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# *Investigating Inflation Persistence Across Monetary Regimes*
## *I: Empirical Evidence*

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Abstract

Is inflation persistence a structural feature of the economy? Has the extent of inflation persistence been basically constant, or has it changed over time? What role does the monetary regime play in determining the extent of inflation persistence? This paper uses random-coefficients autoregressive representations with generalised autoregressive conditional heteroskedasticity to investigate shifts in inflation persistence over time and across monetary regimes in the US (since 1793) and in the UK (since 1662). Empirical evidence questions the notion that inflation is *intrinsically* persistent: on the contrary, inflation persistence appears to be a typical feature of the post-commodity standard (i.e., post-1914) world, and especially of the period after 1947, and is instead absent from the data generated by economic systems operating under metallic standards. Both in the US and in the UK, inflation persistence is estimated to have decreased after the beginning of Bretton Woods, and to have increased after mid-1960s. In the US, persistence has markedly decreased after the beginning of the Volcker disinflation, while in the UK it has decreased starting from the beginning of the 1990s, corresponding to the introduction of an inflation targeting regime.

Several implications are discussed. It is argued that trying to replicate inflation persistence as an entirely structural feature of a macroeconomic model is potentially flawed, and that both the evaluation of alternative monetary policy frameworks, and the computation of optimal monetary policies based on models with built-in inflation persistence may deliver misleading indications. The finding that the serial correlation of inflation has significantly decreased in recent years is cited as evidence in favor of Taylor's (1998) and Sargent's (1999) warning against 'natural rate recidivism'—that under low inflation persistence policymakers may be attracted to exploit an illusory output-inflation tradeoff.

Keywords: Lucas critique; Inflation; Gold Standard; dynamic inconsistency; monetary policy; Kalman filter; time-varying coefficients models; Fourier analysis; Great Inflation; sticky prices; Taylor rule.

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> In earlier periods before roughly 1965, the monetary regime guaranteed some long-run stability in monetary growth and therefore in long-term inflation, which in turn restricted the effect of shifting inflationary expectations […]. The international economy has been moving gradually away from this type of monetary setup since World War I and especially since the 1930s, although some remnants of the gold standard and fixed exchange rates […] arrangements were in operation as recently as 1971. […] Although there were earlier periods when the United States did not adhere to a gold or silver standard these episodes typically occurred in times of war and could reasonably be perceived as temporary. […] The period since 1971 seems to be the first time that we have completely severed, both currently and prospectively, the link between our money and a commodity base.
>
> —Robert Barro (1982)

## *1. Introduction*

Inflation is generally regarded as a fairly persistent process. Fuhrer (1995), for example, speaks of a

> […] wide agreement that inflation is persistent […],

while Nelson (1998) lists inflation persistence as one of the key stylised facts any sensible sticky-price, dynamic stochastic general equilibrium (DSGE) model should be capable of replicating. Figure 1 reports some simple empirical evidence, by plotting estimated autocorrelation functions[1] for consumer price inflation for nine *OECD* countries over the post-WWII period. For all countries, estimated autocorrelations display the typical pattern of persistent processes, starting from relatively large values at lag 1, and decaying very slowly. In particular, for two countries, France and Italy, the autocorrelation at lag 1 is greater than 0.8; for four countries (United States, United Kingdom, Canada, and West Germany), it is between 0.6 and 0.8; and for the remaining three countries (Sweden, Japan, and Switzerland) it is between 0.4 and 0.6.

Where does inflation persistence originate from? At a very general level, the stochastic properties of any macroeconomic time series can be thought of as resulting from the interaction between three separate elements: (1) the data generation process for the structural shocks hitting the economy; (2) the intrinsic structure of the economic system; and (3) the (monetary and fiscal) policy regime prevailing over the sample period. Inflation persistence may therefore originate from three separate—but not mutually exclusive—sources. First, inflation could be persistent simply because it has inherited the strong serial correlation properties of the structural shocks affecting the economy, even in the absence of a strong internal propagation mechanism, or of a policy regime inducing persistence[2]. The

[1] Autocorrelations are plotted starting from lag one. Horizontal lines contain the 95% confidence region for the null hypothesis that estimated autocorrelations are equal to zero. Inflation has been computed as the first difference of the log of the CPI, quoted at an annual rate.

[2] Reproducing the strong serial correlation found in macroeconomic data by appealing to autocorrelated structural shocks has been one of the strategies pursued by the macroeconomic profession in recent years—see for example Rotemberg and Woodford (1997), and Ireland (2002). As stressed by Fuhrer (1997) in his comment on Rotemberg and Woodford (1997), however, such an approach is vulnerable to an important criticism. To the extent that the autocorrelated structural shocks capture a significant portion of the dynamics found in the data—in Rotemberg and Woodford's (1997) model, as shown by Fuhrer (1997, p. 350), they '[…] capture almost all of the covariance information […]'—this raises the obvious issue that, in the end, the model is not really explaining that much. 'What does this exercise

problem with this explanation, quite obviously, is that it possesses a distinctly unpalatable 'black box' flavor.

Second, inflation could be persistent because specific structural features of the economy create a powerful propagation mechanism, converting (possibly) serially uncorrelated structural shocks into highly correlated macroeconomic time series, irrespective of the specific fiscal and/or monetary regime in place. This is the position taken, for example, by Fuhrer and Moore (1995), Fuhrer (2000), Christiano, Eichenbaum, and Evans (2001), Mankiw and Reis (2002), and Altig, Christiano, Eichenbaum, and Linde (2002). A common theme among these papers is that the inflation persistence found in post-WWII data is implicitly treated as an *entirely structural* feature of the economy, to be 'hardwired' into the macroeconomic model by introducing frictions of various nature. As I will argue, such an approach is potentially flawed, for the simple reason that empirical evidence strongly questions the notion that inflation is *intrinsically* persistent[3]. On the contrary, inflation persistence appears to be a typical feature of the post-commodity standard (i.e., post-1914) world, and especially of the period after 1947, and is instead absent from the data generated by economic systems operating under metallic standards—either silver-based, or gold-based[4]. Further, there is empirical evidence[5] pointing towards a *decrease* in inflation persistence in recent years, as advanced economies have reacted to the inflationary mayhem of the 1970s by pursuing more aggressive monetary policies (in a number of cases officially introducing inflation targets), which is compatible with the notion that the persistence properties of inflation are not invariant to the monetary rule in place, and on the contrary crucially depend on it.

This leads us to the third possible explanation: *inflation persistence could largely, or even entirely, originate from specific features of the operating rules of the monetary regime in place over the sample period*. According to such an explanation, inflation persistence may not be (entirely) structural[6], and could instead be (partially or entirely) *historically determined*, in the sense of being the historical product of the specific way in which monetary policy has been conducted over the sample period[7]. The dramatic changes in the extent of inflation persistence over time and across monetary regimes I document in this paper should therefore be regarded as a straightforward consequence of the Lucas critique: *ceteris paribus* (i.e., for a

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tell us? In short, I think it tells us that [Rotemberg and Woodford] should raise the white flag. It seems fair to ask economists to surrender when they are forced to conclude that the dynamics present in the data can only be explained by things whose dynamics arise for reasons that we can't explain' (Fuhrer, 1997, p. 350)).

3 Exactly the same point is made by Ball (2000), who however fails to stress the key link between the stochastic properties of inflation, the monetary policy regime prevailing over the sample period, and its impact on private agents' expectation formation mechanism. An *ante litteram* critique of Ball (2000) can be found in the pioneering work of Benjamin Klein (1975), where, in footnote 3, he stresses that '[…] merely fitting a Box-Jenkins ARMA model (or an adaptive regression model) to past rate of price change to make price forecasts at every point in time will yield misleading results. A major point of this paper is that *the public considers other information when forming price expectations, such as the nature of the underlying monetary institutions*' (emphasis added).

4 Historically, bi-metallic standards have displayed a tendency to degenerate into systems based either on gold, or on silver, through the operation of Gresham's law.

5 Besides the evidence produced in the present paper, see for example the recent work of Cogley and Sargent (2002a, 2002b), Brainard and Perry (2000), and Kim, Nelson, and Piger (2001) for the United States, and of Ravenna (2000) for Canada.

6 By 'structural', I mean 'structural in the sense of Lucas (1976)'. On this, see the discussion in Goodfriend and King (2001, section 5.4., "Inflation persistence and the Lucas critique").

7 Changes in the conduct of monetary policy, and more generally changes in the operating rules of the underlying monetary institutions, are not the only persistence-generating devices I have in mind. In particular, it is my conviction that any convincing explanation of the peculiar (evolution of the) stochastic properties of inflation over the post-WWII period must assign a central role to the learning process on the part of private economic agents about a monetary environment that was literally shifting under their feet. Learning about the conduct of monetary policy as a persistence-generating device is explored in the work of Sargent (1999) and Erceg and Levin (2001).

given macroeconomic structure, and for a given data generation process for the structural shocks), a change in the rules of the 'monetary game' should, in general, be expected to induce changes in the stochastic properties of macroeconomic time series—among them inflation persistence[8]. Which specific features of monetary regimes could be responsible for (fluctuations in) the extent of inflation persistence? According to Bordo and Schwartz (1999),

> [e]vidence of persistence in the inflation rate suggests that market agents expect that monetary authorities will continue to pursue an inflationary policy; its absence would be consistent with market agents' beliefs that the authorities will pursue a stable monetary rule such as the gold standard's convertibility rule.

Bordo and Schwartz—like Barro (1982) in the opening quotation—point therefore towards the impact of the strength and credibility of the nominal anchor of the monetary regime on private agents' expectation formation mechanism, and through this to actual inflation. Commodity-based monetary standards are well known for providing strong nominal anchors, by taking money creation away from government control, thus eliminating at the root the opportunity for manipulation of the money stock[9]. A low degree of inflation persistence within such monetary systems should therefore come as no surprise. As for fiat money systems, the recent work of Clarida, Gali, and Gertler (2000, henceforth, CGG), and Cogley and Sargent (2002a, 2002b, henceforth, CS), points towards a link between the degree of activism of the monetary policy rule and the extent of inflation persistence. Specifically, CGG (2000), show that a passive monetary policy rule (i) allows the economy to experience self-fulfilling fluctuations characterised by a remarkable degree of persistence, even in the absence of fundamental shocks; and (ii) can generate highly persistent fluctuations in both inflation and the output gap as a response to fundamental shocks. CS (2002a, 2002b), using a random-coefficients Bayesian VAR(2) for inflation, unemployment, and the *ex-post* real rate, estimate a time-varying Taylor rule and compute time-varying spectral statistics for inflation, showing how the degree of activism on the monetary rule displays a striking negative correlation with the logarithm of the spectral density of inflation at frequency zero.

The key question therefore is: *Is inflation persistence structural in the sense of Lucas (1976)?* Currently, a significant portion of the macroeconomic profession answers—implicitly or explicitly—in the affermative to such a question. The recent attempts of Fuhrer and Moore (1995), Fuhrer (2000), Christiano, Eichenbaum, and Evans (2001), Mankiw and Reis (2002), and Altig, Christiano, Eichenbaum, and Linde (2002) to generate inflation persistence by introducing frictions of various nature within a macroeconomic model are a testimony to the fact that these authors regard the inflation persistence found in post-WWII data as entirely structural in nature. In recent years, however, some authors have started questioning such an assumption[10]. Working with a model without structural inflation persistence, Goodfriend and King (2001) conjecture that the inflation persistence found in post-WWII US data may result

> […] from the way that the Federal Reserve has pursued monetary policy, specifically how the central bank has allowed the markup to covary with inflation.

Erceg and Levin (2001) explore an alternative channel to generate inflation persistence within a model in which persistence is not 'hardwired' into the structure of the economy, by

[8] This is the position taken in the pioneering investigations of Alogouskoufis and Smith (1991) and Alogouskoufis (1992). For a critical perspective, see Burdekin and Siklos (1999).

[9] On the Gold Standard as a commitment mechanism—i.e., as a way of eliminating the inflationary bias originating from the dynamic inconsistency problem first discussed by Kydland and Prescott (1977) and Barro and Gordon (1983)—see Barro (1979) and Bordo and Kydland (1996). Barro (1979, p. 13), in particular, stresses how '[…] an important aspect of the gold standard or similar standards in relation to fiat systems is the (partial) separation of price level determination from government policy'.

[10] West (1988) explored the notion that the persistence properties of GNP may crucially depend on the conduct of monetary policy.

assuming that private economic agents face a filtering problem about the shifting inflation target of the central bank, and show that such a mechanism

> […] accounts quite well for several important features of the Volcker disinflation episode: a pronounced initial rise in the nominal interest rate, a sluggish decline in the inflation rate, a persistently negative output gap, and persistent inflation forecast errors. In this framework, inflation persistence is not an inherent characteristic of the model economy, but rather arises whenever agents must learn about shifts in the monetary policy regime.

Finally, Sargent's *Conquest of American Inflation* can be read, for our purposes, as a way of generating shifts in the stochastic properties of inflation, with alternating periods of high and low persistence, as a result of a specific learning problem on the part of the policymaker[11].

This paper uses random-coefficients autoregressive representations with generalised autoregressive conditional heteroskedasticity to investigate shifts in inflation persistence over time and across monetary regimes in the US (since 1793) and in the UK (since 1662), in order to produce empirical evidence relevant to the following three questions.

*(1) Is inflation persistence a structural feature of the economy?*
*(2) Has the extent of inflation persistence been basically constant, or has it changed over time?*
*(3) What role, if any, does the monetary regime play in determining the extent of inflation persistence?*

There are several reasons for being interested in these issues. Starting from question (1), first, as already mentioned, the fact that inflation persistence is—or is not—regarded as an entirely structural feature of the economy has crucial implications for the design and estimation of DSGE models featuring nominal stickiness. Assume, for example, that the Goodfriend-King (2001) position is entirely correct, and that the inflation persistence found in post-WWII US data uniquely results from the specific way the Federal Reserve has pursued monetary policy over the sample period. Then, it immediately follows that (a) all those models that 'hardwire' inflation persistence into the structure of the economy are misspecified, and (b) empirical estimates (however obtained, via MLE, or impulse-response based) of the structural parameters of those models are either wrong or distorted. Second, the evaluation of alternative monetary policy frameworks, and the computation of optimal monetary policies, necessarily require a model structural in the sense of Lucas (1976). Assume, once again, that the Goodfriend-King (2001) position is entirely correct. Then, as a simple corollary of the previous point, it follows that all those models that build in inflation persistence as a structural feature cannot possibly be used for either evaluating alternative monetary policy frameworks, or computing optimal monetary policies. As an extreme example, the welfare evaluation of a price-level targeting regime—which, on logical grounds, should introduce *negative* serial correlation in inflation rates—can hardly be performed based on a macroeconomic model designed to generate *positive* serial correlation in inflation!

As for question (2), both Taylor (1998a) and Sargent (1999) have recently warned against the dangers of 'natural rate recidivism'—that under low inflation persistence, the application of erroneous econometric tests, coupled with the fading of the memories of the 'Great Inflation' of the 1970s, may induce policymakers to try to exploit an illusory output-inflation trade-off, with eventually catastrophic consequences. As I discuss in more detail in section 7, the fact that inflation persistence has, or has not, decreased in recent years is crucial for this issue. If inflation persistence is high and basically constant—as claimed for example by Stock (2002), and Pivetta and Reis (2002)—then the dangers identified by Taylor and Sargent are most likely imaginary. If, on the other hand, inflation persistence fluctuates over time, and, in particular, if it has decreased in recent years, then, at least on empirical grounds, Taylor and Sargent's worries are indeed justified.

[11] I am here focusing on one of the two stories Sargent explores in the *Conquest*, the 'vindication of econometric policy evaluation'.

As for question (3), first, everything I mentioned concerning question (1) applies here too. Second, as stressed by Goodfriend and King (2001), if inflation persistence is independent of the monetary regime, there is no way to design a monetary framework capable of eliminating a trade-off between inflation and the output gap which is intrinsic to the structure of the economy. If, on the other hand, persistence is not structural, then it may be possible to design a monetary framework capable of stabilizing both inflation and the output gap. Understanding whether inflation persistence is structural in the sense of Lucas (1976) therefore bears crucial implications for the optimal design of monetary institutions.

The paper is organized as follows. The next section discusses the econometric methodology I use. Section 3 describes the data. Section 4 illustrates and discusses the empirical evidence. Section 5 discusses the crucial issue of the comparability of price indices across historical periods. Section 6 assesses several potential explanations for the previously discussed findings. Section 7 discusses the implications of previous findings for Taylor's (1998a) and Sargent's (1999) warning on 'natural rate recidivism'. Section 8 concludes, and outlines a number of directions for future research.

## *2. Econometric Methodology*

In order to investigate changes in the extent of inflation persistence over time and across monetary regimes without imposing any prior knowledge on the data, I estimate the following random coefficients AR($k$) model for the rate of inflation:

$$(1)\quad \left(1 - f_{1,t}L - f_{2,t}L^2 - \ldots - f_{k,t}L^k\right)\left(p_t - m_t\right) = e_t$$

$$(2)\quad e_t \,\big|\, I_{t-1} \sim N\left(0, s_{e,t}^2\right)$$

$$(3)\quad s_{e,t}^2 = a_0 + a_1 e_{t-1}^2 + a_2 s_{e,t-1}^2$$

$$(4)\quad m_t = r m_{t-1} + u_t$$

$$(5)\quad f_{i,t} = f_{i,t-1} + x_{i,t} \qquad i = 1, 2, \ldots, k$$

where $p_t$ is the rate of inflation prevailing between periods $t$-1 and $t$, which, according to (1), is postulated to evolve according to an AR($k$) process, with random autoregressive coefficients $f_{1,t}$, …, $f_{k,t}$—in what follows, the lag order $k$ is chosen based on the Akaike information criterion; $m_t$ is a 'drift' term designed to capture low-frequency shifts in the equilibrium level of inflation, which, according to (4) is postulated to evolve according to a zero-mean, stationary AR(1) process[12]; $e_t$ is a shock to the rate of inflation whose distribution at time $t$ conditional on information at time $t$-1 is, according to (2), normal with conditional variance $s_{e,t}^2$; $s_{e,t}^2$, in turn, is postulated, according to (3), to evolve according to a GARCH(1,1) process; and the random autoregressive coefficients in the AR($k$) representation for inflation, $f_{1,t}$, …, $f_{k,t}$, are postulated, according to (5), to evolve according to a random walk. The structure (1)-(5) is specifically designed to capture the notions that (a) over the sample period, the persistence properties of inflation—here captured by the time-varying

[12] In including a drift term in the inflation equation I follow CS (2002a, 2002b). My results are therefore, conceptually, exactly comparable to theirs. I experimented with three different representations for the low-frequency component of inflation: a zero-mean stationary AR(1); a non zero-mean stationary AR(1); and a random walk. Results based on the non zero-mean stationary AR(1) and on the random walk representations (not reported here, but available upon request) are qualitatively similar to those discussed herein. On strictly logical grounds, a stationary AR(1) representation for the low-frequency component of inflation appears as more plausible than a random walk, given that for countries like the US and the UK trend inflation should gravitate, in the long run, around a value close to zero (as for the US, see for example DeLong (2000).

autoregressive coefficients, $f_{1,t}$, …, $f_{k,t}$—may not have remained constant, and could have changed in a systematic way with changes in the monetary regime; (b) different historical periods may have been associated with different volatilities of the shocks to the rate of inflation [13]; and (c) different historical periods may have been associated with different equilibrium levels of inflation.

One obvious criticism of the structure (1)-(5) is the assumption of zero correlation among the shocks. In particular, it may be reasonable to expect a positive correlation between $e_t$ and $u_t$: as a succession of positive (negative) $e_t$ shocks push the rate of inflation up (down), we may expect an increase (decrease) in the equilibrium level of inflation. More generally, the restriction of zero correlation among the shocks should be tested, instead of being imposed from the outset. Although I am going to relax such an assumption in a future version of the paper, for the time being a simple defense of the assumption of zero correlation among the shocks is to notice that CS (2002a, 2002b) obtain qualitatively the same results based on a VAR(2) with time-invariant covariance matrices, and allowing for correlation among the shocks, and based on a VAR(2) with stochastic volatility, but allowing no correlation among the shocks. So the issue of correlation/no correlation among the shocks, although important in principle, is probably in practice not really that relevant.

Given that the shocks to the rate of inflation are not observed, in the spirit of Harvey, Ruiz, and Sentana (1992), and following the discussion in Kim and Nelson (2000, section 6.1.3), I augment the state vector to include $e_t$, and I replace, within the Kalman filtering algorithm, $e_{t-1}^2$ with its estimate conditional on information at time $t$-1, $E_{t-1}(e_{t-1}^2)$:

$$(6)\quad s_{e,t}^2 = a_0 + a_1 e_{t-1}^2 + a_2 s_{e,t-1}^2 \cong a_0 + a_1 E_{t-1}\left(e_{t-1}^2\right) + a_2 s_{e,t-1}^2 = \\ = \ldots = a_0 + a_1\left[\left(e_{t-1|t-1}\right)^2 + E_{t-1}\left(e_{t-1} - e_{t-1|t-1}\right)^2\right] + a_2 s_{e,t-1}^2$$

where $E_{t-1}(x)\equiv E(x|I_{t-1})$, and $e_{t-1|t-1}=E_{t-1}(e_{t-1})$, with $E_{t-1}(e_{t-1}-e_{t-1|t-1})^2$ being its estimated precision, conditional on information at time $t$-1. Both $e_{t-1|t-1}$ and $E_{t-1}(e_{t-1}-e_{t-1|t-1})^2$ can then be easily recovered from the approximated, extended Kalman filter described below. The system to be estimated is therefore given by (1)-(2) and (4)-(6). By defining the state vector, $s_t$, as

$$(7)\quad s_t = \left[f_{1,t} \quad \ldots \quad f_{k,t} \quad m_t \quad m_{t-1} \quad \ldots \quad m_{t-k} \quad e_t\right]'$$

and by further defining

$$(8)\quad w_t \equiv \left[x_{1,t} \quad x_{2,t} \quad \ldots \quad x_{k,t} \quad u_t \quad 0 \quad 0 \quad \ldots \quad 0 \quad e_t\right]'$$

$$(9)\quad c_t \equiv f_{1,t|t-1} m_{t-1|t-1} + f_{2,t|t-1} m_{t-2|t-1} + \ldots + f_{k,t|t-1} m_{t-k|t-1}$$

$$(10)\quad H_t' \equiv \left[\left(p_{t-1} - m_{t-1|t-1}\right) \quad \left(p_{t-2} - m_{t-2|t-1}\right) \quad \ldots \quad \left(p_{t-k} - m_{t-k|t-1}\right) \quad \ldots \right. \\ \left. \ldots \quad 1 \quad -f_{1,t|t-1} \quad -f_{2,t|t-1} \quad \ldots \quad -f_{k,t|t-1} \quad 0\right]$$

[13] This is apparent from simply eyeballing figures like 2 and 24. A second reason for introducing conditional heteroskedasticity is to take into account of the key criticism raised by Stock (2002) in his comment on CS (2002a). In particular, Stock has conjectured that CS' (2002a) main result—inflation persistence in post-WWII US was comparatively low in the 1960s, high in the 1970s, it peaked around the beginning of the Volcker disinflation, and it has been decreasing ever since—crucially depends on the fact that they did not control for conditional heteroskedasticity.

$$(11) \quad F \equiv \begin{bmatrix} I_k & & 0_{k\times(k+2)} \\ 0_{1\times k} & \rho & 0_{1\times(k+1)} \\ 0_{k\times k} & I_k & 0_{k\times 2} \\ & 0_{1\times(2k+2)} & \end{bmatrix}$$

where $I_j$ and $0_{i\times j}$ are the $j\times j$ identity matrix and, respectively, an $i\times j$ matrix of zeros, the transition equation is given by

$$(12) \quad s_t = Fs_{t-1} + w_t$$

with time-varying covariance matrix

$$(13) \quad Q_t \equiv E_{t-1}\left[w_t w_t^{'}\right] = \text{diag}\left(\left[\sigma_{x,1}^2 \quad \sigma_{x,2}^2 \quad \ldots \quad \sigma_{x,4}^2 \quad \sigma_u^2 \quad 0 \quad 0 \quad \ldots \quad 0 \quad \sigma_{\varepsilon,t}^2\right]^{'}\right)$$

while the linearised[14] observation equation of the approximated, extended Kalman filter is given by:

$$(14) \quad \pi_t = c_t + H_t^{'} s_t$$

Following Harvey (1989), Hamilton (1994b), and Kim and Nelson (2000) the prediction error decomposition of the log-likelihood can be written as

$$(15) \quad \ln L = -\frac{T}{2}\ln(2\pi) - \frac{1}{2}\sum_{t=1}^{T}\ln\left\|H_t^{'}P_{t|t-1}H_t\right\| - \frac{1}{2}\sum_{t=1}^{T}\frac{\tilde{\varepsilon}_t^2}{\left(H_t^{'}P_{t|t-1}H_t\right)}$$

where the one-step-ahead forecast error is given by

$$(16) \quad \tilde{\varepsilon}_t = \left(1 - \phi_{1,t|t-1}L - \phi_{2,t|t-1}L^2 - \phi_{3,t|t-1}L^3 - \phi_{4,t|t-1}L^4\right)\left(\pi_t - \mu_{t|t-1}\right)$$

while the prediction equations for the approximated, extended Kalman filter are given by

$$(17) \quad s_{t+1|t} = Fs_{t|t-1} + FP_{t|t-1}H_t\left(H_t^{'}P_{t|t-1}H_t\right)^{-1}\tilde{\varepsilon}_t$$

and

$$(18) \quad P_{t+1|t} = Q_t + F\left[P_{t|t-1} - P_{t|t-1}H_t\left(H_t^{'}P_{t|t-1}H_t\right)^{-1}H_t^{'}P_{t|t-1}\right]F^{'}$$

Estimation of the model given by (1)-(2) and (4)-(6) has been performed via maximum likelihood[15]. Since the analysis that follows is entirely based on the theoretical spectral statistics recovered from the estimated time-varying AR($k$), and given that Fourier analysis cannot be applied to non-stationary processes, a crucial issue is how to make sure

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[14] Following Harvey (1989), linearisation has been implemented by taking a Taylor expansion of (1) around $s_{t|t-1}$.

[15] The log-likelihood function has been maximised numerically with respect to unknown parameters by means of the MATLAB subroutine `fminsearch.m`, based on the Nelder-Mead simplex algorithm. All the data and the computer programs (written in MATLAB) used for this paper are available upon request.

that the process for inflation remains stationary[16], while at the same time allowing $f_{1,t}, \ldots, f_{k,t}$ to shift stochastically over time. In estimating the model I have adopted the following rule[17]: when a new observation of $p_t$ becomes available, I allow for updating of the state vector $s_t$=[$f_{1,t} \ldots f_{k,t}\, m_t\, m_{t-1} \ldots m_{t-k}\, e_t$]' if the resulting estimate, $s_{t|t}$, maintains the process for inflation stable (The stability condition is checked based on the autoregressive roots of the AR($k$)). If, on the other hand, the resulting process turns out to be unstable, I project the update onto the nearest point in the stable region[18]. Quite remarkably, as I further discuss in the following section, the stability condition was almost never violated for any country. For the United States, for example, based on the Balke-Gordon GNP deflator-based inflation series, out of 504 observations over the period 1875:2-2001:1, the stability condition was violated in only 7 cases based on the one-sided estimates (specifically in 1932:1, 1945:4-1946:1, 1946:3, 1974:3-1974:4, 1980:4), and in zero cases based on the two-sided ones. For the UK, based on the linked retail price-CPI series plotted in figure 17, the stability condition was violated in 13 cases based on the one-sided estimates (specifically in 1971:1-1971:2, 1973:4-1974:2, 1974:4-1975:3, 1979:3, 1980:2, 1989:2, 1990:2), and in zero cases based on the two-sided ones[19].

Based on the estimated structure—specifically, based on either one-sided or two-sided estimates of the state variables, $f_{1,t}, \ldots, f_{k,t}, m_t, m_{t-1}, \ldots, m_{t-k}, e_t$—the time-varying spectral density of inflation can then be computed according to the formula

$$(19) \quad S_{p,t|t}(w) = \frac{s^2_{e,t|t}}{2p} \frac{1}{\left\| 1 - f_{1,t|t} e^{-iw} + f_{2,t|t} e^{-2iw} + f_{3,t|t} e^{-3iw} + f_{4,t|t} e^{-4iw} \right\|^2} + \frac{s^2_u}{2p} \frac{1}{\left\| 1 - re^{-iw} \right\|^2}$$

for $t$=$t$ in the case of one-sided estimates, and $t$=$T$ (with $T$ being the sample length) in the case of two-sided ones, thus providing a complete characterization of the time-varying time series properties of inflation over the sample period. For our specific purposes—evaluating changes in inflation persistence—expression (19) suffers from the disadvantage that, in general, $S_{p,t|t}(w)$ will experience shifts both as a result of changes in the conditional volatility of shocks to inflation, $s_{e,t}^2$, and as a result of changes in inflation persistence, captured by $f_{1,t}, \ldots, f_{k,t}$. In particular, changes in $s_{e,t}^2$ will shift the entire spectral density either up or down, without however 'twisting' it[20], while changes in inflation persistence for a given value of $s_{e,t}^2$ will twist the shape of the spectral density, with an increase in persistence increasing the amount of spectral power at the very low frequencies. In order to be capable of correctly assessing changes in inflation persistence over time we therefore need to separate the two effects, and in what follows I will therefore focus on the 'corrected' expression for the spectral density one obtains from (19) by replacing $s_{e,t|t}^2$ with $s_{e,T|T}^2$—in other words, I keep the estimated conditional volatility of shocks to the rate of inflation constant at the estimated value for the most recent quarter, thus making shifts in the estimated spectral densities of inflation to uniquely depend on changes in inflation persistence[21]. Finally, since inflation

[16] As stressed for example by CS (2002a) for the US, imposing a stationarity condition on a time-varying autoregressive representation for a (vector of) macroeconomic variable(s) from an advanced capitalistic economy may be justified based on the entirely reasonable assumption that for an advanced country explosive dynamics are extremely unlikely. I feel that such a 'stability prior' should not be relaxed even in the face of extreme events like the two World Wars and the Great Depression, for the simple reason that, as history has clearly shown, in advanced economies the policymaker acts as a 'stability supplier of last resort'. (Obviously, this does not hold for all countries and sample periods).

[17] I thank Tim Cogley for suggesting such an approach.

[18] Specifically, I compute the autoregressive roots, and I project the unstable roots onto the nearest point in the stable region.

[19] For the UK, it is interesting to notice how all of the violations of the stability condition took place during the period 1970-1990.

[20] In other words, the slope of the spectral density at each frequency will remain unaffected.

[21] Another possibility, adopted by CS (2002b), is to focus on the normalised spectrum.

persistence is defined in terms of the persistence of the deviations from the low-frequency component of inflation, I drop the spectral density of $m_t$ from (19), thus getting the following corrected expression:

$$(20) \qquad S^{*}_{p,t|t}(w) = \frac{s^{2}_{e,T|T}}{2p} \frac{1}{\left\| 1 - f_{1,t|t} e^{-iw} + f_{2,t|t} e^{-2iw} + f_{3,t|t} e^{-3iw} + f_{4,t|t} e^{-4iw} \right\|^{2}}$$

Expression (20) is the key expression I will use in what follows.

### *3. The Data*

The consumer price indices used for figure 1 are from the *OECD* database for all countries except the US, for which data are from the *Federal Reserve* database[22]. The sample periods are the following: US, 1947:1-2001:1; West Germany, 1962:1-1996:4; UK, Canada, Sweden, France, Italy, Japan, and Switzerland, 1962:1-2000:4.

The US GNP deflator series used for figure 2 is from Balke and Gordon (1986) for the period 1875:1-1950:1, and from US Department of Commerce, *Bureau of Economic Analysis*, for the period 1950:2-2001:1. The US wholesale price index plotted in figure 5 has been constructed by linking the classic Warren-Pearson (1933) index, available from 1793:4 to 1913:12; the wholesale price index from the *NBER* historical database[23], available from 1890:1 to 1968:12; the wholesale price index from *U.S. Department of Labor, Bureau of Labor Statistics*, available since January 1946[24]; and the wholesale price index from the *Federal Reserve* database for the most recent period.

The seasonally unadjusted UK retail price index, available for the period 1914:4-1962:1, is from Capie and Webber (1985), and has been linked to the seasonally unadjusted CPI from the OECD database, available from 1962:1. The long run annual series plotted in figure 16 has been constructed by linking the Elisabeth Schumpeter consumer price indices, the Gayer-Rostow-Schwartz index, and the Sauerbeck-Statist index, all from Mitchell and Deane (1962), with the series from the OECD database for the most recent period.

Old price series for categories of goods with different degree of processing are from the *NBER* historical database. The series codes are: raw materials, 04167; semi-manufactured goods, 04168; manufactured goods, 04169. All the three series are monthly, and are available from 1913:1 to 1951:12. The most recent series—'Crude materials for further processing', 'Intermediate materials, supplies, and components', and 'Finished goods', all available from 1947:2 to 2000:4—are from the *Federal Reserve* database, but have been produced by the *Bureau of Labor Statistics*. Long historical series for the prices of raw commodities are from the *NBER* historical database. The series codes are: cattle, 04007 (sample period: 1858:1-1940:4); fresh eggs, 04143 (sample period: 1890:1-1942:4); copper, 04015 (sample period: 1860:1-1940:4); industrial commodities, 04189 (sample period: 1904:1-1959:3); wheat, 04001 (sample period: 1841:1-1951:4); corn, 04005 (sample period: 1860:1-1951:4); and cotton, 04006 (sample period: 1871:1-1955:4).

The series used for the top panel of figure 30 are from *Historical Statistics of the United States, Colonial Times to 1970*, p. 240 ("National income and persons engaged in production, by industry divisions: 1869 to 1970")[25], while the series used for the bottom panel

[22] At http://www.stls.frb.org/fred. The series is CPIAUCSL (consumer price index for all urban consumers, all items, monthly, seasonally adjusted).
[23] At http://www.nber.org.
[24] At http://www.bls.gov/ppi. Acronym: PPIACO (producer price index: all commodities, 1982=100, not seasonally adjusted).
[25] National income, percent distribution: Martin estimates until 1929-1937, Commerce estimates after that.

are from Tables 6.1A, B, C of the *National Income and Product Accounts*[26] ("National Income Without Capital Consumption Adjustment by Industry Group, Billions of dollars").

As for the indicators of supply-side developments used in figure 31, the spot oil price is from the *Dow Jones Energy Service* ("West Texas Intermediate: Prior 82 = Posted Price, Dollar Per Barrel"). The CPI for food ("Consumer Price Index for All Urban Consumers: Food 1982-84 = 100, Seasonally Adjusted"), the PPI for fuels and related products ("Fuels & Related Products & Power, 1982 = 100, Not Seasonally Adjusted"), and the PPI for crude materials for further processing ("Crude Materials for Further Processing 1982=100, Seasonally Adjusted") are from the *US Department of Labor, Bureau of Labor Statistics*.

## *4. Empirical Results*

### *4.1. Evidence from the United States*

Let's start with some empirical evidence from the US over the last 125 years. Figure 2 shows quarterly US inflation, measured as the first difference in the log of the GNP deflator, quoted at an annual rate, over the period 1875:2-2001:1. Even a simple visual inspection gives an impression of dramatic changes in the stochastic properties of inflation over the sample period. Inflation appears to have been extremely volatile, and weakly persistent, during the Classical Gold Standard period (1879:2-1913:4); still very volatile, but significantly more persistent, during the period between the collapse of the Classical Gold Standard[27] and the beginning of the Bretton Woods regime (1914:1-1947:1), which comprises the two World Wars and the Great Depression[28] (in particular, the impact of the Great Depression is visible in the deflationary episode during the first half of the 1930s); still volatile during the very first years of the Bretton Woods regime (1947:2-1971:3)[29], but more and more persistent towards the end; finally, during the post-Bretton Woods 'pure discretion' regime[30] (1971:4-present) inflation appears to have been very highly persistent during the 'Great Inflation' years, from the breakdown of Bretton Woods to the beginning of the 1980s, but less so during the more recent period. The uniqueness of the 'Great Inflation' episode in the US economic history stressed, for example, by De Long (1997), i.e. readily apparent from the graph.

Table 1 reports sample moments of US GNP deflator inflation since 1879. Inflation was very low on average, but markedly volatile, during the Classical Gold Standard period; relatively high, and extremely volatile, during the turbulent years between the collapse of the Classical Gold Standard and the beginning of Bretton Woods; lower, and much less volatile, during the Bretton Woods regime; and highest on average, but least volatile, during the post-Bretton Woods period.

[26] At http://www.bea.doc.gov/bea/dn/nipaweb/SelectTable.asp?Selected=N.
[27] The creation of the Federal Reserve System was almost contemporaneous to the collapse of the Classical Gold Standard.
[28] Given the extremely peculiar nature of the interwar period, empirical evidence concerning those years should be considered with extreme caution.
[29] The official date marking the end of the Bretton Woods regime is taken to be August 15, 1971, the day in which Richard Nixon announced the closure of the 'gold window'.
[30] It is quite customary to divide the post-Bretton Woods economic history of the United States into two distinct sub-periods, pre- and after-Paul Volcker, and it is not uncommon to find scholars who state that 'Paul Volcker launched *a new monetary policy regime'* (see Barsky and Kilian, 2001, p. 6, emphasis added). For our purposes, I treat the post-1971 period as a *unique, internally homogenous* monetary regime. Indeed, I see the essence of the post-Bretton Woods regime in the US as represented by the absence of a clearly defined monetary constitution—which 'makes pure discretion the name of the game'—and I see Paul Volcker as inaugurating a change in attitudes/preferences/theoretical convictions towards inflation within a given, unchanged set of 'rules of the game', rather than introducing a *new* set of rules of the game.

Table 2, and Figures 3 and 4, provide three alternative perspectives on the extent of changes in US inflation persistence across monetary regimes. Both Dickey-Fuller and augmented Dickey-Fuller test statistics[31], and estimated autocorrelation functions confirm the visual impression of a very low degree of inflation persistence during the Classical Gold Standard period[32]. The post-Bretton Woods period, on the other hand, appears overall as the one characterized by the greatest extent of inflation persistence: the null of a unit root in inflation cannot be rejected at the 10 per cent level, while the estimated autocorrelation function exhibits the slow decay typical of highly persistent processes. Finally, in between we find the period between the collapse of the Classical Gold Standard and the beginning of Bretton Woods, and the Bretton Woods regime, with the former period being characterized, overall, by a greater persistence than the latter—in particular, estimated autocorrelation functions clearly point towards a lower inflation persistence of Bretton Woods compared with the period 1914-1947[33]. Finally, figure 4 plots rolling autocorrelations for US GNP deflator inflation based on three different sizes of the rolling window, 6, 8, and 10 years. (Each autocorrelation is plotted against the middle quarter of the rolling window.) The three panels provide a crude but consistent picture of the evolution of US inflation persistence over several decades. Persistence was essentially non-existent during the Gold Standard years, it markedly increased corresponding to the collapse of the Classical Gold Standard, and fluctuated at comparatively high levels until around the beginning of Bretton Woods. After 1947, it decreased until around 1960, and then started increasing well before the collapse of Bretton Woods, peaking around the beginning of the Volcker disinflation. After the first half of the 1980s, it progressively decreased, to the point that the most recent estimate of the autocorrelation function at lag one is, depending on the window size, between 0.1682 and 0.2564.

Let's go back in time even further. Figure 5 plots the logarithm of the US wholesale price index, and US wholesale price inflation, since 1793, while figure 6 and 7 plot estimated autocorrelation functions of wholesale price inflation for several alternative monetary regimes/historical periods and, respectively, rolling autocorrelations based on three sizes of the rolling window, 6, 8, and 10 years. Figures 5 and 6 divide US monetary history since 1793 into seven distinct monetary regimes/historical periods: the de facto *silver standard* prevailing until 1837[34]; the *de facto* gold standard prevailing between 1837 and the beginning of the US Civil War; the 'greenback period', from 1862 until the Gold Standard resumption in 1879; the Classical Gold Standard regime; the transitional period between 1914 and the beginning of Bretton Woods; the Bretton Woods regime; and the post-Bretton Woods 'purely discretionary' period. It is apparent from figure 5 how the US price level at the time of the collapse of the Gold Standard was essentially the same as in 1793: despite upwards and downwars fluctuations—the most significant of which associated to the Civil War—US prices displayed no significant trend over a period of 120 years. Ignoring the turbulent years between 1914 and 1947, the dynamics of the US price level displays a clear regime shift during the Bretton Woods years and, especially, after Richard Nixon's closing of the 'gold window', in August 1971. In particular, the uniqueness of the 'Great Inflation' episode in US history is readily apparent from the graph. Turning to figure 6, the difference between the

[31] Dickey-Fuller and augmented Dickey-Fuller test statistics reported in Table 2 are based on a model with an intercept but no time trend. Qualitatively similar results (not reported here, but available upon request) can be obtained based on a model with an intercept and a time trend.

[32] A pioneering investigation of the stochastic properties of inflation during the Classical Gold Standard period can be found in Barsky (1987).

[33] Qualitatively similar results can be found for example in Backus and Kehoe (1992), based on long spans of annual data for ten countries.

[34] As recollected for example in Bordo and Kydland (1996, p. 213), the shift from a *de facto* silver standard to a *de facto* gold standard was prompted by the Coinage Acts of 1834 and especially 1837, '[…] which changed the bimetallic ratio to 16:1, presumably in an attempt to restore bimetallism. As it turned out, gold became overvalued at the mint, silver became undervalued, and the United States switched to a *de facto* gold standard.' In other words, the shift was caused, once again, by the operation of Gresham's Law.

'metallic standard world' and the post-1914 period appears as striking: irrespective of the specific *de facto* or *de jure* standard, and of the particular historical period, the pre-1914 world does not display any evidence of inflation persistence whatsoever—the only exception being the *de facto* silver standard prevailing between 1793 and 1837, for which some weak evidence of persistence is indeed detectable. Particularly telling is the absence of persistence during the 'greenback period', i.e. during a period in which the gold standard was temporarily suspended and the US operated under a fiat money regime. Despite the fact that the period 1862-1879 comprises the single most catastrophic event in United States history—the Civil War—still it is not possible to reject, at the 95% level, the null that inflation during those years was white noise. The contrast with the post-Bretton Woods years, a prosperous and relatively peaceful period, could not be starker. How is this possible? A plausible explanation seems to be what McKinnon (1993) defines as the 'restoration rule'. From his 'Rule Box' for the gold standard I report the following two rules.

**I.** Fix an official gold price or 'mint parity', and convert freely between domestic money and gold at that price.

[…]

**V.** If Rule I is temporarily suspended, restore convertibility at traditional mint parity as soon as practicable—if necessary by deflating the domestic economy.

This mechanism—the same mentioned by Barro (1982) in the opening quotation—is sufficient, if credible, to anchor inflation expectations, thus preventing inflation from 'taking off' and acquiring persistence[35]. Empirical evidence is not incompatible with such a conjecture. As recollected by by Bordo and Kydland (1996, pp. 214-215),

[u]nder the Legal Tender Acts, [the greenback] notes *were issued on the presumption that they would be convertible, but the date and provisions for convertibility were not specified*. Shortly after the war, the government made its intenctions clear to resume payments at the prewar parity in the Contraction Act of April 12, 1866, which provided for the limited withdrawal of U.S. notes. […] Finally, the decision to resume payments on January 1, 1879 was made in the Resumption Act of 1875 […]. (emphasis added)

The top panel of figure 5 shows how, after the price spike of the last months of 1864, the prolonged period of deflation that ultimately allowed the U.S. to resume the Gold Standard in 1879 started precisely around the time of the Contraction Act of April 1866. A plausible explanation for the difference between the stochastic properties of inflation during the 'Greenback period' and the post-Bretton Woods period is therefore that, as stressed by Barro in the opening quotation, after the collapse of Bretton Woods (a) there was no presumption whatsoever that the dollar would be made again convertible into gold at some future, albeit unspecified, date, and (b) no law in that sense was ever passed, thus severing not only currently, *but also prospectively*, the link between gold and the amount of notes in circulation.

Let's now turn to estimated time-varying statistics[36]. Based on the Akaike information criterion, the optimal value of $k$ turned out to be 1 for both the Balke-Gordon, and the Warren-Pearson series. Figures 8 to 15 show results from estimating model (1)-(2) and (4)-(6) based on the two series plotted in figures 2 and 5. Figures 8, 9, and 10 plot the equilibrium level of inflation, together with the estimated time-varying autoregressive coefficient; the time-varying variance of the inflation shocks (plotted on a logarithmic scale) and the absolute value of the inflation shocks; and the logarithm of the (non-corrected) spectral density of US GNP deflator inflation. Figures 11 and 12 show the one-sided and, respectively, two-sided log corrected spectral densities of US inflation based on the GNP

[35] To put it differently, in a world of rational expectations the credible promise to restore the gold standard 10 or 15 years down the road is sufficient to anchor inflation expectations now.

[36] Results from maximum likelihood estimation of model (1)-(2), (4)-(6), are reported in table 8, together with estimated standard errors (in parentheses). Standard errors have been computed by taking the square root of the diagonal elements of the inverse Hessian. The Hessian has been computed via the 'outer product' formula of Berndt, Hall, Hall, and Hausman (1974).

deflator series, while figure 13 shows the one-sided and two-sided log corrected spectral densities at frequency zero. Finally, as for the Warren-Person-based inflation series, figures 14-15 only plot the two-sided log corrected spectral densities, and respectively the one-sided and two-sided log corrected spectral densities at frequency zero.

Estimated equilibrium levels of inflation, especially the one-sided one[37], well capture some of the most significant events in US macroeconomic history since 1875: the pre-Gold Standard resumption deflation which ended abruptly in 1879, the rise in average inflation associated to WWI, the Great Depression deflation, the 'Great Inflation' of the 1970s, and the most recent period of relative price stability. Figure 10, plotting the two-sided log spectral density of inflation, dramatically illustrates the marked changes in the stochastic properties of the series since 1875. For the purpose of measuring persistence, however, is suffers from the drawback that it does not allow to disentangle shifts in persistence and shifts in the conditional volatility of the shocks, which, as figure 9 illustrates, have indeed been substantial. Figures 8 (bottom panels) and 11-13 provide alternative evidence on shifts in persistence. Several features stand out: (a) the low persistence during the Classical Gold Standard period, with the upward jump corresponding to the collapse of the regime[38]; (b) the period of comparatively high persistence between 1914 and 1947 (in particular, figures 12-13 clearly illustrate the marked persistence of the Great Depression deflation)[39]; (c) the steady decrease in persistence from the beginning of Bretton Woods up until around 1960, with persistence estimated to have reached, at the times of John Kennedy, levels comparable to those of the Classical Gold Standard; (d) the increase in persistence well before the collapse of Bretton Woods, and the marked upward jump immediately following the closing of the 'gold window' in August 1971; (e) the peak reached around the beginning of the Volcker disinflation, and the drastic and steady decline over the following two decades, with persistence estimated to be, today, at levels comparable to those of the Gold Standard.

What precedes suggests that, different from what conjectured by Stock (2002) in his comment on CS (2002a), CS' main finding—US inflation persistence was low during the 1960s, high during the 1970s, it peaked around the beginning of the Volcker disinflation, and it has been basically decreasing ever since—

[37] As pointed out by Sims (2002) in his comment on CS (2002a), one-sided estimates suffer from the drawback that they may exhibit temporary fluctuations even in time-invariant systems. In order to avoid such potential pitfalls, the present paper mostly focuses on two-sided estimates. It is important, however, to stress how Sims' position is not entirely warranted. Although two-sided estimates are by definition statistically optimal, in the sense of representing the linear projection of the object of interest upon the entire sample, instead of being the linear projection of the same object only upon information up until time $t$, in the case of stochastic processes experiencing sharp breaks—like, it seems reasonable to assume, the data generation process for US inflation following the collapse of the Gold Standard and of Bretton Woods—two-sided estimates tend to 'mix the future with the past', thus, in our case, 'transferring persistence back in time'. In general, a proper evaluation of changes in the stochastic properties of inflation over time seems therefore to require some careful judgement in evaluating both one-sided and two-sided estimates. Particularly interesting is the difference between the one-sided and the two-sided estimates of the equilibrium level of inflation in the two top panels of figure 8, as far as the Gold Standard resumption is concerned. While the one-sided estimate perfectly captures the end of the 1866-1879 deflation that allowed the U.S. to return to gold, the two-sided estimate misses it completely. This represents clear *prima facie* evidence that one-sided estimates, although noisier, are probably 'truer' than two-sided ones.

[38] It has been argued that a more plausible explanation for the upward jump in inflation persistence around 1914 is the First World War. This seems hard to believe, given that WWI only lasted a few years, while persistence remained at comparatively high levels until the beginning of Bretton Woods.

[39] Given the peculiarity and the remarkable turbulence of the interwar period, results concerning those years should be taken with more than the usual grain of salt. Both Friedman and Schwartz (1963), and Sachs (1980), discuss the 'perverse' nature of wage and price dynamics during that period, and especially during the 1930s, stressing how such a dynamics was largely influenced by the industrial recovery measures undertaken by the Roosevelt administration.

- does not depend on CS' Bayesian priors: the same results have been obtained based on frequentist methods;
- it does not depend on the fact that CS did not control for the presence of conditional heteroskedasticity: the present model does indeed allow the conditional volatility of shocks to inflation to change over time according to a GARCH(1,1) specification[40];
- finally, it does not depend on the dimension of the estimated system and on the variables included or excluded: I have obtained the same result based on a time-varying univariate representation for inflation, while CS (2002a) used a VAR(2) for inflation, the logit of the rate of unemployment, and a short-term *ex-post* real rate.

Although such empirical evidence, quite obviously, does not prove anything, the fact that four of the most significant events in the monetary history of the United States since 1879—the collapse of the Gold Standard, the beginning of Bretton Woods, the collapse of Bretton Woods, and the beginning of the Volcker disinflation—appear to be associated with marked changes in inflation persistence is suggestive of a possible role of monetary regimes in determining the extent of persistence. In particular, all those researchers who, implicitly or explicitly, assume that inflation persistence is high and basically constant, and therefore has to be 'hardwired' in the structure of a macroeconomic model[41], ought to be capable of explaining such a historical pattern. Why was persistence all but absent during the Gold Standard period, and why did it jump upwards after the collapse of the system? Why did persistence evolve in such a peculiar way during the Bretton Woods years? Why did it jump upwards after 1971, and why did it decrease even more markedly after the beginning of the Volcker disinflation? Although, as I discuss in section 6, a number of alternative explanations are, at least in theory, possible, the impact of the operating rules of the monetary regime in place on the stochastic properties of inflation appears, at least to me, a very strong candidate.

As for wholesale price inflation, figures 14 and 15 plot the two-sided log corrected spectral densities and, respectively, the one-sided and two-sided log corrected spectral densities at the frequency zero. As for the period after 1879, evidence based on the Warren-Pearson index essentially confirms what we have discussed up until now, with the only exception of the most recent years, for which there is evidence of a mild increase in persistence. As for the period 1792-1879, consistent with the evidence reported in figure 6, persistence appears to have been fluctuating at comparatively low levels, with the possible exception of the silver standard prevailing up until 1837, for which some mild evidence of persistence is indeed detectable.

### *4.2. Evidence from the United Kingdom*

Let's now turn to the United Kingdom. Figure 16 plots the logarithm of the UK annual price level, and UK annual inflation, since the times of the Great Fire of London, while figure 17 plots UK consumer price inflation over the period 1914:4-2000:4. The key periods in the monetary history of the United Kingdom over the last 340 years are readily apparent from the top panel of figure 16, starting from the *de facto* silver standard prevailing until 1717, when the UK accidentally switched to a *de facto* gold standard due to a mistake of the then Master of the Mint, Sir Isaac Newton, in fixing the official parity between gold and silver[42]. The *de facto* gold standard[43] prevailed until the wars with France, when, in 1797, the

[40] CS (2002b) obtain very similar results based on an extension of the model used in CS (2002a), in which they allow for stochastic volatility in the covariance matrix of the observation equation of their time-varying Bayesian VAR.
[41] Pivetta and Reis (2002), for example, state that the 'persistence of inflation has been high and approximately constant over time [i.e., over the post-WWII period]. […] [An] implication of our results is that theories should predict very persistent inflation rates'.
[42] Once again, the *de facto* switch was due to the operation of Gresham's law.
[43] The gold standard was established *de jure* in 1816.

government relieved the *Bank of England* from its legal obligation of converting notes into gold on demand. The 'suspension period' lasted until 1821, when convertibility was restored at the prewar parity—again, McKinnon's Rule V in action. After that, the gold standard prevailed until 1914. Exactly as for the US (figure 5), figure 16 shows how the UK price level at the time of the collapse of the Classical Gold Standard was not significantly different from the beginning of the sample, in 1661: over a period of 253 years, no trend in the price level emerged. A comparison with the post-1947 world, on the other hand, is striking: both during Bretton Woods, and especially after 1971, the price level appears to literally take off.

Figure 17 shows quarterly UK inflation from 1914:2 to 2000:4. Inflation is here measured as the first difference in the log of the retail price index (from 1914:2 to 1962:1), and as the first difference in the log of the consumer price index (from 1962:2 to 2000:4), both quoted at an annual rate[44]. It is important to stress that both series are seasonally unadjusted. Given our use of frequency-domain techniques, this will have no impact on the analysis that follows (and in particular on our time-varying spectral-based measures of inflation persistence), but must be taken into account when 'eyeballing' figure 17.

Table 6 reports sample moments of UK inflation since 1914. Inflation was comparatively low on average, but remarkably volatile, during the years between 1914 and the immediate aftermath of WWII. It is worth stressing how both the mean and the standard deviation of UK inflation during those years were significantly close to the corresponding figures for the US (see for example Table 1). As in the case of the US, the Bretton Woods regime saw a marked decrease in the volatility of inflation, with its standard deviation falling by about two-thirds, but different from the US, average inflation during those years actually *increased*, and quite significantly so. In particular, Figure 17 clearly shows that such an increase cannot be attributed to the years immediately preceding the collapse of Bretton Woods: as the graph makes clear, inflation was comparatively high on average over the entire Bretton Woods period[45]. Over the period between the collapse of Bretton Woods and the adoption of inflation targeting, in 1992, inflation has been both remarkably high on average, 9.7%, and extremely volatile, with a standard deviation of 7.8%. Finally, over the most recent period since the adoption of inflation targeting, inflation has been both lowest on average, 2.6%, and least volatile, with a standard deviation of 2.1%, thus providing informal, *prima facie* evidence on the comparatively superior performance of the current monetary framework when seen from a historical perspective.[46] Table 7 reports results from Dickey-Fuller and augmented Dickey-Fuller tests for UK inflation since 1914.[47] Finally, figures 18 and 19 show estimated autocorrelations and, respectively, log estimated spectral densities of UK inflation since 1914. It is apparent how the seasonal component of inflation was comparatively large during the period between 1914 and the immediate aftermath of WWII, and has been still significant during the most recent period, from Bretton Woods to the creation of the *MPC*, but was quite negligible during the Bretton Woods period[48] (this pattern is particularly clear from

[44] The retail price index from Capie and Webber (1985) is available from 1914:3 to 1982:4, while the CPI, from the *OECD* database, is available starting from 1962:1. Over the period of overlapping, 1962:2-1982:4, the inflation sderies computed based on the two price indices are virtually identical, which makes their linking justified.

[45] For example, the average inflation rate for the subperiod ending in 1964:4 is 0.0386, still markedly higher than the 0.0294 for the period between 1914 and the beginning of Bretton Woods. Analogous results (available upon request) hold for subperiods with alternative ending dates up until the collapse of Bretton Woods in 1971.

[46] A very important point to stress, however, is that the price index analysed here *is not the one actually being targeted within the current monetary framework*, so that these figures do not bear an automatic link to the inflation measure based on which the performance of such a framework is actually evaluated. To put it differently, the figures in Table 6 should *only* be used for historical comparisons.

[47] Once again, results are based on a model with an intercept but no time trend.

[48] For a brief analysis of changes over time in the seasonal pattern of UK inflation, see appendix A.

figure 19).[49] Figure 20 plots rolling autocorrelations at lag 1 for three different window sizes, 6, 8, and 10 years. As in the case of the US, persistence seems to have experienced marked changes over the sample period. In particular, the period after 1947 displays a pattern very similar to the US, with the only exception of the years around 1990—the period of the so-called 'Lawson boom'.

Table 5 reports autocorrelations at lag one for UK annual inflation[50] for the period 1662-2000, based on the same series plotted in figure 16 (due to the limited number of observations for the most recent period, I do not report the autocorrelation for the inflation targeting regime). Consistent with the analysis of the previous section, the period of metallic standards (1662-1914) appears as lacking any persistence whatsoever, with the only possible exception of the 'Suspension period' between 1797 and 1821, when the United Kingdom was operating under a fiat money regime. It is important to stress, however, that even during this period—which comprises the Napoleonic Wars—the estimated autocorrelation at lag one is only 0.275, and is estimated very imprecisely. As in the case of the US, a comparison with the post-Bretton Woods period is striking, with the estimated autocorrelation at lag one equal to 0.667 (with a $t$-statistic of 3.697). Exactly as for the US, a plausible explanation for such a difference between the serial correlation properties of inflation under two alternative *fiat money* regimes is McKinnon's 'restoration rule': while a crucial characteristic of the Gold Standard was the explicit, or implicit, promise on the part of the government that convertibility would be restored as soon as possible at the pre-war parity[51], after 1971 no promise in that sense was ever made, so that the system completely lacked an anchor for inflation expectations.

Figures 21-24, based on the inflation series plotted in figure 17, show time-varying statistics recovered from the estimated random-coefficients model (in this case, the AIC selected $k=4$). Persistence is estimated to have been comparatively low during the very first years of the sample, and to have progressively increased reaching a peak around the time of WWII. Exactly as in the US, Bretton Woods saw a marked decline in the extent of inflation persistence until the first half of the 1960s, and then a rapid increase, with a peak reached shortly after the collapse of Bretton Woods. After fluctuating at comparatively high levels for about two decades, persistence is estimated to have decreased starting from the beginning of the 1990s[52]. As for the MPC years, the sample period is too short to make any meaningful statement, but persistence does not seem to have increased—in anything, the spectral density at $w=0$ seems to have been pointing downwards over the most recent years[53].

## *5. On the Comparability of Price Indices Across Historical Periods*

The logical possibility of investigating shifts in inflation persistence over time and across monetary regimes is predicated on the assumption that price indices from different

[49] Log estimated spectral densities, together with 95% confidence bands, have been computed by means of programs based on the formulas found in Fuller (1996, ch. 7). All of the programs (written in MATLAB) are available upon request.

[50] Estimation of the random-coefficients model based on the annual inflation series proved unfeasible, due to problems in getting plausible estimates of the low-frequency component (in particular, the algorithm estimates a trend component of inflation basically flat at zero).

[51] In the present case, convertibility with gold was even introduced *de jure* in 1816.

[52] Very similar results—in particular, a decrease in persistence over the most recent period—are obtained by Cogley, Morozov, and Sargent (2002, in progress), based on a Bayesian VAR(2) for inflation, unemployment, a short-term bill rate, and the real exchange rate appreciation, estimated over the period 1951:1-2000:4.

[53] Figure 23 also displays a striking pattern as far as the seasonal component of consumer price inflation is concerned. Consistent with the results reported in figures 18 and especially 19, the data reveal the existence of an 'old' seasonal component concentrated mostly in the 1920s and 1930s, and of a new one becoming truly sizeable only starting from mid-1960s. (As the figure makes clear, however, some seasonality was present also in the years in between.)

historical periods are indeed comparable. If, on the other hand, price indices for the Classical Gold Standard period were not comparable to price indices for (say) the Bretton Woods regime, or the post-Bretton Woods period, the entire exercise would obviously become non-sensical. The problem of the comparability of price indices across different historical period was first investigated in the seminal paper by Cagan (1975), but since then it has only been briefly discussed by Sachs (1980), and Schultze (1981). An important exception is the work of Christopher Hanes, who, in a series of recent papers[54], has strongly questioned the meaningfulness of comparing price indices across different historical periods, stressing how price indices for the most recent years do contain a greater proportion of comparatively highly processed goods—say, computers, televisions, and cars, as compared to little processed goods like most foodstuff, or (in the extreme case) raw commodities—than price indices for the older periods[55]. Since inflation appears to be more persistent for highly processed goods than for less processed ones, he argues that the crude, unadjusted comparison between the serial correlation properties of inflation across historical periods is systematically biased towards finding a greater extent of inflation persistence in recent years than in previous historical periods[56]. He therefore constructs a yearly price index whose composition is exactly comparable to that of the classic Warren-Pearson (1933) wholesale price index, and he shows that, based on such a fixed-bundle index, inflation persistence in the post-WWII period has only slightly increased compared to the Classical Gold Standard regime and the interwar period[57].

Although Hanes' results are challenging, in what follows I will argue that they can only represent a minor part of the overall story. Specifically, I will argue that, first, the empirical evidence in favor of Hanes' position is less solid than it appears at first sight; second, it cannot explain the fact that inflation persistence seems not only to increase, but also to *decrease* over the sample period; third, Hanes' story cannot possibly explain the *timing* of the shifts in inflation persistence we see in the data—specifically it cannot explain the fact that (for example) US inflation persistence seems to have increased at the time of the collapse of the Classical Gold Standard and of the Bretton Woods regimes, and to have decreased after the beginning of the Volcker disinflation.

Let's start by analysing, first of all, how solid the empirical evidence in favour of Hanes' position is, ignoring, for the time being, the previous findings about fluctuations in the extent of inflation persistence across monetary regimes. Figures 25 and 26 show long-run series for quarterly inflation (quoted at an annual rate) for a number of raw/basic commodities[58] (wheat, copper, corn, cotton, fresh eggs, and cattle), and for an index of basic

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[54] See Hanes (1992, 1998), and especially Hanes (1999).

[55] As pointed out by Sachs (1980, p. 80), '[…] cyclically flexible agriculture and food prices composed 43.06 per cent of the WPI [wholesale price index] in 1926 and only 20.95 per cent in 1970'. Schultze (1981, p. 538) similarly stresses how '[…] before 1947 the [WPI] did not include any significant coverage of machinery and equipment'.

[56] As discussed by Hanes (1999, p. 39), a second, related problem is that '[…] standard price series exaggerate the change over time in the composition of aggregate output. Nowadays the BLS [*Bureau of Labor Statistics*] collects large sample of prices, representing all stages of production in almost all sectors of the economy. Before the Second World War, however, and especially around the turn of the century, the BLS collected a much smaller sample of prices, concentrating on prices that were easy to get and goods that were easy to define. That meant mostly less processed goods and no services. […] Thus [price indices] for the prewar period, and to a lesser degree the interwar period, represent few of the more-processed products of the day.' As stressed by Hanes, such a problem also plagues the GNP deflator series reconstructed by Balke and Gordon (1986, 1989), for the simple reason that the lack of reliable price series for (comparatively highly) processed goods for the least recent years compelled them to base their reconstructed series on the available price series for less-processed goods. As he gloomily notes, '[t]here is no way around the hole in the historical record. We will never have time series of prices for most processed goods and services in the early periods'.

[57] See, in particular, Hanes (1999), Table 4.

[58] In other words, commodities whose basic characteristics may reasonably be expected to have remained unchanged over the sample period: wheat, and fresh eggs, today, are the same as wheat and fresh eggs in the XIX century.

industrial commodities, all based on price indices downloaded from the *NBER* historical database. Both a simple visual inspection, and empirical evidence based on autocorrelation functions and log estimated spectral densities for different sub-periods (not reported here, but available upon request) point towards essentially *no change* in the persistence properties of the seven inflation series over periods of several decades comprising different monetary regimes—a result which is clearly compatible with Hanes' position. The evidence displayed in figures 27 and 28, on the other hand, partly contradicts one of the pillars of Hanes' argument. Both during the Bretton Woods regime, and over the post-Bretton Woods period, quarterly inflation rates (quoted at an annual rate) based on three price indices for goods with different degree of processing do not exhibit the monotone increase in persistence (as measured by estimated autocorrelations) we would expect in going from the least processed to the most processed goods. Quite surprisingly, in both periods the greatest extent of inflation persistence is found for 'Intermediate materials, supplies, and components', while 'Crude materials for further processing' exhibit, as expected, no persistence whatsoever[59]. Finally, figure 29, based on quarterly inflation rates (quoted an at annual rate) for three categories of goods with different degrees of processing over the period 1914:1-1947:1, display an even more puzzling ranking, with the greatest persistence associated with finished products, followed by raw materials, and then by semi-manufactured goods. Overall, the empirical evidence concerning Hanes' position considered in itself seems therefore mixed.

More serious reservations, however, relate to the fact that Hanes' argument does not convincingly explain the following facts.

(a) Inflation persistence is estimated not only to have increased, but also to have *decreased*, in different sub-periods during the sample period. Taken literally, Hanes' argument implies that, as the composition of both the basket used to compute the CPI, and of overall production in the economy, progressively shifts from less processed to more processed goods, the extent of inflation persistence should tend to increase over time. The fact that US inflation persistence has been estimated to have significantly decreased during at least two sub-periods (from the beginning of the Bretton Woods regime up until around 1960, and following the Volcker disinflation), and that UK inflation persistence seems to have decreased in the 1990s, cannot be rationalised in this way.

(b) Equally important, the *timing* of the estimated shifts in inflation persistence is highly suggestive. In particular, Hanes' story does not explain the facts that (for example) US inflation persistence is estimated to have (i) significantly increased when the Classical Gold Standard collapsed; (ii) decreased following the creation of the Bretton Woods regime; (iii) progressively increased during the second half of the 1960s, and especially after the collapse of Bretton Woods; (iv) decreased immediately after the beginning of the Volcker disinflation. In order to be able to explain these phenomena within Hanes' framework, one has to make counterfactual assumptions about the evolution of the composition of both the CPI, and of overall production in the economy.

Overall, therefore, although the phenomenon discussed by Hanes may introduce a systematic tendency towards an increase, over time, in the overall extent of inflation persistence, it can only explain a minor part of the fluctuations in inflation persistence discussed in this paper.

## *6. Assessing Alternative Potential Explanations*

Changes in the stochastic properties of inflation can ultimately be traced back to changes in the data generation process for the structural shocks, changes in the structure of the economy, and changes in the policy regime. Which of these non-mutually exclusive

[59] These results therefore contradict the evidence reported in Hanes (1999, Table 3), which is based exactly on the same idea—comparing the serial correlation properties of inflation rates computed based on price indices for goods with different degree of processing (in his case he considers crude materials, intermediate products, and finished products).

explanations appear as more plausible? In this section I try to assess a number of alternative potential explanations.

### *6.1. Changes in the economic structure*

#### *6.1.1. Changes in the composition of overall production*

If the different sectors of the economy produce goods whose prices are characterised by systematic differences in the serial correlation properties of their rates of change, any change in the structure of the economy will necessarily affect the serial correlation properties of either the GNP or the GDP deflator inflation[60]. Agricultural prices, for example, are well-known for being significantly more volatile than the prices either of industrial goods, or of services. The shift from agriculture to manufacturing, and then to services, which took place in both the US and the UK over the last several decades may therefore have affected the persistence of aggregate inflation rates. Figure 30 presents empirical evidence on the structural transformation of the US economy since 1869, by plotting the percentage distribution of national income in current dollars by industry group. The various sectors are grouped into four main categories: (a) government; (b) agriculture, forestry, fisheries, and mining; (c) contract construction and manufacturing; and (d) services. Based on this evidence, it appears as implausible that changes in the composition of overall production may have played more than a minor role in determining the shifts in inflation persistence documented in section 4.1. Quite simply, the shifts are too gradual to be able to account for the wide and sometimes sharp fluctuations in persistence that took place over the sample period. For example: (i) the composition of production in 1910-1913 was basically the same as in 1918-1920, when instead figures 11-13 clearly show that a major increase in persistence had taken place; (ii) over the period 1950-1970 the composition of production did not register drastic changes, when instead, as we have seen, persistence first markedly decreased, and then markedly increased; (iii) around both 1971 and 1980 changes in the composition of production were very gradual, when on the contrary, in both cases persistence shifted markedly. Finally, after 1980, a slow but quite significant change in the composition of overall production took place, with a shift from manufacturing to services equal to about 15 percentage points. Although, in theory, it is certainly possible to imagine stories in which the increased importance of services represents the ultimate cause of the decrease in US inflation persistence over the last two decades, this appears, at least to me, quite a heroic enterprise.

#### *6.1.2. Changes in the extent of price and/or wage stickiness*[61]

A number of authors—Cagan (1975), Sachs (1980), Gordon (1983), and Taylor (1986)—have produced empirical evidence pointing towards a decrease in the responsiveness of wage and price inflation to measures of the cyclical component of economic activity in the post-WWII period, compared to previous decades, and interpret this as evidence in favor of an increase in the extent of wage and price stickiness. Let's assume, for the sake of the argument, that their interpretation is entirely correct, and that stickiness has indeed increased in the post-WWII period. Still, as stressed for example by Sachs (1980) the inference to be drawn from this is not clear, as stickiness should be considered, to a large extent, an *endogenous* variable, reacting to macroeconomic developments such as (a) changes in the equilibrium level of inflation[62] (and therefore, ultimately, to the operating rules of the monetary regime in place), or (b) changes in the policy regime. Sachs (1980, p. 87), for example, stresses how such evidence is entirely compatible with the notion that

[60] An analogous argument applies to changes in the patterns of consumption as reflected in changes in the composition of the CPI.
[61] [Get more recent references and discuss]
[62] See for example Kiley (1999).

> […] the emergence of countercyclical macro-economic policy since World War II has […] changed the cyclical behavior of wage and price setters. […] [G]rowing expectations of countercyclical macro-economic policy have smoothed the cyclical adjustments of production and employment in the private sector. It is also likely that such expectations have smoothed the cyclical movements of wages and prices.

Other possibilities he entertains are (a) the increase in the degree of unionisation of the labor force[63], and (b) the progressive spreading of long-term contracts. As for the first, most likely it can be fairly regarded as an entirely exogenous development, and therefore a potential explanation for the patterns in persistence discussed in section 4[64]. As for the second, it is not clear to which extent the progressive spread of long-term contracts should be considered as an entirely exogenous development.

Finally, it ought to be stressed that a number of specific episodes appear as difficult to rationalise in terms of changes in the extent of price stickiness. Estimated US inflation dynamics during the 1970s, in particular, seems to reject such a notion. As previously discussed in section 4.1., the equilibrium level of inflation in the US rose from about 2% during the 1960s to around 6% during the years between the collapse of Bretton Woods and the beginning of the Volcker disinflation. As a result, price stickiness should have, if anything, decreased, bringing about, *ceteris paribus*, a *decrease* in inflation persistence. The fact that, on the contrary, persistence is estimated to have markedly increased during those years cannot be rationalised within such a framework—at the very least, it is apparent that something else was going on.

*6.1.3. Changes in the extent of serial correlation of the structural shocks*

Changes in the extent of serial correlation of the structural shocks can, in theory, explain the previously discussed shifted in inflation persistence. For many years, for example, the dominant explanation of the stagflation of the 1970s appealed to the 1973 and 1979 oil shocks, and an analogous argument can be made for inflation persistence. My counter-arguments to this are the following. First of all, on strictly logical grounds, it appears as hard to believe that over the period 1792-1914 in the US, and 1662-1914 in the UK, the structural shocks hitting the economy were not highly serially correlated, and that they became serially correlated only after 1914. Second, let's consider the post-WWII period. Here the most popular alternative story[65] ascribes the increase in inflation persistence of the 1970s, and the decrease thereafter, to the oil price shocks of 1973 and 1979. Here a number of things have to be pointed out. First, while for many years oil price shocks represented the dominant explanation for the stagflation of the 1970s, in recent years a number of papers have questioned such a conventional wisdom. Clarida, Gali, and Gertler (2000) argue that the impact of supply shocks on both inflation and the output gap crucially depends on the nature of the monetary rule in place—so that the same pattern of supply shocks as in the 1970s would have produced, conditional on an activist monetary rule, completely different results—while Barsky and Kilian (2000) argue that the stagflation of the 1970s can be explained as an entirely monetary phenomenon, without the need to appeal to exogenous supply shocks. Second, empirical evidence appears as difficult to reconcile with the notion that the increase in persistence of the 1970s was caused by supply-side developments, simply because of timing considerations. Figure 31 plots the spectral density of inflation at zero, together with a number of alternative indicators of supply-side developments for the US over the post-WWII period (all series have been demeaned and standardised). The top panels show how over the period 1947-1980, inflation persistence does not display any clear correlation with either the

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[63] 'In the manufacturing sector, for instance, only 11.6 percent of production workers were organised in 1910, while by 1973, approximately 49 percent of manufacturing production employees were organised by labor unions. Economy wide, 5.8 percent of the civilian labor force belonged to unions in 1910, while 23.4 percent belonged in 1970' (Sachs, 1980, p. 88).

[64] [here get some data, and discuss].

[65] I.e., a story I have heard many times while presenting this paper at seminars.

real price of oil, or the PPI for fuel and related products. Further, the increase in persistence which started around mid-1960s well preceded both the jump in the price of oil in 1971, and the increase in the PPI for fuels and related products around the same time. As for food prices, during the period between up to mid-1960s there is indeed some evidence of correlation between persistence and the real CPI for food. Over the following years, however, (a) persistence increases well before the jump in the real CPI for food in the first half of the 1970s, and (b) over the most recent period the correlation is actually negative.

#### *6.1.4. The impact on changes in the extent of measurement noise on the serial correlation properties of inflation*[66]

It appears as reasonable to assume that recent price level series are measured with less error than, say, series from the Classical Gold Standard. Let's assume that the measurement error for the log price level is white noise, with a variance which, over the sample period, has decreased over time. Since measurement error in the log price level introduces negative serial correlation in the inflation rate, a decrease in the extent of measurement error over time will tend, *ceteris paribus*, to cause a steady increase in inflation persistence. My counter-arguments to this are the same previously used to refute the 'Hanes hypothesis'. First, persistence has not only increased, but also decreased over the sample period. Second, the timing is highly suggestive. Finally, the extent of the jumps in the persistence of US inflation around, say, 1914, 1971, and 1980 are simply impossible to rationalise in terms of changes in the extent of measurement error (similar arguments can be made for the UK over the post-WWII period).

#### *6.1.5. The Lucas critique, monetary regimes, and inflation persistence*

How plausible is an interpretation of the previous evidence in terms of the Lucas critique? Here two are the main issues. First, the empirical relevance of the Critique. Second, the issue of whether, over the sample period, the operating rules of monetary regimes did indeed change in a significant way.

The current consensus within the macroeconomics profession seems to be that, although logically impeccable, the Critique lacks empirical relevance. Since 1976, the Critique has indeed undergone a quite remarkable downsizing process. Writing in 1983, Fischer[67] already stressed that

> [it] is indeed remarkable that the Lucas policy evaluation critique has triumphed without any detailed empirical support beyond Lucas' accusation that macroeconometric models in the 1960s all predicted too little inflation for the 1970s. The general [theoretical] point made by the critique is correct […]. That the point has been important empirically however, is something that should have been demonstrated rather than asserted.

In recent years the skepticism over the Critique's empirical relevance has become even more widespread. The most recent, and so far harshest judgement comes from Ericsson and Irons (1996), who, in their recent literature survey of the available evidence on the empirical relevance of the Lucas critique, conclude that

> […] the Lucas critique is a possibility theorem, not an existence theorem. An extensive search of the literature reveals virtually no evidence demonstrating the empirical applicability of the Lucas critique.[68]

[66] I thank Tim Cogley and Geoffrey Wood for pointing out this potential problem.
[67] See Fischer (1983, p. 271).
[68] Ericsson and Irons' (1996) position, however, has not gone unchallenged. In his comment, for example, Leeper (1996, p. 131) states that '[Ericsson and Irons'] claim that 'little evidence exists to support the empirical applicability of the Lucas critique' is simply false. Lucas' criticisms gained wide and rapid acceptance in large measure *because* of their empirical applicability. In many economists'

Evidence against the empirical applicability of the Lucas critique, as surveyed by Ericsson and Irons (1996), is routinely based on superexogeneity tests—specifically, tests that the parameters of a conditional model for, say, money demand, or the consumption function, be invariant with respect to changes in the parameters of the conditioning process for a policy variable. Although superexogeneity tests almost invariably refute the empirical applicability of the Lucas critique, the fact that such evidence is, or is not, damning for the Critique crucially depends on the power of such tests. The recent work of Linde (2001), however, suggests that, in small samples, superexogeneity tests may have a surprisingly low power, while Rudebusch (2002), based on a simple sticky-price monetary model, shows that shifts in monetary rules of the magnitude historically observed over the post-WWII period are too small to be statistically detectable at conventional significance level. The lack of evidence in favor of the empirical applicability of the Lucas critique may therefore have a very simple explanation: given the small sample size typical of post-WWII data, and given the limited magnitude of policy shifts historically observed over this period, available statistical tests may simply lack the power to detect the impact of the Critique.

Turning to the issue of whether the operating rules of monetary regimes did indeed change in a significant way over the sample period, lets' first distinguish between before and after 1947. It is simply unquestionable that both for the US and for the UK the departure from the Gold Standard represented a dramatic change in the underlying monetary framework. Major changes in the stochastic properties of macroeconomic time series should therefore logically be expected. As for the period after 1947, we need to distinguish between the US and the UK. As for the US, things are not clear-cut. Conventional wisdom—exemplified for example in the work of DeLong (1997), Taylor (1999), and Clarida, Gali, and Gertler (2000)—maintains a sharp distinction between the 'bad old days' before Paul Volcker, and the last two decades. By estimating Taylor rules for the two periods, they find the pre-Volcker monetary rule to be passive and destabilising, and the Volcker-Greenspan one to be active and stabilising. Such reduced-form evidence, however, has recently been called into question by Hanson (2002) and Sims and Zha (2002), who, based on structural VARs, do not detect evidence of statistically significant instability in the monetary rule over the post-WWII period[69]. Given that the reduced-form equation approach which is typical of the Taylor rule literature is vulnerable, in principle, to the criticism that it may assign to the policy rule instability that originates elsewhere in the economy, the Hanson-Sims-Zha position, if correct, would clearly call into question my interpretation of the evidence discussed in section 4.1. As for the UK, things seem clearer. The work of Nelson (2000) on estimating Taylor rules, which detects strong evidence of instability over the sample period, is still vulnerable to the Hanson-Sims-Zha criticism. But Nelson and Nikolov (2002), largely based on an analysis of several policymakers' actual policy statements, and of the overall intellectual climate dominating post-WWII UK macroeconomic thinking, provides strong corroborating evidence that the shifts in UK monetary policy identified by Nelson (2000) are indeed for real. As Nelson and Nikolov (2002) stress, in the 1960s and 1970s

> […] UK policy-makers viewed monetary policy as disconnected from inflation, for two reasons. First, inflation was perceived as largely driven by factors other than the output gap; second, policy-makers were highly sceptical about the ability of monetary policy to affect aggregate demand or output appreciably.

In describing the intellectual climate surrounding UK monetary policymaking in the 1960s ands 1970s, King (2000) stresses how

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minds, the critique provides the most plausible (that is, economically reasonable and empirically consistent) explanation of the empirical breakdown of econometric models in the 1970s.'

[69] Interestingly, Hanson (2002) detects instead statistically significant evidence of instability in the CPI equation over the post-WWII period, which is compatible with the evidence presented herein.

[f]ifty years of amateurs in economic policy—aided and abetted by an economic establishment that seemed to believe that inflation was always and everywhere a real phenomenon—led to two decades of high and volatile inflation in Britain. […] For a country whose economic history was founded on a stable monetary and fiscal framework, and which could claim that prices in Germany rose in only one month (October 1923) by more than prices had risen in the UK since the arrival of William the Conqueror, the post-war record of economic management was a dismal failure.[70]

To the best of my knowledge, no structural VAR analysis in the spirit of Hanson-Sims-Zha has ever been performed for the UK. It appears as hard to believe, however, that results from VAR studies may overturn such evidence on changes in UK monetary policymaking over the last several decades.

## *7. Taylor and Sargent's Warning on 'Natural Rate Recidivism'*

For a brief period around 1970, macroeconomists thought they could test Friedman's natural rate hypothesis by estimating Phillips curves and testing whether the sum of the coefficients on past inflation was equal to one, a test originally proposed by Solow and Tobin[71]. Based on post-WWII US data through the late 1960s—a sample which, as we have seen in section 4.1, contains relatively low inflation persistence, at least compared with what was about to come—the Solow-Tobin test routinely rejected the natural rate hypothesis, thus implying the existence of a stable trade-off between inflation and unemployment. As shown by Sargent (1971) and Lucas (1972), the Solow-Tobin test is correct if and only if inflation contains permanent shifts, i.e., it contains a unit root. This was not the case for that sample, and, based on the results I discussed in section 4, it does not seem to be the case for the most recent period.

As stressed by CS (2002a), despite having been shown to be logically incorrect by Sargent and Lucas, the Solow-Tobin version of the natural rate hypothesis is still surprisingly popular: CS (2002a) list a number of recent papers—among them Rudebusch and Svensson (1999), King and Watson (1994, 1996), Fair (1996), and Estrella and Mishkin (1999)—which cast the natural rate hypothesis within the Solow-Tobin characterisation. The enduring popularity of the Solow-Tobin version of the natural rate hypothesis has recently induced Taylor (1998a, 1998b) to lament the possibility of 'natural rate recidivism': as the data from the recent, more stable monetary regime (characterised by a comparatively low level of inflation persistence) accumulate, the application of the erroneous Solow-Tobin test might—exactly as around 1970—signal the existence of an exploitable trade-off between inflation and unemployment, thus inducing the policymaker, once again, to 'play the Phillips curve', with eventually disastrous consequences.

Figure 38 provides some empirical evidence on this, by plotting results from recursive Solow-Tobin tests of the natural rate hypothesis based on US data, both for the post-WWII period, and for the Classical Gold Standard regime. Due to the unavailability of unemployment data for the Classical Gold Standard period, the rate of unemployment has been replaced by the HP-filtered logarithm of real GNP. Inflation is measured as the first difference in the logarithm of the GNP deflator, quoted at an annual rate[72]. The estimated equation is therefore:

$$(22) \quad \pi_t = k + \sum_{i=1}^{8} \alpha_i \pi_{t-i} + \sum_{j=0}^{4} \beta_j g_{t-j} + \epsilon_t$$

[70] King's (2000) description of how a once proudly hard-money country like the UK fell into the spiral of runaway inflation is a useful reminder of the naïveté of oft-heard statements like 'the lessons of the 1970s cannot possibly be forgotten'.

[71] On this, see the extensive discussion in Sargent (1999), and Cogley and Sargent (2002a).

[72] Data are again from Balke and Gordon (1986) until 1950:1, and from the *Department of Commerce, Bureau of Economic Analysis* for the most recent period.

where $p_t$ is the rate of inflation prevailing between quarters $t$-1 and $t$, and $g_t$ is the HP-filtered logarithm of real GNP. The sample periods are 1875:2-1913:4 and 1947:1-2001:1. As for the post-WWII sample, I started the rolling estimation in 1965:1, thus leaving 72 observations as pre-sample information. By the same token, in order to make results for the two periods exactly comparable, I used the first 72 quarterly observations of Gold Standard data as pre-sample information. Panel (a) shows the $F$-statistic for testing the restriction that the sum of the coefficients on past inflation—the $a_i$'s—be equal to one, together with the 90, 95, and 99% critical values, for the post-WWII period, while panel (b) plots the $F$-statistic together with the logarithm of the (two-sided) estimated spectral density of inflation at $w$=0 (both series in panel (b) have been demeaned and standardised). Panel (c) displays a scatterplot of the $F$-statistic together with the logarithm of the (two-sided) estimated spectral density of inflation at $w$=0 (again, demeaned and standardised). Finally, panel (d) shows the $F$-statistic for testing the restriction that the sum of the coefficients on past inflation—the $a_i$'s—be equal to one, together with the 90, 95, and 99% critical values, for the Classical Gold Standard regime.

Several features are apparent from the graphs. First, as conjectured by Sargent (1971) and Lucas (1972), results from the Solow-Tobin test crucially depend on the serial correlation properties of inflation. As panel (b) shows, the $F$-statistic for the Solow-Tobin test displays a striking negative correlation with the logarithm of the spectral density at $w$=0, with an increase in inflation persistence decreasing the likelihood of rejecting the natural rate. The correlation is particularly clear from the scatterplot in panel (c)[73]. Second, panel (a) shows the evolution over time of the results from the Solow-Tobin test. During the second half of the 1960s, the low serial correlation of inflation over the sample period caused the Solow-Tobin test to reject the natural rate hypothesis at the 99% level. As inflation persistence started to increase, however, the value taken by the $F$-statistic drastically declined, reaching the point that, around mid-1970s, it was no longer possible to reject the natural rate hypothesis even at the 90%. After the Volcker disinflation, the marked decrease in inflation persistence caused a progressive increase in the $F$-statistic, so that, today, the natural rate hypothesis can be rejected at the 95% level. The contrast with the Gold Standard period is striking. Due to the absence of serial correlation in inflation rates under that regime, the Solow-Tobin test rejects the natural rate hypothesis at the 90% over the entire sample period; it rejects it at the 95% over the entire period with the exception of a few quarters around the turn of the century; and it rejects it at the 99% level more than 50% of the times. If we believe that the natural rate hypothesis was true under both regimes, these results provide strong corroboration for the Sargent-Lucas conjecture that accepting or rejecting the natural rate hypothesis based on the Solow-Tobin test has nothing to do with the fact that such an hypothesis is actually true or not, and crucially depends, on the contrary, on the specific nature of the monetary regime in place.

To conclude, how serious is the possibility of 'natural rate recidivism'? In general, the seriousness of the problem identified by Taylor crucially depends on policymakers' willingness to forget the lessons of the past. On strictly empirical grounds, the results illustrated in this paper clearly suggest that, unless the monetary framework is robust against this temptation, the past could return[74].

[73] Qualitatively identical results can be found in Cogley and Sargent (2002a).

[74] It is very common to hear statements like 'the lessons of the Great Inflation cannot possibly be forgotten', implying that Taylor and Sargent's worries are unfounded. Such a blind faith in a steady accumulation of economic knowledge that does not suffer any detour or setback is not only naïve, but it is in fact contradicted by historical experience. Sweden represents a case in point. As discussed by Jonung (1979), after having been, in the 1930s, the first (and only) country in the world to experiment with a price-level targeting regime inspired by the work of Wicksell, during the post-WWII period Sweden all but forgot Wicksell's lessons, to embrace a policy [here quotation from Jonung, 1979].

## 8. *Conclusions*

This paper has used random-coefficients autoregressive representations with generalised autoregressive conditional heteroskedasticity to investigate shifts in inflation persistence over time and across monetary regimes in the US (since 1793) and in the UK (since 1662), in order to produce empirical evidence relevant to the following three questions. (1) Is inflation persistence a structural feature of the economy? (2) Has the extent of inflation persistence been basically constant, or has it changed over time? (3) What role does the monetary regime play in determining the extent of inflation persistence? Empirical strongly questions the notion that inflation is *intrinsically* persistent: on the contrary, inflation persistence appears to be a typical feature of the post-commodity standard (i.e., post-1914) world, and especially of the period after 1947, and is instead absent from the data generated by economic systems operating under metallic standards. In several cases, the null of structural invariance can be rejected at the 1% level. Both in the US and in the UK, inflation persistence is estimated to have decreased after the beginning of Bretton Woods, and to have increased after mid-1960s. In the US, persistence has markedly decreased after the beginning of the Volcker disinflation, while in the UK it has decreased starting from the beginning of the 1990s, corresponding to the introduction of an inflation targeting regime.

Several implications have been discussed. It has been argued that trying to replicate inflation persistence as an entirely structural feature of a macroeconomic model is potentially flawed, and that both the evaluation of alternative monetary policy frameworks, and the computation of optimal monetary policies based on models with built-in inflation persistence may deliver misleading indications. The finding that the serial correlation of inflation has significantly decreased in recent years has been cited as evidence in favor of Taylor's (1998) and Sargent's (1999) warning against 'natural rate recidivism'—that under low inflation persistence policymakers may be attracted to exploit an illusory output-inflation tradeoff.

## *Appendix A*
## *Changes Over Time in the Pattern of Seasonality of UK Inflation*

As figures 18-19 and especially 23, clearly show, the seasonal component of UK inflation has experienced quite significant fluctuations over time and across different historical periods. Figure 23, in particular, suggests that such a component was comparatively large during the 1920s and 1930s, it became much more subdued (without however disappearing) during the 1940s-1960s, and, quite surprisingly, it has reappeared over the most recent period. The fact that both the least and the most recent periods do appear to contain a sizeable seasonal component in no way implies, however, that the pattern of seasonality should be the same in both periods. In order to investigate changes over time in the pattern of seasonality in UK inflation, I use band-pass filtering techniques[75] to extract from the inflation series plotted in figure 24 all the components with a frequency of oscillation faster than 6 quarters, and I regress the resulting filtered series on four seasonal dummies for the four quarters. Results for three different sample periods[76]—1914:4-1939:4, 1947:1-1971:2, and 1971:3-2000:4—are reported in Table A1, and clearly show how the seasonal patterns in the least and most recent periods are indeed different. In particular, while in the period 1914:4-1939:4 the regression coefficients on the seasonal dummies are negative for Q1 and Q2, and positive in Q3 and Q4, over the period 1971:3-2000:4 an almost symmetrical pattern emerges, with the coefficient on the Q1 dummy being insignificant, the one on the Q2 one being positive, and the other two being negative. Such a pattern is compatible with the notion that and old cause of seasonality faded away over time, and a new one appeared.

***Table A1 Changes over time in the pattern of seasonality in UK inflation***

| ***Sample period*** | ***Quarter*** | | | |
|---|---|---|---|---|
| | **Q1** | **Q2** | **Q3** | **Q4** |
| 1914:4-1939:4 | -0.034 | -0.078 | 0.038 | 0.075 |
| | (0.013) | (0.015) | (0.018) | (0.016) |
| 1947:1-1971:2 | -0.001 | 0.024 | -0.030 | 0.008 |
| | (0.006) | (0.007) | (0.007) | (0.006) |
| 1971:3-2000:4 | -0.003 | 0.044 | -0.026 | -0.015 |
| | (0.004) | (0.009) | (0.011) | (0.006) |

*Newey-West (1987) standard errors in parentheses.*

[75] The approximated band-pass filter I use is the frequency-domain filter of Englund, Persson, and Svensson (1992), and Hassler, Lundvik, Persson, and Söderlind (1994). Specifically, I take the Fourier transform of the inflation series, I 'zero out' all the Fourier coefficients associated with the frequencies I am not interested in, and I take the inverse Fourier transform of the resulting vector of complex coefficients, thus getting the frequency-domain filtered series.

[76] I exclude the period 1940:1-1946:4, which appears to be anomalous.

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| *Table 1 Sample moments of US inflation since 1879* | | | | |
|---|---|---|---|---|
| | **Mean** | **Standard Deviation** | **Skewness** | **Kurtosis** |
| Classical Gold Standard | 0.009 | 0.087 | 1.559 | 9.813 |
| Collapse of the Gold Standard to Bretton Woods | 0.034 | 0.114 | 0.673 | 5.806 |
| Bretton Woods regime | 0.028 | 0.029 | 1.403 | 7.490 |
| Post-Bretton Woods period | 0.044 | 0.028 | 0.948 | 3.011 |

*Inflation: first difference of log GNP deflator, quoted at annual rate. Data sources: Balke and Gordon (1986), and US Department of Commerce, Bureau of Economic Analysis.*

| *Table 2 Dickey-Fuller and augmented Dickey-Fuller test statistics for US inflation since 1879* | | | | | | |
|---|---|---|---|---|---|---|
| | **LAGS** | | | | | |
| | **0** | **1** | **2** | **4** | **6** | **8** |
| Classical Gold Standard | -12.59 | -8.38 | -6.98 | -6.43 | -4.71 | -3.12 |
| Collapse of the Gold Standard to Bretton Woods | -5.23 | -4.88 | -4.33 | -3.45 | -3.38 | -2.88 |
| Bretton Woods regime | -5.36 | -4.34 | -4.60 | -4.60 | -3.88 | -2.58 |
| Post-Bretton Woods period | -2.54 | -1.93 | -1.65 | -1.82 | -1.79 | -1.55 |

*The estimated model is with an intercept, but without a time trend. Inflation: first difference of log GNP deflator, quoted at annual rate. Data sources: Balke and Gordon (1986), and US Department of Commerce, Bureau of Economic Analysis.*

| *Table 3 Sample moments of US inflation since 1793* | | | | |
|---|---|---|---|---|
| | **Mean** | **Standard Deviation** | **Skewness** | **Kurtosis** |
| *De facto* silver standard | 0.013 | 0.169 | 0.917 | 4.474 |
| *De facto* gold standard | 0.001 | 0.179 | 0.106 | 2.936 |
| 'Greenback period' | 0.024 | 0.296 | 1.342 | 5.369 |
| Classical Gold Standard | 0.011 | 0.136 | 0.910 | 5.713 |
| Collapse of the Gold Standard to Bretton Woods | 0.036 | 0.182 | 0.244 | 6.259 |
| Bretton Woods regime | 0.018 | 0.057 | 1.665 | 9.047 |
| Post-Bretton Woods period | 0.044 | 0.068 | 1.242 | 6.034 |

*Inflation: first difference of log wholesale price index, quoted at annual rate. Data sources: Warren-Pearson (1933) NBER historical database and Federal Reserve Board.*

***Table 4 Dickey-Fuller and augmented Dickey-Fuller test statistics for US inflation since 1793***

| | **LAGS** | | | | | |
|---|---|---|---|---|---|---|
| | **0** | **1** | **2** | **4** | **6** | **8** |
| *De facto* silver standard | -9.71 | -7.86 | -6.12 | -5.29 | -4.92 | -4.69 |
| *De facto* gold standard | -8.20 | -7.12 | -6.51 | -5.25 | -3.25 | -2.66 |
| 'Greenback period' | -6.33 | -4.90 | -4.03 | -3.27 | -3.27 | -3.34 |
| Classical Gold Standard | -10.74 | -9.05 | -7.27 | -6.23 | -4.95 | -3.56 |
| Collapse of the Gold Standard to Bretton Woods | -5.87 | -5.08 | -4.66 | -4.05 | -3.29 | -3.78 |
| Bretton Woods regime | -6.30 | -5.32 | -5.46 | -6.23 | -5.47 | -3.96 |
| Post-Bretton Woods period | -6.30 | -4.06 | -3.00 | -2.45 | -2.72 | -2.96 |

*The estimated model is with an intercept, but without a time trend. Inflation: first difference of log wholesale price index, quoted at annual rate. Data sources: Warren-Pearson (1933) NBER historical database and Federal Reserve Board.*

***Table 5 Autocorrelations at lag 1 of UK annual inflation, 1662-2000***

| | |
|---|---|
| *De facto* silver standard (1662-1716) | 0.0420 (0.2275) |
| *De facto* gold standard (1717-1796) | 0.0077 (0.1151) |
| 'Suspension period' (1797-1821) | 0.2753 (0.1925) |
| Gold standard* (1822-1914) | 0.0988 (0.1577) |
| WWI to Bretton Woods (1915-1946) | 0.3437 (0.2391) |
| Bretton Woods (1947-1971) | 0.1463 (0.4487) |
| Bretton Woods to inflation targeting (1972-1992) | 0.6672 (0.1805) |

*Newey-West (1987) standard errors in parentheses.*
* *Gold standard introduced* de jure *in 1816.*

***Table 6 Sample moments of UK inflation since 1914***

| | **Mean** | **Standard Deviation** | **Skewness** | **Kurtosis** |
|---|---|---|---|---|
| From 1914 to Bretton Woods | 0.029 | 0.126 | 0.059 | 3.470 |
| Bretton Woods regime | 0.043 | 0.044 | 0.502 | 3.837 |
| From Bretton Woods to inflation targeting | 0.097 | 0.078 | 1.910 | 8.583 |
| Post-inflation Targeting | 0.026 | 0.021 | 0.477 | 2.364 |

*Inflation: first difference of log retail price index, quoted at an annual rate, from 1914:4 to 1962:1; first difference of log CPI, quoted at an annual rate, from 1962:2 to 2000:4. All data are quarterly, and seasonally unadjusted. The retail price index is from Capie and Webber, 1985; the CPI is from the OECD database*

| ***Table 7 Dickey-Fuller and augmented Dickey-Fuller test statistics for UK inflation since 1914*** | | | | | | |
|---|---|---|---|---|---|---|
| | **LAGS** | | | | | |
| | **0** | **1** | **2** | **4** | **6** | **8** |
| From 1914 to Bretton Woods | -6.17 | -6.51 | -3.85 | -3.94 | -3.06 | -3.23 |
| Bretton Woods regime | -7.71 | -4.48 | -4.40 | -2.97 | -3.18 | -3.04 |
| From Bretton Woods To inflation targeting | -5.16 | -3.43 | -3.01 | -2.17 | -1.77 | -1.83 |
| Post-inflation Targeting | -5.55 | -6.56 | -4.15 | -3.61 | -2.86 | -1.89 |

*Inflation: first difference of log retail price index, quoted at an annual rate, from 1914:4 to 1962:1; first difference of log CPI, quoted at an annual rate, from 1962:2 to 2000:4. All data are quarterly, and seasonally unadjusted. The retail price index is from Capie and Webber, 1985; the CPI is from the OECD database*

| ***Table 8 Maximum likelihood estimates for the random coefficients AR models*** | | | |
|---|---|---|---|
| | **US** | | **UK** |
| | *Based on GNP deflator* | *Based on the wholesale price index* | *Based on the linked retail price-CPI series* |
| $a_0$ | 1.20E-06 | 1.02E-04 | 2.31E-05 |
| | (1.13E-06) | (2.90E-05) | (3.02E-05) |
| $a_1$ | 0.187 | 0.153 | 0.210 |
| | (2.37E-02) | (1.39E-02) | (0.043) |
| $a_2$ | 0.813 | 0.846 | 0.790 |
| | (2.37E-02) | (1.38E-02) | (0.039) |
| $r$ | 0.988 | 0.988 | 0.996 |
| | (6.75E-03) | (8.57E-04) | (1.98E-03) |
| $s_u$ | 2.84E-03 | 1.53E-03 | 9.10E-04 |
| | (6.38E-04) | (9.44E-03) | (6.58E-04) |
| $s_{x1}$ | 8.33E-02 | 7.54E-02 | 0.065 |
| | (1.78E-02) | (1.16E-02) | (0.013) |
| $s_{x2}$ | | | 0.015 |
| | | | (8.63E-03) |
| $s_{x3}$ | | | 2.61E-03 |
| | | | (0.024) |
| $s_{x4}$ | | | 0.057 |
| | | | (0.019) |

*Sample periods: US, based on the wholesale price index 1794:1-2001:1; US, based on the GNP deflator, 1875:2-2001:1. UK, based on the linked retail price index-CPI series 1914:2-2000:4 . For details on estimation and data sources, see text.*

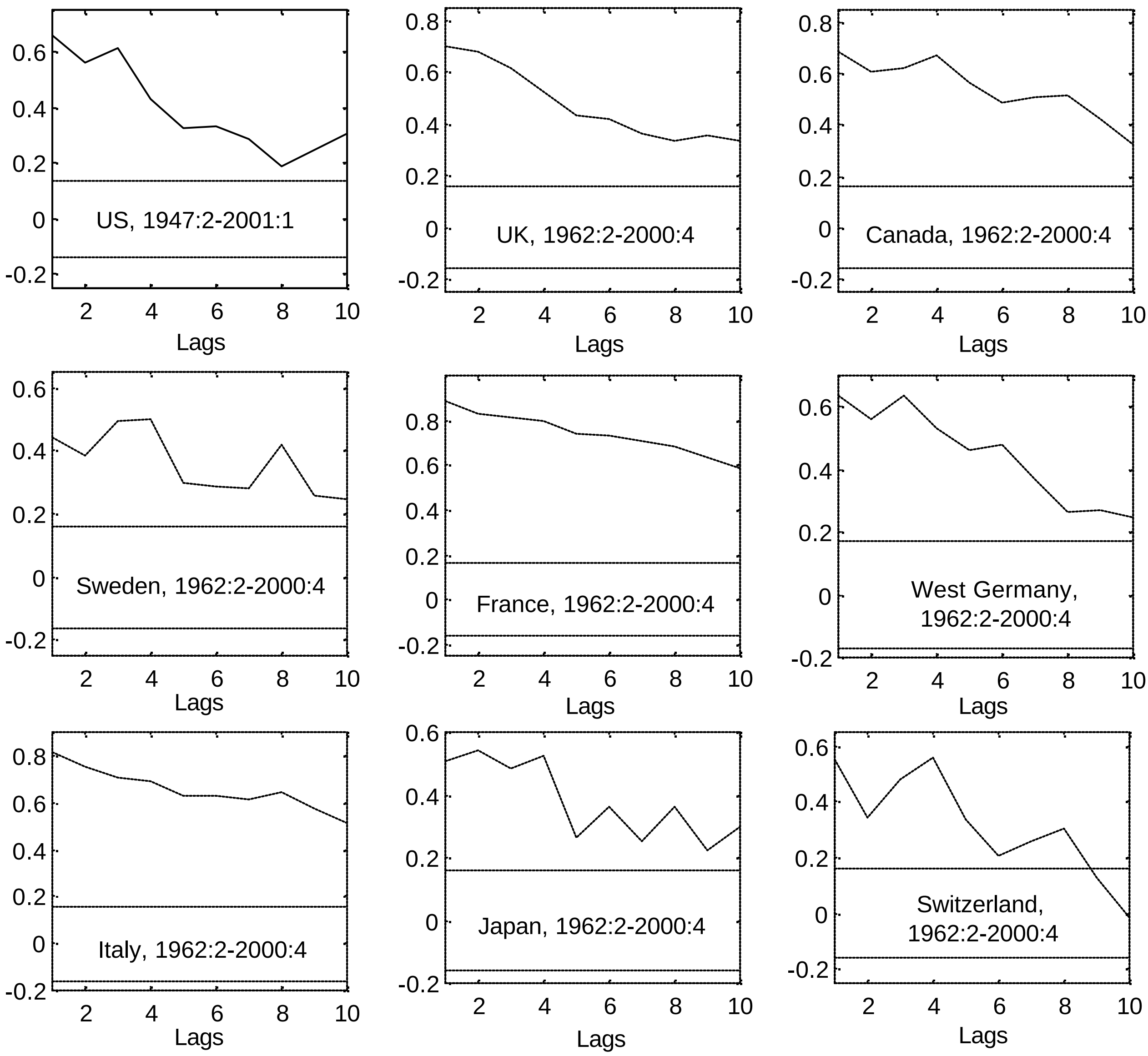



Figure 1
Autocorrelations of consumer price inflation in nine *OECD* countries over the post-WWII period
(Autocorrelations are plotted starting from lag 1. Inflation: first difference of log quarterly consumer price index, quoted at annual rate. Data are from the *Federal Reserve Board* for the US, and from the *OECD* database for all other countries.)

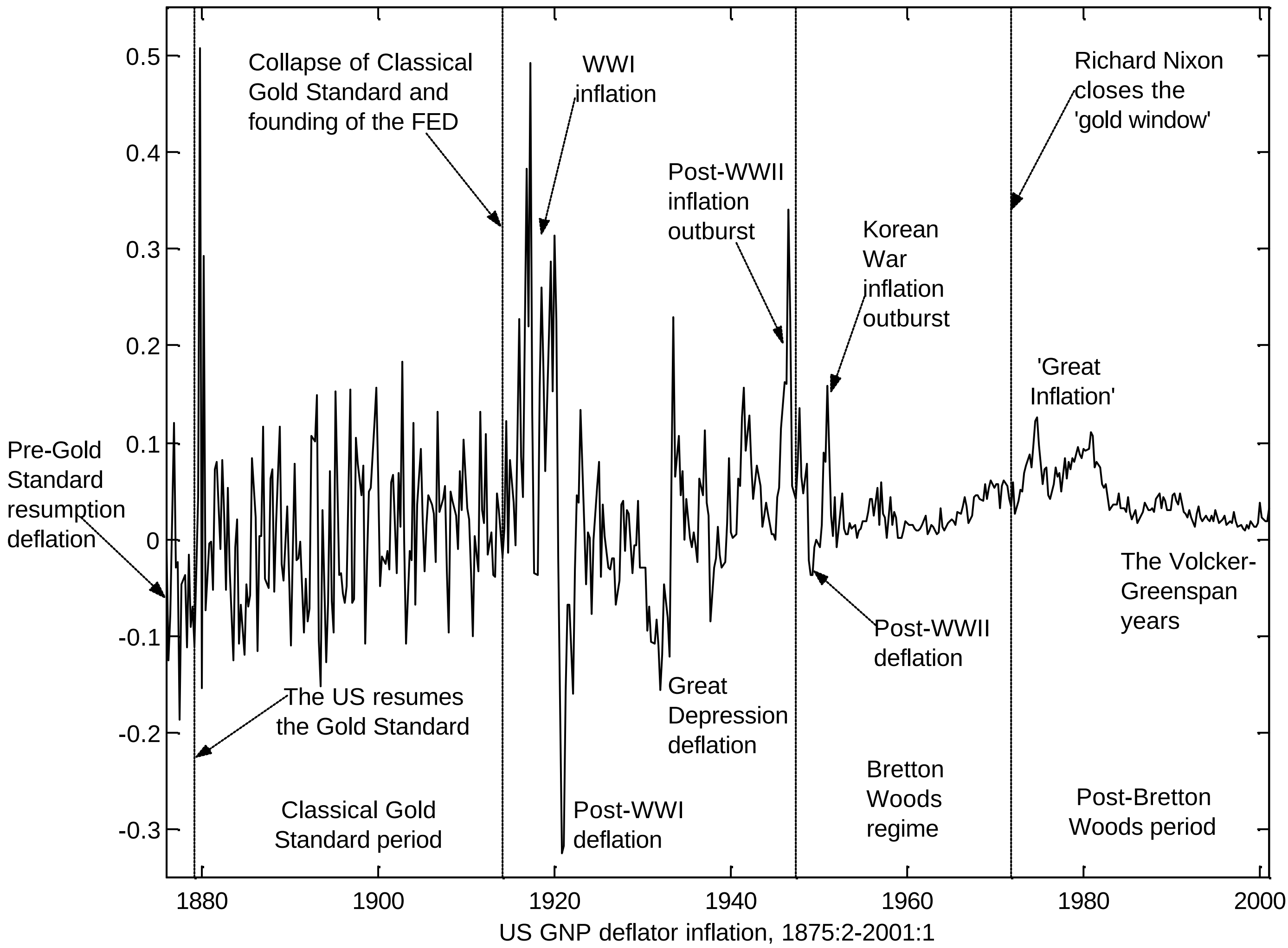



Figure 2
US GNP deflator inflation, 1875:2-2001:1

(Inflation: first difference of log GNP deflator, quoted at annual rate; data are from Balke and Gordon, 1986, 'Appendix B: Historical Data', and from *U.S. Department of Commerce, Bureau of Economic Analysis*)

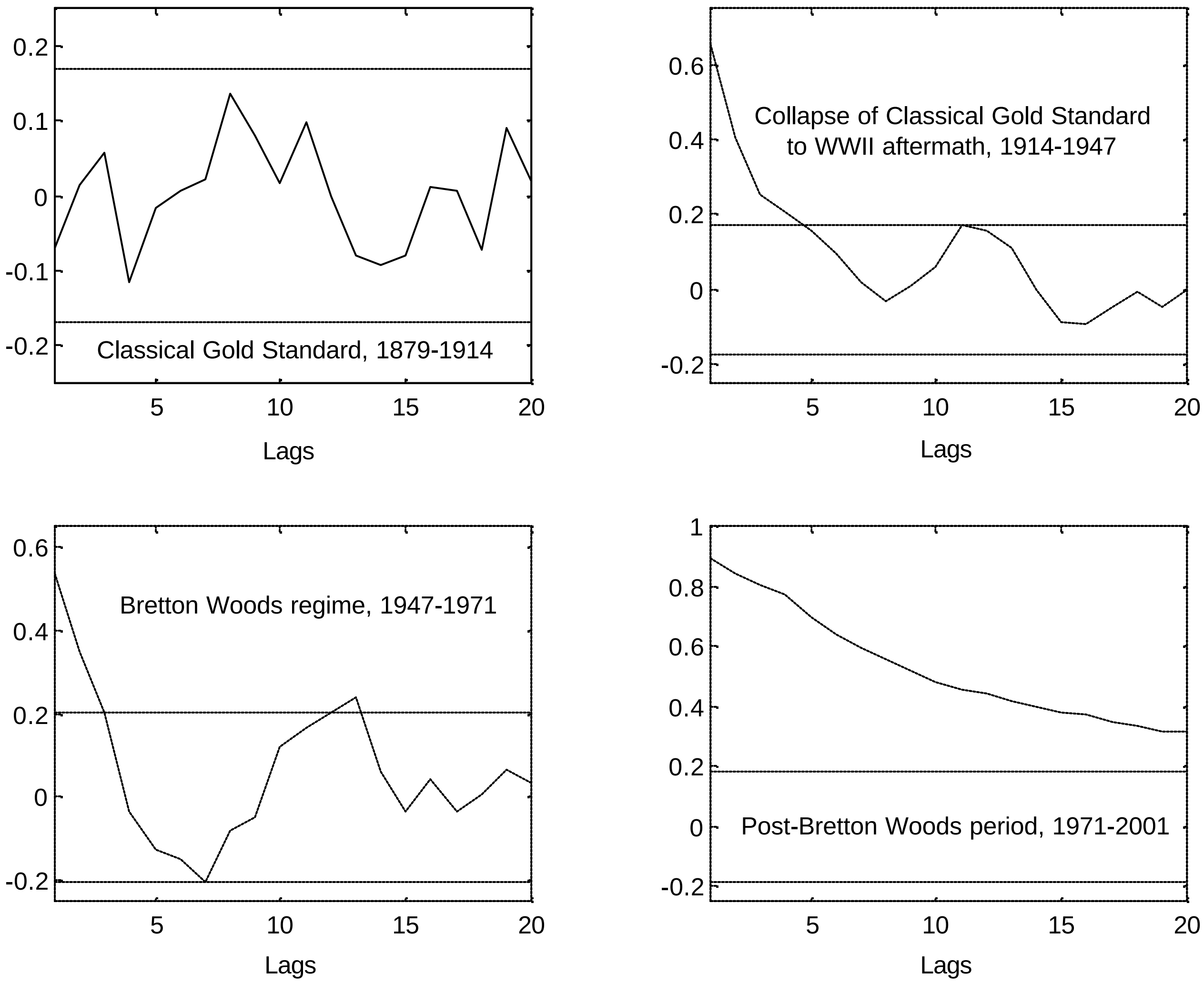



Figure 3
Autocorrelations of US GNP deflator inflation, 1875:2-2001:1

(Autocorrelations are plotted starting from lag 1. Inflation: first difference of log GNP deflator, quoted at annual rate; data are from Balke and Gordon, 1986, 'Appendix B: Historical Data', and from *U.S. Department of Commerce, Bureau of Economic Analysis*)

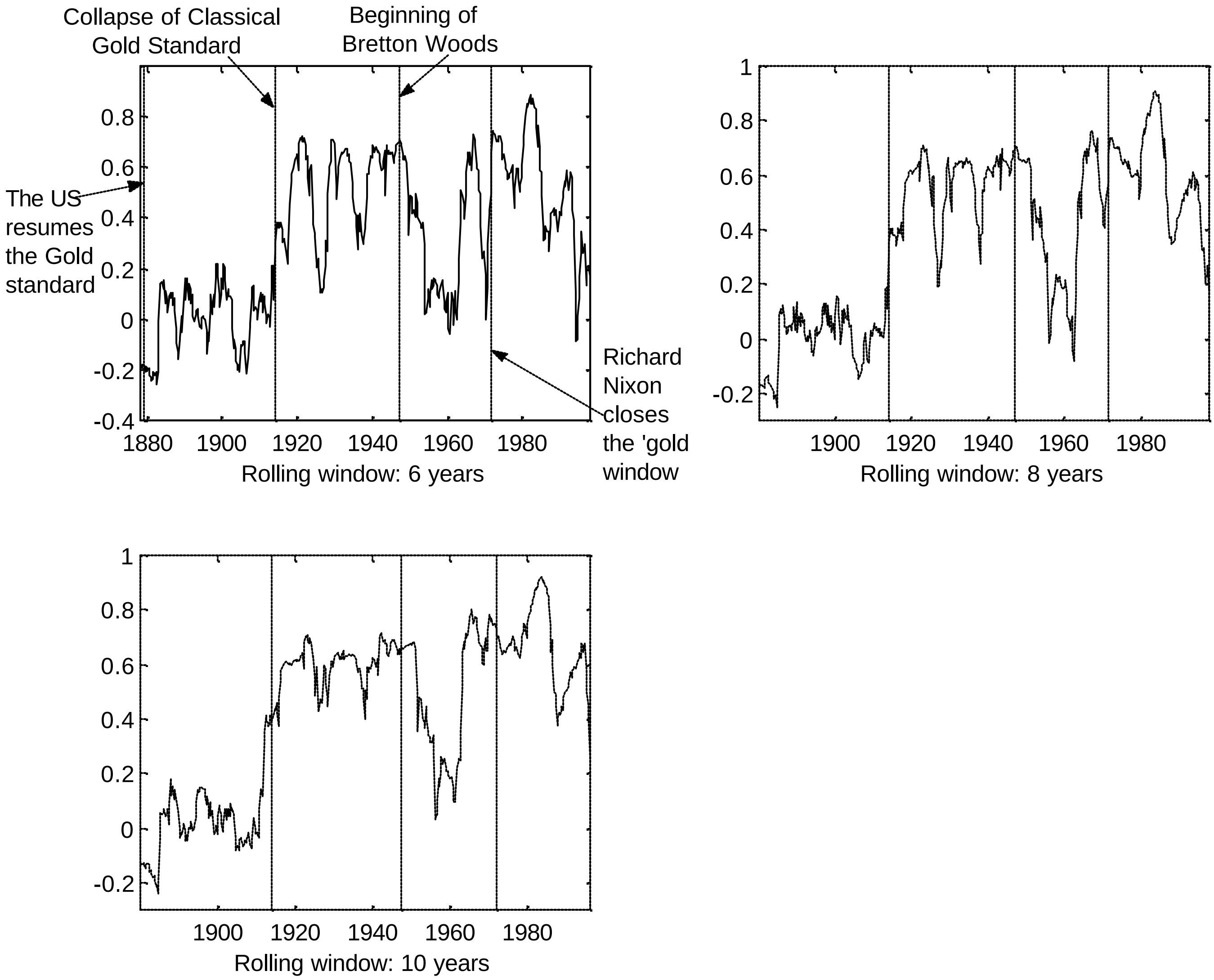



Figure 4
Rolling autocorrelations of US GNP deflator inflation at lag 1, 1880:2-2001:1.

(Inflation: first difference of log GNP deflator, quoted at annual rate; data are from Balke and Gordon, 1986, 'Appendix B: Historical Data', and from *U.S. Department of Commerce, Bureau of Economic Analysis*)

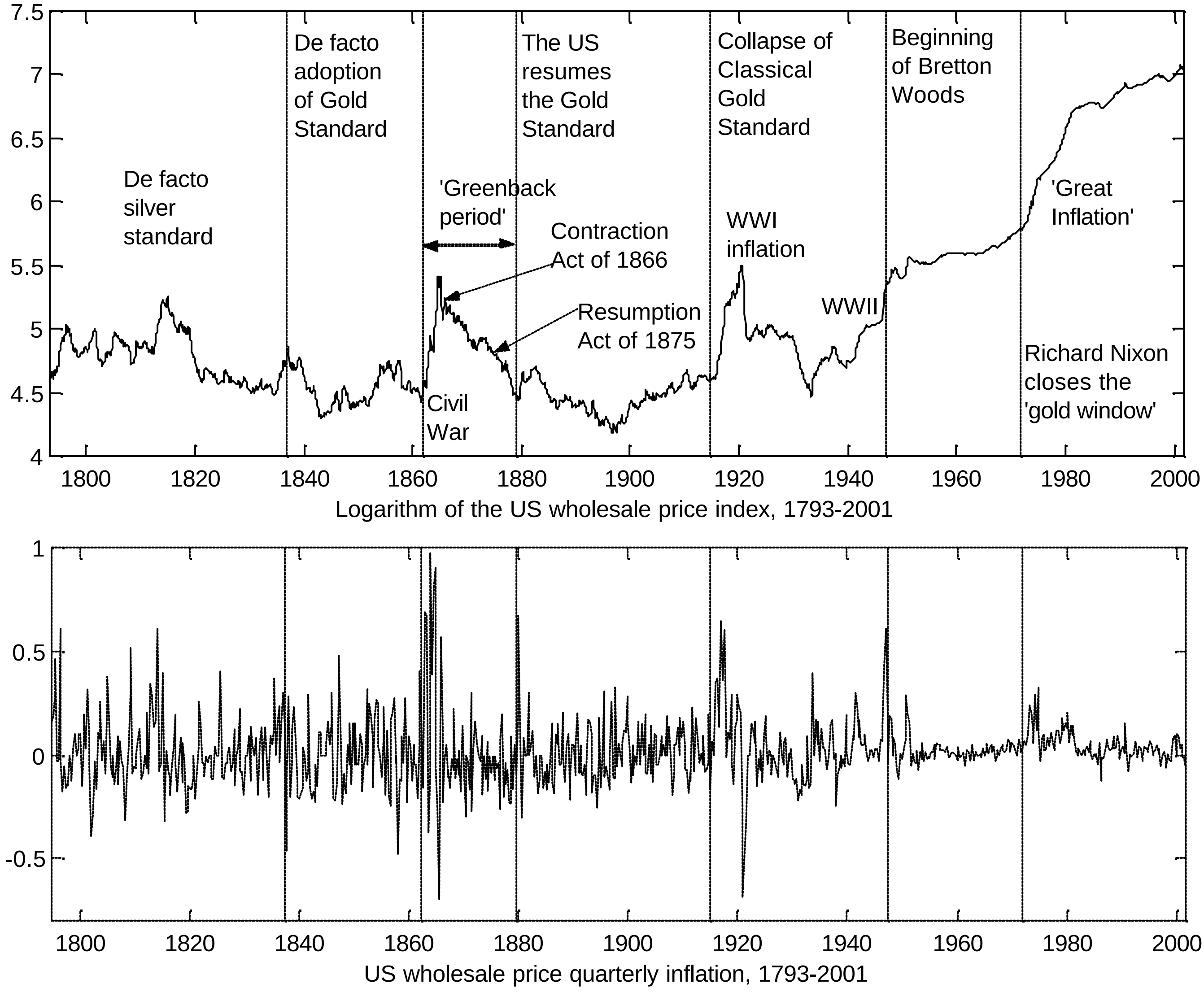



Figure 5
Logarithm of the US wholesale price index and US wholesale price inflation, 1793:4-2001:1

(Inflation: first difference of log quarterly wholesale price index, quoted at annual rate; data from Warren and Pearson, 1933, *NBER Historical Database*; and *Federal Reserve Board*)

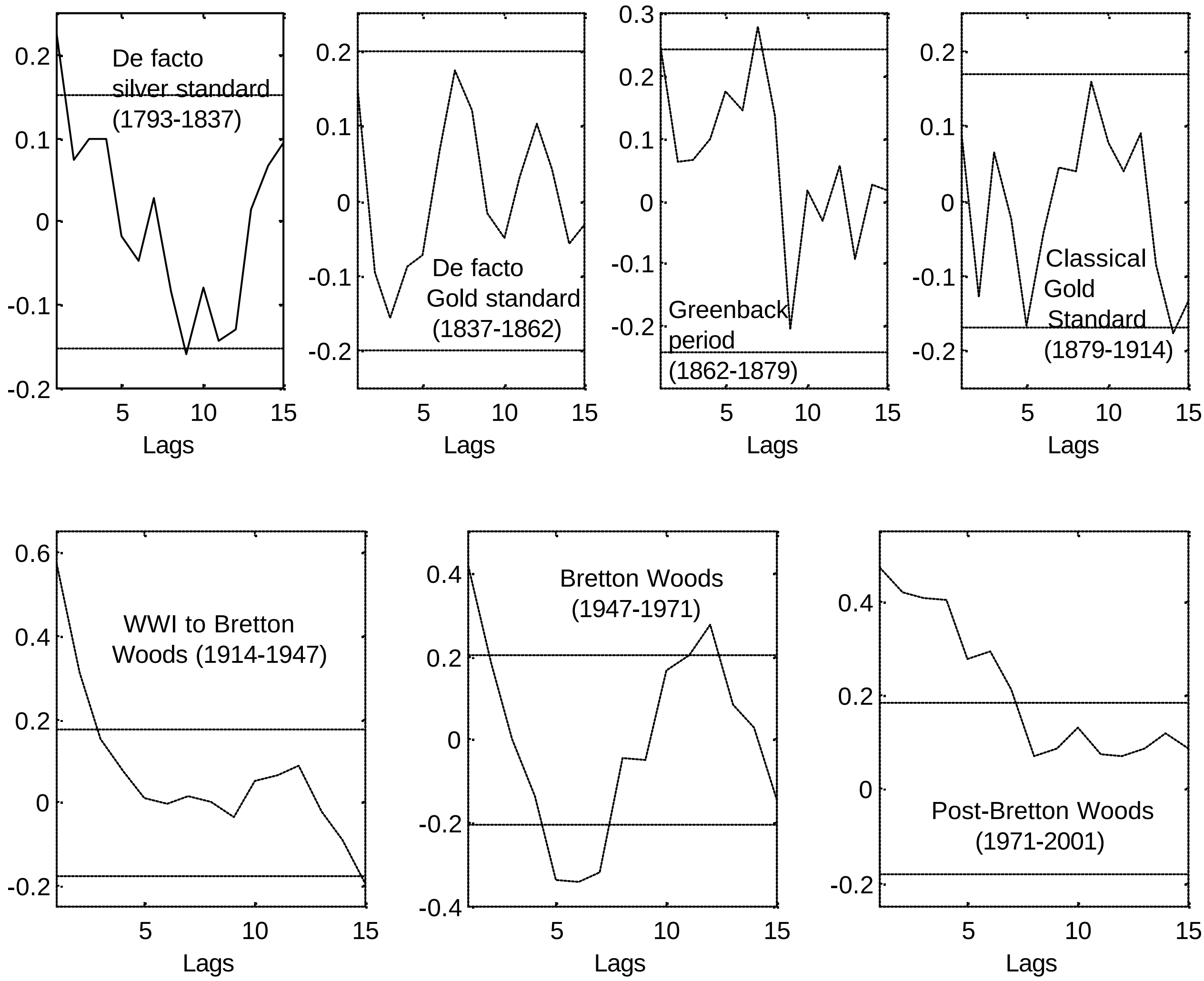



Figure 6
Autocorrelations of US wholesale price inflation, 1793:4-2001:1

(Autocorrelations are plotted starting from lag 1. Inflation: first difference of log quarterly wholesale price index, quoted at annual rate; data from Warren and Pearson, 1933, *NBER Historical Database*; and *Federal Reserve Board*)

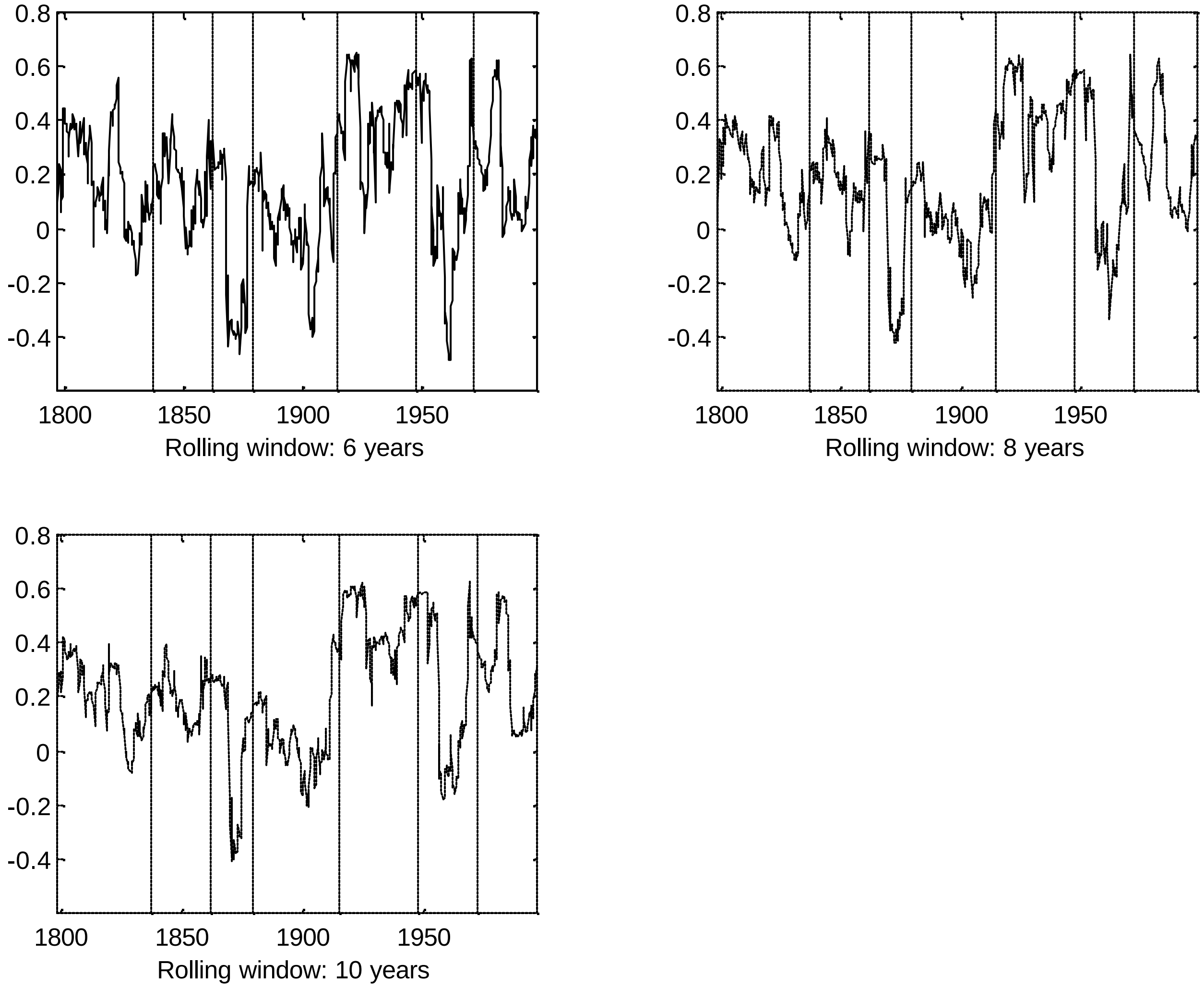



Figure 7
Rolling autocorrelations of US wholesale price inflation at lag 1, 1793:4-2001:1.

(Inflation: first difference of log quarterly wholesale price index, quoted at annual rate; data from Warren and Pearson, 1933, *NBER Historical Database*; and *Federal Reserve Board*)

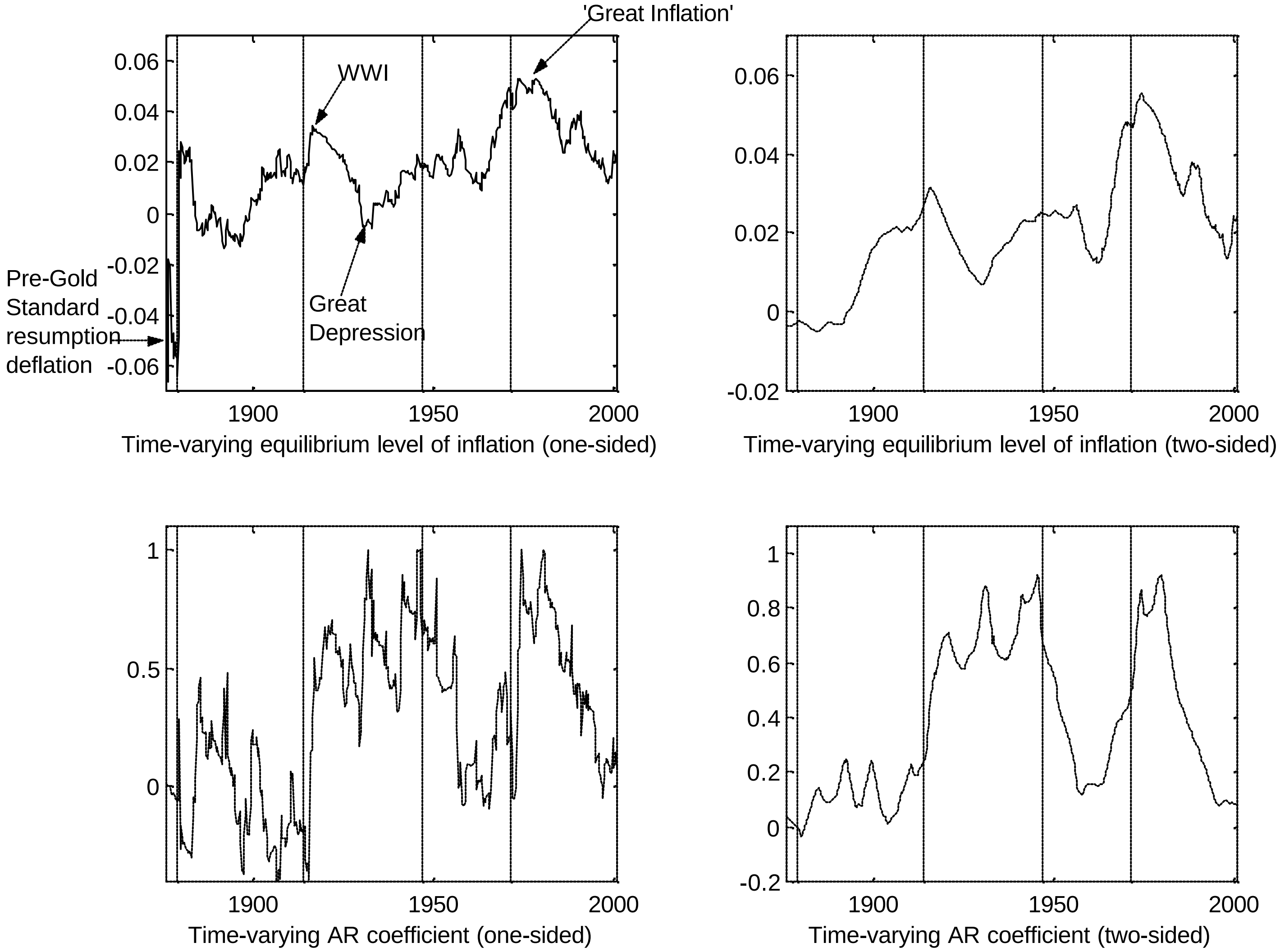



Figure 8
Time-varying equilibrium level of inflation, and time-varying AR coefficient, from a random-coefficients AR(1) model for inflation

(Inflation: first difference of log GNP deflator, quoted at annual rate; data are from Balke and Gordon, 1986, 'Appendix B: Historical Data', and from *U.S. Department of Commerce, Bureau of Economic Analysis*)

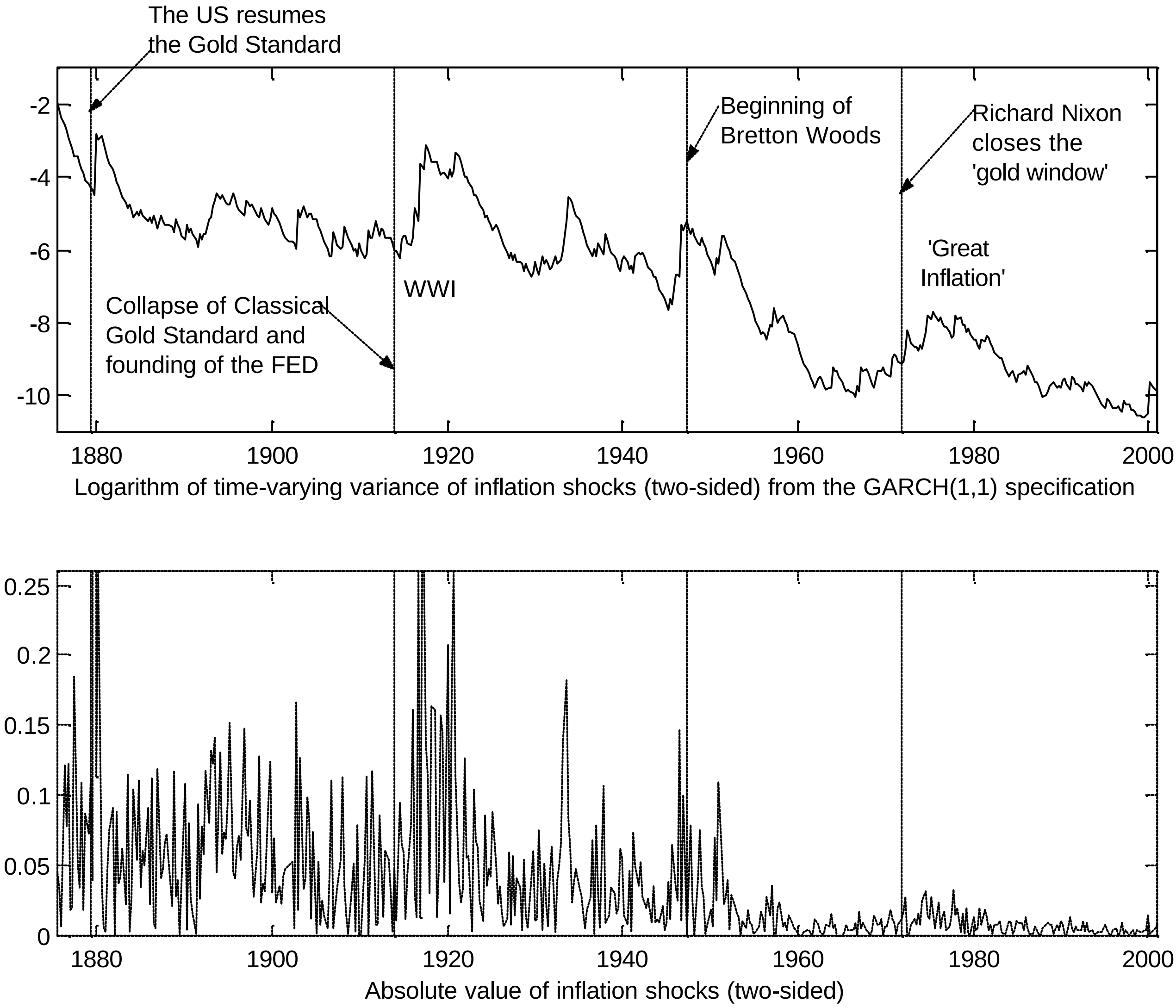



Figure 9
Logarithm of time-varying variance, and absolute value of inflation shocks, from a random-coefficients AR(1) model for inflation (two-sided).

(Inflation: first difference of log GNP deflator, quoted at annual rate; data are from Balke and Gordon, 1986, 'Appendix B: Historical Data', and from *U.S. Department of Commerce, Bureau of Economic Analysis*)

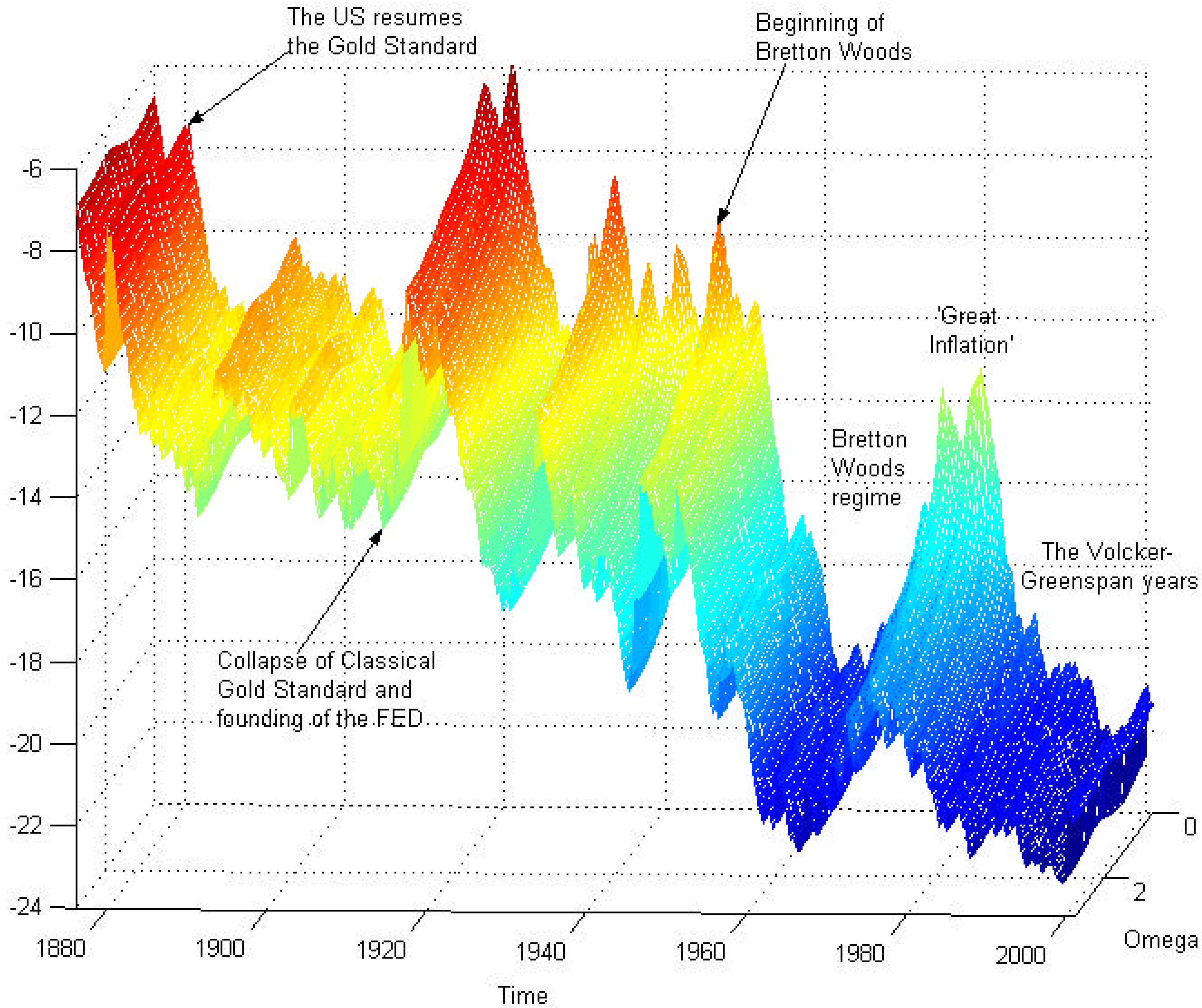



Figure 10
Log spectral densities of US GNP deflator inflation, 1876:2-2001:1, from a random-coefficients AR(1) model for inflation (two-sided)

(Inflation: first difference of log GNP deflator, quoted at annual rate; data are from Balke and Gordon, 1986, 'Appendix B: Historical Data', and from *U.S. Department of Commerce, Bureau of Economic Analysis*)

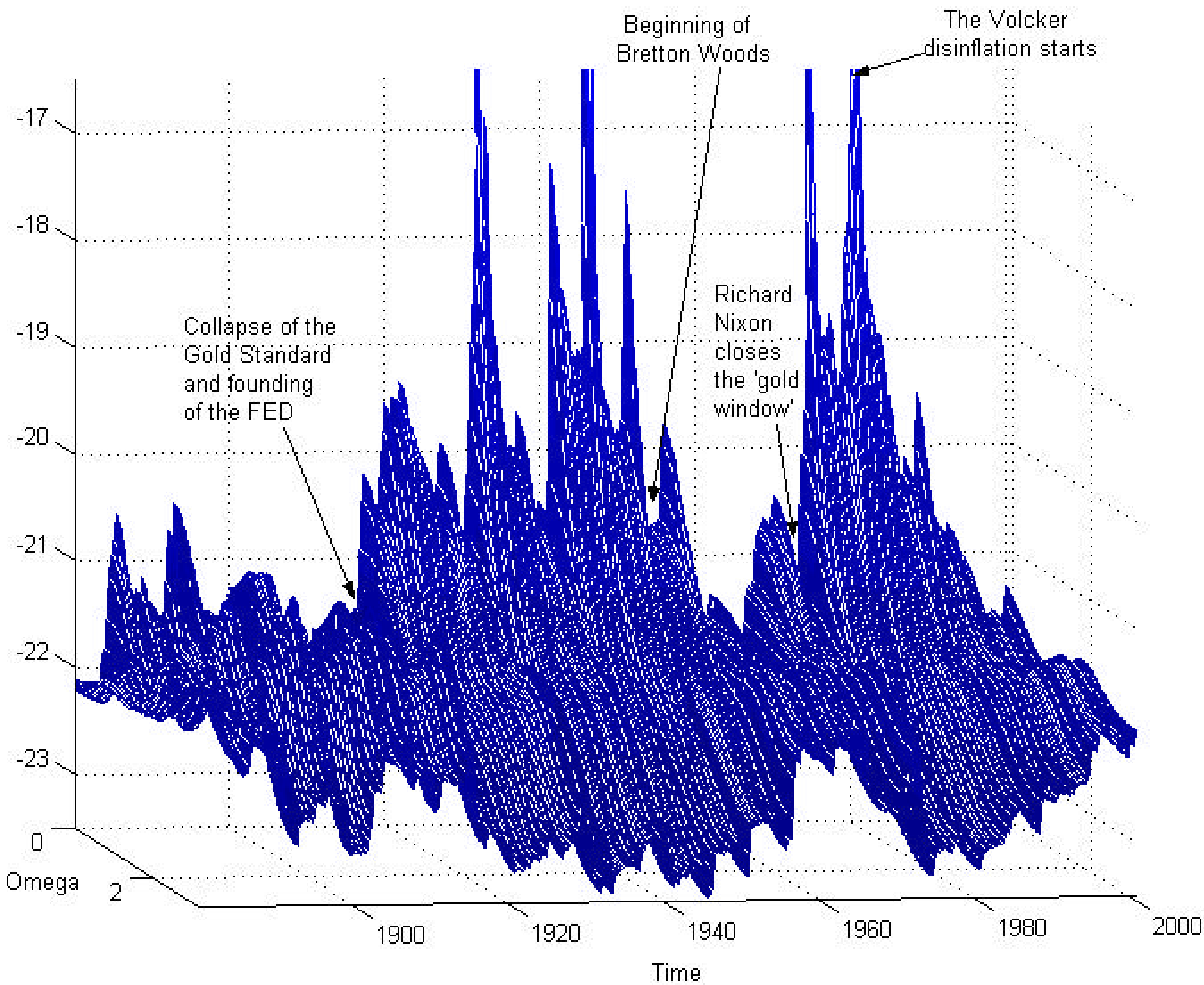



Figure 11
Log corrected spectral densities of US GNP deflator inflation, 1880:2-2001:1, from a random-coefficients AR(1) for inflation (one-sided)

(Inflation: first difference of log GNP deflator, quoted at annual rate; data are from Balke and Gordon, 1986, 'Appendix B: Historical Data', and from *U.S. Department of Commerce, Bureau of Economic Analysis*)

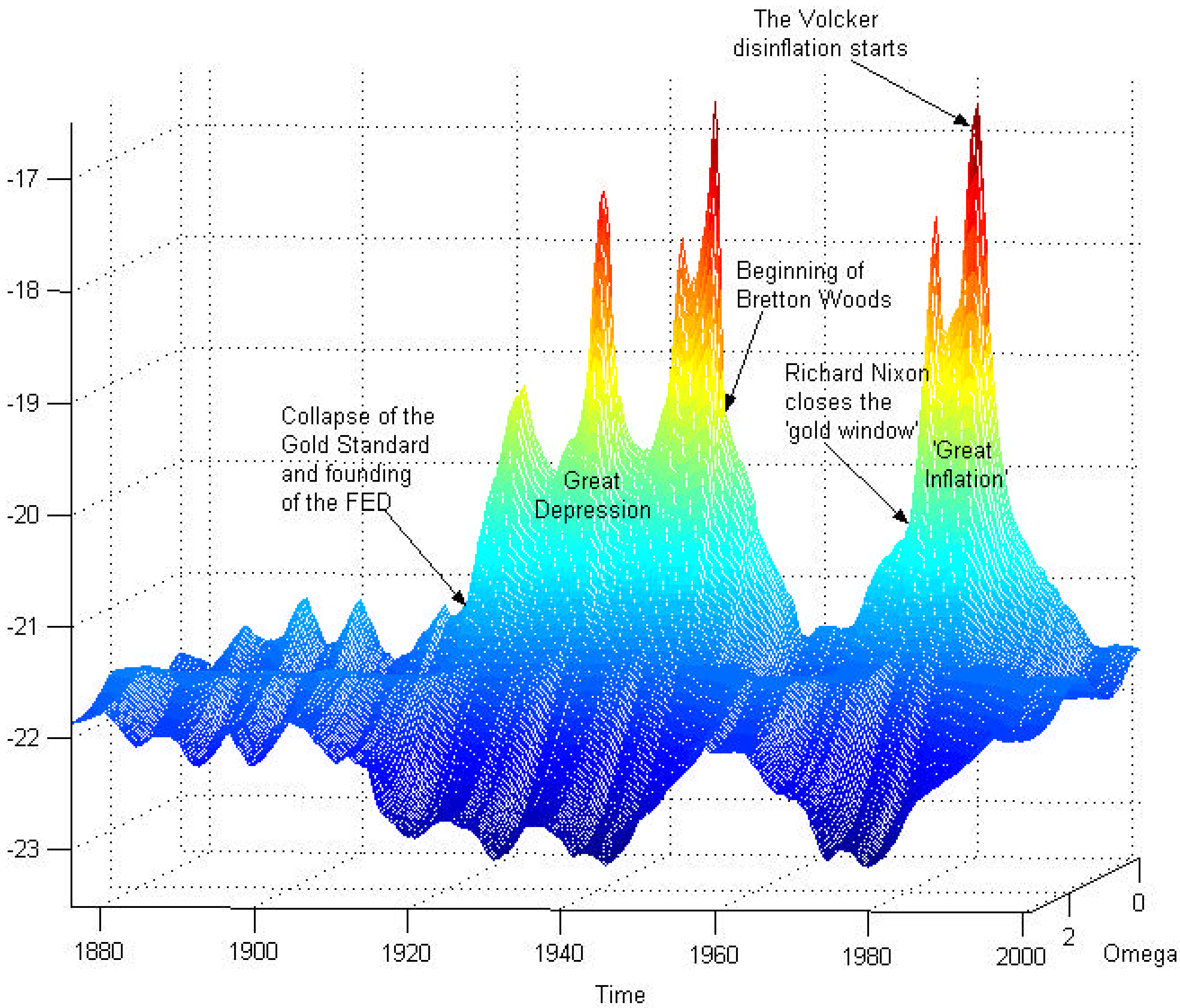



Figure 12
Log corrected spectral densities of US GNP deflator inflation, 1876:2-2001:1, from a random-coefficients AR(1) model for inflation (two-sided)

(Inflation: first difference of log GNP deflator, quoted at annual rate; data are from Balke and Gordon, 1986, ‘Appendix B: Historical Data’, and from *U.S. Department of Commerce, Bureau of Economic Analysis*)

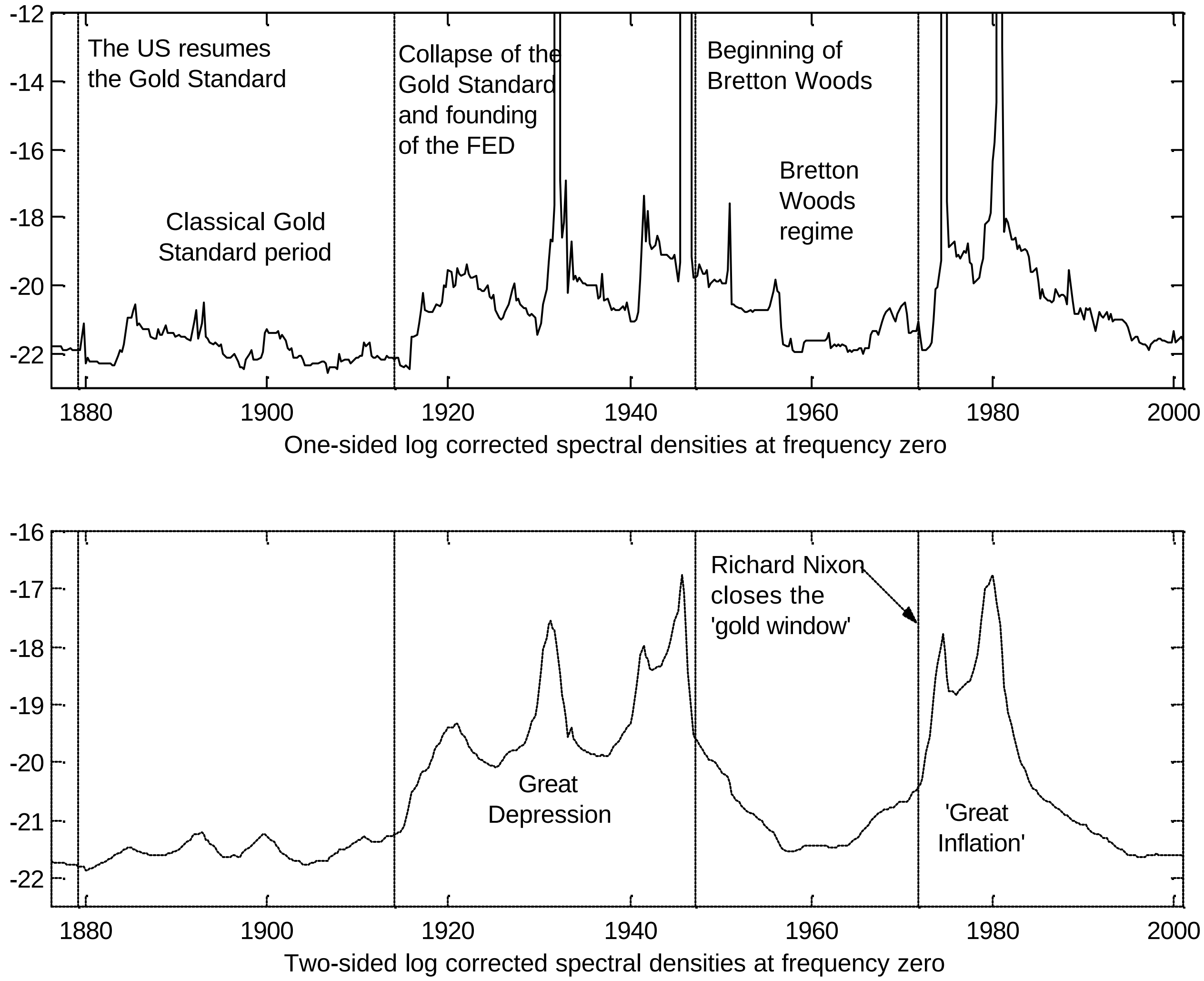



Figure 13
Log corrected spectral densities of US GNP deflator inflation at frequency zero, from a random-coefficients AR(1) model for inflation.

(Inflation: first difference of log GNP deflator, quoted at annual rate; data are from Balke and Gordon, 1986, 'Appendix B: Historical Data', and from *U.S. Department of Commerce, Bureau of Economic Analysis*)

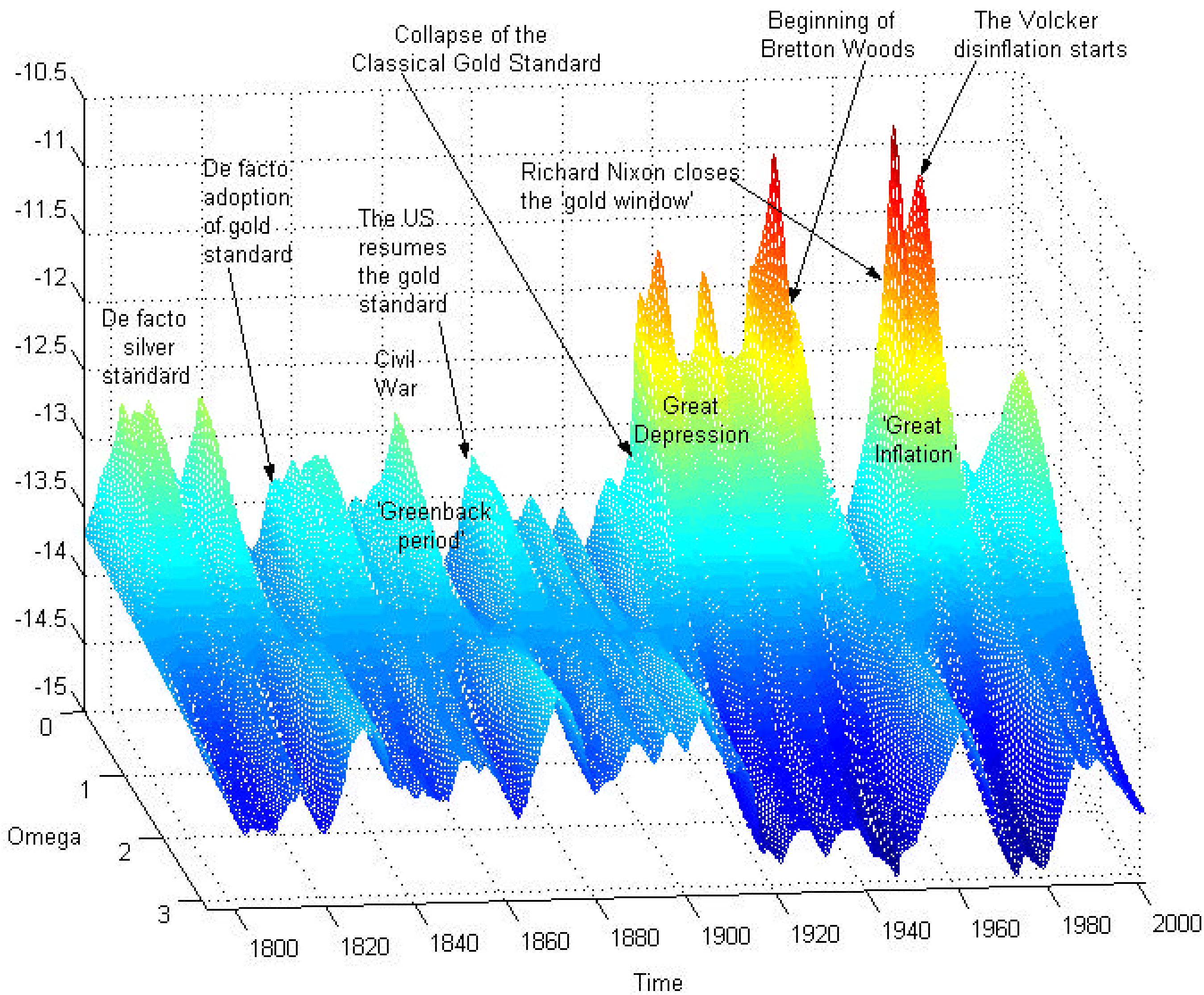



Figure 14
Log corrected spectral densities of US wholesale price inflation, 1793:4-2001:1, from a random-coefficients AR(1) model for inflation (two-sided)

(Inflation: first difference of log quarterly wholesale price index, quoted at annual rate; data from Warren and Pearson, 1933, *NBER Historical Database*; and *Federal Reserve Board*)

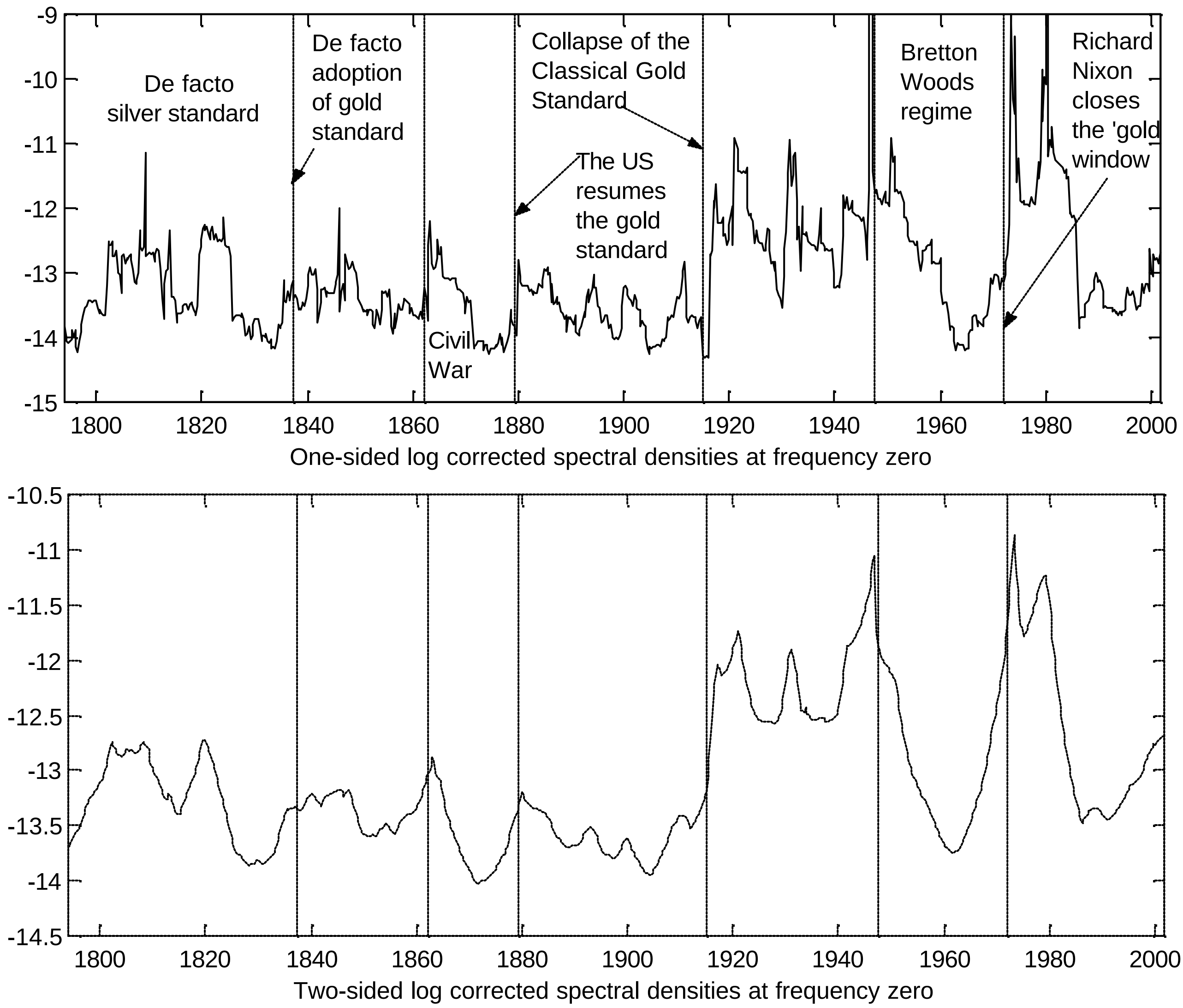



Figure 15
Log corrected spectral densities of US wholesale price inflation at frequency zero, 1793:4-2001:1, from a random-coefficients AR(1) model for inflation

(Inflation: first difference of log quarterly wholesale price index, quoted at annual rate; data from Warren and Pearson, 1933, *NBER Historical Database*; and *Federal Reserve Board*)

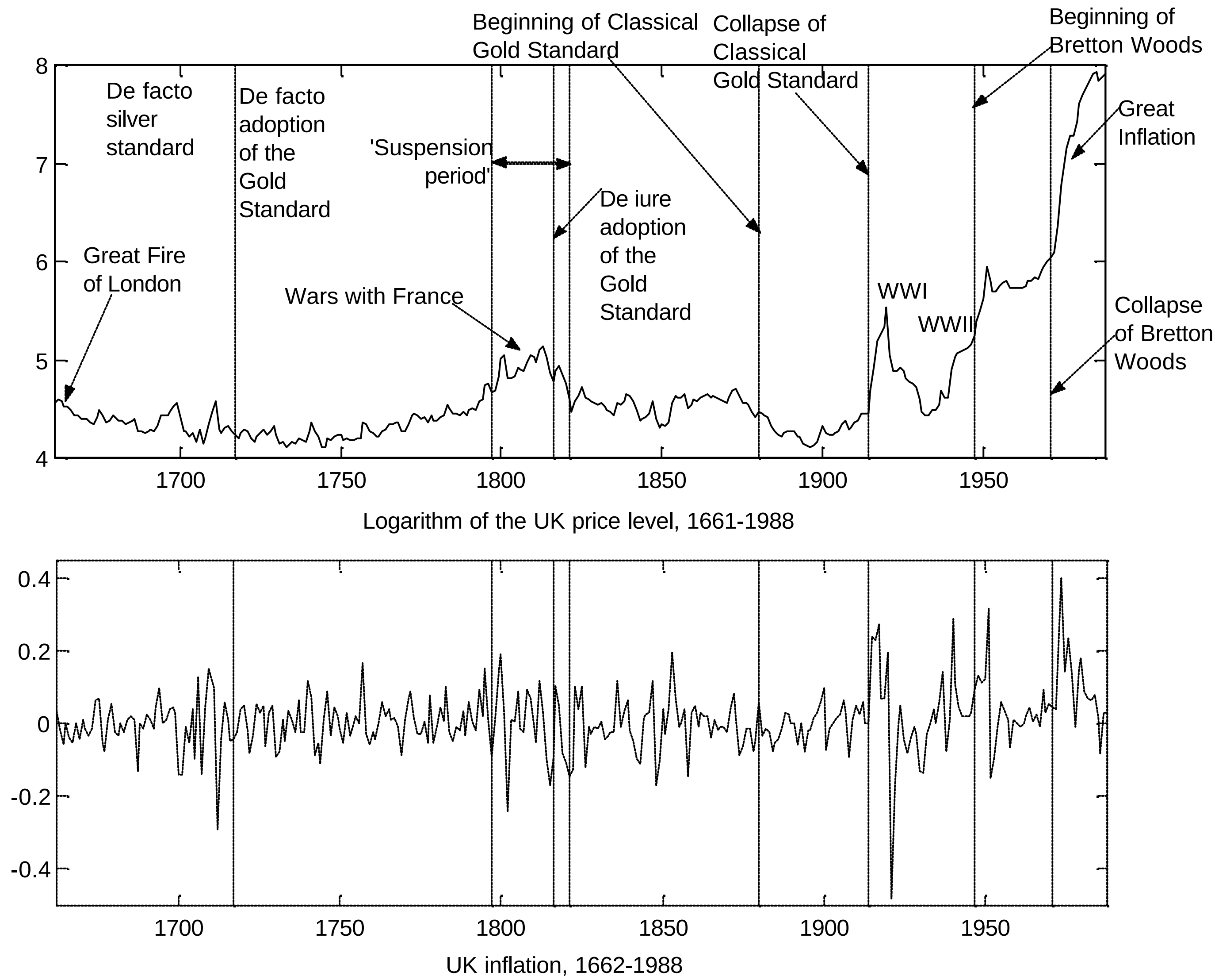



Figure 16
Logarithm of the UK price level and UK inflation since the XVII century

(Inflation: first difference of the log of the price level. The price index has been constructed by linking the Elisabeth Schumpeter consumer price indices, the Gayer-Rostow-Schwartz index, and the Sauerbeck-Statist index, all from Mitchell and Deane, *Abstract of British Historical Statistics*, with data from Mitchell, *International Historical Statistics, Europe 1750-1988*, for the most recent period)

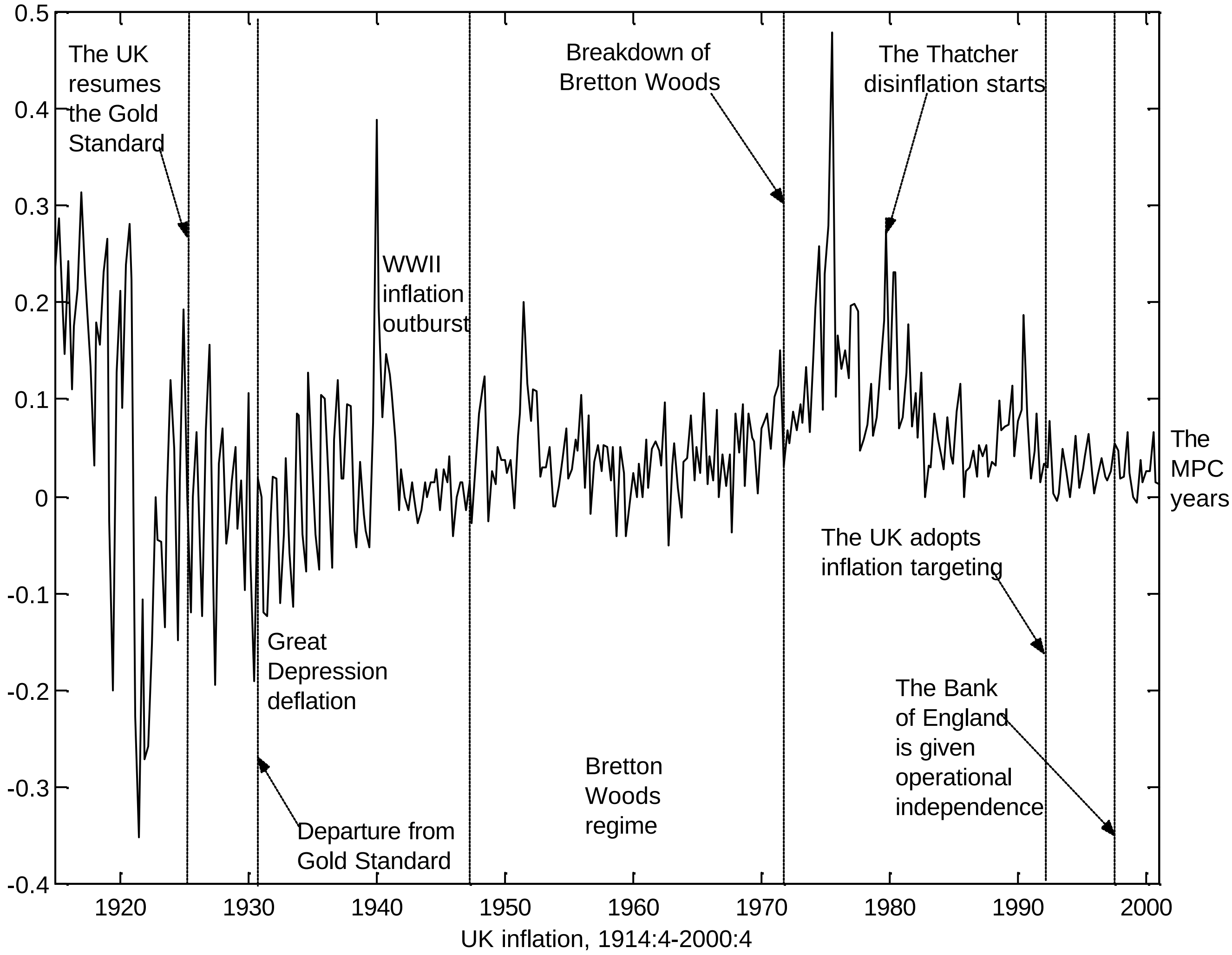



Figure 17
UK consumer price inflation, 1914:4-2000:4

(Inflation: first difference of log retail price index, quoted at an annual rate, from 1914:4 to 1962:1; first difference of log CPI, quoted at an annual rate, from 1962:2 to 2000:4. All data are quarterly, and seasonally unadjusted. The retail price index is from Capie and Webber, 1985, *A Monetary History of the United Kingdom, 1870-1982*; the CPI is from the *OECD* database).

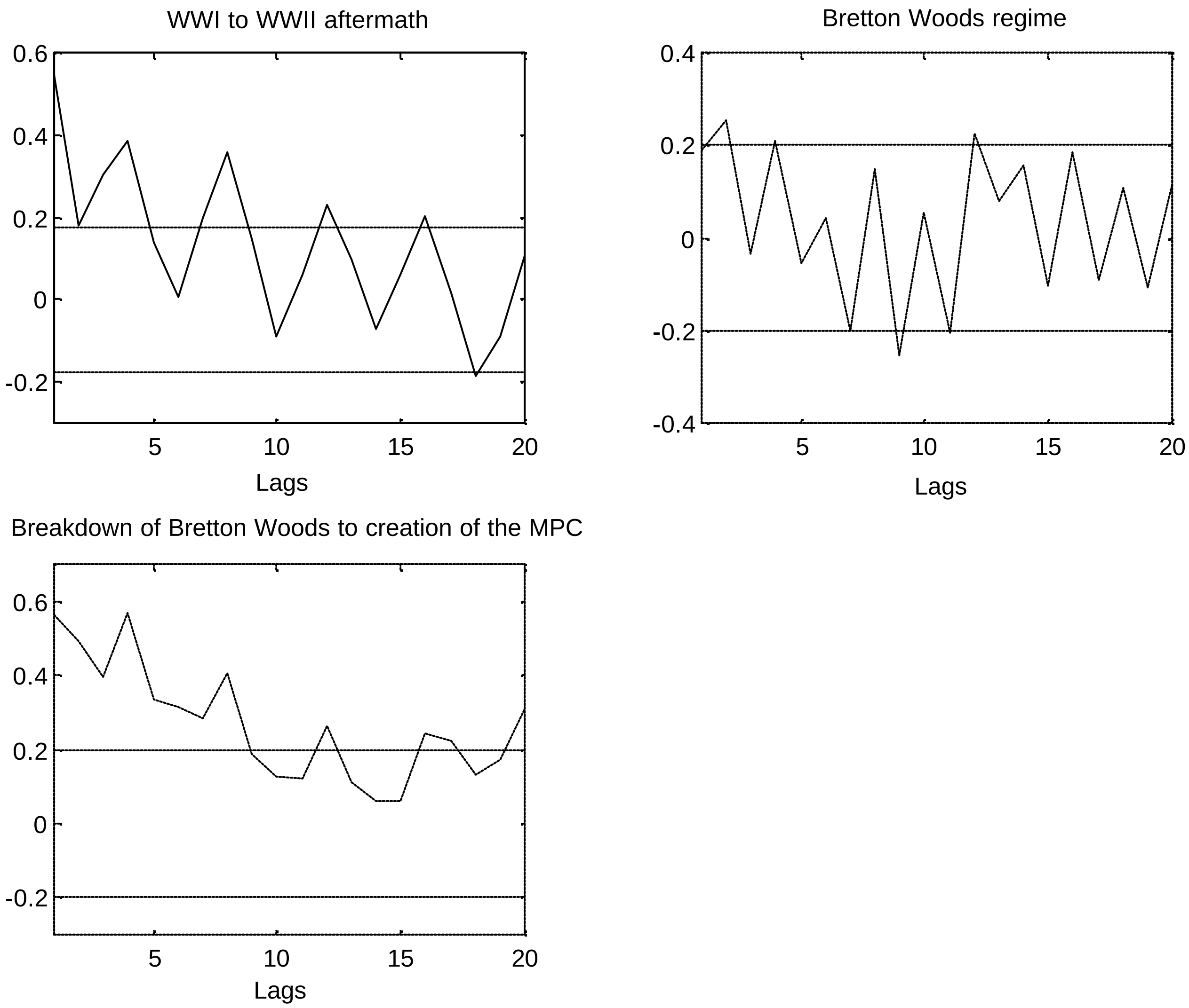



Figure 18
Estimated autocorrelations of UK consumer price inflation, 1914:4-2000:4
(Inflation: first difference of log retail price index, quoted at an annual rate, from 1914:4 to 1962:1; first difference of log CPI, quoted at an annual rate, from 1962:2 to 2000:4. All data are quarterly, and seasonally unadjusted. The retail price index is from Capie and Webber, 1985, *A Monetary History of the United Kingdom, 1870-1982*; the CPI is from the *OECD* database).

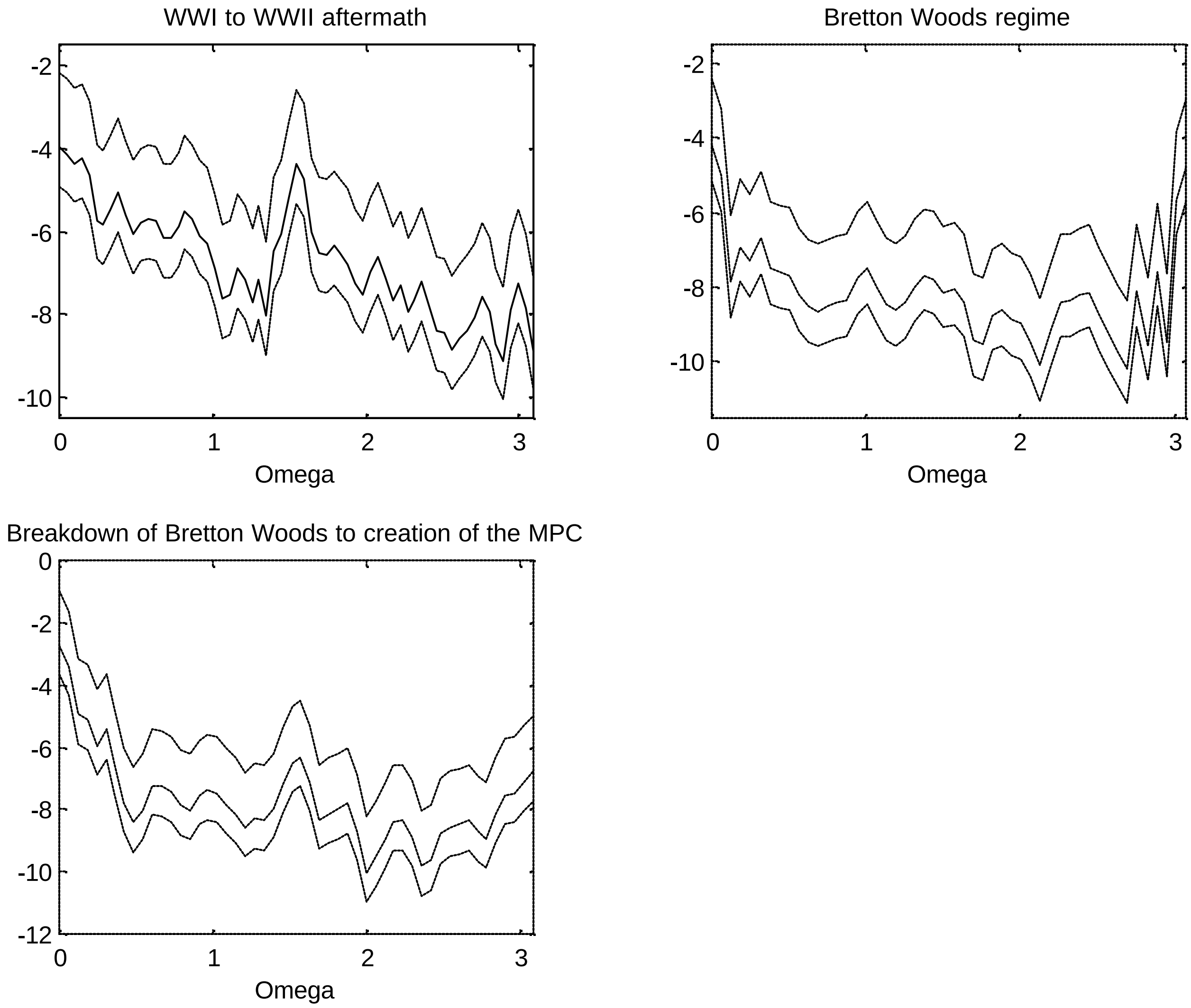



Figure 19
Log estimated spectral densities of UK consumer price inflation, 1914:4-2000:4, and 95% confidence bands (for technical details, see text).
(Inflation: first difference of log retail price index, quoted at an annual rate, from 1914:4 to 1962:1; first difference of log CPI, quoted at an annual rate, from 1962:2 to 2000:4. All data are quarterly, and seasonally unadjusted. The retail price index is from Capie and Webber, 1985, *A Monetary History of the United Kingdom, 1870-1982*; the CPI is from the *OECD* database).

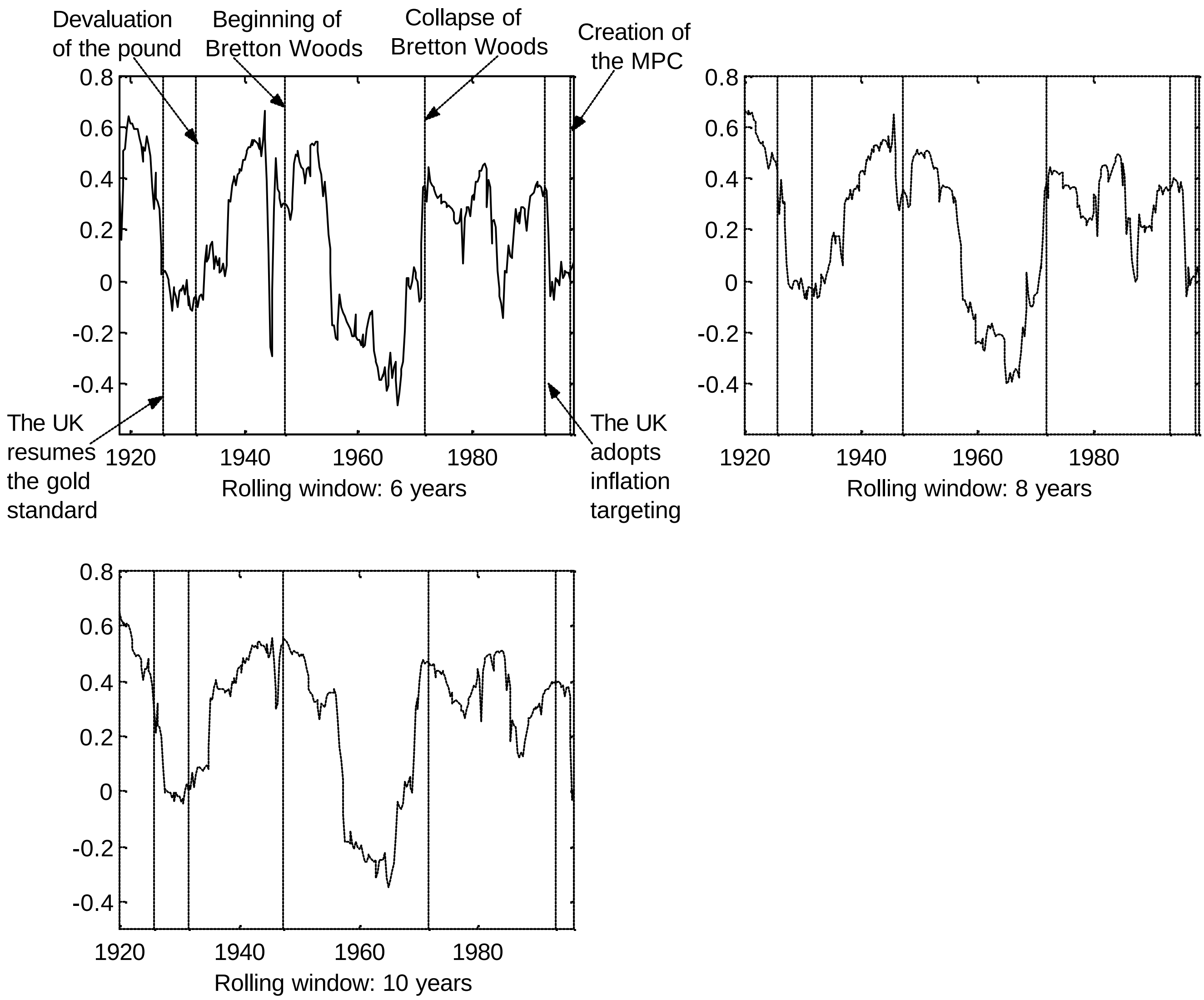



Figure 20
Rolling autocorrelations of UK consumer price inflation at lag 1, 1914:4-2000:4

(Inflation: first difference of log retail price index, quoted at an annual rate, from 1914:4 to 1962:1; first difference of log CPI, quoted at an annual rate, from 1962:2 to 2000:4. All data are quarterly, and seasonally unadjusted. The retail price index is from Capie and Webber, 1985, *A Monetary History of the United Kingdom, 1870-1982*; the CPI is from the *OECD* database).

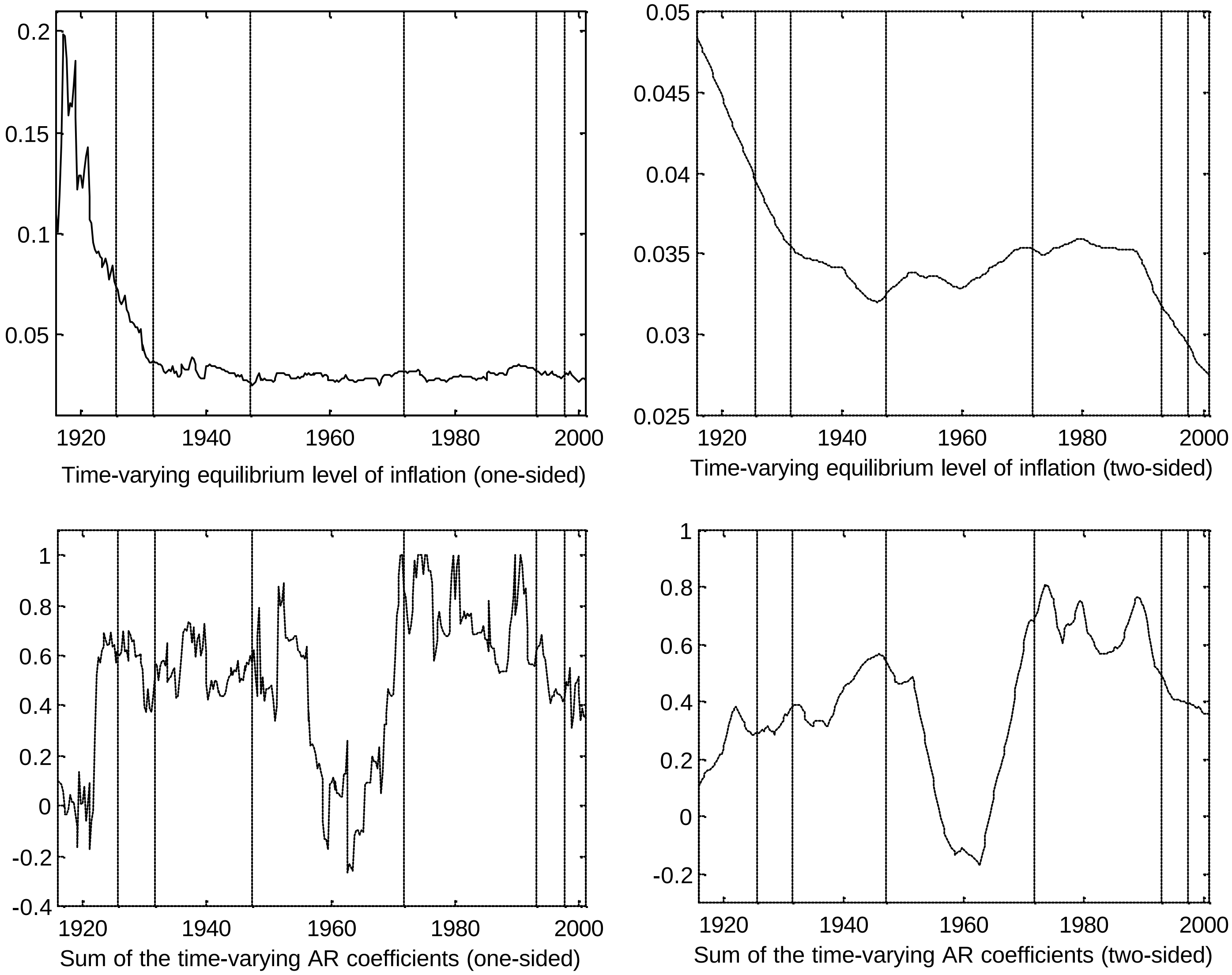



Figure 21
Time-varying equilibrium level of inflation, and sum of the time-varying AR coefficients, 1915:4-2000:4, from a random-coefficients AR(4) for inflation (two-sided) (Inflation: first difference of log retail price index, quoted at an annual rate, from 1914:4 to 1962:1; first difference of log CPI, quoted at an annual rate, from 1962:2 to 2000:4. All data are quarterly, and seasonally unadjusted. The retail price index is from Capie and Webber, 1985, *A Monetary History of the United Kingdom, 1870-1982*; the CPI is from the *OECD* database).

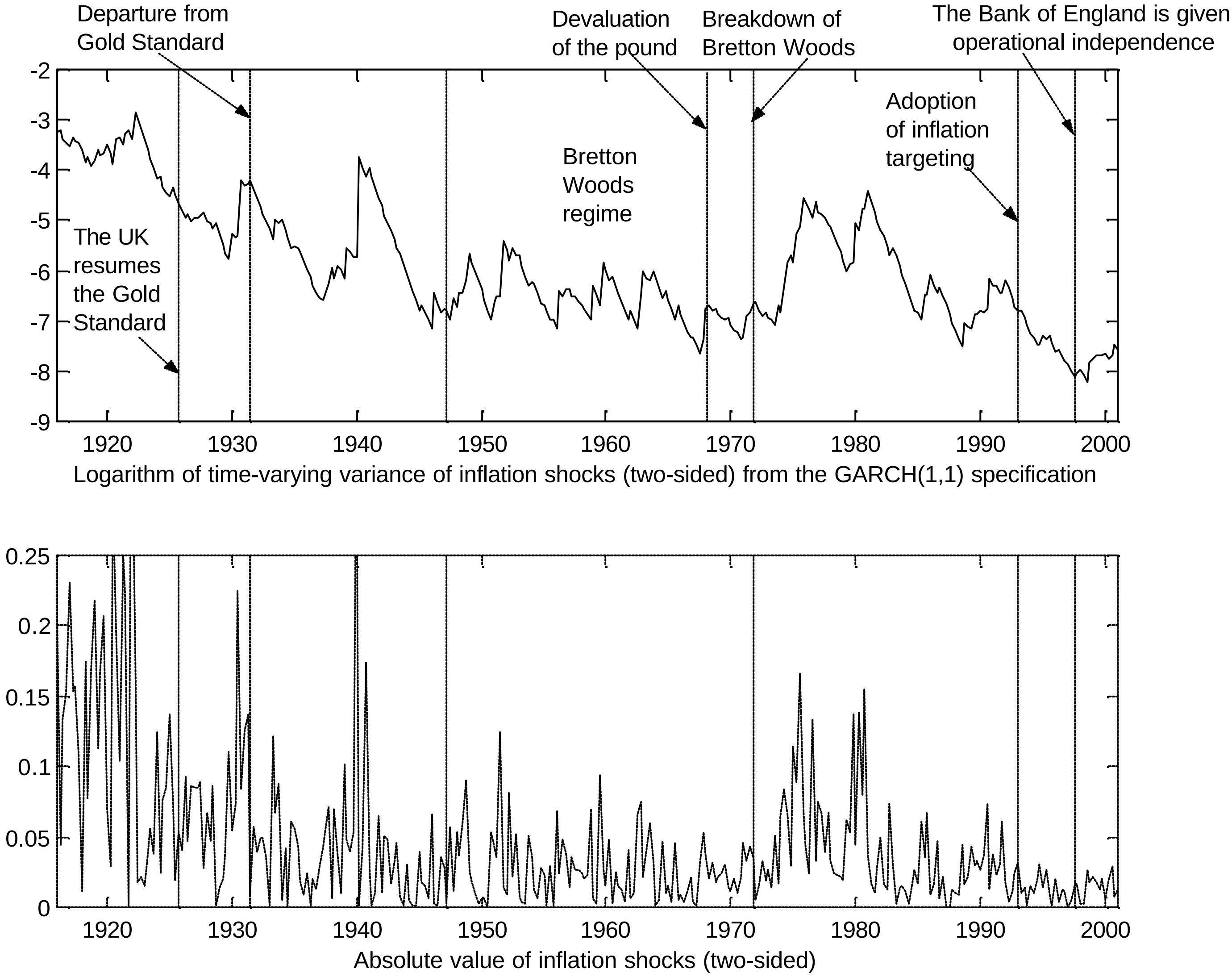



Figure 22
Logarithm of time-varying variance, and absolute value of inflation shocks, 1915:4-2000:4, from a random-coefficients AR(4) for inflation (two-sided)

(Inflation: first difference of log retail price index, quoted at an annual rate, from 1914:4 to 1962:1; first difference of log CPI, quoted at an annual rate, from 1962:2 to 2000:4. All data are quarterly, and seasonally unadjusted. The retail price index is from Capie and Webber, 1985, *A Monetary History of the United Kingdom, 1870-1982*; the CPI is from the *OECD* database).

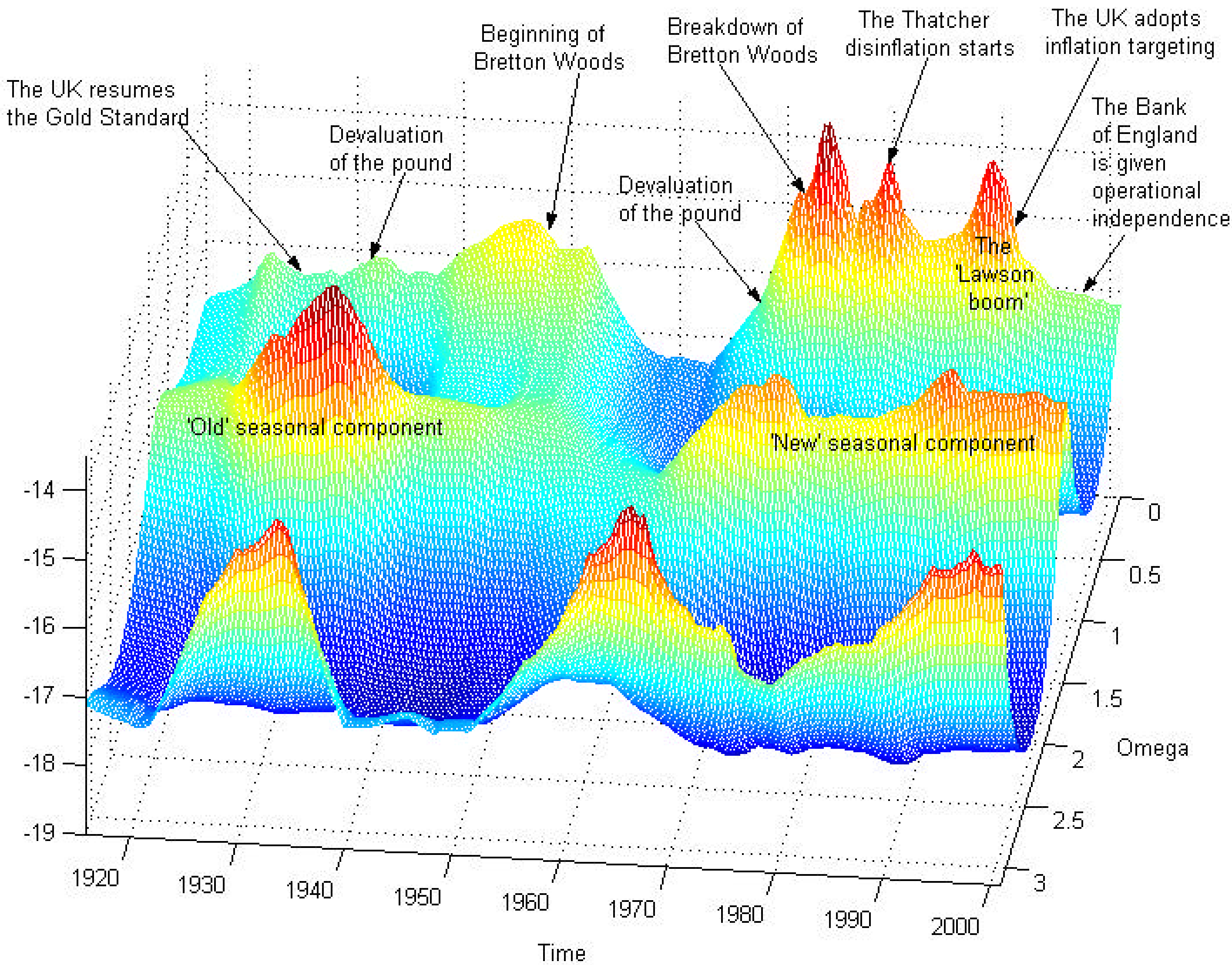



Figure 23
Log corrected spectral densities of UK consumer price inflation, 1915:4-2000:4, from a random-coefficients AR(4) for inflation (two-sided)
(Inflation: first difference of log retail price index, quoted at an annual rate, from 1914:4 to 1962:1; first difference of log CPI, quoted at an annual rate, from 1962:2 to 2000:4. All data are quarterly, and seasonally unadjusted. The retail price index is from Capie and Webber, 1985, *A Monetary History of the United Kingdom, 1870-1982*; the CPI is from the *OECD* database).

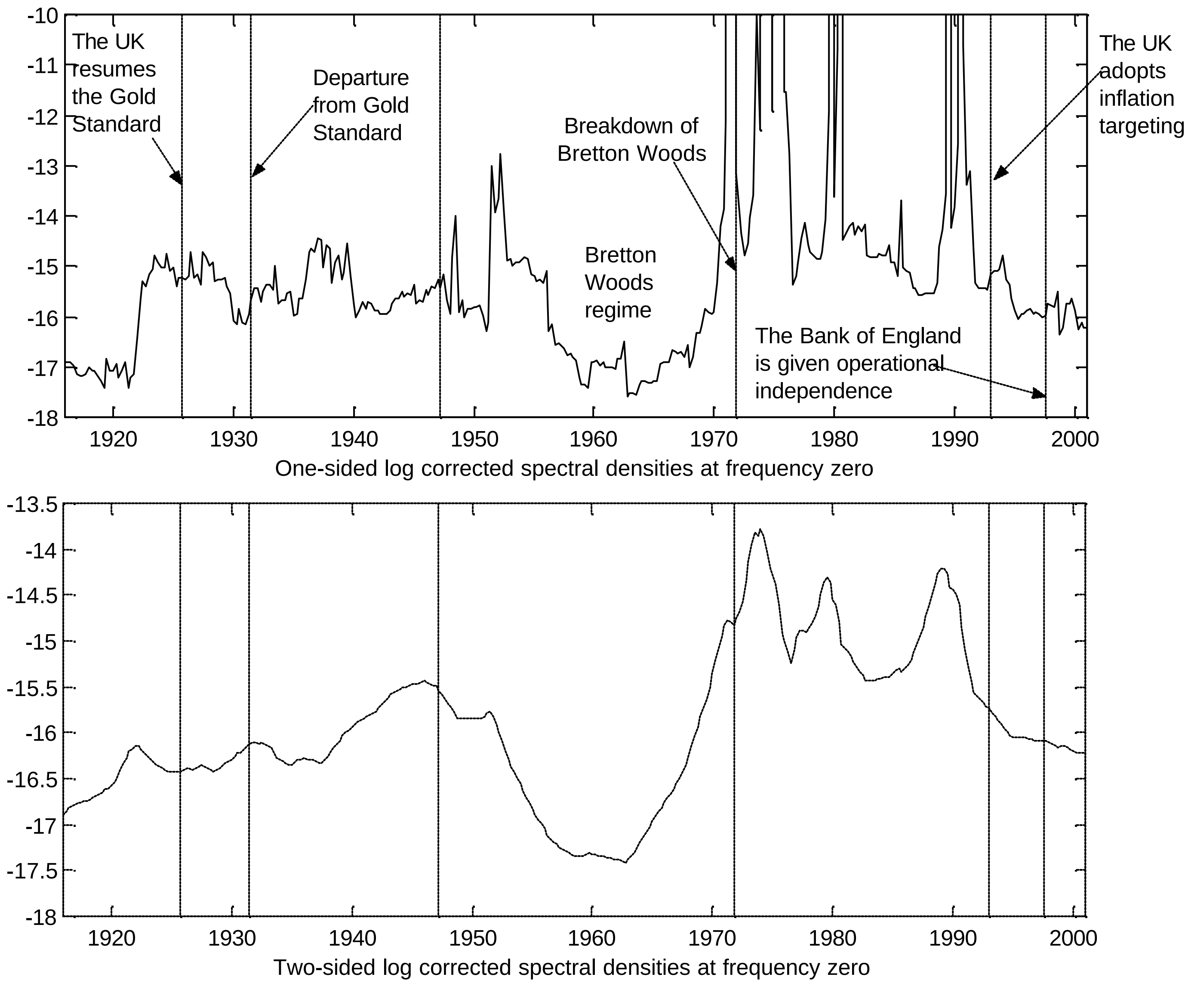
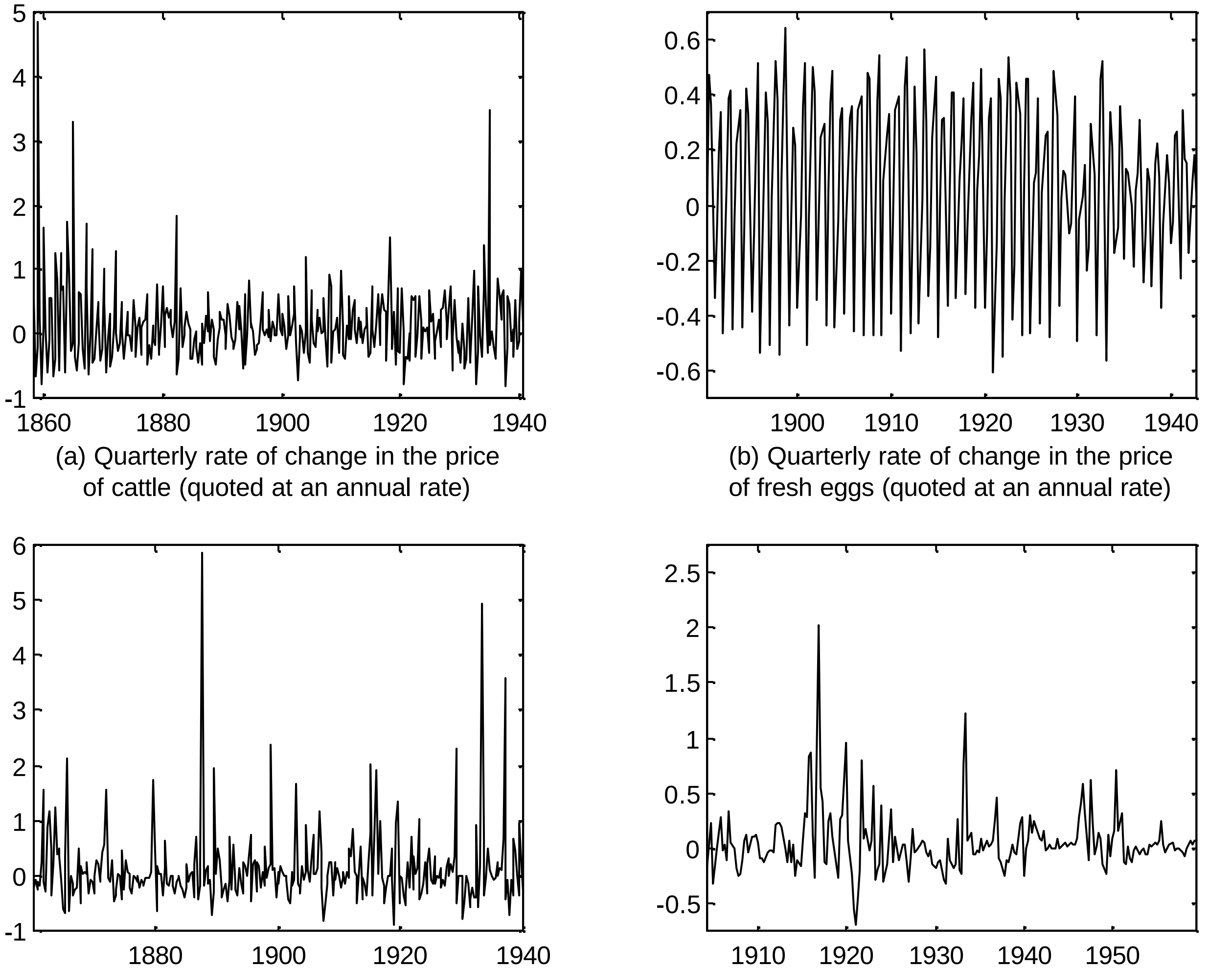



Figure 24
Log estimated spectral densities of UK consumer price inflation at frequency zero, from a random-coefficients AR(4) model for inflation
(Inflation: first difference of log retail price index, quoted at an annual rate, from 1914:4 to 1962:1; first difference of log CPI, quoted at an annual rate, from 1962:2 to 2000:4. All data are quarterly, and seasonally unadjusted. The retail price index is from Capie and Webber, 1985, *A Monetary History of the United Kingdom, 1870-1982*; the CPI is from the *OECD* database).



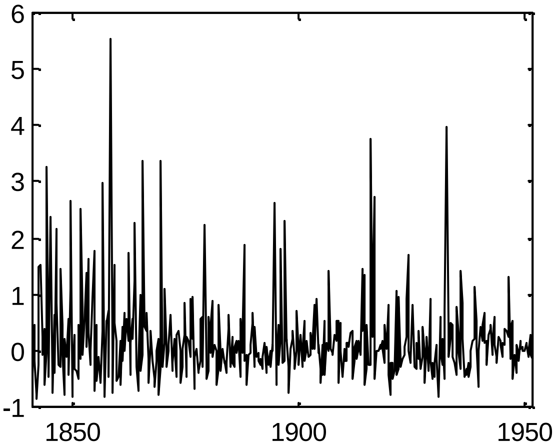

(a) Quarterly rate of change in the price of cattle (quoted at an annual rate)

(b) Quarterly rate of change in the price of fresh eggs (quoted at an annual rate)

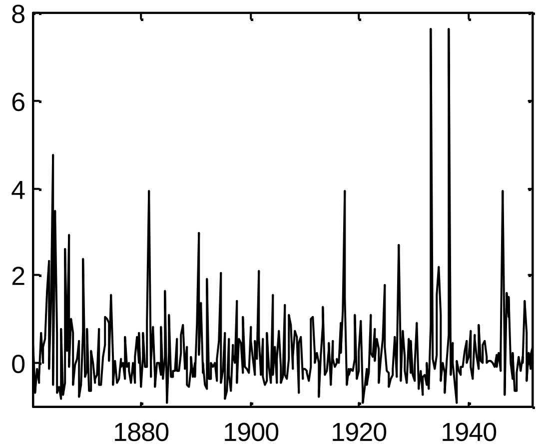
(c) Quarterly rate of change in the price of copper (quoted at an annual rate)

(d) Quarterly rate of change in the price of industrial commodities (quoted at an annual rate)

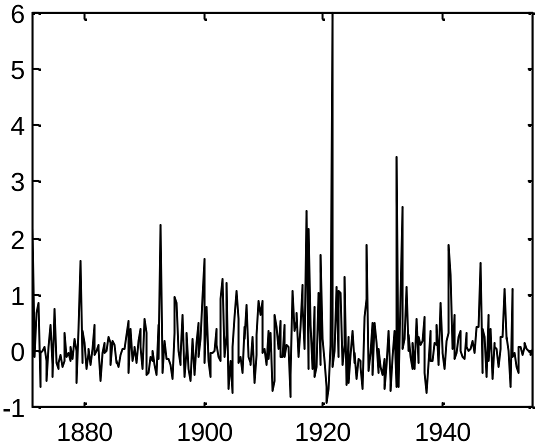
Figure 25
Empirical evidence on the ‘Hanes hypothesis’: quarterly rates of change in the prices of three raw commodities, and of the *Babson* wholesale index for prices of industrial commodities, across monetary regimes.
(Data source: *NBER Historical Database*).




(a) Quarterly rate of change in the price of wheat (quoted at an annual rate)




(b) Quarterly rate of change in the price of corn (quoted at an annual rate)




(c) Quarterly rate of change in the price of cotton (quoted at an annual rate)

Figure 26
Empirical evidence on the ‘Hanes hypothesis’: quarterly rates of change in the prices of three raw commodities across monetary regimes.
(Data source: *NBER Historical Database*).

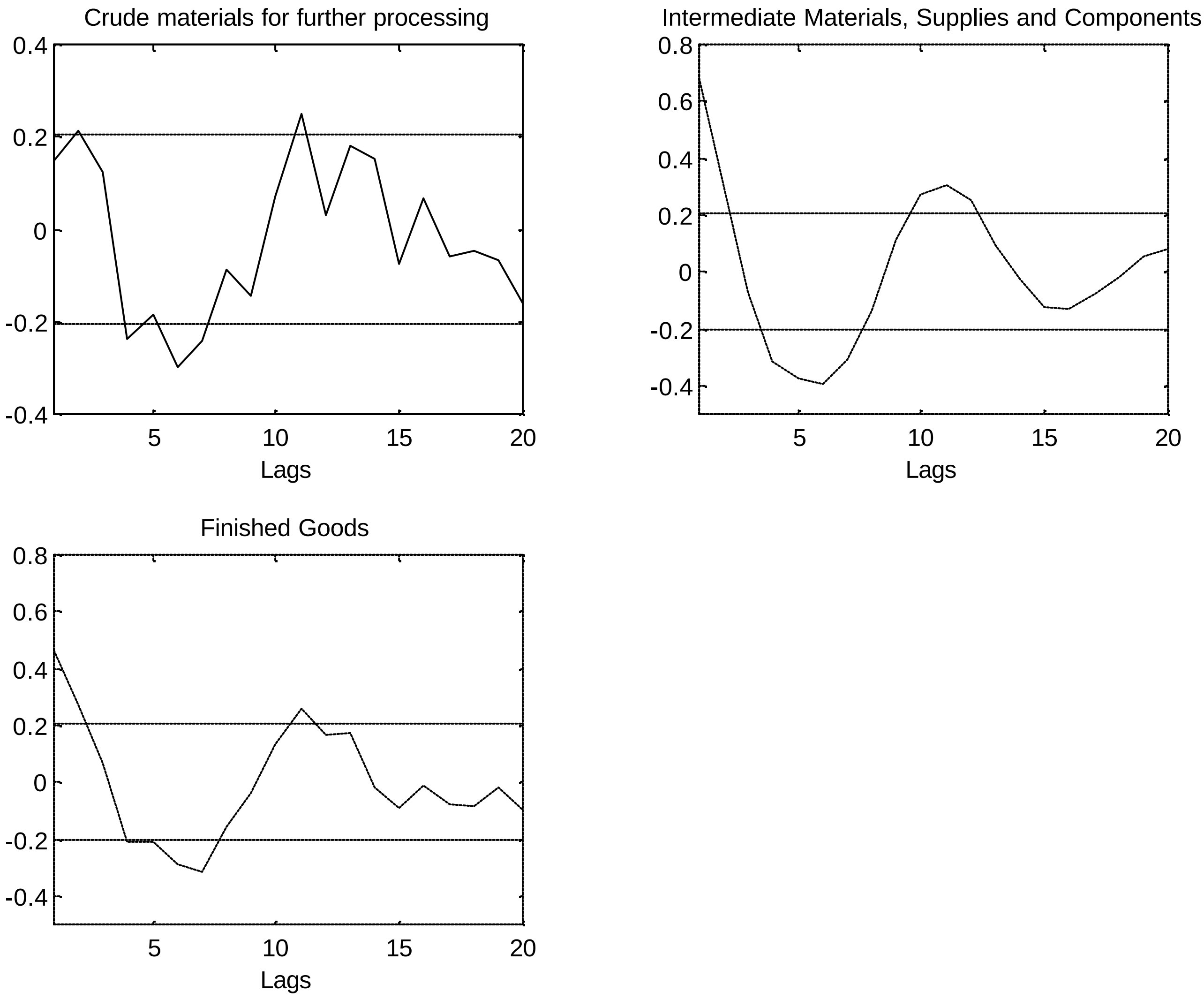



Figure 27
Empirical evidence on the ‘Hanes hypothesis’: estimated autocorrelation functions of inflation based on three price indexes for goods with different degrees of processing.
(Sample period: 1947:3-1971:3. Data source: *Bureau of Labor Statistics*)

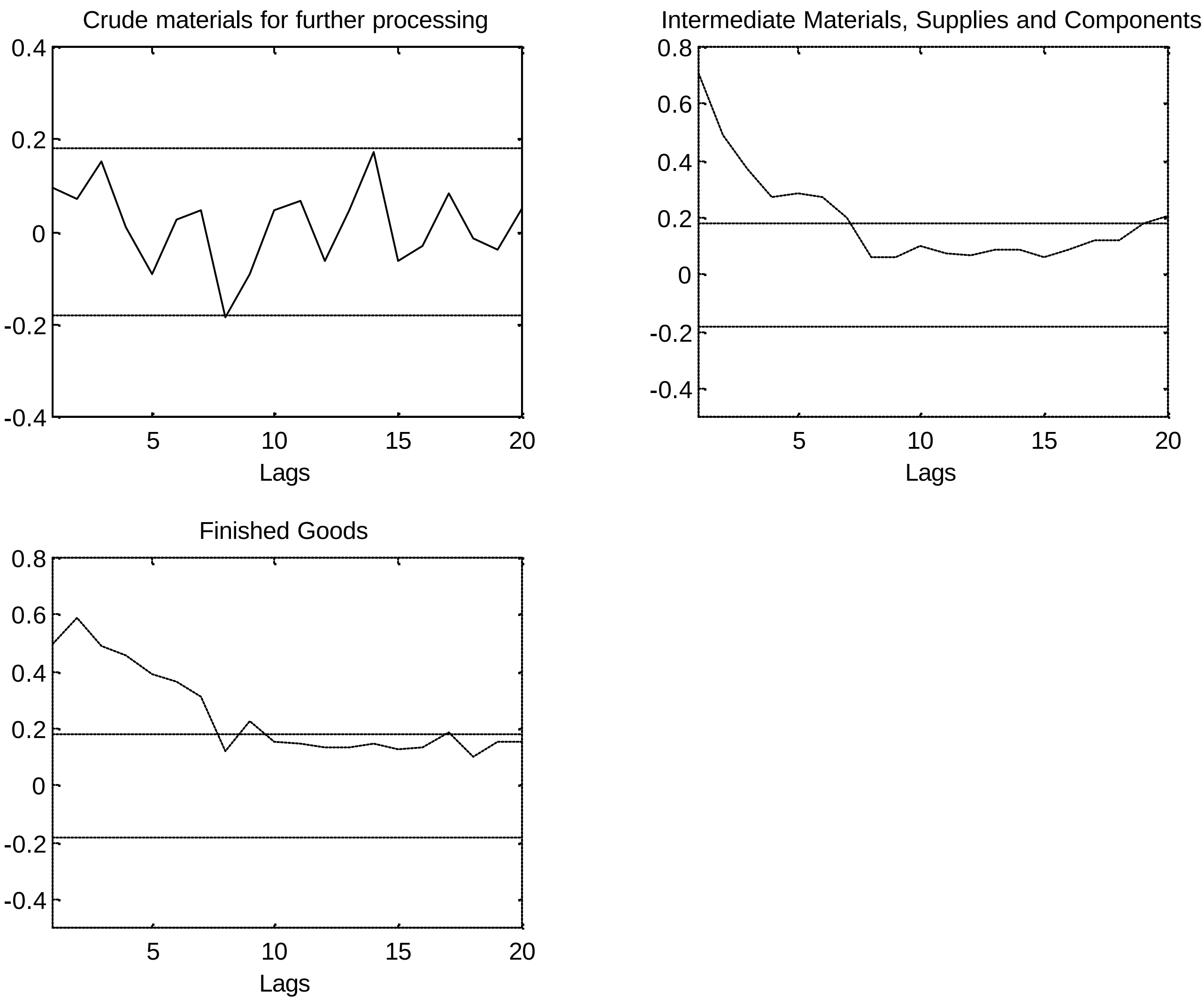



Figure 28
Empirical evidence on the ‘Hanes hypothesis’: estimated autocorrelation functions of inflation based on three price indexes for goods with different degrees of processing.
(Sample period: 1971:4-2001:3. Data source: *Bureau of Labor Statistics*)

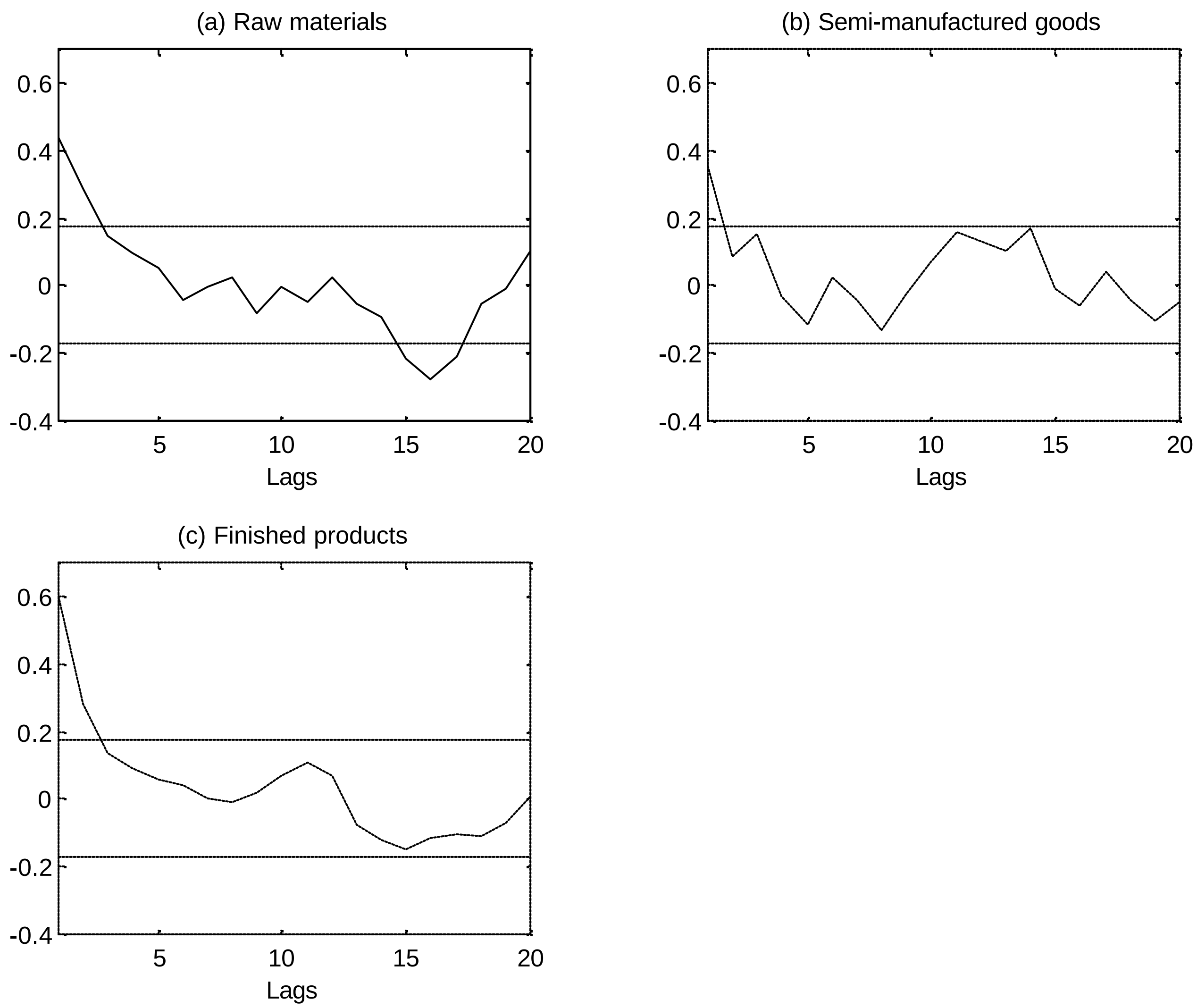



Figure 29
Empirical evidence on the 'Hanes hypothesis': estimated autocorrelation functions of inflation based on three price indexes for goods with different degrees of processing.
(Sample period: 1914:1-1947:1. Data source: *NBER Historical Database*).

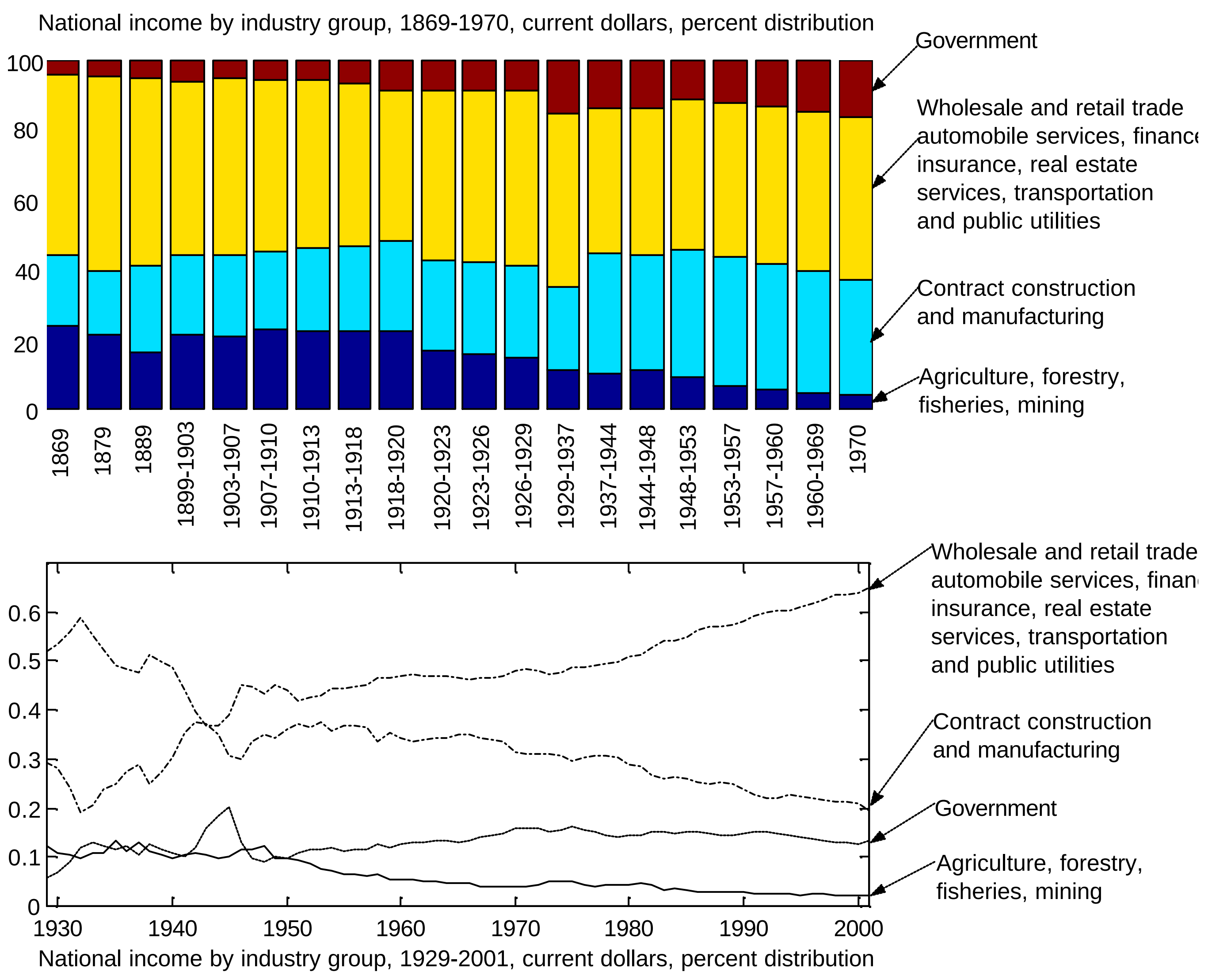
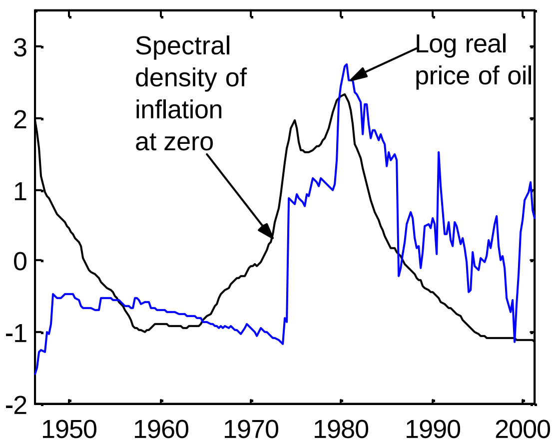
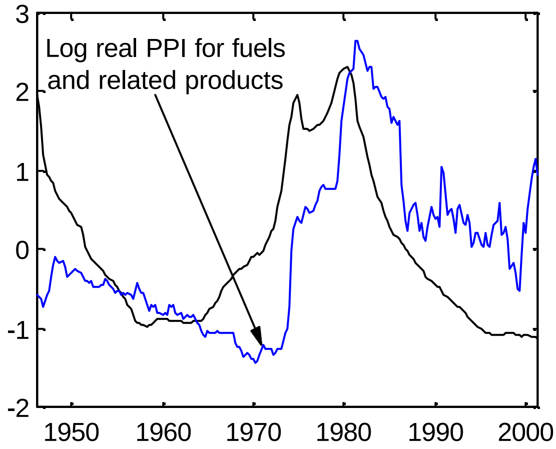



Figure 30
The structural transformation of the US economy, 1869-2001: US national income by industry group

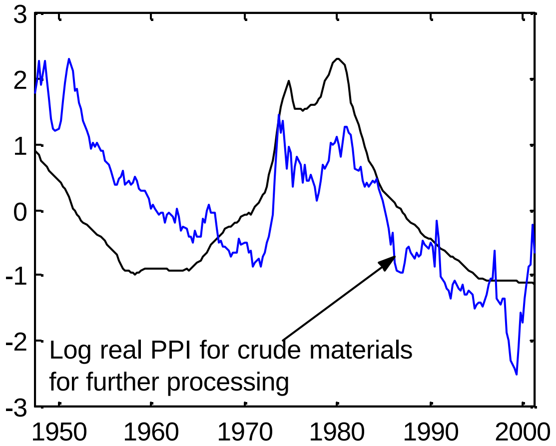
(Data sources: US Bureau of the Census, *Historical Statistics of the United States, Colonial Times to 1970*; and *National Income and Product Accounts,* Tables 6.1A, B, C).



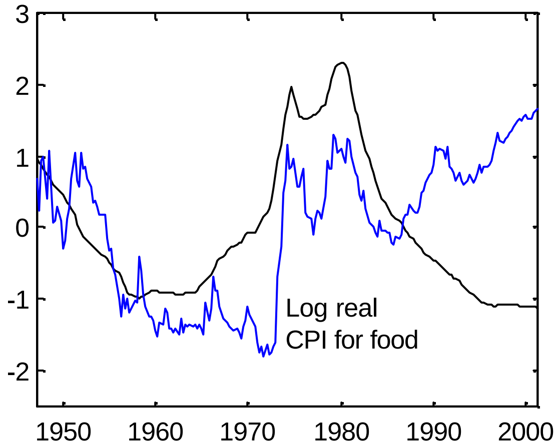

Spectral density of inflation at zero and log real price of oil




Spectral density of inflation at zero and log real PPI for fuels and related products




Spectral density of inflation at zero and log real PPI for crude materials for further processing




Spectral density of inflation at zero and log real CPI for food

Figure 31
Inflation persistence and alternative indicators of supply-side developments, U.S., post-WWII

(Data sources: spot price of West Texas intermediate, *Dow Jones Energy Service*; PPIs for fuels and related products, and for crude materials for further processing, and the CPI for food, *Federal Reserve Board*).

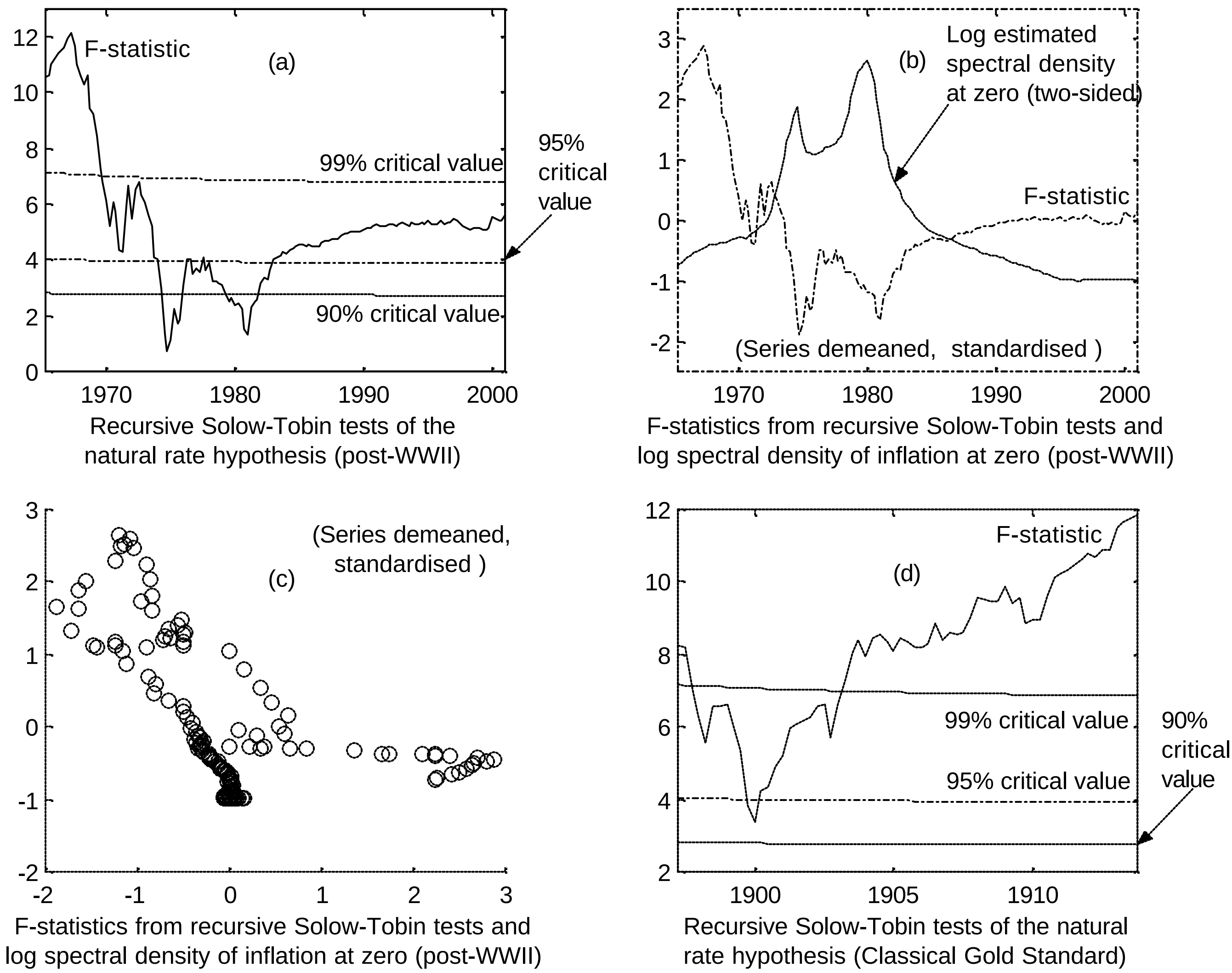



Figure 32
Recursive Solow-Tobin tests of the natural rate hypothesis and inflation persistence: results from the post-WWII period and from the Classical Gold Standard

(Inflation: first difference of log GNP deflator, quoted at annual rate; data are from Balke and Gordon, 1986, 'Appendix B: Historical Data', and from *U.S. Department of Commerce, Bureau of Economic Analysis*)