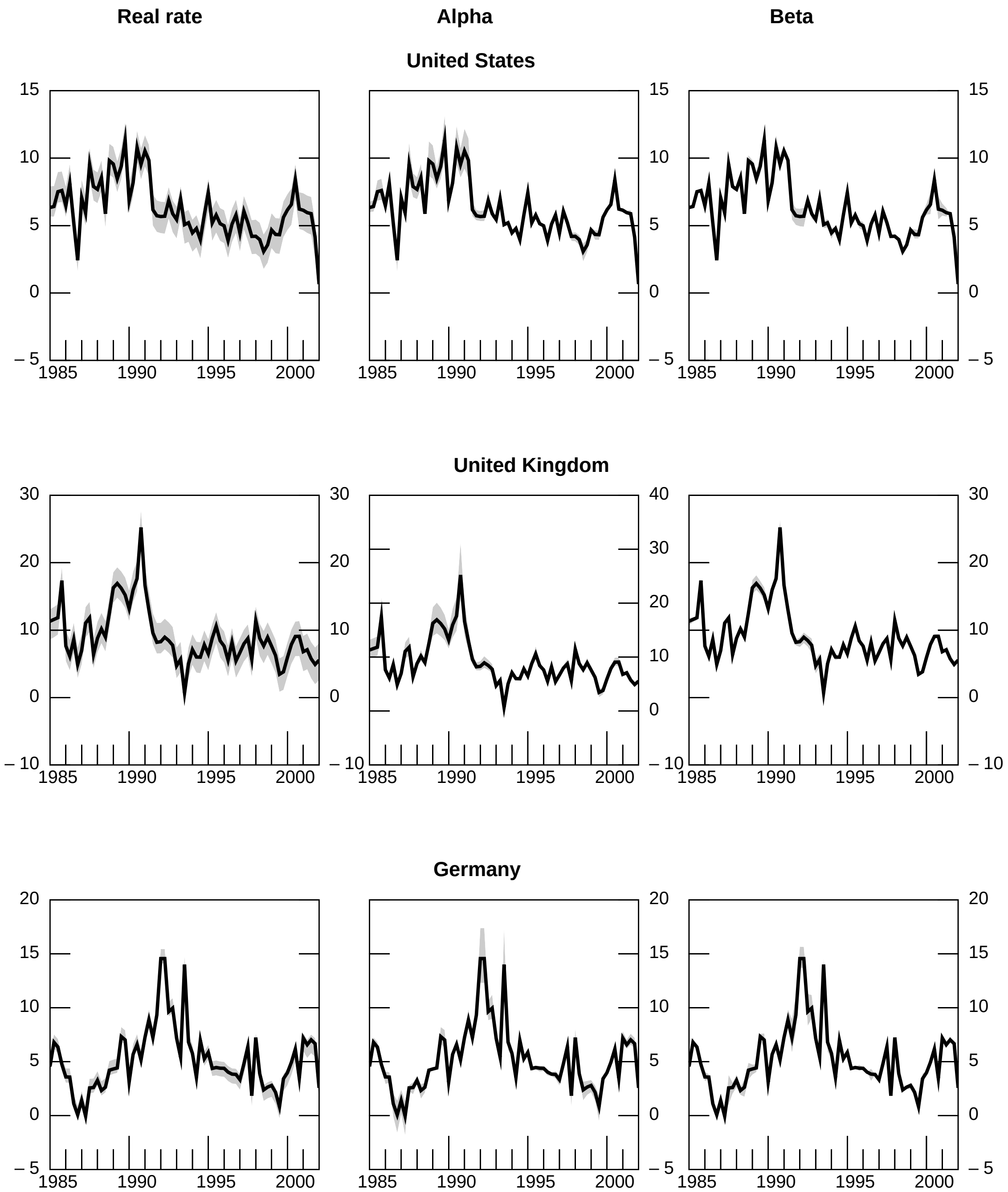
Table 1

Correlations between inflation and cumulative real rate gaps

		Real rate gap 1 ("short run")				Real rate gap 2 ("long run")			
Lead (+) or lag (–) on rate gap		**J = –8**	**J = –4**	**J = 4**	**J = 8**	**J = –8**	**J = –4**	**J = 4**	**J = 8**
Lead (+) or lag (–) on inflation	K = 8	0.29	0.06	–	–	0.00	–0.17	–	–
	K = 4	0.32	0.38	–	–	0.08	0.16	–	–
	K = 0	0.20	0.12	0.38	0.29	0.09	0.02	0.16	0.00
	K = –4	–	–	0.12	0.32	–	–	0.02	0.08
	K = –8	–	–	0.24	0.20	–	–	0.16	0.09

Graph 1

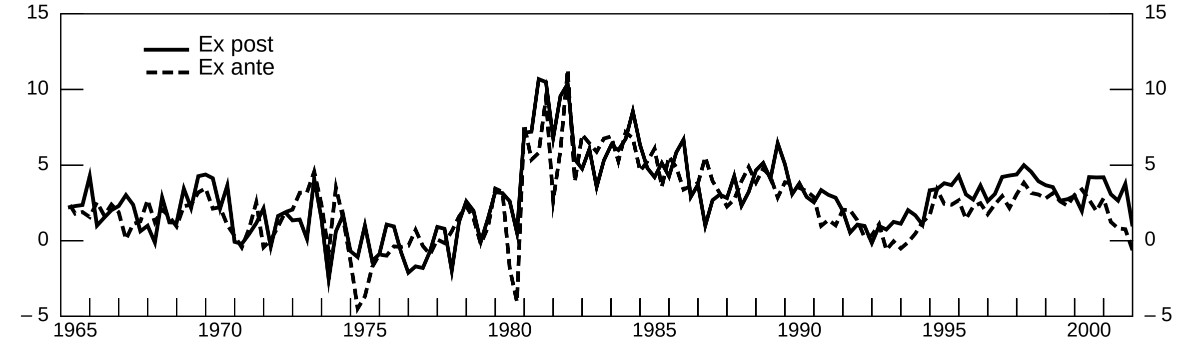
Sensitivity of policy rules to uncertainty about parameters



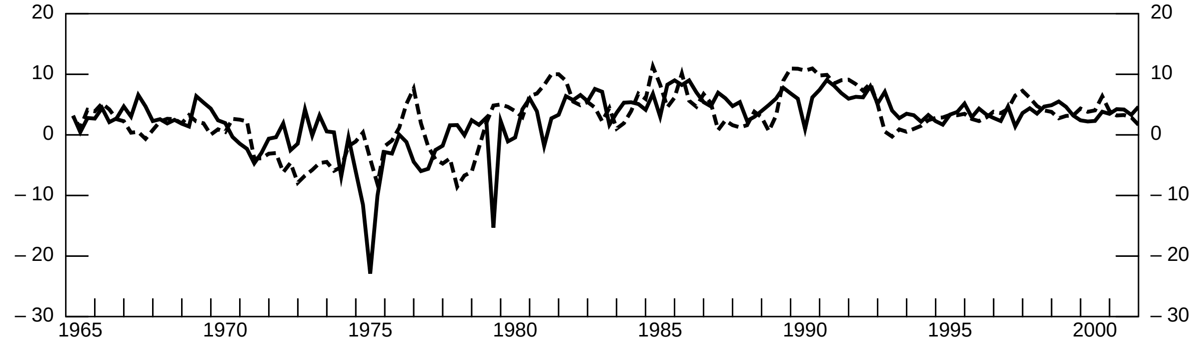
Graph A1

Ex ante and ex post short-term real interest rates

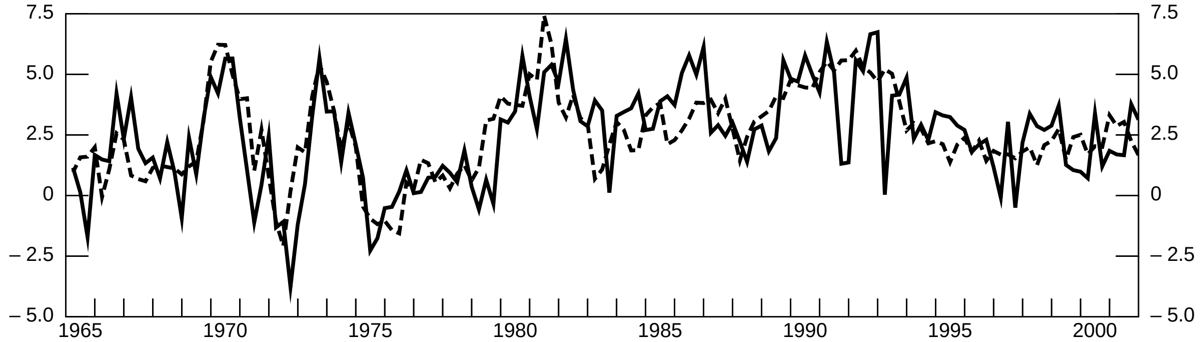
United States



United Kingdom

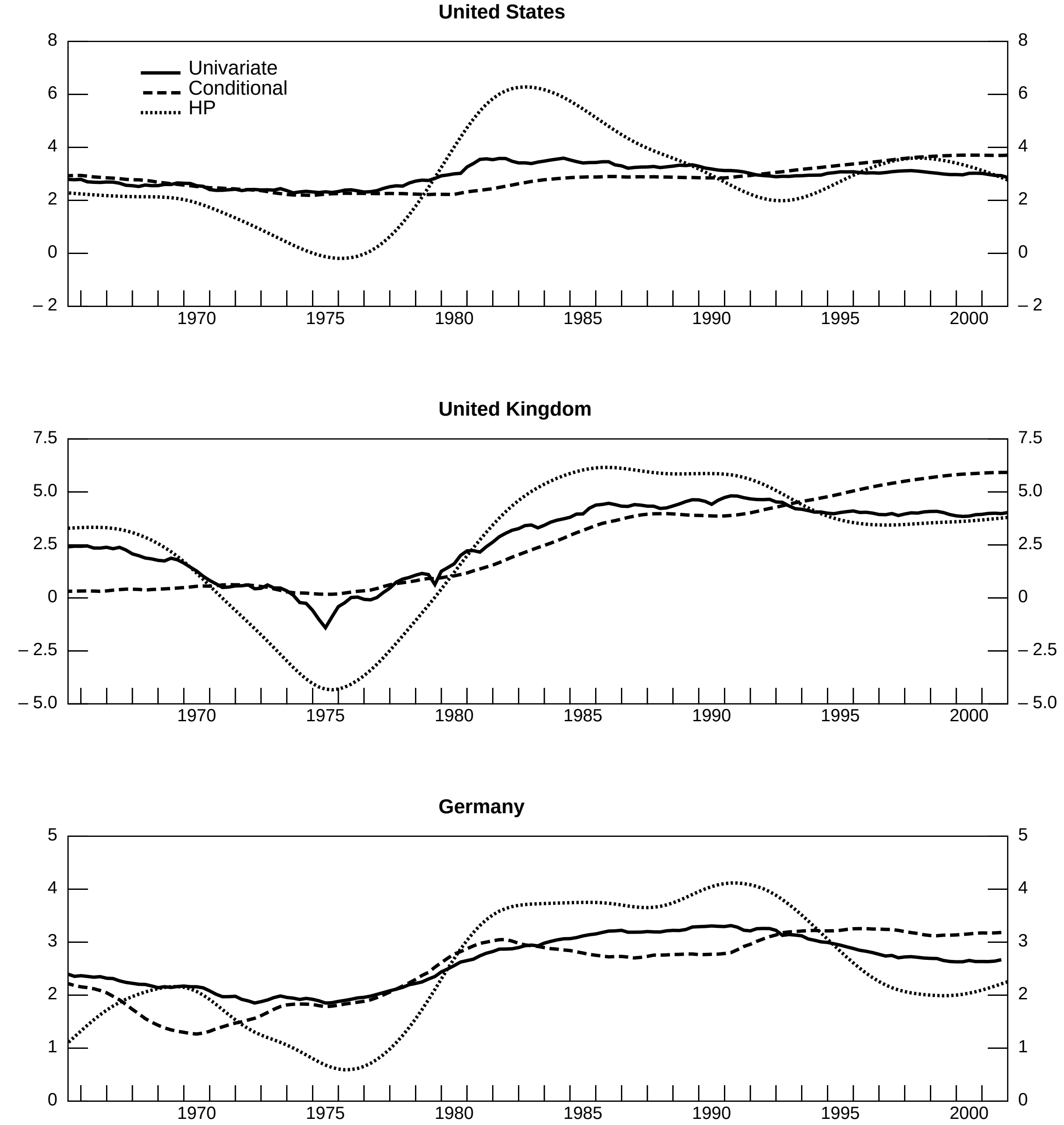


Germany



Graph A2

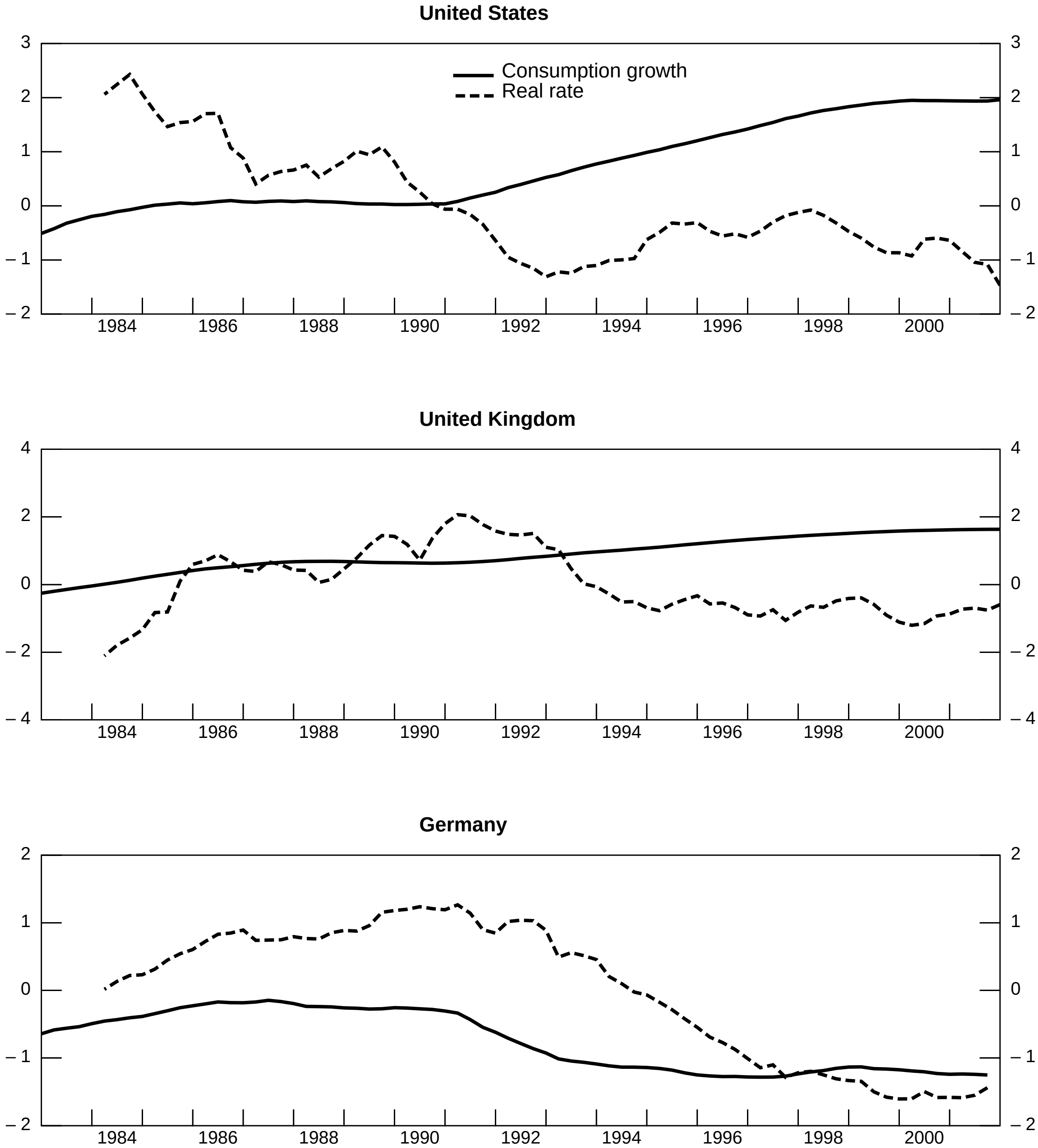
Estimates of the long-run natural rate of interest



Graph A3

Time-varying means of ex post real interest rates and consumption growth

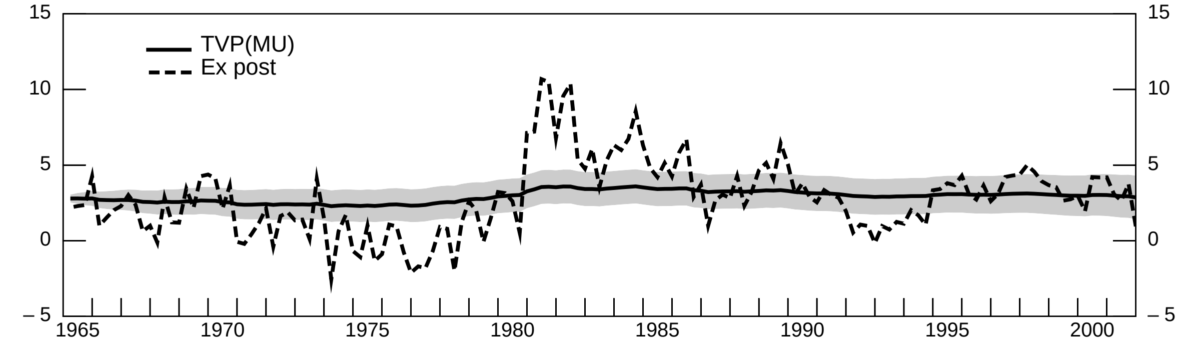
(normalised to have zero mean and unit standard deviation)



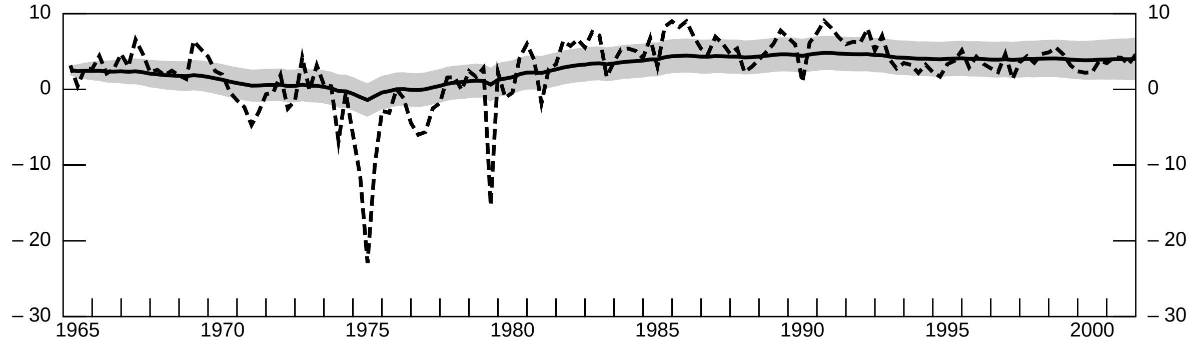
Graph A4

Ex post real interest rates and confidence bands for the long-run natural rate

United States



United Kingdom



Germany