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ABSTRACT

Liquidity Traps: How to Avoid Them and How to Escape Them*

The Paper considers ways of avoiding a liquidity trap and ways of getting out of one. Unless lower short nominal interest rates are associated with significantly lower interest volatility, a lower average rate of inflation, which will be associated with lower expected nominal interest rates, increases the odds that the zero nominal interest rate floor will become a binding constraint. The empirical evidence on this issue is mixed.

Once in a liquidity trap, there are two means of escape. The first is to use expansionary fiscal policy. The second is to lower the zero nominal interest rate floor. This second option involves paying negative interest on government 'bearer bonds': coin and currency, that is 'taxing money', as advocated by Gesell. This would also reduce the likelihood of ending up in a liquidity trap. Taxing currency amounts to having periodic 'currency reforms', that is, compulsory conversions of 'old' currency into 'new' currency, say by stamping currency. The terms of the conversion can be set to achieve any positive or negative interest rate on currency. There are likely to be significant shoe leather costs associated with such schemes. The policy question then becomes how much shoe leather it takes to fill an output gap?

Finally the Paper develops a simple analytical model showing how the economy can get into a liquidity trap and how Gesell money is one way of avoiding it or escaping from it.

JEL Classification: B22, E31, E32, E51, E52, E58, N12, N13, N14
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NON-TECHNICAL SUMMARY

The credible targeting of a low rate of inflation should result, on average, in low nominal interest rates. The administratively determined zero nominal interest rate on currency sets a floor under the nominal interest rate on non-monetary financial claims. An important policy issue then is the following: how likely is it that the economy ends up, as a result of shocks or endogenous fluctuations, in a situation where the zero short nominal interest floor becomes a binding constraint, that is, how likely is the economy to end up in a liquidity trap?

If low average nominal interest rates also tend to be stable rates, the risk of ending up in a liquidity trap need not be enhanced much by targeting a low rate of inflation. The empirical evidence on the relationship between the level and volatility of short nominal rates is, however, mixed. The cross-sectional evidence supports a strong positive correlation between the average level of the short nominal interest rate and its (unconditional) variance. The time-series evidence for the UK is ambiguous. At very high (daily) frequencies, the correlation between the level of short sterling futures and a volatility index derived from short sterling futures options is negative. At weekly frequencies, the correlation is positive for most of the post-1975 period, but the correlation is negative since 1993, the beginning of inflation-targeting in the UK.

Once an economy lands itself in a liquidity trap, there are just two policy options. The first is to wait for some positive shock to the excess demand for goods and services, brought about through expansionary fiscal measures or through exogenous shocks to private domestic demand or to world demand. The second option is to lower the zero nominal interest rate floor on currency by taxing currency. A negative interest rate on currency would also reduce the likelihood of an economy landing itself in a liquidity trap.

The Paper revisits a proposal by Gesell for implementing a negative nominal interest rate on currency. Under this proposal, currency would cease to be current and could be subject to confiscation, unless the bearer makes a predetermined periodic payment to the issuer. Currency would have become ‘stamp scrip’. Another perspective on Gesell money is to view it as involving periodic monetary reform, in which the conversion terms between old and new currency define their own interest rate on currency.

The transactions and administrative costs associated with such periodic currency reforms would be non-negligible. Such currency conversion costs could be reduced by lengthening the interval between conversions, but they would remain significant. These ‘shoe-leather costs’ would have to be set against the risk of ending up in a liquidity trap, if a very low rate of inflation is targeted without taxing currency, or against the cost of targeting a higher rate of inflation. It may take a lot of shoe leather to fill an output gap or to rub out the distortions associated with the inflation tax.

We then analyse the behaviour of a small analytical macroeconomic model in which negative interest on currency is a policy option. In the Keynesian, sticky price version of the model, there are two kinds of equilibria, ‘normal’ equilibria and liquidity trap equilibria. If the inflation rate falls to a sufficiently low level, the economy may end up in the liquidity trap zone in which it will cycle permanently around the liquidity trap steady state. Imposing a negative interest rate on currency lowers the critical rate of inflation at which the economy enters the liquidity trap zone. Once caught in the liquidity trap zone, a reduction in the nominal interest rate on currency provides a means of escape.

If there are indeed benighted countries threatened by, or even caught in, a liquidity trap, the policy makers there have one more option they might wish to consider on its merits: Gesell money.

(I) Introduction

Liquidity trap talk is with us again. Liquidity traps may be with us. An economy is said to be in a liquidity trap when the ability to use monetary policy to stimulate demand has vanished because the nominal interest rate has reached an unbreachable floor. The textbook treatment of liquidity traps, based on Hicks's [1936] interpretation of Keynes [1936], involves the assumption that the demand for money becomes infinitely sensitive to the opportunity cost of holding money, the spread between the pecuniary yield on some non-monetary asset, i, and the pecuniary own yield on money, i_M, at some low level (typically zero) of that opportunity cost. With portfolio holders indifferent a regards the composition of their financial wealth between money and non-money assets, changes in the supply of money cannot affect the spread. Specifically, increases in the supply of money cannot push the spread below the level at which the demand for money becomes infinitely elastic.

The argument assumed that the pecuniary own rate of return on money was zero, an appropriate assumption for coin and currency, although not for the liabilities of private deposit-taking institutions that make up most of the broader monetary aggregates, which now typically have positive nominal returns. With the own rate of return on currency administratively fixed at zero, a floor for the spread becomes a floor for the nominal yield on some non-monetary financial instrument, i, the short nominal interest rate. [1]

When, as is institutionally more relevant, the short nominal interest rate is taken to be the monetary instrument, rather than some monetary aggregate, the argument is not changed in any essential way. Since money is, by assumption, the asset with the highest non-pecuniary rate of return, the equilibrium spread between the pecuniary return on non-

[1] With the nominal rate on currency fixed at zero, the nominal interest rate on other financial claims can be negative if the cost of holding and storing currency exceeds that of holding and

monetary assets and that on money, has to be non-negative. The authorities therefore cannot drive the short nominal interest rate below the pecuniary own rate of return on money. This is zero if (some component of) money is non-interest-bearing. Non-interest-bearing coin and currency therefore prevent the short nominal interest rate on non-monetary financial claims from falling below zero. This produces liquidity trap at (or possibly above) a zero nominal rate of interest.

This liquidity trap used to be treated, in the mainstream accounts of the monetary transmission mechanism, as a theoretical curiosum without practical relevance.[2] The revival of interest in the liquidity trap is not surprising. First, Japan is in a protracted economic slump. Short nominal interest rates there are near zero. Zero is the absolute nominal interest rate floor in Japan because yen notes and coin bear a zero nominal interest rate. Monetary policy in Japan currently appears to have a very limited effect on aggregate demand. The conclusion that there is a liquidity trap at work is hard to resist (see e.g. Krugman [1998a,b,c,d; 1999], Ito [1998] and McKinnon and Ohno [1999]); for a view that liquidity traps are unlikely to pose a problem, see Meltzer [1999]).

Second, inflation in Euroland is below one percent per annum. The official short rate now [3]is 2.5 percent. Euroland economic activity is slowing down. This raises the question as to whether a margin of two hundred and fifty basis points provides enough insurance against a slump. Demand could weaken to such an extent that a cut in the short nominal rate of more than two hundred and fifty points would be required to boost aggregate demand sufficiently

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storing these other claims (see Porter [1999]). This is unlikely to be important quantitatively and for expositional simplicity it is ignored in what follows.

[2] [2]See e.g. Romer [1996], which covers the topic as half of an exercise at the end of the chapter 5, "Traditional Keynesian Theories of Fluctuations".

[3] June 1999.

The monetary instrument is, almost invariably, a short nominal interest rate.[4] Aggregate demand is influenced primarily by real interest rates, short and long, that is, by nominal interest rates corrected for (expected) changes in the purchasing power of money. The transmission of monetary policy through other real asset prices, including the real exchange rate, depends on the ability of the monetary authorities to influence real interest rates. For the monetary authority to affect real demand, changes in nominal interest rates have to be translated, at least temporarily, into changes in real interest rates. In a moderate or low-inflation environment, inflation and inflation expectations tend to move only gradually and sluggishly. This Keynesian feature of the economy gives monetary policy a temporary handle on the real economy.

If short nominal interest rates cannot fall any further, short real rates can only be pushed down if there is a rise in the expected rate of inflation. If the price stability gospel has been widely internalised by market participants, expected inflation is unlikely to rise to produce the required cut in real rates.

Once an economy is in such a situation, it is not possible to get out of it using the conventional monetary policy instruments - changes in the short nominal interest rates. Inflation expectations are not a policy instrument. Why would inflation expectations rise when monetary policy cannot stimulate demand? It is a trap - an inefficient equilibrium. Conventional monetary policy advice then can only be preventive, not curative: do not get

[4]The argument could be recast in terms of the monetary authority using some monetary aggregate as the instrument, with the short nominal interest rate on risk-free non-monetary financial claims treated as endogenous. Taking the short nominal rate as the instrument has two advantages. First, the exposition in simpler. Second, it is what central banks actually do. Changes in reserve requirements, open market operations etc. are best viewed as ways of changing the interest rate. .In an open economy, the other institutionally relevant instrument of monetary policy is the nominal exchange rate. When capital mobility is limited, the short nominal interest rate and the nominal exchange rate both can be instruments of policy, at any rate in the short run.

into this situation.[5] Make sure inflation expectations (and actual inflation) are targeted at a level high enough to ensure that nominal interest rates will not hit the floor, even during periods during which aggressively expansionary monetary policy is in order.

Of course, in a liquidity trap, expansionary fiscal policy, or any other exogenous shock to aggregate demand, is supposed to be at its most effective. There are, however, conditions under which fiscal policy cannot be used to stimulate aggregate demand. Debt-financed lump-sum tax cuts could fail to stimulate aggregate demand if there is Ricardian equivalence or debt neutrality. Alternatively, the government's creditworthiness may be so impaired that it cannot borrow. Finally, there could be external, Maastricht Treaty or Stability and Growth Pact-like external constraints on a government's ability to use deficit financing.

If Ricardian equivalence holds, a temporary increase in exhaustive public spending will, even with a balanced budget, and in virtually any model of the economy, boosts aggregate demand. For this fiscal policy channel also to be ineffective, exhaustive public spending must be a direct perfect substitute for exhaustive private spending, say because public consumption is a perfect substitute for private consumption in private utility functions, and public investment is a perfect substitute for private investment in private production functions..[6]

If expansionary fiscal policy can be used to work the economy out of a liquidity trap, the problem is clearly rather less pressing. In what follows, it is assumed that this option is not available.

[5]This advice is a variant on the following familiar dialogue. Question: "How do I get there from here?" Answer: "I would not start from here".
[6]See Buiter [1977].

(II) Can the zero nominal interest rate floor become binding in the UK?

Most estimates of the current level of the long real interest rate in the UK put it somewhere between 2.0 and 3.0 percent per annum. Figures 1 and 2 show the recent behaviour of medium-term and long-term real rates of interest on index-linked government securities.[7]

Figure 1 here

Figure 2 here

With an inflation target of 2.5 percent per annum (as in the UK), the long-run nominal interest rate (ignoring term- and risk premia) would be between 4.5 and 5.5 percent per annum. In steady state, the short-term nominal interest rate would also be between 4.5 and 5.5 percent per annum. We can regard this as the 'normal' level of the short nominal interest rate. If one believed that there were contingencies (such as a dramatic, spontaneous collapse of aggregate demand) under which a cut in short rates of more than 4.5 to 5.5 percent would be in order, the monetary authority would be at risk of hitting the zero interest floor.

Historically, in the UK, there have been occasions when Bank Rate has swung by more than 4.5 or 5.5 percentage points. On 15 November 1979, the Bank's Minimum Lending Rate hit 17.00 percent. On March 11, 1981, it stood at 12.00 percent. On October 6, 1989, the Bank's Minimum Band 1 Dealing Rate stood at 14.88 percent. On 8 February 1994, it was down to 5.13 percent. Clearly, very large swings in Bank Rate, in excess of the 4.5 or

[7] Jenny Salvage prepared Figures 1 through 5.

5.5 percent 'safety margin' associated with a 2.5 percent inflation target and a 2.0 to 3.0 percent long real interest rate, have occurred in the past.

The emphasis should, however, be on 'in the past'. These very large cuts in Bank Rate invariably took place from a very high level of rates associated with prior macroeconomic mismanagement, generally an inflationary surge that threatened to get out of control (or had indeed done so) or the desperate defence of an overvalued exchange rate peg. Figure 3 shows the behaviour of Bank Rate, the inflation rate and the sterling-US$ exchange rate for the UK in the post-World War II period.

Figure 3 here

Neither situation applies today. Nor should it apply again if the political commitment to low and stable inflation and its institutional expression in an operationally independent central bank remain intact.

The longer-term historical record can also be viewed as encouraging. The UK got through the period 1800-1914 without ever landing itself in a liquidity trap. As Figure 4 shows, the average rate of inflation over this 115-year period was slightly negative and the variability of the inflation rate was high. Figure 5 shows that Bank Rate did not fall below 2 per cent throughout 115 years preceding World-War I.[8]

Figure 4 here

Figure 5 here

[8] The temporary collapse in the external value of the U.S. dollar starting in 1861 is American Civil War related.

There is a marked positive association, over time and across countries, between the level of the inflation rate and its variability (see Okun [1971, 1975], Taylor [1981], Ball and Cecchetti [1990]). If such a relationship were to be found also between the level of short nominal rates and their variability or volatility, it would further reduce the likelihood of ending up in a liquidity trap in an environment with sustained low inflation and therefore, on average, with low nominal interest rates.

As will become apparent, the available statistical evidence on the association between the level and volatility of short-term nominal interest rates is mixed. It is indeed very difficult to offer a convincing test of our prior belief, that it is hard to conceive of situations in which the zero nominal interest rate floor would become a binding constraint on monetary policy in the UK, with the current symmetric annual inflation target of 2.5 percent.

In principle, one could try to test this hypothesis by estimating a dynamic stochastic process for the short nominal interest rate, using either time series or Markov chain models. If one were brave enough to make distributional assumptions about the disturbances in this process, it would be possible to calculate the odds on the short nominal rate falling below zero, given the starting values of the process. We do indeed make some attempts in this direction, but our efforts must be accompanied by a clear health warning.

There is an obvious, and in our view virtually insurmountable, problem with any assessment, based on historical data, of the odds that the non-negativity constraint on short nominal rates will become binding. During the sample, markets undoubtedly were operating under the assumption that short nominal rates could never fall below zero. In the UK over the past 200 years, the annual Bank Rate series indeed never fell below 2 percent. With the support of the empirical distribution of nominal short rates truncated from below at zero, the historical interest rate record is unlikely to be informative about the odds on the economy getting into a liquidity trap in the future, since this would require a structural break in the interest rate process, about which the sample is uninformative. If we were to assume (counterfactually, as can be seen from Figures 7 and 8) that the distribution of Bank Rate or of the error term in the Bank Rate equation is normal, there will always be a positive probability that Bank rate will go negative. If we assume instead that the distributions in question are, say, lognormal, the probability of breaching the zero floor (even asymptotically) is a-priori constrained to be zero. We try to circumvent this by calculating the asymptotic confidence bands for Bank Rate reported below from the empirical distribution of the sample residuals. Since the empirical distribution of the residuals obviously has finite support, this procedure will, if anything, underestimate the likelihood of the economy ending up in a liquidity trap.

Even ignoring the unavoidable small-sample problems, this procedure is vulnerable to the following criticism. What we are interested in estimating is the probability that the interest rate would have had to be negative (or below the possibly positive liquidity trap level) in order to avoid the economy getting into a liquidity trap equilibrium. If the economy *had* been in a liquidity trap in the sample, the data would reflect the liquidity trap configuration of the economy, including the response of real activity and inflation that supported the liquidity trap floor as an equilibrium. Information on the 'deep' structural parameters of the model (the invariant parameters governing money demand and its determinants) is necessary to recover the 'first passage' probabilities into the liquidity trap region of the economy.

What do the data tell us about the statistical association between the level and volatility of the short nominal interest rate? The very high-frequency association between short nominal sterling rates and a measure of volatility derived from short sterling futures over the period 1987-1999 is shown in Figure 6. The association between the level of short sterling and its volatility is, if anything, weakly negative.

Figure 6 here

The slightly lower frequency time-series evidence on the association between the level of short nominal interest rate and a statistical measure of its variability using weekly data is also mixed. Table 1 shows the time series record for the UK for the period 1997-1999.

Table 1 here

For the whole period 1975-1999, volatility and level of the three month interbank rate are positively contemporaneously correlated, but for the post-inflation targeting period 1993-1999, the correlation is slightly negative. The statistical model that generated the conditional variance measure used in Table 1 can be found in Appendix 2. We also provide an estimate of the steady state (long-run) value of the three month interbank rate implied by the statistical model, together with 95% steady state confidence bands for three month interbank rate.

We also investigated the statistical properties of Bank Rate at significantly lower frequencies, using a 200 year time series of annual observations. Our time series model (described in Appendix 2) implies a strong positive correlation (0.81) between the level of Base Rate and its contemporaneous conditional variance. Table 2 plots the level of Base Rate and our estimates of its conditional variance. We also provide an estimate of the steady state (long-run) value of Base rate implied by the statistical model, together with 95% steady state confidence bands for Base Rate.

Table 2 here

The confidence bands were calculated using the distribution of the estimated sample residuals. Not surprisingly, the distribution of sample residuals is distinctly non-normal. The same holds for Base rate itself. Figure 7 shows the frequency distribution of Base Rate and Figures 8 and 9 those of the estimated interest rate residuals. The sample distribution of Bank Rate is significantly skewed to the right. Its empirical distribution is truncated from below at 2.0 percent. The distribution of the sample residuals from the two main interest rate models is rather more symmetric.

Figure 7 here

Figure 8 here

Figure 9 here

Krugman [1998d] has suggested that deflation (negative inflation) makes a liquidity trap more likely. This is indeed an implication of just about any model of liquidity traps, including the model we develop in Section IV of this paper. We therefore estimate a simple time series process for annual RPI inflation over the 200 year period, and for its conditional variance. The results are reported in Table 3, together with its estimated steady state value and steady state 95% confidence intervals. The statistical inflation model is described in Appendix 2. Surprisingly, the contemporaneous correlation between inflation and its conditional variance turns out to be negative.

Table 3 here

The steady state confidence intervals for the annual rate of RPI inflation show that there is quite a large probability of deflation. Before one gets too worried about this, three points should be kept in mind. First, the relationship between interest rates and expected inflation depends on the behaviour of the inflation risk premium. Second, the UK experienced negative trend inflation and short bouts of sharp deflation in the 19th century, without landing itself in a liquidity trap. Third, the monetary policy target in the UK is, since June 1997, a symmetric inflation target. Deviations of inflation below the 2.5 percent target are to be avoided as much as deviations above that target. The risk of sharp deflation is therefore diminished. The new monetary regime has been in operation for too short a period, however, for this to show up as a structural break in the inflation time series process.

McKinnon and Ohno [1999] have argued that, at any rate in the Japanese case, a large expected appreciation of the currency could create a liquidity trap. We investigated the likelihood of a sharp appreciation of sterling by using almost 200 years of £/$ exchange rate data to estimate a simple stochastic process for the proportional rate of depreciation of the exchange rate and its conditional variance. The results are reported in Table 4, together with the expected long-run sterling depreciation rate and the 95% asymptotic confidence intervals. The statistical model underlying these calculations is described in Appendix 2. The contemporaneous correlation between exchange rate depreciation and its conditional variance is low but negative.

Table 4 here

It suggests that, based on this particular statistical model, there is quite a significant probability of a sizeable appreciation of sterling. Again, the caveat about the dangers of ignoring risk premia applies. It is surprising that our simple statistical model appears to handle such episodes as the American Civil War, two World Wars and the Great Depression of the Thirties quite well.

Finally, Table 5 reports cross-sectional evidence on the relationship between the level of short nominal rates and their volatility based on a sample of .59 countries between 1989 and 1998. The source of the data is IFS.[9] The correlation between the two variables is very high at 0.89, suggesting that across countries high short-term nominal rates are accompanied by high unconditional variances.

Table 5 here

On balance, the data fail to offer convincing support either for or against the contention that a regime of low short nominal interest rates is likely to be a regime of stable short nominal interest rates. This is therefore not unambiguously good news, nor unambiguously bad news for a policy maker targeting low inflation, although the current UK target would seem to provide quite handsome room for monetary manoeuvre. Two hundred years of UK monetary history also favour the contention that liquidity traps are unlikely to become a policy concern.

(III) Options for avoiding a liquidity trap

[9] We would like to thank Nick Hanchard for preparing this Table.

The lower the inflation target, and, if it is credible, the lower the underlying rate of inflation, the narrower is the 'safe range' above the zero floor for the short nominal rate. A credible target of zero inflation, would, with the long real rate at 2.0 to 3.0 percent, reduce the safe range to 2.0 to 3.0 percent.

Does this mean that targeting zero inflation would be a high-risk strategy? There would be risks if, despite a credible commitment to zero inflation, the economy is likely to be hit by shocks that would make interest rate cuts of more than 200 or 300 basis points desirable. If fiscal policy cannot be used to escape from the liquidity trap and if the risk of ending up in a trap is considered unacceptable, two options remain.

Raising the inflation target

The first option is to accept the nominal interest rate floor as immutable, and to target a rate of inflation high enough to reduce to acceptable levels the risk of hitting the zero interest floor. This would have to be done before the country gets into a liquidity trap. Targeting a higher rate of inflation after you are caught in the trap would be like pushing toothpaste back into the tube. All one can do is hope and wait for fiscal policy, or some other shock to aggregate demand, to boost the economy out of the trap.

Lowering the nominal interest rate floor: stamping money à la Gesell

The only other option is to stick to the inflation target but to lower the floor on the nominal interest rate. A floor below zero would reduce the likelihood that the floor would ever become a binding constraint on policy. In addition, the option of further lowering the floor, would provide a mechanism for escaping from a liquidity trap even after a country had been caught in it.

That nominal interest rate floor at zero is not a God-given immovable barrier. It is the result of a policy choice - the decision by governments or central banks to set the administered nominal interest rate on coin and currency at zero, rather than at some other (negative) level. Coin and currency are government *bearer* bonds[10]. A bearer bond is a debt

[10] Bearer securities are securities for which ownership is established by possession, without any need for registering title. Thus, a bearer bond is a bond with no owner information attached to it. The legal presumption is that the bearer is the owner. If the issuer of the bond is credit-worthy, they are almost as liquid and transferable as cash. Cash (coin and currency) is a special case of a zero interest (or zero-coupon) bearer bond issued by the state (generally through the central bank). Currency can be viewed as a zero coupon bearer consol or bearer perpetuity, since it can be interpreted as having an infinite maturity. . (It is always amusing to ask a finance expert to price a zero coupon perpetuity in a world where positive coupon perpetuities co-exist). In Appendix 1, we argue that it may be more informative to view currency as a zero coupon *finite* maturity bearer bond, which is issued and redeemed at par, with redemption taking the form of the one-for-one exchange of old currency for new currency which is indistinguishable from the old currency.

The vast majority of 'international bonds', historically called 'eurobonds' are bearer. Bearer bonds can take two main forms. First, the traditional 'definitive' style, where the bonds literally are individual pieces of security-printed paper in denominations of, say, $10,000, which individual holders bring in to paying agents so as to receive payment of interest and principals. Second, 'global' bonds, which are technically bearer instruments but consist of a single piece of paper representing the entire issue (and so worth hundreds of millions or even billions of dollars). In practice, the terms of the global bond say that only Euroclear (the settlement system based in Brussels) or Cedelbank (the settlement system based in Luxembourg) are entitled to the proceeds of the global bond, and that Euroclear and Cedelbank will in turn divide the proceeds up amongst the end-investors whose details are stored in their electronic records. Thus the global bond is not an instrument which in practice can be passed from one owner to another, even though it is technically 'bearer'. Effectively the bonds are dematerialised.

Bearer bonds are legal and quite common in the UK. While the bearer debenture went out of use, replaced by the non-negotiable debenture or debenture stock, transferable (in the same way as common stocks) by entry in the company's register, a number of new negotiable investment securities have evolved. They include the modern bearer bond, the negotiable certificate of deposit, and the floating rate note. A limited number of gilts have also been issued with a bearer option.

Before July 1983, municipal securities in the U.S. were issued for the most part in certificate form with coupons attached. Some of these so-called old-style bearer bonds are still available in the marketplace. The issuer has no record of who owns these bonds. The owner clips the coupons and collects the interest from the issuer's paying agent. Transferring the bonds requires physical delivery and payment. Bearer bonds issued by municipal authorities were made illegal in the U.S. in 1982 (no doubt because they provided ideal investments for those security in paper form whose ownership is transferred by delivery rather than by written notice and amendment to the register of ownership. We shall refer to all bonds that are not bearer bonds as *registered* bonds. Bearer bonds are negotiable, just as e.g. money market instruments such as Treasury Bills, bank certificates of deposit, and bills of exchange are negotiable. A financial instrument is negotiable if it is transferable from one person to another by being delivered with or without endorsement so that the title passes to the transferee.[11] Coin and currency therefore are bearer bonds. They are obligations of the government, made payable not to a named individual or other legal entity, but to whoever happens to present it for payment - the bearer. Coin and currency have three further distinguishing properties: they are government bearer bonds with infinite maturities (perpetuities or consols)[12]; their coupon payments (which define the own (or nominal) rate of interest on coin and currency) are zero, and they are legal tender (they cannot be refused in final settlement of any obligation).

There are two reasons why interest is not paid on currency.[13] The first and currently less important one, has to do with the attractions of seigniorage (issuing non-interest-bearing

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who did not welcome close examination of their financial position). Bearer bonds with a negative interest rate are especially awkward to administer, because inducing the bearer to present the issuer with coupons obliging the bearer to make a payment to the issuer presents non-trivial enforcement problems. This creates the need for mechanisms such as the compulsory conversion of old cash into new cash (on terms implying a negative nominal interest rate), backed by the credible threat of confiscation of the old cash, as discussed in the body of the paper.

[11] Key elements of negotiability include the following: (1) transfer by physical delivery; (2) transfer is such as to confer upon its holder unchallengeable title and (3) a negotiable instrument benefits from a number of evidential and procedural advantages in the event of a court action.

[12] But see Foonote 9 and Appendix one on a different interpretation.

[13] From here on, 'currency' will be taken to include both coin and currency. There obviously are more severe technical problems with attaching coupons or stamps to coin than to currency notes.

monetary liabilities) as a source of government revenue in a historical environment of positive short nominal rates on non-monetary government debt.[14]

The second, and more important, reason why no interest is paid on coin and currency, are the practical, administrative difficulties of paying a negative interest rate on bearer bonds. It can be done, but it cannot be done elegantly. Significant 'shoe leather' costs are involved.

There is no practical or administrative barrier to paying negative nominal interest rates (market-determined or administered) on those private financial instruments or on government interest-bearing securities that are not bearer bonds but have registered owners.[15] The reason is that, for registered securities, whether issued by private or public agents, the identities of both the issuer and the holder (the debtor and the creditor) are easily established. This makes it easy to verify whether interest due has been paid and received, be it at a positive or at a negative rate. Thus the non-bearer bond part of the monetary base, that is, banks' balances with the central bank, could earn a negative nominal interest rate without any technical problems. For these balances, the debtor (the central bank) and the creditor (the commercial bank) are easily identified. Positive interest payments or negative interest payments just involve simple book-keeping transactions, debit or credit, between known parties.

We will highlight the technical, administrative problem with paying negative interest on bearer bonds (be they private or public) is by considering the problems of paying a negative coupon on the bearer bond part of the central bank's monetary liabilities, coin and

[14][14]Of course, issuing negative interest-bearing monetary liabilities would be even more attractive, from a seigniorage point of view.

[15]The only exception is that it would not be possible to have a consol or perpetuity with a negative nominal interest rate. Assume the constant nominal coupon payment of the consol is positive. If the infinite sequence of short nominal rates is negative, the value of the consol would be unbounded positive. A negative coupon would yield an unbounded negative value for the consol.

currency. While the identity of the issuer (the debtor, that is the Central Bank) is easily verified, the identity of the holder (the creditor) is not. There is no obligation to register title to currency in order to establish ownership. Possession effectively provides complete title. This creates problems for paying any non-zero interest rate, because it is difficult to verify whether a particular note or coin has already been credited or debited with interest. With verifiability of interest payments, currency could be turned into an interest-bearing bearer bond, and the interest rate could be negative (or positive), if circumstances required this.

The problem of verifying whether interest due on bearer bonds has been paid is present, in a milder form, even when the interest rate is positive. However, the problem of getting the (anonymous) owner of the currency to come forward to claim his positive coupon receipt from the government is much less acute than the problem of getting the (anonymous) owner to come forward to make a payment to the government. In both cases, however, each individual monetary claim has to be marked, or identified clearly, as being 'current', that is, as having all interest due paid or received. Without such clear marking, positive interest-bearing money could be presented repeatedly for interest payment. Historically, the problem of paying positive coupons on bearer bonds was solved by attaching coupons or stamps to the title certificate of the bearer bond. When claiming his periodic coupon payment, the appropriate coupon was physically removed ('clipped') from the title certificate and retained by the issuer. Clipping coupons used to be a popular pastime among investors.[16]

Without further amendment, the 'coupon clipping' or stamping route would not work for bearer bonds with negative coupons. The enforcement problems involved in getting the unregistered, anonymous holders of the negative coupon bearer bonds to come forward to pay the issuer would be insurmountable. The only practical way around this problem, is to make

[16] Physically attaching the coupons to the ownership certificate would not work for consols (perpetuities), as certificates of infinite size would be awkward stores of value.

the bearer bond subject to an expiration date and a conversion procedure. In the case of currency, this could be achieved by periodically attaching coupons or stamps to currency, without which the currency would cease to be ‘current’.

For currency to cease to be ‘current’, it is not enough for the monetary authority to declare that after a certain date, t_1, currency issued before another date $t_0 < t_1$ shall cease to be legal tender. Being legal tender certainly enhances the attractiveness of currency as a store of value, medium of exchange and means of payment, but these advantages need not be enough to induce holders of 'old' currency, which is about to lose its legal tender status, to come forward and exchange it, at a price, for 'new' currency which does have legal tender status. What serves as medium of exchange and means of payment is socially determined. Being legal tender is but one among many considerations that induce people to use certain classes of objects as means of payment and medium of exchange. For currency to cease to be current, it effectively has to be subject to confiscation if the appropriate coupon or stamp has not been attached. In other words, there have to be periodic 'monetary reforms'[17].

There is a long tradition on the crankier fringes of the economics profession of proposals for taxing money or taxing liquidity, which is another way of describing negative interest-bearing currency. Many of these proposals were part of wider, and generally hare-brained, schemes for curing the world's economic and social ills. The mechanics of taxing currency are straightforward main-stream economics, however.

The best-known proponent of taxing currency was probably Silvio Gesell (1862-1930), a German/Argentinean businessman and economic scribbler of suspect political judgement, but admired by Keynes, who wrote of him *"I believe that the future will learn more from the spirit of Gesell than from that of Marx"* (Keynes [1936, p. 355]). Gesell

[17] Appendix 1 contains a slightly more formal discussion of the payment of negative interest on currency.

wanted to stimulate the circulation of money by getting the state to issue money that, like capital assets, depreciated in value.[18] If inflation could not be relied upon to do the job of making holding money unattractive, an alternative was "Stamp Scrip" - dated bills that would lose a certain percentage of value each year unless new stamps were put on them. Stamp Scrip was actually issued briefly during the Great Depression of the Thirties in parts of the Canadian province of Alberta by the Social Credit provincial government of the day.[19] The scheme was a resounding failure, not least because the provincial government in the end refused to accept its own scrip in payment.[20] Similar local currency experiments were tried in Wörgl, Austria during the 1930s.

Thus, for negative interest on bearer bonds such as currency to be enforceable, the bearer bond has to expire after a certain date. The desired (negative or positive) interest rate on currency would be determined by the terms on which the old, expiring currency could be exchanged with the central bank for new currency. The 'conversion' could be effected by

[18] Gesell's motivation was not, as far as we can determine, the avoidance of or escape from liquidity traps. His aim was to eliminate the interest component of costs and prices completely from the economic system, not just in the extreme circumstances of the liquidity trap, but as a permanent feature. Our reading of his works suggest that he was a bit vague about the distinction between real and nominal interest rates. While, by stamping currency, the nominal interest rate on non-monetary assets can indeed be brought down to zero (or to any other level), the endogeneity of the rate of inflation means that the ability of the monetary authorities to influence the long-run real interest rate is much more doubtful. The formal model analysed in Section IV of this paper has the property that the monetary authorities cannot influence the long-run real interest rate.

[19] In August 1935 the first social credit government was elected in the Canadian province of Alberta. While its ideology owed more to the writings of two other great economic cranks, Alfred Richard Orage [1917] and Major Clifford Hugh Douglas [1919] (and to the personal involvement of the latter as economic adviser to the provincial government), the Alberta Prosperity Certificates introduced in 1936 by Premier William Aberhart, were pure Gesell. Similar in appearance to a dollar bill, the certificates required a weekly endorsement of a 2c stamp, amounting to a 104 percent annual capital levy (see Hutchinson and Burkitt [1997] and Mallory [1954]).

[20] It also had failed to convince the Federal government in Ottawa to match its negative interest rates. Since Federal currency was at least as useful as a means of payment, this would require to scrip to trade at a discount with respect to the Federal currency and to appreciate

stamping the old currency, or by issuing completely new currency which was verifiably distinct from the old currency.

Taxing currency (or paying negative interest on currency) through expiration of old currency and conversion into new currency can be visualised as follows. After the expiration date, t_1 , the issuer (the central bank) or its agents can confiscate the old currency without compensation.[21] Provided the forces of the law are strong enough, this could induce holders of the old currency to convert it, at a price, on or before the expiration date, rather than continue to use it in transactions or as a store of value after the expiration date and risk having it confiscated. At fixed intervals of length Δt (Gesell periods, say) whose duration could, for convenience, be set at a year (or several years, in order to reduce conversion costs), and on a specific day, (Gesell day), old currency would legally revert to the issuer (the central bank). After Gesell day, the old currency has no value (because of the credible threat of confiscation) and will not be used in transactions or as a store of value. On Gesell day, *1* £ worth of new currency would be issued in exchange for $e^{-i_M \Delta t}$ £s worth of old currency, where i_M would be the policy-determined (instantaneous) nominal interest rate on currency.[22] For simplicity, we assume i_M to be constant, although it could be time-varying. The nominal rate of interest on currency would be administratively determined, that is, set by the central bank. To avoid long queues at the central bank's conversion offices on Gesell days, earlier exchanges of old for new money might be allowed at the rate of *1 £* worth of the new currency for $e^{-i_M \Delta t} e^{-\int_{t_e}^{t_1} i(s)ds}$ £s worth of the old currency, where t_1 is the date of the next Gesell day, $t_e \leq t_1$ is the time before

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vis-à-vis the federal currency at a rate that compensated for the interest differential between Federal and provincial currency.

[21]Less drastic penalties might work also. For instance, old money found in circulation after its 'expiry' date would be forcibly converted into new money at the rate offered on the conversion date, but subject to an additional penalty. The confiscation scenario makes the key point very clearly, however.

the next Gesell day on which the old currency is exchanged for the new, and i is the instantaneous nominal interest rate on the government's non-monetary liabilities. For currency to remain rate-of-return-dominated as a store of value, it is necessary that $i_M < i$. Both rates could be negative, and may have to be, if liquidity traps are to be ruled out. Coin and currency would effectively become time-limited, finite maturity financial claims.

New currency could, in principle, be used in transactions before midnight on the Gesell day before they are formally introduced. During this earlier Gesell period, the value of the old currency in terms of the co-existing new currency would decline steadily. The relative value of the old currency in terms of the new currency would change at an instantaneous rate i_M , so as to ensure that, at the moment the old currency expires and the new currency comes in officially (at midnight on Gesell day), there is no discrete jump in the value of old money in terms of new money, or of goods and services in terms of money.[23] It follows that, during the period of coexistence of old and new money, the rate of inflation of the prices of goods and services would be higher in terms of old money than for in terms of money, with the excess of the old money inflation rate over the new money inflation rate equal to $-i_M$. If the coexistence of two currencies is thought to be confusing, one could try to enforce a ban on the use of new currency in transactions before its Gesell day.

Clearly there are costs associated with such a scheme, even if one can come up with a slightly higher-tech (and tamper-proof) alternative to physically stamping currency. These shoe leather costs have to be set against the benefits of removing the zero floor on the nominal interest rate.

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[22] $e^{-i_M \Delta t} - 1$ would be the effective (Gesell) period tax rate on currency. The instantaneous tax rate would be $-i_M$.

[23] This is just like the ex-dividend price of a share of common stock being equal, on the day the dividend is paid, to the dividend-inclusive price of the stock minus the dividend. In our example, the dividend would be negative

There are costs (and benefits) other than shoe-leather costs associated with taxing currency. Taxing currency would be regressive, since only the relatively poor hold a significant fraction of their wealth in currency. Taxing currency would, however, have the nice feature of constituting a tax on the grey, black and outright criminal economies, which are heavily cash-based.

(IV) A Simple Model of the Escape from a Liquidity Trap Through Gesell Money

We model a simple, closed endowment economy with a single perishable commodity that can be consumed privately or publicly.

Households

A representative infinite-lived, competitive consumer maximises for all $t \geq 0$ the utility functional given in (1) subject to his instantaneous budget identity (2), solvency constraint (3) and his initial financial wealth. We use the simplest money-in-the-direct-utility-function approach to motivate a demand for money despite it being dominated as a store of value. We define the following notation; c is real private consumption, y is real output, τ is real (lump-sum taxes), M is the nominal stock of base money (currency), B is the nominal stock of zero maturity non-monetary debt, i is the instantaneous risk-free nominal interest rate on non-monetary debt, i_M is the instantaneous risk-free nominal interest rate on money, p is the price level in terms of money, a is the real stock of private financial wealth, m is the stock of real currency and b the stock of real non-monetary debt.

$$\int_t^{\infty} e^{-\delta(v-t)}[\frac{1}{1+\eta}\ln c(v) + \frac{\eta}{1+\eta}\ln m(v)]dv$$

$$\eta > 0 \quad \textbf{(1)}$$

$$\delta > 0$$

$$\dot{M} + \dot{B} \equiv p(y - \tau - c) + iB + i_M M$$

$$c \geq 0; M \geq 0 \quad \textbf{(2)}$$

$$\lim_{v\to\infty} e^{-\int_t^v i(u)du}[M(v) + B(v)] \geq 0 \quad \textbf{(3)}$$

$$M(0) + B(0) = \overline{A}(0) \quad \textbf{(4)}$$

Using

$$a \equiv \frac{M+B}{P} \quad \textbf{(5)}$$

the household budget identity (2) can be rewritten as follows

$$\dot{a} \equiv ra + y - \tau - c + (i_M - i)m \quad \textbf{(6)}$$

where *r*, the instantaneous real rate of interest on non-monetary assets, is defined as

$$r \equiv i - \pi \quad \textbf{(7)}$$

and $\pi \equiv \frac{\dot{p}}{p}$ is the instantaneous rate of inflation.

The household solvency constraint can now be rewritten as

$$\lim_{v \to \infty} e^{-\int_t^v r(u)du} a(v) \geq 0 \quad \textbf{(8)}$$

and the intertemporal budget constraint for the household sector can be rewritten as:

$$\int_t^{\infty} e^{-\int_t^v r(u)du}\Big[c(v) + \tau(v) + [i(v) - i_M(v)]m(v) - y(v)\Big]dv \leq a(t) \quad \textbf{(9)}$$

The first-order conditions for an optimum imply that the solvency constraint will hold with equality. Also,

$$\dot{c} = (r - \delta)c \qquad \textbf{(10)}$$

and for $i > i_M$,

$$m = \left(\frac{\eta}{i - i_M}\right)c \qquad \textbf{(11)}$$

If $i < i_M$, currency would dominate non-monetary financial assets ('bonds') as a store of value. Households would wish to take infinite long positions in money, financed by infinite short positions in non-monetary securities. The rate of return on the portfolio would be infinite. This cannot be an equilibrium.

If $i = i_d$, currency and bonds are perfect substitutes as stores of value. Because of the direct utility of money, the equilibrium will be the Friedman equilibrium, characterised by satiation in money. With the logarithmic utility function, satiation occurs only when the stock of money is infinite (relative to the finite consumption level). Provided the authorities provide government money and absorb private bonds in the right (infinite) amounts, this can be an equilibrium.

There is a continuum of identical consumers whose aggregate measure is normalised to *1*. The individual relationships derived in this section therefore also characterise the aggregate behaviour of the consumers.

Government

The budget identity of the consolidated general government and central bank is given in (12). The level of real public consumption is denoted $g \geq 0$.

$$\dot{M} + \dot{B} \equiv iB + i_M M + p(g - \tau) \qquad \textbf{(12)}$$

Again, the initial nominal value of the government's financial liabilities is predetermined

$M(0)+B(0)=\overline{A}(0)$

This budget identity can be rewritten as

$$\dot{a} \equiv ra + g - \tau + (i_M - i)m \qquad \textbf{(13)}$$

The government solvency constraint is

$$\lim_{v\to\infty} e^{-\int_t^v r(u)du} a(v) \leq 0 \qquad \textbf{(14)}$$

Equations (13) and (14) imply the intertemporal government budget constraint:

$$\int_t^{\infty} e^{-\int_t^v r(u)du} \left[\tau(v) + [i(v) - i_M(v)]m(v) - g(v)\right] dv \geq a(t) \qquad \textbf{(15)}$$

Government consumption spending is exogenous. To ensure that public consumption spending does not exceed total available resources, $\bar{y} > 0$, we therefore have to impose

$g < \bar{y}$

With a representative consumer, this model will exhibit debt neutrality or Ricardian equivalence. Without loss of generality, we therefore assume that the government's solvency constraint is always satisfied because lump-sum taxes are continuously adjusted to keep the nominal stock of public debt (monetary and non-monetary) constant, $\dot{A}(t) = 0, \; t \geq 0$, that is,

$$\begin{aligned}\tau &= g + ia + (i_M - i)m \\ &= g + i\frac{\overline{A}(0)}{p} + (i_M - i)m\end{aligned} \qquad \textbf{(16)}$$

Monetary policy is specified as an exogenous value for the nominal interest rate on currency and either an exogenous value for the short nominal interest rate on non-monetary financial claims or an exogenous value of the initial nominal money stock and a subsequent exogenous growth rate of the nominal money stock. In either case, the short nominal bond rate is required to be no lower than the short nominal rate on currency.

Thus, monetary policy is characterised by

$$i_M = \bar{i}_M \tag{17}$$

and either

$$i = \bar{i} \geq \bar{i}_M \tag{18}$$

or

$$M(0) = \overline{M}(0) > 0$$

$$\frac{\dot{M}(t)}{M(t)} = \overline{\mu}(t), \qquad t \geq 0 \tag{19}$$

$$i(t) \geq i_M, \qquad t \geq 0$$

I will only consider in detail the case where the short nominal bond rate is the instrument. The case where the nominal money stock path is the instrument only involves trivial amendments to the earlier analysis.

Equilibrium and the liquidity trap with full employment

In the full-employment, flexible price version of the model, output always equals the exogenously given level of capacity output, $\bar{y}$. Therefore

$$c + g = y = \bar{y} \tag{20}$$

The equilibrium instantaneous real interest rate is given by

$$r = \delta + \frac{\bar{y}}{c}\frac{\dot{\bar{y}}}{\bar{y}} - \frac{g}{c}\frac{\dot{g}}{g} \tag{21}$$

For simplicity, let *g = 0*. Let the exogenous growth rate of capacity output be denoted $n(t) \equiv \frac{\dot{\bar{y}}}{\bar{y}}$. It follows that the equilibrium instantaneous real rate of interest simplifies to

$$r(t) = \delta + n(t) \tag{22}$$

The remaining equilibrium conditions can be summarised as follows

$$i(t) = r(t) + \pi(t) \qquad \textbf{(23)}$$

$$\pi(t) \equiv \frac{\dot{p}(t)}{p(t)} \qquad \textbf{(24)}$$

$$\frac{M(t)}{P(t)} = \left(\frac{\eta}{i(t) - \bar{i}_M} \right) \bar{y}(0) e^{\int_0^t n(s) ds} \qquad \textbf{(25)}$$

$$i(t) \geq \bar{i}_M \qquad \textbf{(26)}$$

Note from (22) and (23), that

$$i(t) = \delta + n(t) + \pi(t) \qquad \textbf{(27)}$$

When the short nominal bond rate is exogenous (equation (18)), the model exhibits price level indeterminacy. Since the behaviour of real money balances, the inflation rate and the nominal and real interest rates are not affected by this, and since the conditions under which a liquidity trap occurs or its consequences are not affected by the nominal indeterminacy, no further attention is paid to this issue.

In the flexible price level version of the model, the equilibrium real interest rate and real private consumption sequences are the same when the economy is in a liquidity trap as when it isn't. The liquidity trap matters here only because is may stop the economy from achieving an inflation target. Of course, in the model under consideration, the welfare motivation for an inflation target is not obvious. Pareto-efficiency requires that the economy be satiated with real money balances, that is, that $i = i_M$. All Pareto-efficient equilibria are therefore liquidity trap equilibria.

Whatever the motivation for the inflation target, it is clear that a liquidity trap may prevent the authorities from achieving the target. Let π^* be the target rate of inflation, assumed constant.

From (26) and (27), it follows that an inflation target cannot be achieved if

$$\pi^* < i_M - \delta - n \qquad \textbf{(28)}$$

Since $\delta > 0$, a non-negative inflation target can be achieved, even with the nominal interest rate on currency at zero, unless the growth rate of capacity output were sufficiently negative. This hardly seems a serious concern. Nevertheless, equation (28) makes it clear, that an inflation target is always achievable, if the authorities set the nominal interest rate on currency, i_M, at a sufficiently low (negative) value. Note that by setting $i = i_M = \delta + n + \pi^*$, the authorities can follow the Friedman rule for Pareto-efficiency (satiation in real money balances) and achieve the inflation target at the same time.

The analysis is not affected in any material way when the initial value and subsequent growth rates of the nominal money stock are the monetary policy instrument and the short nominal bond rate becomes endogenous. This is most easily seen when both the growth rate of capacity output and the growth rate of the nominal money stock are constant at $\overline{n}$ and $\overline{\mu}$ respectively.

Under this monetary rule, the inflation rate is given by

$$\pi = \overline{\mu} - \overline{n} \qquad \text{if} \quad \delta + \overline{\mu} \geq \bar{\mathrm{i}}_{\mathrm{M}}$$

$$= \bar{i}_M - (\delta + n) \qquad \text{if} \quad \delta + \overline{\mu} < \bar{\mathrm{i}}_{\mathrm{M}}$$

It follows that an inflation target below $\bar{i}_M - (\delta + n)$ cannot be achieved. It also follows that by setting a sufficiently negative nominal interest rate on currency, any inflation target can be achieved.

The liquidity trap in the Keynesian variant

In the Keynesian variant, output is demand-determined, the price level and the rate of inflation are assumed to be predetermined, and the rate of inflation adjusts to the gap between actual and capacity output through the simplest kind of accelerationist Phillips curve.

$$c + g = y \qquad \textbf{(29)}$$

$$\dot{\pi} = \beta(y - \bar{y})$$

$$\beta > 0 \qquad \textbf{(30)}$$

For simplicity, we assume capacity output to be exogenous and constant.

Monetary policy

The monetary authorities are again assumed to peg the nominal interest rate on currency exogenously

$$i_M = \bar{i}_M$$

We assume in what follows that the other monetary instrument is the short nominal interest rate on bonds, rather than the level or the growth rate of the nominal money stock. There are two reasons for this. First, it simplifies the exposition. Second, it is how monetary policy is actually conducted.

The monetary authorities are assumed to follow a simplified Taylor rule for the short nominal interest rate on non-monetary financial claims, as long as this does not put the short nominal bond rate below the interest rate on currency. A standard Taylor rule for the short nominal bond rate which restricts the short nominal bond rate not to be below the short nominal rate on currency, would be

$$\begin{aligned} i &= \bar{i} + \gamma\pi + \varepsilon y \quad \text{if} \quad \bar{i} + \gamma\pi + \varepsilon y \geq i_M \\ &= i_M \qquad\qquad\quad \text{if} \quad \bar{i} + \gamma\pi + \varepsilon y < i_M \end{aligned}$$

For our purposes, all that matters is the responsiveness of the short bond rate to the inflation rate. We therefore omit feedback from the level of real GDP (or from the output gap) in what follows. The short nominal interest rate rule therefore simplifies to

$$\begin{aligned} i &= \bar{i} + \gamma\pi \quad \text{if} \quad \bar{i} + \gamma\pi \geq i_M \\ &= i_M \qquad\ \ \text{if} \quad \bar{i} + \gamma\pi < i_M \end{aligned} \qquad \textbf{(31)}$$

The Taylor rule is sometimes justified as a simple, ad-hoc rule consistent with inflation targeting. If the target rate of inflation is constant at π^* (and equal to the steady-state rate of inflation), the intercept in the Taylor rule, $\bar{i}$, can be given the following interpretation

$$\bar{i} = \delta + (1-\gamma)\pi^* \qquad \textbf{(32)}$$

This implies

$$i = \delta + \pi^* + \gamma(\pi - \pi^*) \qquad \textbf{(33a)}$$

or

$$r = \delta + (\gamma - 1)(\pi - \pi^*) \qquad \textbf{(33b)}$$

The behaviour of the economy can be summarised in two first-order differential equations in the non-predetermined state variable *c* and the predetermined state variable π. The equation governing the behaviour of private consumption growth switches, however, when the floor on the short nominal interest rate becomes binding (when the economy is in a liquidity trap).

$$\dot{\pi} = \beta(c + g - \bar{y}) \qquad \textbf{(34)}$$

$$\begin{aligned} \dot{c} &= [\bar{i} + (\gamma - 1)\pi - \delta]c \quad \text{if } \bar{i} + \gamma\pi \geq i_M \\ &= [i_M - \pi - \delta]c \quad \text{if } \bar{i} + \gamma\pi < i_M \end{aligned} \qquad \textbf{(35)}$$

When the liquidity trap constraint is not binding (we shall refer to this as the 'normal' case), saddlepoint stability for the dynamic system requires $\gamma > 1$. A higher rate of inflation leads, through the policy reaction function, to a larger increase in the short nominal bond rate so as to raise the short real rate. As shown in Figure 10, the $\dot{c} = 0$ locus in the normal case (denoted $(\dot{c} = 0)_N$), is vertical in a phase diagram with π on the horizontal axis and *c* on the vertical axis, at $\pi = \frac{\bar{i} - \delta}{1-\gamma} = \pi^*$. [24]

Figure 10 here

In the liquidity trap regime, the $\dot{c}=0$ locus (denoted $(\dot{c}=0)_L$) is vertical at $\pi = i_M - \delta$. With $i_M = 0$, the locus $(\dot{c}=0)_L$ is to the left of $(\dot{c}=0)_N$. This is the case we shall be considering as the benchmark henceforth.

As long as the rate of inflation exceeds $\frac{i_M - \bar{i}}{\gamma}$, the short nominal bond rate exceeds the short nominal interest rate on currency, and the economy is in the normal regime. For inflation rates at or below $\frac{i_M - \bar{i}}{\gamma}$, the economy is in the liquidity trap regime. The switch from the normal to the liquidity trap regime occurs at $\pi = \frac{i_M - \bar{i}}{\gamma} = \frac{i_M - \delta}{\gamma} + \left(\frac{\gamma - 1}{\gamma}\right)\pi^*$. We shall refer to the boundary of the normal and the liquidity trap locus as the *LN* locus in Figure 10. Taking again as our reference point the situation where $i_M = 0$ and noting that $\delta > 0$ and that $\gamma > 1$, we need only assume that the target inflation rate π^* is nonnegative, for the switching value of π to lie between the two $\dot{c}=0$ loci. This is assumed in Figure 10 and thereafter. The *LN* locus could either be to the left or to the right of the *c* axis.

The steady state of the model is as follows. There are two steady states (the normal one and the liquidity trap one) for the nominal bond rate and the rate of inflation. The normal steady state values are given first.

$$c = \bar{y} - g$$

$$r = \delta$$

$$\pi = \frac{\delta - \bar{i}}{\gamma - 1} = \pi^* \qquad \text{(Normal case)}$$

or

$$\pi = \bar{i}_M - \delta \qquad \text{(Liquidity trap)}$$

[24] Here and in what follows we ignore the *c = 0* segment of the c isocline.

$$i = \frac{\gamma\delta - \bar{\imath}}{\gamma - 1} \qquad \text{(Normal case)}$$

or

$$i = \bar{i}_M \qquad \text{(Liquidity trap)}$$

When $\gamma > 1$, as we assume throughout, the equilibrium configuration in the neighbourhood of the normal steady state is a saddlepoint.

The linear approximation of the normal dynamics at $c = \bar{c}$ and $\pi = \bar{\pi}$ is

$$\begin{bmatrix} \dot{c} \\ \dot{\pi} \end{bmatrix} \approx \begin{bmatrix} \bar{i} + (\gamma - 1)\bar{\pi} - \delta & (\gamma - 1)\bar{c} \\ \beta & 0 \end{bmatrix} \begin{bmatrix} c - \bar{c} \\ \pi - \bar{\pi} \end{bmatrix}$$

At the normal steady state, with $\bar{c} = \bar{y} - g$ and $\bar{\pi} = \frac{\delta - \bar{i}}{\gamma - 1}$, this reduces to

$$\begin{bmatrix} \dot{c} \\ \dot{\pi} \end{bmatrix} \approx \begin{bmatrix} 0 & (\gamma - 1)(\bar{y} - g) \\ \beta & 0 \end{bmatrix} \begin{bmatrix} c - \bar{c} \\ \pi - \bar{\pi} \end{bmatrix}$$

The determinant of the state matrix is $(1 - \gamma)(\bar{y} - g)\beta < 0$ if $\gamma > 1$. The two characteristic roots are $\pm\sqrt{\beta(\gamma - 1)(\bar{y} - g)}$.

The normal steady state configuration Ω^N in Figure 10 illustrates the saddlepoint property of the normal steady state.

From (34) and the normal version of (35) it follows that the slope of the integral curves in $c - \pi$ space is given by

$$\frac{dc}{d\pi} = \frac{[\bar{i} - \delta + (\gamma - 1)\pi]c}{\beta(c + g - \bar{y})}$$

This can be rewritten as

$$\beta(1 + \frac{g - \bar{y}}{c})dc = [\bar{i} - \delta + (\gamma - 1)\pi]d\pi$$

As this is separable in c and π, it can be integrated to yield

$$\beta[c + (g - \bar{y})\ln c] = (\bar{i} - \delta)\pi + \frac{(\gamma - 1)}{2}\pi^2 + k$$

where *k* is an arbitrary constant of integration.

Provided $(\bar{i}-\delta)^2+2(1-\gamma)\left(k-\beta[c+(g-\bar{y})\ln c]\right)\geq 0$,

the integral curves in the normal case (c > 0, $\pi > \frac{i_M-\bar{i}}{\gamma}$) are given by:

$$\pi=\frac{\bar{i}-\delta\pm\sqrt{(\bar{i}-\delta)^2+2(1-\gamma)\left(k-\beta[c+(g-\bar{y})\ln c]\right)}}{1-\gamma}$$

The equilibrium configuration near the liquidity trap steady state (Ω^L in Figure 10) is neutral and cyclical (the linearised dynamic system at Ω^L has two complex conjugate roots with zero real parts). The integral curves for the liquidity trap case (c > 0, $\pi \leq \frac{i_M-\bar{i}}{\gamma}$) are given by

$$\pi=i_M-\delta\pm\sqrt{(i_M-\delta)^2+2\left(k-\beta[c+(g-\bar{y})\ln c]\right)}$$

The liquidity trap steady state is a center.[25] Some neighbourhood of this steady state is completely filled by closed integral curves, each containing the steady state in its interior. Figure 10 also shows the behaviour of the system near the liquidity trap steady state.

At a common level of consumption, the slope of the integral curve in the normal case, $\left.\frac{dc}{d\pi}\right|^N$ is the same as the slope of the integral curves in the liquidity trap case $\left.\frac{dc}{d\pi}\right|^L$ on the boundary of the two regimes (when $\pi=\frac{i_M-\bar{i}}{\gamma}$). It is easily checked that

$$\left.\frac{dc}{d\pi}\right|^N_{\pi=\frac{i_M-\bar{i}}{\gamma}}=\left.\frac{dc}{d\pi}\right|^L_{\pi=\frac{i_M-\bar{i}}{\gamma}}=\frac{\left[\left(\frac{\gamma-1}{\gamma}\right)i_M+\frac{1}{\gamma}\bar{i}-\delta\right]c}{\beta(c+g-\bar{y})}$$

[25] Anne Sibert provided the mathematical solution and graphical representation for the behaviour of the system in the liquidity trap zone.

We want to consider shocks for which the liquidity trap can be sprung, that is, shocks for which the constraint $i \geq i_M$ becomes binding. In our model that has to be either a demand shock or a supply shock that lowers current aggregate demand below current capacity output. As regards demand shocks, the simplest candidate in our model is the unexpected announcement, at time $t = t_0$ of a future increase in public spending, *g*, starting at $t_1 > t_0$. For simplicity, we will treat the expected future increase in public spending as permanent.

An anticipated future increase in public spending is contractionary between the announcement date (t_0) and the implementation date (t_1) because forward-looking Ricardian households realise that higher future public spending means a higher present discounted value of future taxes. Human capital falls and with it private consumption. Because of the Taylor-style interest rate reaction function, the profile of expected future short real rates is actually lower with the public spending shock than without. Future after-tax endowments are therefore discounted at a lower rate, but this is not enough to negate the negative effect on aggregate demand.[26]. Essentially the same results obtain when we consider the unexpected announcement of a lower future path of capacity output. This was the main shock considered by Krugman [1998d]. Figure 11 represents the behaviour of the system following the public spending shock.

Figure 11 here

Assume the system starts in steady state at the normal steady state equilibrium Ω_1^N, with government spending expected to be constant. An unanticipated, immediate, permanent

[26] If instead of the logarithmic instantaneous utility function we had adopted the constant elasticity of marginal utility function with an intertemporal substitution elasticity larger than 1, the negative effect on consumption would have been reinforced.

increase in public spending will result in an immediate transition to the new steady state at Ω_2^N. In the new steady state, the rate of inflation, and all real and nominal interest rates are the same as before. The level of private consumption has fallen by the same amount as the level of public consumption has increased.

When the increase in public consumption is not immediate, the transition is as follows. Assume that at the announcement date, t_0, there is news of a future permanent increase in public spending, starting at $t_1 > t_0$. The increase in public spending, when it occurs, is of the same magnitude as the immediate increase in public spending analysed earlier. We shall refer to t_1 as the implementation date. For a 'moderate' postponement in the implementation of the public spending increase (defined below), private consumption drops immediately (on the announcement date t_0) to Ω_{12}^N, say. The reason again is that a higher sequence of future taxes is anticipated by the Ricardian consumers, immediately upon the announcement of the future spending increase. Human capital falls and with it private consumption, albeit by less that when the public spending increase was immediate. Between the announcement date, t_0, and the implementation date, t_1, consumption and inflation both fall gradually as the system moves from Ω_{12}^N to Ω_{22}^N, where it arrives at t_1 when the public spending increase in actually implemented. From t_1 on, the system moves along the convergent saddlepath through the new steady state (Ω_2^N), from Ω_{22}^N to the new steady state at Ω_2^N.

The initial jump in the level of consumption at t_0 is such as to place the system on that divergent trajectory, drawn with reference to the initial steady state, that will put it on the unique continuously convergent trajectory through the new steady state, Ω_2^N, at the moment the public spending increase is actually implemented (at the implementation date t_1). Note that the rate of inflation is assumed to be predetermined in the Keynesian version of the model.

A *moderate* delay in the public spending increase in defined by the requirement that the intersection of the disequilibrium trajectory drawn with reference to the initial steady state, and the saddlepath through the new steady state, be at a level of inflation greater than or equal than the one that triggers the liquidity trap. In Figure 11 this means that the disequilibrium trajectory passing through Ω_{13}^{N} is the trajectory with the longest gap between the announcement of the future spending increase and its implementation that is consistent with the system not ending up in the liquidity trap region. This solution trajectory intersects the convergent saddlepath through Ω_{2}^{N} at Ω_{23}^{LN}, which corresponds to an inflation rate equal to $\frac{i_M - \bar{i}}{\gamma}$, which separates the normal region from the liquidity trap region.

With any longer postponement of the public spending increase, the initial drop in consumption would be to, say, Ω_{14}^{N} in Figure 11. From there the system would travel along the divergent trajectory drawn with reference to Ω_{1}^{N} that would bring it to Ω_{24}^{LN} on the LN locus some time before t_1. The system would then switch to the closed orbit, drawn with reference to Ω_{1}^{L} that passes through Ω_{24}^{LN}. It would travel in clockwise fashion around this orbit until t_1. Assume that at t_1 it has arrived at Ω_{34}^{L}. At t_1, it would switch (without a discontinuous jump in either c or π) to the closed orbit drawn with reference to the new liquidity trap steady state (Ω_{2}^{L}) that passes through Ω_{34}^{L}. If this orbit (labelled $\alpha\omega$) stays entirely within the liquidity trap domain (that is, if this orbit does not cross the *LN* locus) the system would continue to circumnavigate the new liquidity trap steady state on this closed orbit. This is the case drawn in Figure 11. If the $\alpha\omega$ orbit leaves the liquidity trap domain again, the behaviour of the system becomes very hard to pin down. It is possible that no equilibrium exists in this case.

In the Keynesian case also, it is clear how a reduction in the nominal interest rate on currency, i_M, can help avoid a liquidity trap. A lower value of i_M shifts both the $(\dot{c}=0)_L$ locus and the boundary separating the liquidity trap region from the normal region (the *LL* locus) to the left. For any shock to demand or supply, it is always possible to find a value of i_M low enough to stop the economy from entering the liquidity trap region.

Furthermore, if the economy were to get caught in the liquidity trap region, an unexpected permanent reduction in the nominal interest rate on currency could always land it back in the normal region. Cutting the nominal rate on currency can therefore be cure as well as prevention.[27]

(V) Conclusion

The credible targeting of a low rate of inflation should result, on average, in low nominal interest rates. The administratively determined zero nominal interest rate on

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[27] A very similar, but technically more complicated, analysis can be conducted for the case where the growth rate of the nominal money stock rather than the short nominal bond rate is the monetary instrument. When the growth rate of nominal money is the exogenous monetary instrument, the equations of motion of the economic system can be summarised as follows: When $i > i_M$, we have the following three-dimensional dynamic system.

$$\frac{d}{dt}\left(\frac{c}{m}\right) = (i_M + \eta\frac{c}{m} - \delta - \mu)\frac{c}{m}$$

$$\dot{c} = (i_M + \eta\frac{c}{m} - \delta - \pi)c$$

$$\dot{\pi} = \beta(c + g - \bar{y})$$

Note that when $i = i_M$ and the economy is stuck in a liquidity trap, the dynamic system reduces to

$$\dot{c} = (i_M - \delta - \pi)c$$

$$\dot{\pi} = \beta(c + g - \bar{y})$$

which is the same as the liquidity trap-constrained dynamics when the short nominal bond rate was the policy instrument.

currency sets a floor under the nominal interest rate on non-monetary financial claims. An important policy issue then is the following: how likely is it that the economy ends up, as a result of shocks or endogenous fluctuations, in a situation where the zero short nominal interest floor becomes a binding constraint, that is, how likely is the economy to end up in a liquidity trap?

If low average nominal interest rates also tend to be stable rates, the risk of ending up in a liquidity trap need not be enhanced much by targeting a low rate of inflation. The empirical evidence on the relationship between the level and volatility of short nominal rates is, however, mixed. The cross-sectional evidence supports a strong positive correlation. The time-series evidence for the UK is ambiguous, but if anything is consistent with a weak negative correlation.

Once an economy lands itself in a liquidity trap, there are just two policy options. The first is to wait for some positive shock to the excess demand for goods and services, brought about through expansionary fiscal measures or through exogenous shocks to private domestic demand or to world demand. The second option is to lower the zero nominal interest rate floor on currency by taxing currency. A negative interest rate on currency would also reduce the likelihood of an economy landing itself in a liquidity trap.

The paper revisits a proposal by Gesell for implementing a negative nominal interest rate on currency. The transactions and administrative costs associated with what amounts to periodic currency reforms would be non-negligible. Such currency conversion costs could be reduced by lengthening the interval between conversions, but they would remain significant. These 'shoe-leather costs' would have to be set against the risk of ending up in a liquidity trap, if a very low rate of inflation is targeted without taxing currency, or against the cost of targeting a higher rate of inflation.[28] It may take a lot of shoe leather to fill an output gap or to rub out the distortions of a higher inflation tax. If there are indeed benighted countries threatened by, or even caught in, a liquidity trap, the policy makers there have one more option they might wish to consider on its merits: Gesell money.

[28] On the costs of even low rates of inflation see Feldstein [1997], Tödter and Ziebarth [1997] and Chadha, Haldane and Janssen [1998]. On the costs and benefits of low inflation see Akerlof, Dickens and Perry [1996]. For a general survey see Fischer [1994].

Appendix 1: Paying Negative Nominal Interest Rates; Some Further Considerations.

In this section, we ignore uncertainty and time is measured in discrete periods of unit length.

$i_{t,t+1}$ is the one-period nominal interest rate between periods t and $t+1$. At time t, a security obliging the issuer to pay the holder (owner) 1 unit of money in period $t+i$, $i = 1,...,N$, will be worth D_t^N units of period t money. In an efficient market it will be the case that

$$D_t^N = \prod_{\ell=1}^{N} \frac{1}{1+i_{t+\ell-1,t+\ell}}$$

This pricing formula makes sense, for finite N, as long as $i_{t,t+1} > -1$, for all t: the price of money tomorrow in terms of money today, D_t^N, or the N-period nominal discount factor, cannot be negative. The sequence of interest rates can, however be negative. A negative one-period interest rate simply means that *1* £ tomorrow is worth more than *1*£ today: the discount factor exceeds *1*. As $N \to \infty$, the infinite sequence of single-period nominal interest rates cannot all be negative, lest the discount factor become unbounded. A consol or perpetuity with a constant positive coupon would have an infinite price if the infinite sequence of period rates were negative.

Assume that a borrower issues, at time t, a security committing him to pay the lender (the owner or holder of the security) $C_{t+1} \geq 0$ units of money in periods $t+i$, $i = 1,...,N$. The price of the security in period t, V_t^N, is

$$V_t^N = \sum_{j=1}^{N} D_t^j C_{t+j}$$

Assume the purchase price is paid by the lender in period t. The problem for the lender now becomes to enforce payment of the coupons, C_{t+j}, by the borrower in each of the

N periods after the security is issued. Unless we can rely on borrower honesty, or unless the lender and borrower are locked into an infinitely repeated lender-borrower relationship, a necessary condition for performance by the borrower is that the lender knows the identity of the borrower. The borrower need not know the identity of the lender, because the borrower has already received all he wants out of the relationship: money up front. To enforce performance on the contract by the borrower, once the present discounted value to the borrower of the continuation of the relationship has become negative, the lender must be able to identify the borrower to a third party enforcement agency (the courts).

Conventional bearer bonds are therefore incentive-compatible. The anonymous holder of the bearer bond knows the identity of the issuer and it is the issuer who owes money to the holder of the bearer bond. It is of course key that there is a way to establish whether coupon payments have in fact been made. With bearer bonds, negotiable instruments that can change hands freely, the security must be marked unambiguously as 'current' in regard to all payments due. Without such clear and unambiguous marking, the same bearer bond could be presented again and again for payment by the same or by different anonymous holders. Clipping coupons off a bearer bond is a time-honoured technology for establishing whether payments due have indeed been made.

I restrict the discussion to pure fiat currency, which does not have intrinsic value either as a consumption good or as a capital good. A useful way of viewing currency is as an IOU of the state that has a one-period maturity, pays no interest, but can be redeemed at par after one period. Each unit of the 'old' currency is returned to the issuer after one period in exchange for one unit of 'new' currency which is identical in all respects to the old currency. In particular, it is impossible to determine whether a given unit of currency is new or old. Note that this makes one-period currency redeemable at par for indistinguishable new currency equivalent to a zero coupon bearer perpetuity or consol. The value of one unit of currency as a store of value is therefore, in period *t*, $\frac{1}{1+i_{t,t+1}}$.

Currency, of course, yields further utility services (as a means of payment and medium of exchange). The value of the flow of non-pecuniary returns in period *t* (measured in terms of currency) will be denoted $v(M_t)$, where M denotes the nominal stock of currency. The total, pecuniary and non-pecuniary value of an additional unit of currency issued in period t is therefore

$$v'(M_t) + \frac{1}{1+i_{t,t+1}}.$$

Interest-bearing currency involves replacing the assumption that one unit of currency can be exchanged for 1 unit of identical currency after one period, with the assumption that one unit of currency can be exchanged for $1+i_M$ units of identical currency after one period. The value of the interest-bearing currency is therefore

$$v'(M_t) + \frac{1+i_M}{1+i_{t,t+1}}$$

Clearly, if $i_M \geq 0$, money's bearer-bond status remains consistent with incentive-compatible enforcement of the terms of the contract. The anonymous lender (the holder of the bearer bond) knows the identity of the borrower (the state through its agent, the central bank), who owes the lender money. The anonymous party can be relied upon to claim the positive interest due. The problem of marking currency when interest has been paid will of course be present, as with all bearer bonds. Coupons will have to be clipped off currency or currency will have to be stamped.

When the interest rate on money is negative, the anonymous party is also the party who owes money to the known party. This presents a problem in that the anonymous bearer may try to avoid paying interest due to the borrower simply by not turning up to have the currency stamped or have non-detachable coupons attached to it. If private agents continue among themselves to exchange (and accept in payment) old but unstamped money and new or stamped money at par, the attempt to pay negative interest on money would be vitiated. The issuer (the state) has to be able to force the bearer of its currency liabilities to come forward to pay the 'tax on currency'. Tax enforcement when the tax authorities do not know the identity of the tax payer is problematic. The only solution is, first, to make currency on which interest has been paid clearly distinguishable from currency on which interest has not been paid (by stamping or attaching coupons to it) and second, to penalise those holders of currency who are in arrears. The simplest penalty would be partial or complete confiscation of currency on which interest payments are not current.

Appendix 2: A Time-Series Investigation of the Association Between the Level and Volatility of the Short Nominal Interest Rate, the Inflation Rate and the Exchange Rate Depreciation Rate.

(1) UK 3-month interbank rate 1975-1999.

Let *i* denote the UK 3-month interbank rate. The time series model estimated for Table 1 was

$$\begin{aligned} & i_t - i_{t-1} = a + b i_{t-1} + \varepsilon_t , \\ & \varepsilon_t = \rho \varepsilon_{t-1} + u_t + \vartheta u_{t-1}, \\ & E(\varepsilon_t | \Psi_{t-1}) = 0, E(\varepsilon_t^2 | \Psi_{t-1}) = \sigma_t^2 , \\ & \sigma_t^2 = \omega + \beta \sigma_{t-1}^2 + \gamma \varepsilon_{t-1}^2 + \delta i_{t-1} \end{aligned} \qquad \textbf{(A2.1)}$$

This time series model includes *AR(1)* and *MA(1)* terms in the conditional mean equation to account for the autocorrelation of standardised residuals. It includes *GARCH(1,1)* terms in the conditional variance equation to account for the autocorrelation of squared standardised residuals, as well as, a linear function of the lagged interest rate level to capture the potential dependence of the conditional variance on the lagged interest rate level.

Weekly data of the UK 3-month interbank rate from Jan 75 to April 99 were used for the model estimation. The estimation results using maximum likelihood were:

Table A2.1

	Coefficient	Std. Error	Prob
a	0.047	0.030	0.119
b	–0.0062	0.0038	0.103
ρ	0.86	0.06	0.000
ϑ	–0.78	0.08	0.000
ω	–0.00042	0.00036	0.242
β	0.975	0.007	0.000
γ	0.022	0.008	0.005
δ	0.000069	0.000059	0.243

R^2 (adjusted) = 0.016

Standard errors are estimated using Quasi Maximum Likelihood. The estimates of the parameters are consistent even if the conditional normality assumption is violated. They can, however, be inefficient.

The coefficient δ, that determines the dependence of the conditional variance on the lagged interest rate level is insignificant. Alternative models of the conditional variance that include higher order powers or higher order lags of the lagged interest rate level, were also estimated.[29] The coefficients of the higher order powers or higher order lags of the interest rate level were also insignificant. Therefore, the dependence of the conditional variance on past interest rate levels is weak.

However, the ex-post contemporaneous relationship between the interest rate level i_t and the conditional variance σ_t^2 is strong. In fact the two variables have a correlation of 0.66. This is mainly because of the large information shocks in 1970's and 1980's when short interest rates were high. After the introduction of inflation targeting in UK (in late 92) the

[29] This includes a version replacing the conditional variance equation in (A2.1) by $\sigma_t^2 = \omega + \beta\sigma_{t-1}^2 + \gamma\varepsilon_{t-1}^2 + \delta r_{t-1}^2$, a specification suggested by Chan, Karolyi, Longstaff and Sanders [1992].

relationship between the interest rate level i_t and the conditional variance σ_t^2 is weaker. In fact they are slightly negatively correlated, with a correlation coefficient of -0.26.

The steady state forecast of the level of the 3-month interbank rate is 7.546. The 95% confidence intervals are 4.02 and 14.41. The confidence intervals were constructed by assuming that the standardised steady state forecast follows the in-sample distribution of the standardised residuals which, of course, has finite support. In particular the assumed skewness and kurtosis were 0.846 and 10.49 respectively.

Using $\ln(1+i_t)$ rather than i_t as the specification of the interest rate variable in the regressions did not result in significantly different results.

(2) UK base rate 1800-1998:

Let *i* denote the UK base rate. The time series model estimated was an EGARCH model of the form:

$$\begin{aligned}
&i_t - i_{t-1} = a + bi_{t-1} + \varepsilon_t, \\
&\varepsilon_t = \rho\varepsilon_{t-10} + u_t + \vartheta u_{t-2}, \\
&E(\varepsilon_t|\Psi_{t-1}) = 0,\ E(\varepsilon_t^2|\Psi_{t-1}) = \sigma_t^2, \\
&\log(\sigma_t^2) = \omega + \beta\log(\sigma_{t-1}^2) + \alpha\left|\frac{\varepsilon_{t-1}}{\sigma_{t-1}}\right| + \gamma\frac{\varepsilon_{t-1}}{\sigma_{t-1}}
\end{aligned} \qquad \textbf{(A2.2)}$$

The coefficients α and γ capture the potentially asymmetric impact of last periods shocks on conditional variance.

The time series model also includes AR(10) and MA(2) terms in the conditional mean equation to account for the autocorrelation of standardised residuals.

Annual data for the UK base rate from 1800 to 1998 were used for estimation. The estimation results using maximum likelihood were:

Table A2.2

	Coefficient	Std. Error	Prob
a	0.34	0.11	0.002
b	–0.071	0.023	0.002
ρ	0.12	0.07	0.099
ϑ	–0.28	0.08	0.000
ω	–0.064	0.086	0.455
γ	0.29	0.07	0.000
β	0.91	0.02	0.000
α	0.078	0.102	0.446

R^2 (adjusted) = 0.120

Standard errors are estimated using Quasi Maximum Likelihood. The estimates of the parameters are asymptotically consistent even if the conditional normality assumption is violated. They can be inefficient, however, in this case.

The EGARCH model was chosen over alternative GARCH models, because its long run unconditional variance was non-explosive[30]. The coefficient γ is significant[31], but the effect is the opposite of the "leverage[32]" effect, that is, a negative shock has a negative impact on the conditional variance.

The steady state forecast of the base rate is 4.88. The 95% confidence intervals are 1.02 and 10.1. The confidence intervals were constructed by assuming that the standardised steady state forecast follows the in-sample distribution of the standardised residuals. In particular the assumed skewness and kurtosis were 0.49 and 4.197 respectively.

(3) UK annual inflation (RPI annual % changes) 1800-1998:

[30] An asymmetric component ARCH model had also a non-explosive unconditional variance, but the convergence was much slower than EGARCH model.
[31] at 95% confidence level.

Let p denote the RPI and $\pi_t = \frac{p_t - p_{t-1}}{p_{t-1}}$ its annual proportional rate of change. The time series model estimated was

$$\begin{aligned} &\pi_t - \pi_{t-1} = a + b\pi_{t-1} + \varepsilon_t, \\ &\varepsilon_t = \rho_1 \varepsilon_{t-5} + \rho_2 \varepsilon_{t-8}, \\ &E(\varepsilon_t | \Psi_{t-1}) = 0,\ E(\varepsilon_t^2 | \Psi_{t-1}) = \sigma_t^2, \\ &\sigma_t^2 = \omega + \beta\sigma_{t-1}^2 + \gamma\varepsilon_{t-1}^2 \end{aligned} \qquad \textbf{(A2.3)}$$

This time series model includes AR(5) and AR(8) terms in the conditional mean equation to account for the autocorrelation of standardised residuals. It includes GARCH(1,1) terms in the conditional variance equation to account for the autocorrelation of squared standardised residuals.

Annual data of the UK RPI annual proportional changes from 1800 to 1998 were used for the model estimation. The estimation results using maximum likelihood were:

Table A2.3

	Coefficient	Std. Error	Prob
a	0.013	0.006	0.031
b	–0.46	0.085	0.000
ρ_1	0.15	0.08	0.053
ρ_2	0.24	0.08	0.001
ω	0.00009	0.000103	0.380
β	0.81	0.12	0.000
γ	0.16	0.104	0.114

R^2 (adjusted) = 0.294

Standard errors are estimated using Quasi Maximum Likelihood. The estimates of the parameters are asymptotically consistent even if the conditional normality assumption is violated. They can be inefficient, however, in this case.

[32] The “leverage” effect is the negative correlation between current returns and future volatility, found mainly in stock returns data.

Alternative models of the conditional variance that include inflation rate dependence, were also estimated. The coefficient of the inflation rate dependence was insignificant.

The steady state forecast of the inflation rate is 2.7%. The 95% confidence intervals are -10.7% and 21%. The confidence intervals were constructed by assuming that the standardised steady state forecast follows the in-sample distribution of the standardised residuals. In particular the assumed skewness and kurtosis were 0.434 and 5.286 respectively.

(4) £/$ annual changes 1800-1998:

Let s denote the annual spot exchange rate and $e_t = \frac{s_t - s_{t-1}}{s_{t-1}}$ its proportional rate of change. The time series model estimated was

$$\begin{aligned} & e_t - e_{t-1} = a + br_{t-1} + \varepsilon_t, \\ & \varepsilon_t = \rho\varepsilon_{t-2} + u_t + \vartheta u_{t-3}, \\ & E(\varepsilon_t | \Psi_{t-1}) = 0,\ E(\varepsilon_t^2 | \Psi_{t-1}) = \sigma_t^2, \\ & \sigma_t^2 = \omega + \beta\sigma_{t-1}^2 + \gamma\varepsilon_{t-1}^2 + \delta e_{t-1}^2 \end{aligned} \qquad \textbf{(A2.4)}$$

This time series model includes AR(2) and MA(3) terms in the conditional mean equation to account for the autocorrelation of standardised residuals. It includes GARCH(1,1) terms in the conditional variance equation to account for the autocorrelation of squared standardised residuals, as well as a linear term in the square of the growth rate of the exchange rate to capture the potential dependence of the conditional variance on the proportional rate of change of the exchange rate. Annual data on annual percentage changes of the £/$ exchange rate from 1800 to 1998 were used for the model estimation. The estimation results using maximum likelihood were:

Table A2.4

	Coefficient	Std. Error	Prob
a	–0.0059	0.0016	0.000
b	–0.75	0.09	0.000
ρ	–0.18	0.05	0.000
ϑ	–0.25	0.08	0.001
ω	0.00101	0.00027	0.000
β	0.10	0.06	0.113
γ	–0.13	0.06	0.034
δ	0.89	0.32	0.006

R^2 (adjusted) = 0.422

The coefficient δ, which measures the dependence of the conditional variance on the squared proportional exchange rate change is highly significant. The steady state forecast of the £/$ annual percentage change is -0.8%. The 95% confidence intervals are -10.6% and 4.2%. The confidence intervals were constructed by assuming that the standardised steady state forecast follows the in-sample distribution of the standardised residuals. In particular the assumed skewness and kurtosis were 0.864 and 7.57 respectively.

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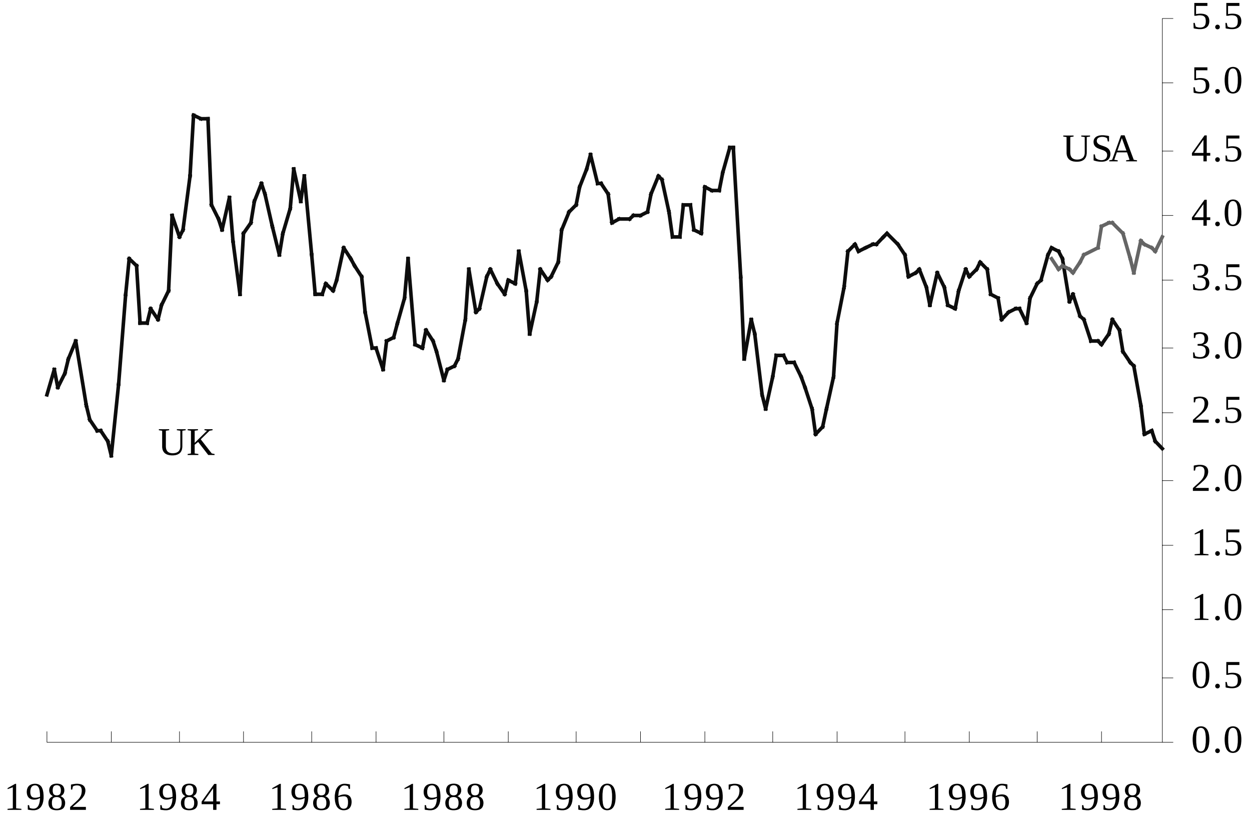
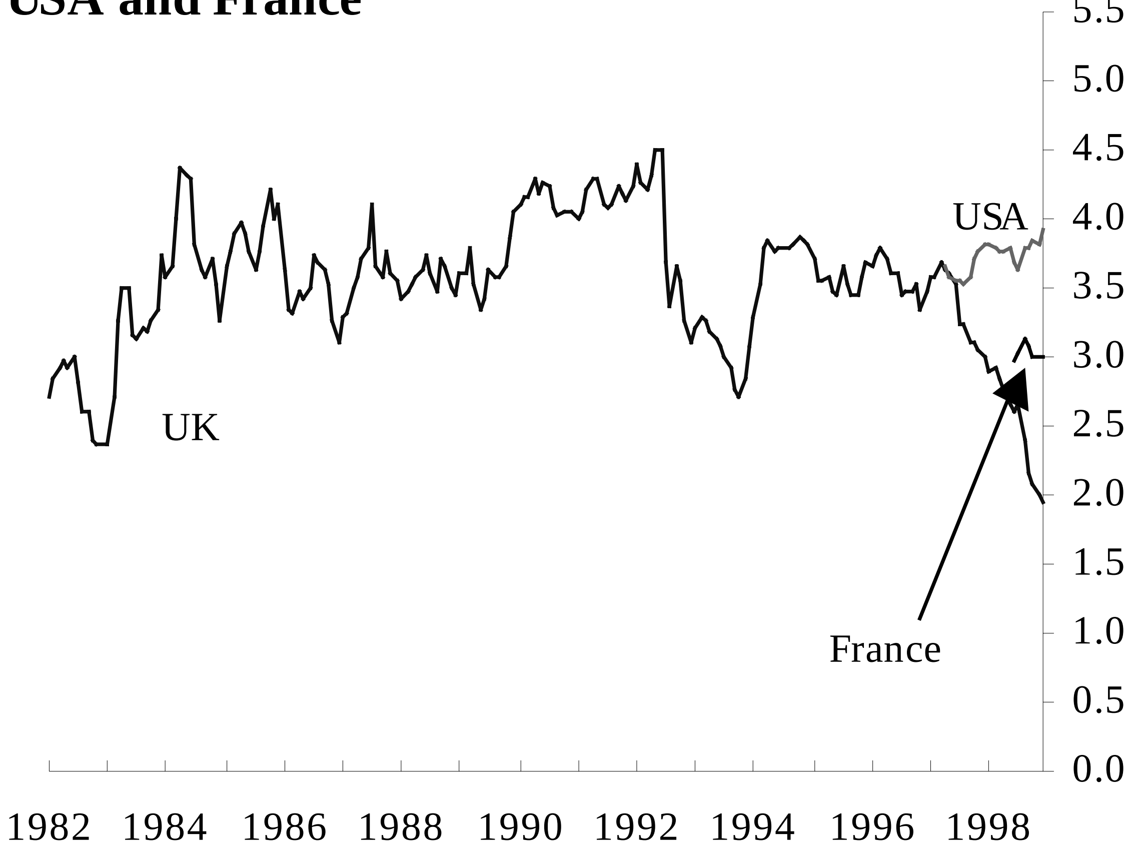
Five year real interest rates in the UK and USA[(a)]



(a) US bonds mature in 2002

Figure 1

Long term year real interest rates in the UK, USA and France[(a)]



(a) UK bonds mature in 2009, US bonds in 2008, French bonds in 20

Figure 2

Bank rate, inflation and £/$ exchange rate, 1945 to date

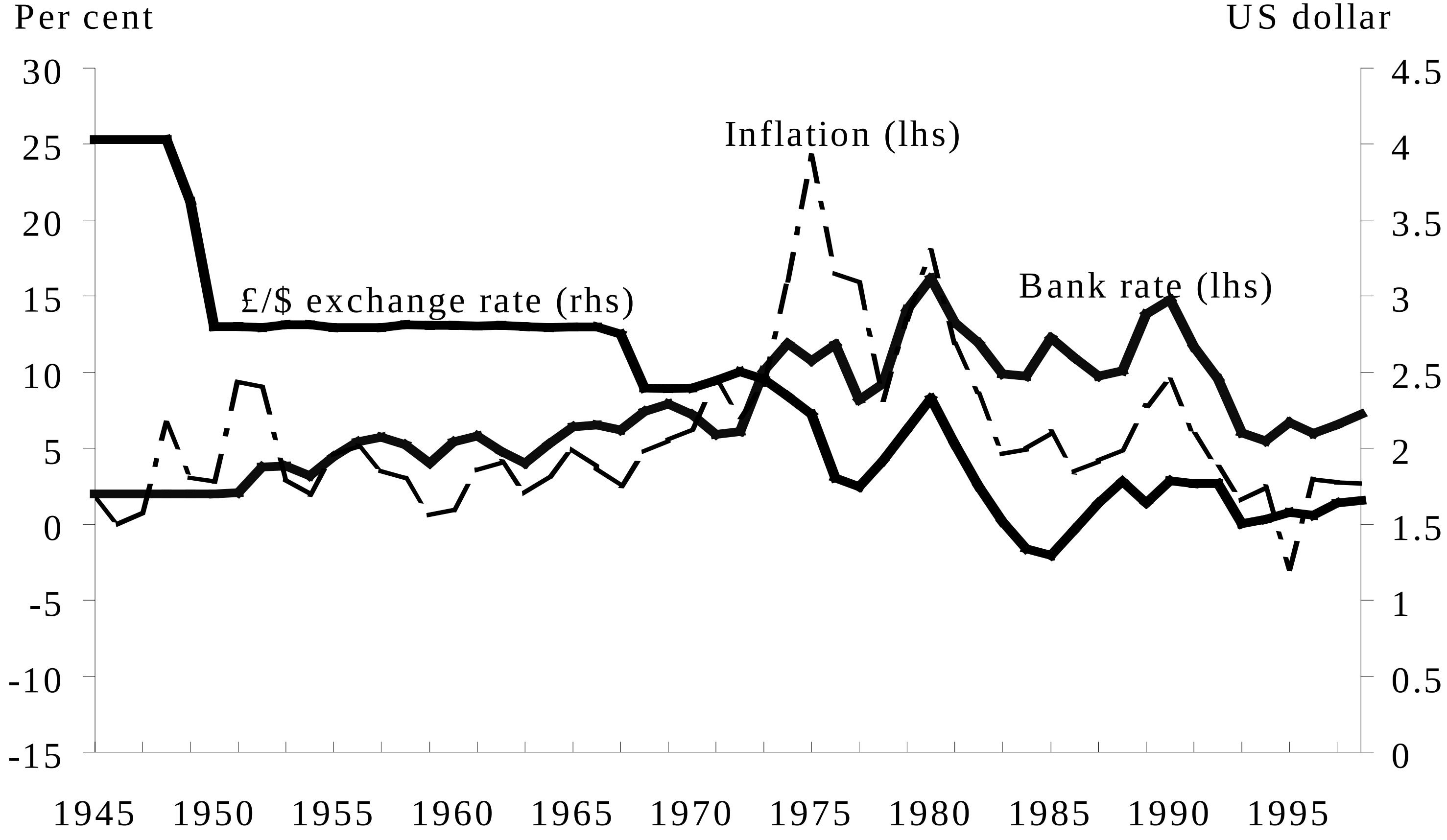


Figure 3

Price Level and Inflation, UK 1800-1914

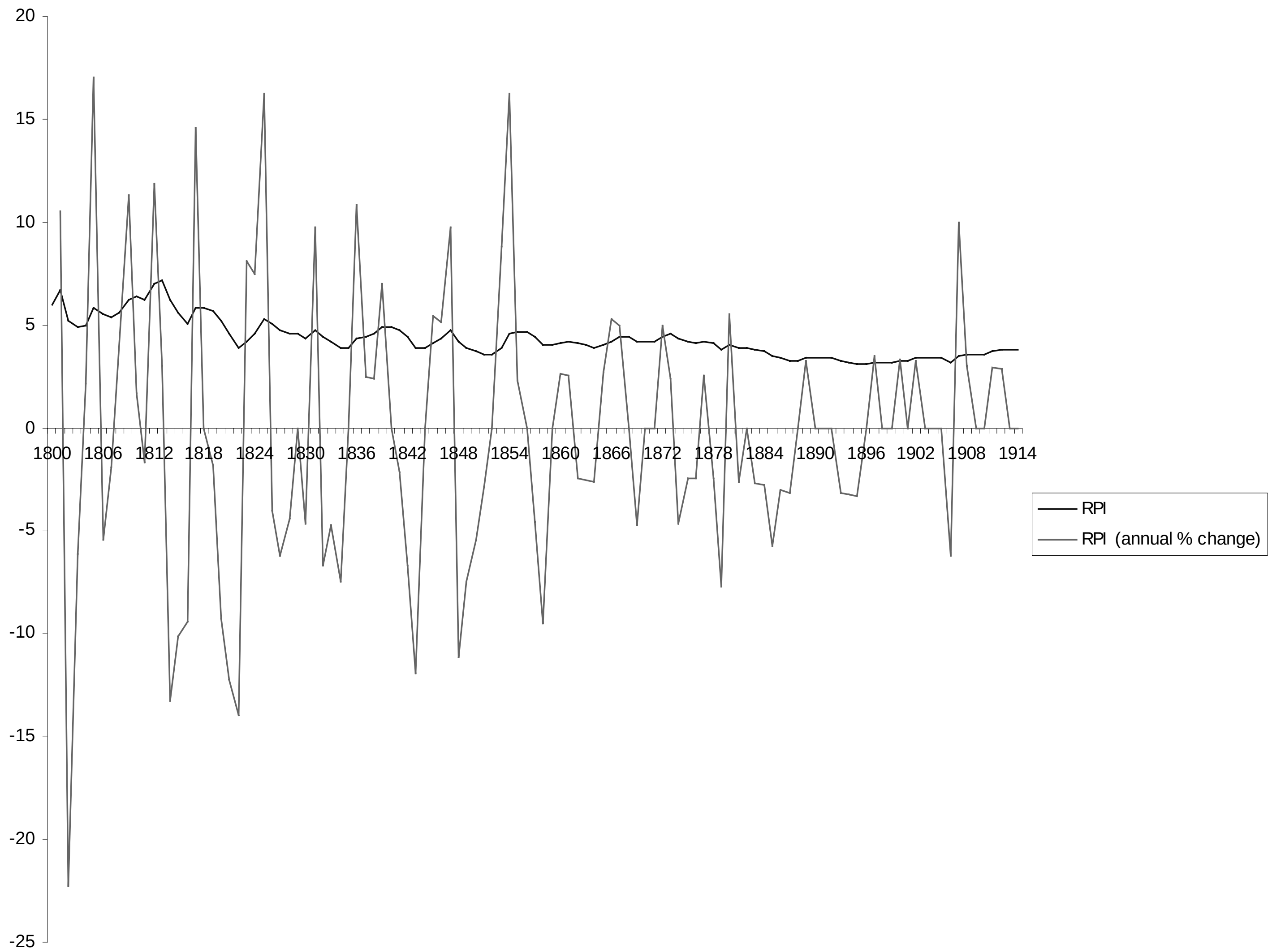


Figure 4

Bank rate, inflation and £/$ exchange rate, 1817-1914

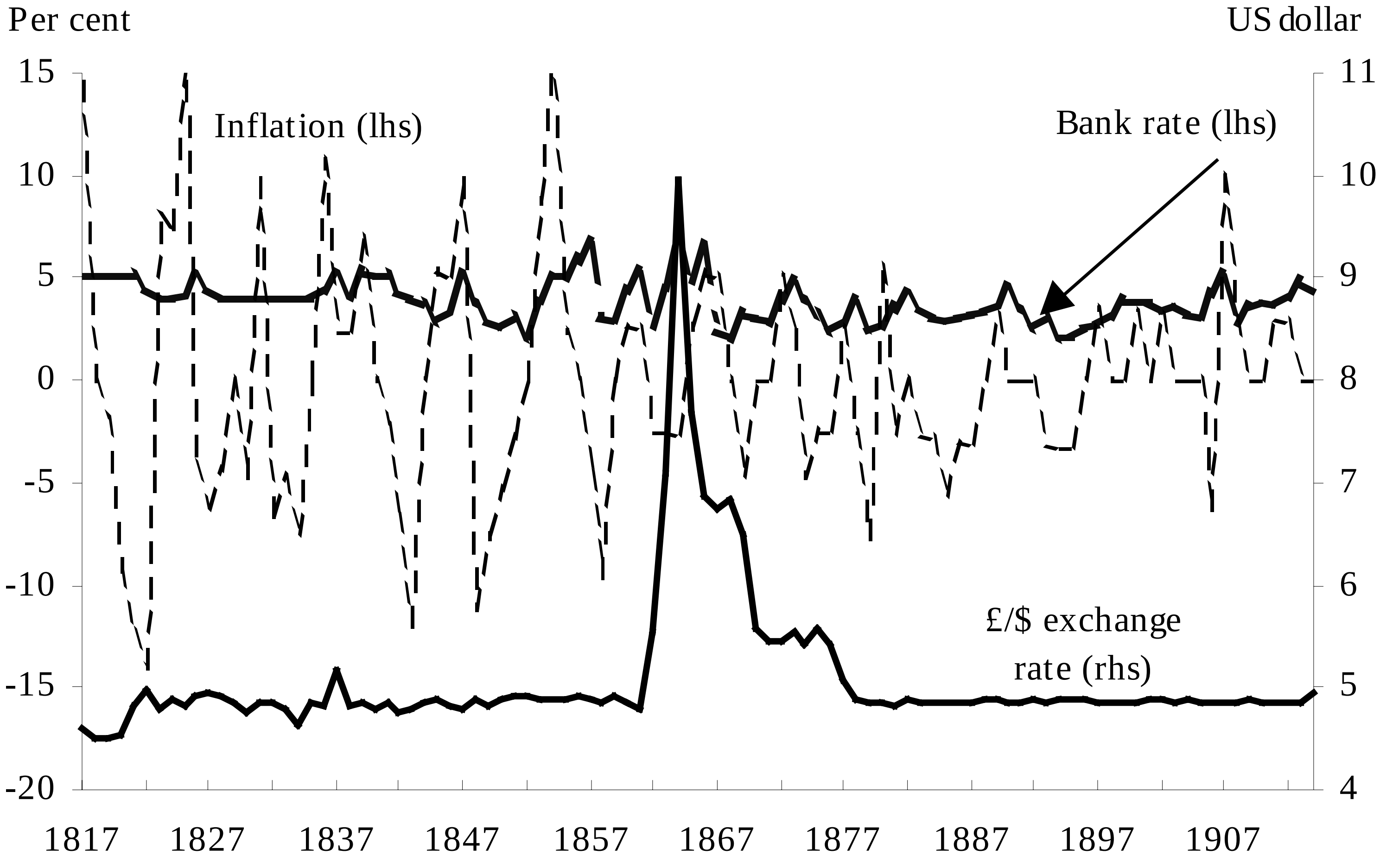


Figure 5

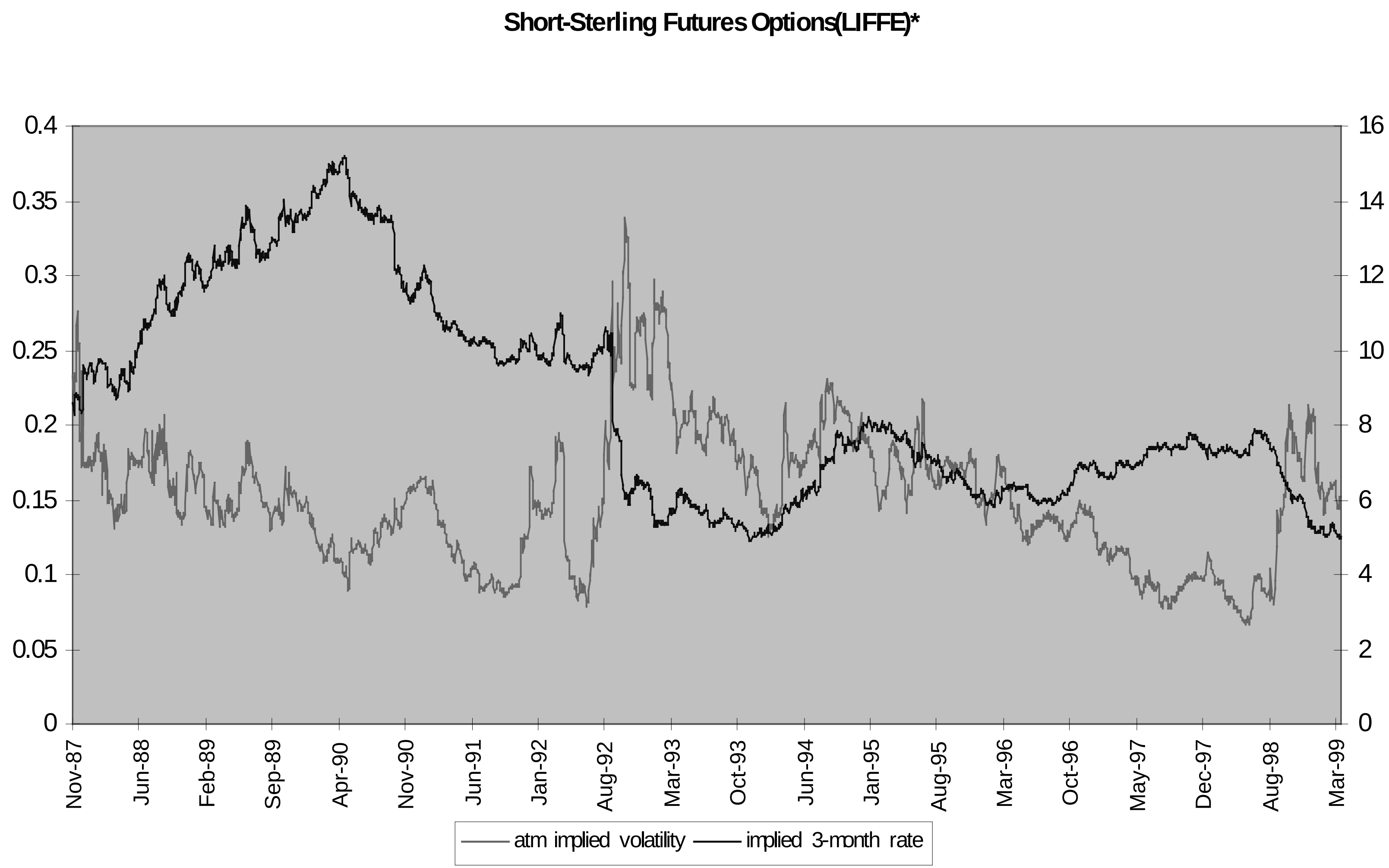


Figure 6

Correlation 1987-1999: -0.26 , 95% confidence intervals: -0.22 -0.30
Correlation 1993-1999: -0.41 , 95% confidence intervals: -0.35 -0.46

*Constant maturity of 6 months

Figure 7

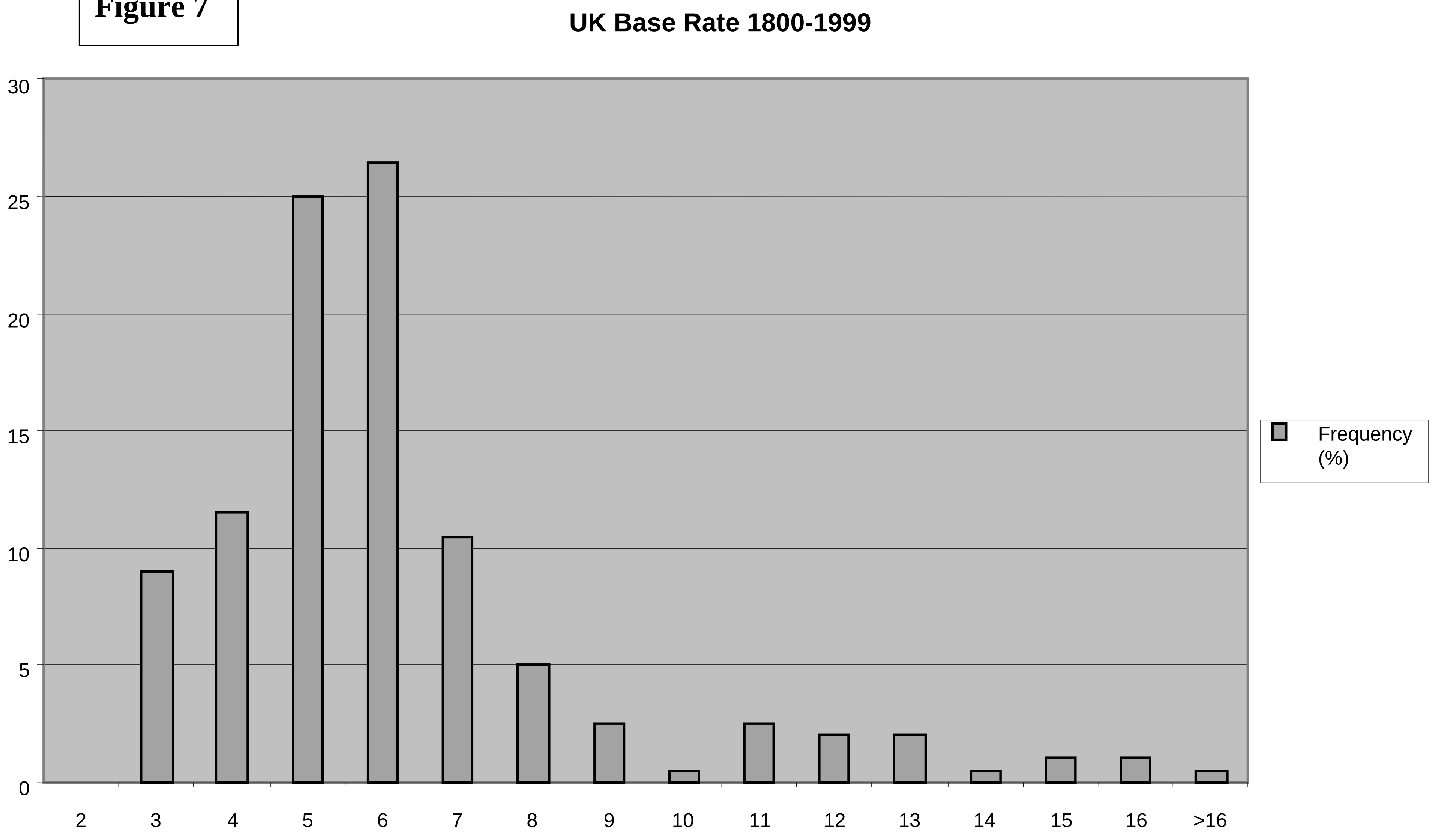
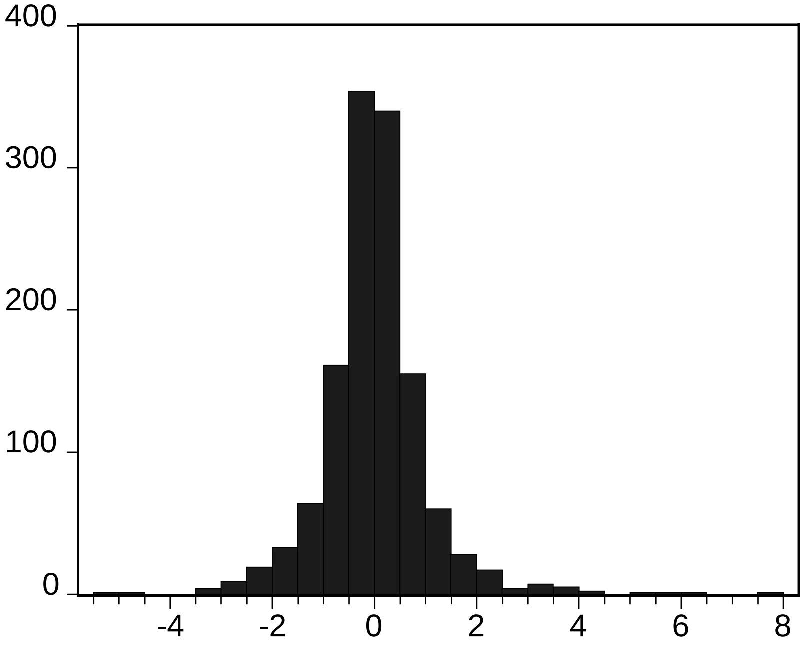

UK Base Rate 1800-1999
30
25
20
15
10
5
0
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
>16
Frequency (%)

Figure 8

Histogram of Standardised Residuals: UK 3-month interbank rate 1975-1999

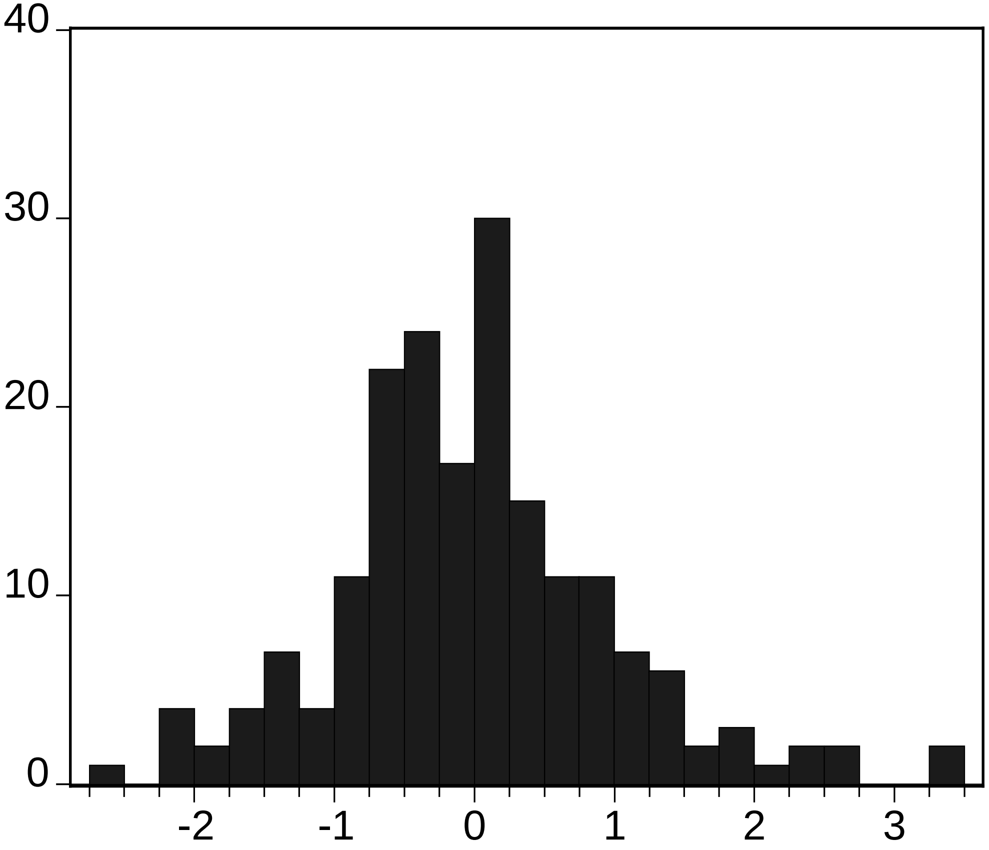


Sample 1/17/1975 4/30/1999
Observations 1268

Mean	0.022144
Median	-0.009907
Maximum	7.955724
Minimum	-5.209383
Std. Dev.	1.005875
Skewness	0.846027
Kurtosis	10.49388
Jarque-Bera	3118.290
Probability	0.000000

Figure 9

Histogram of Standardised Residuals: UK base rate 1800-1998



Sample 1811 1998
Observations 188

Mean	-0.008235
Median	-0.056227
Maximum	3.380759
Minimum	-2.702496
Std. Dev.	0.991252
Skewness	0.496179
Kurtosis	4.196770
Jarque-Bera	18.93341
Probability	0.000077

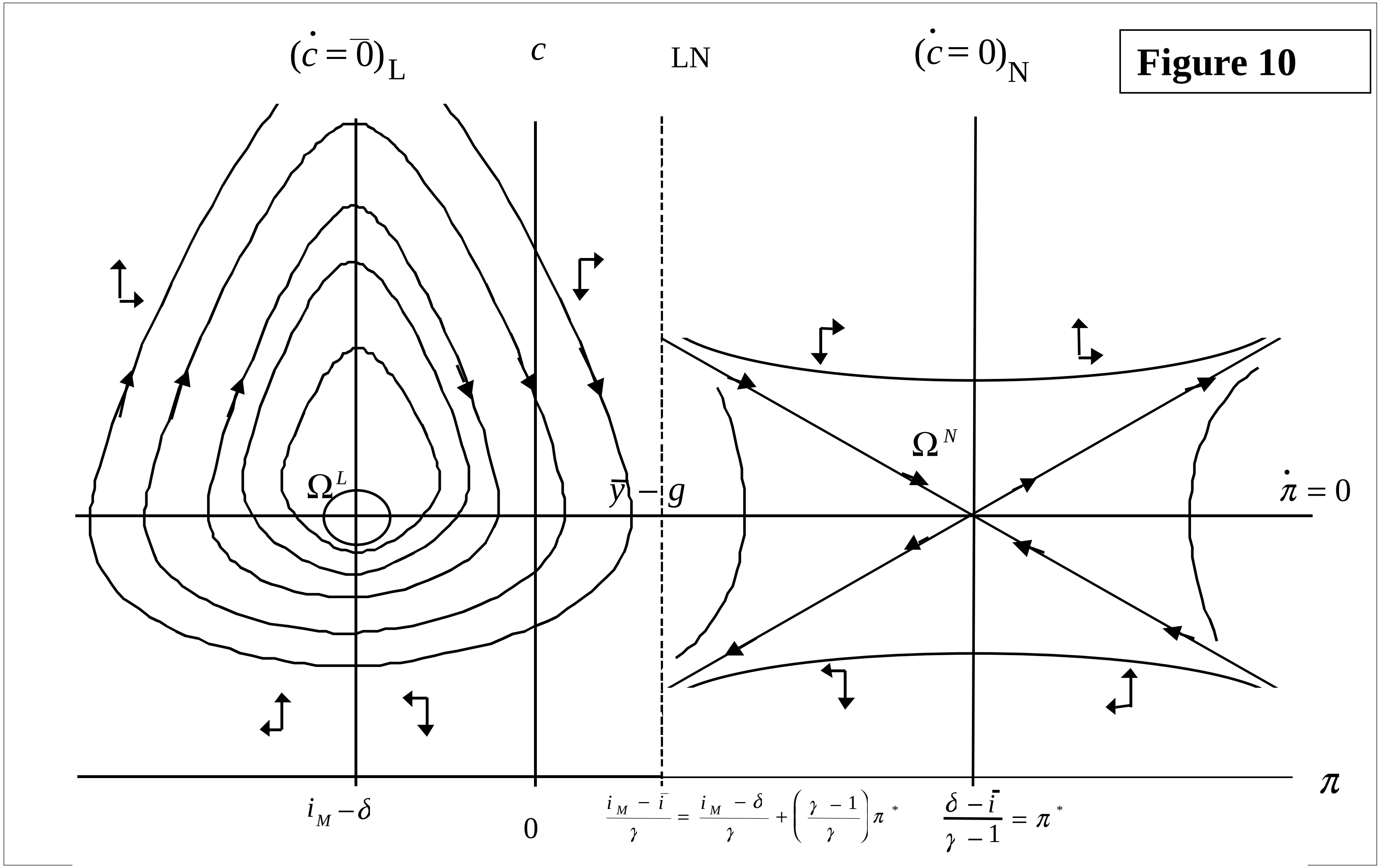

$(\dot{c} = 0)_L$
c
LN
$(\dot{c} = 0)_N$
Ω^L
Ω^N
$\bar{y} - g$
$\dot{\pi} = 0$
π
$i_M - \delta$
0
$\frac{i_M - \bar{i}}{\gamma} = \frac{i_M - \delta}{\gamma} + \left(\frac{\gamma - 1}{\gamma}\right)\pi^*$
$\frac{\delta - \bar{i}}{\gamma - 1} = \pi^*$

Figure 10

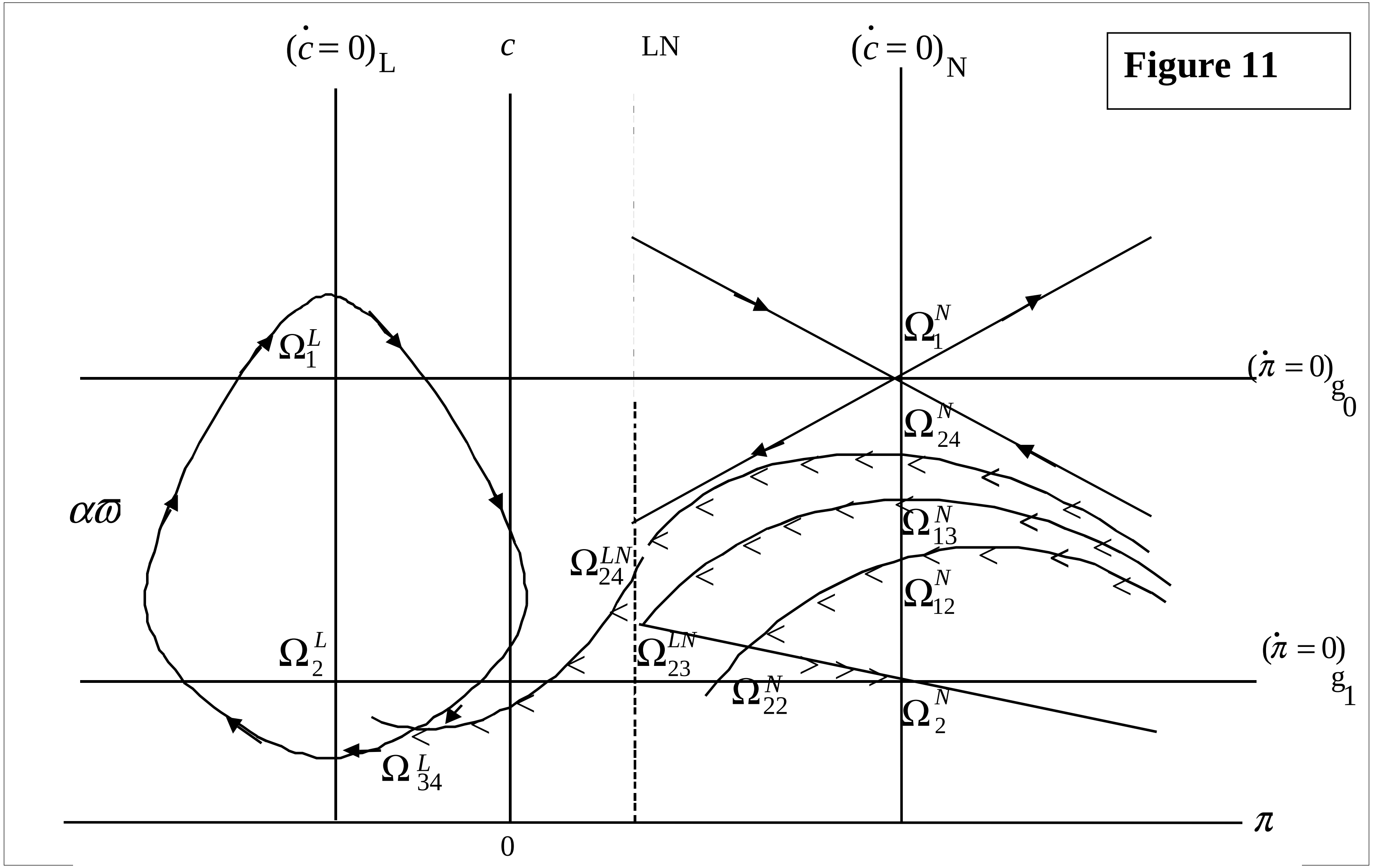


Figure 11
$(\dot{c}=0)_L$
c
LN
$(\dot{c}=0)_N$
Ω_1^L
Ω_1^N
$(\dot{\pi}=0)_{g_0}$
Ω_{24}^N
$\alpha\varpi$
Ω_{13}^N
Ω_{24}^{LN}
Ω_{12}^N
Ω_2^L
Ω_{23}^{LN}
$(\dot{\pi}=0)_{g_1}$
Ω_{22}^N
Ω_2^N
Ω_{34}^L
π
0

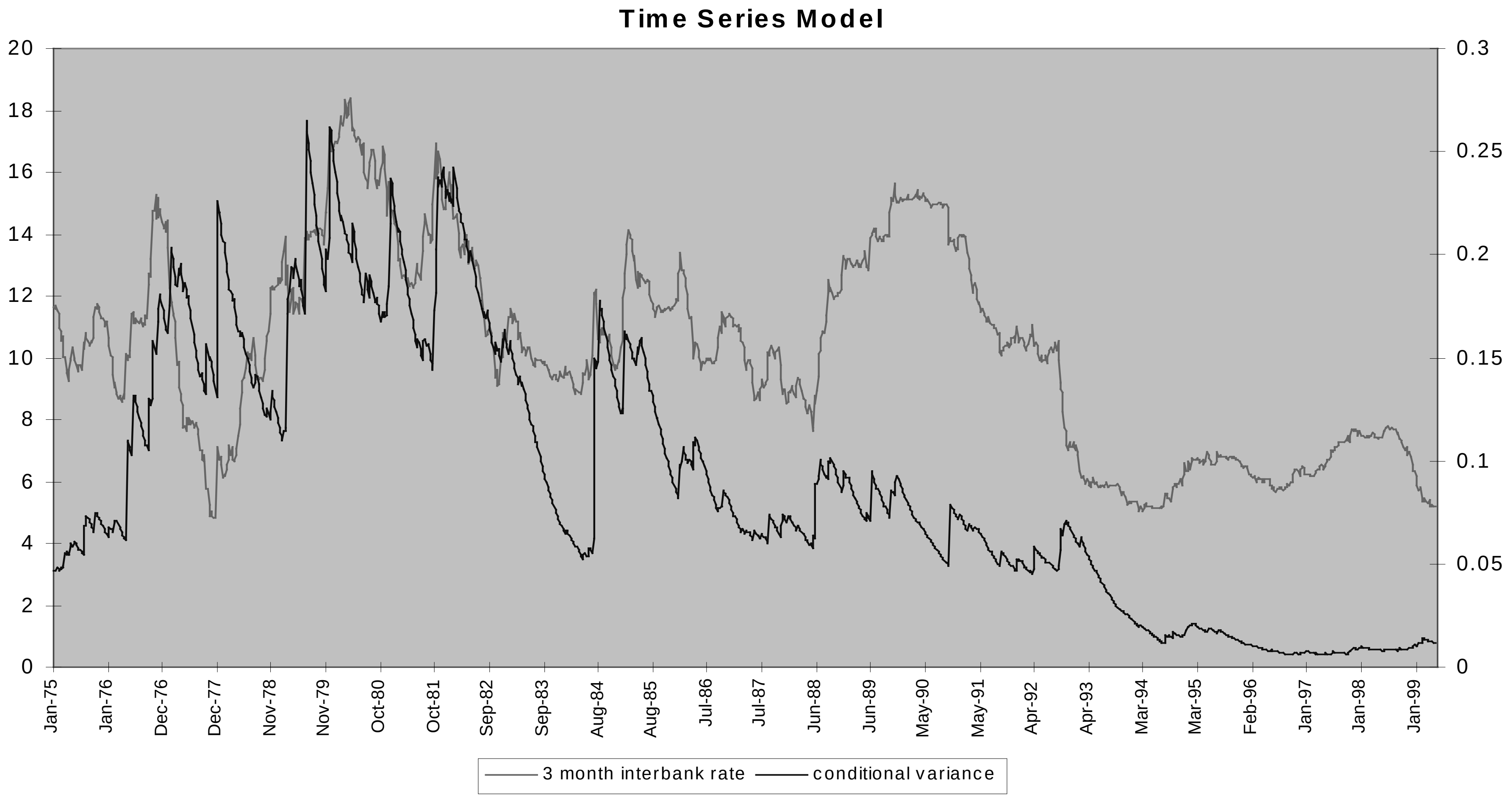


Table 1

Correlation 1975-1999: 0.66 , 95% confidence intervals: 0.72 0.59
Correlation 1993-1999: -0.26 , 95% confidence intervals: -0.13 , -0.38

Steady state 3-month interbank rate: 7.55 ; 95% confidence intervals: 4.02 , 14.41

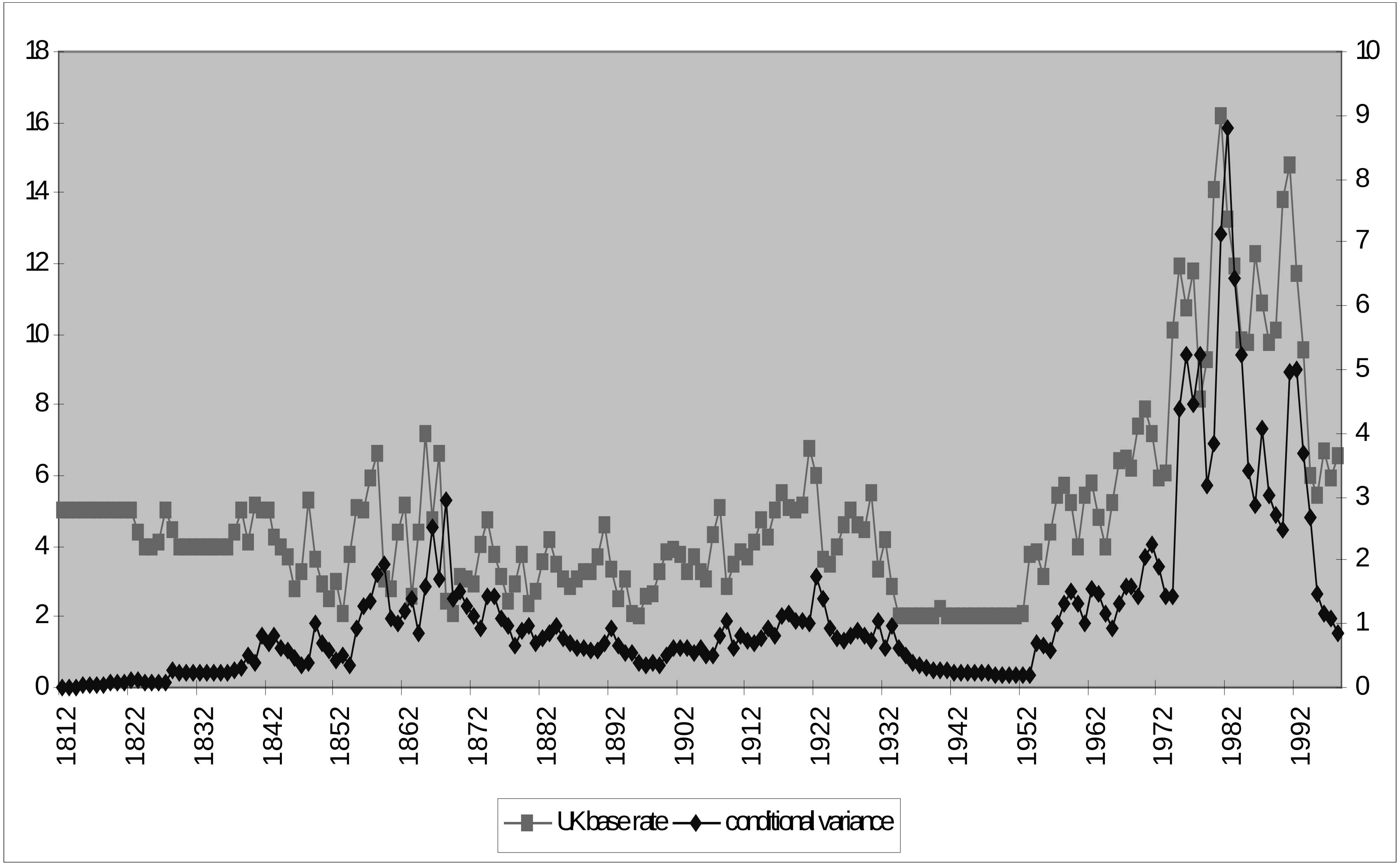


Table 2

Steady state base rate: 4.88%; 95% confidence intervals: 1.02% , 10.10%
Correlation 0.81, 95% ; confidence intervals: 0.66 , 0.97

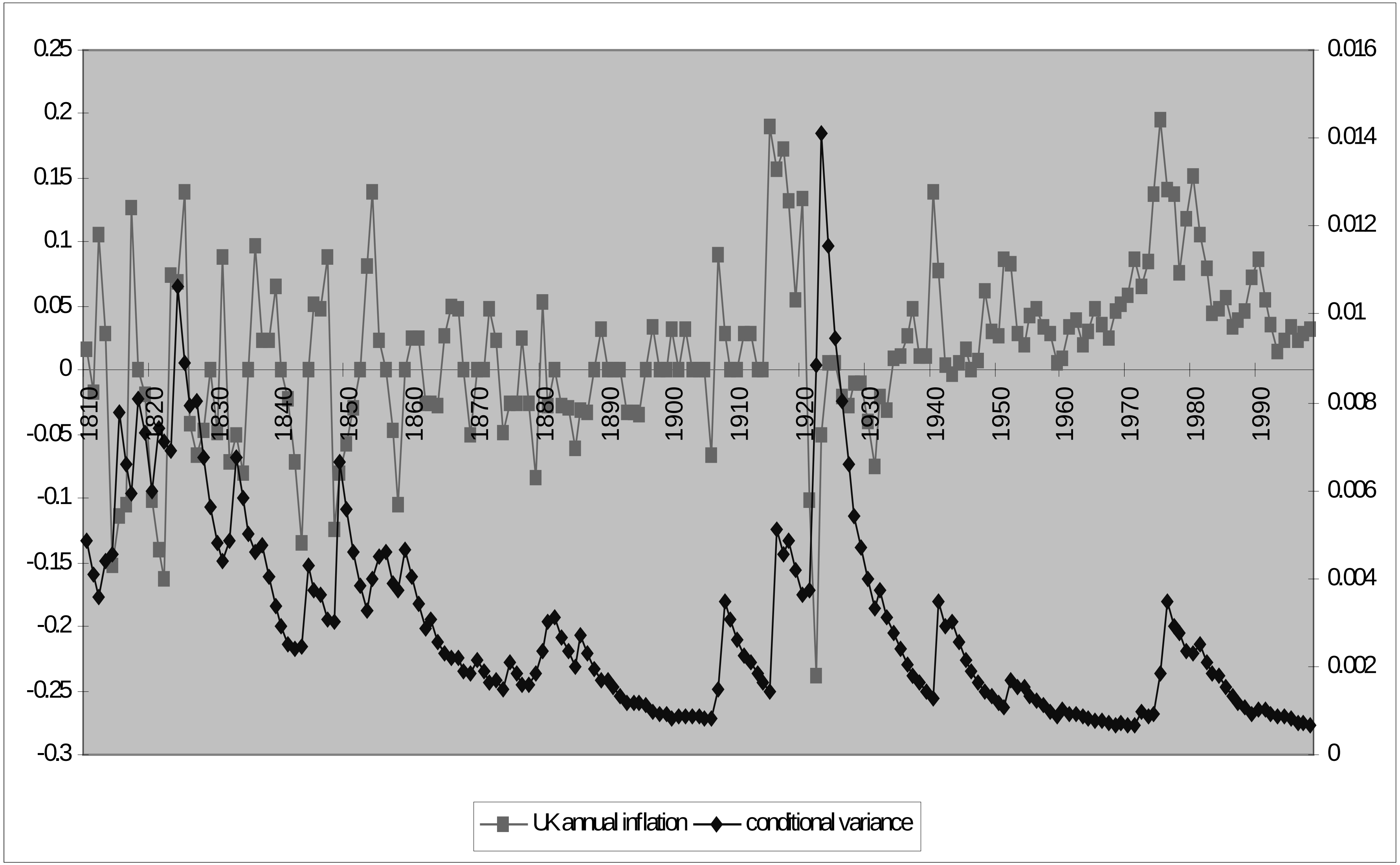


Table 3

Steady state inflation 2.7%; 95% confidence intervals: -10.7% , 21.0%
Correlation: -0.27 ; 95% confidence intervals: -0.43 , -0.12

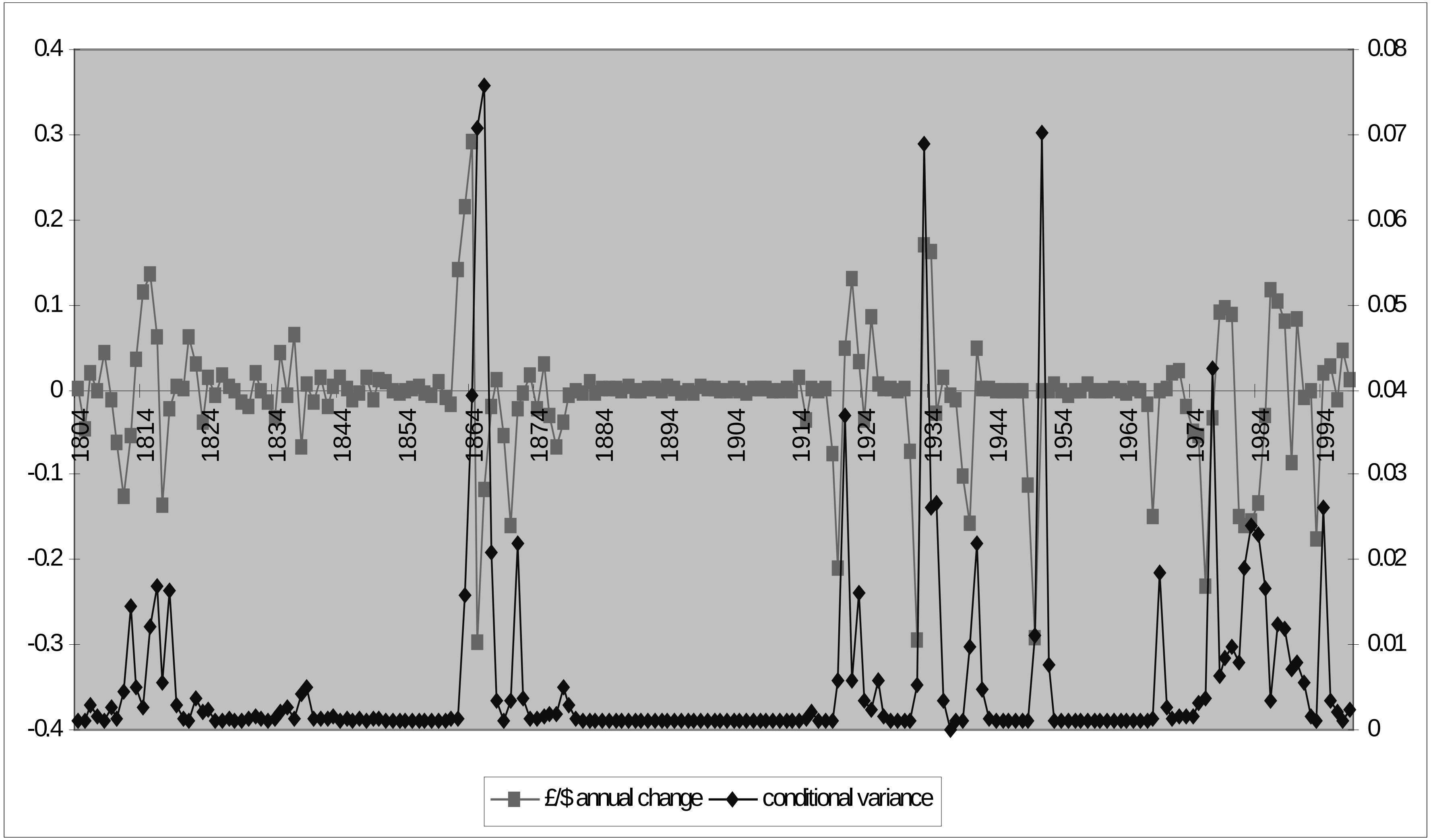


Table 4

Steady state £/$ annual change: -0.8%; 95% confidence intervals: -10.6% , 4.2%
Correlation: -0.03; 95% confidence intervals: -0.19 , 0.13

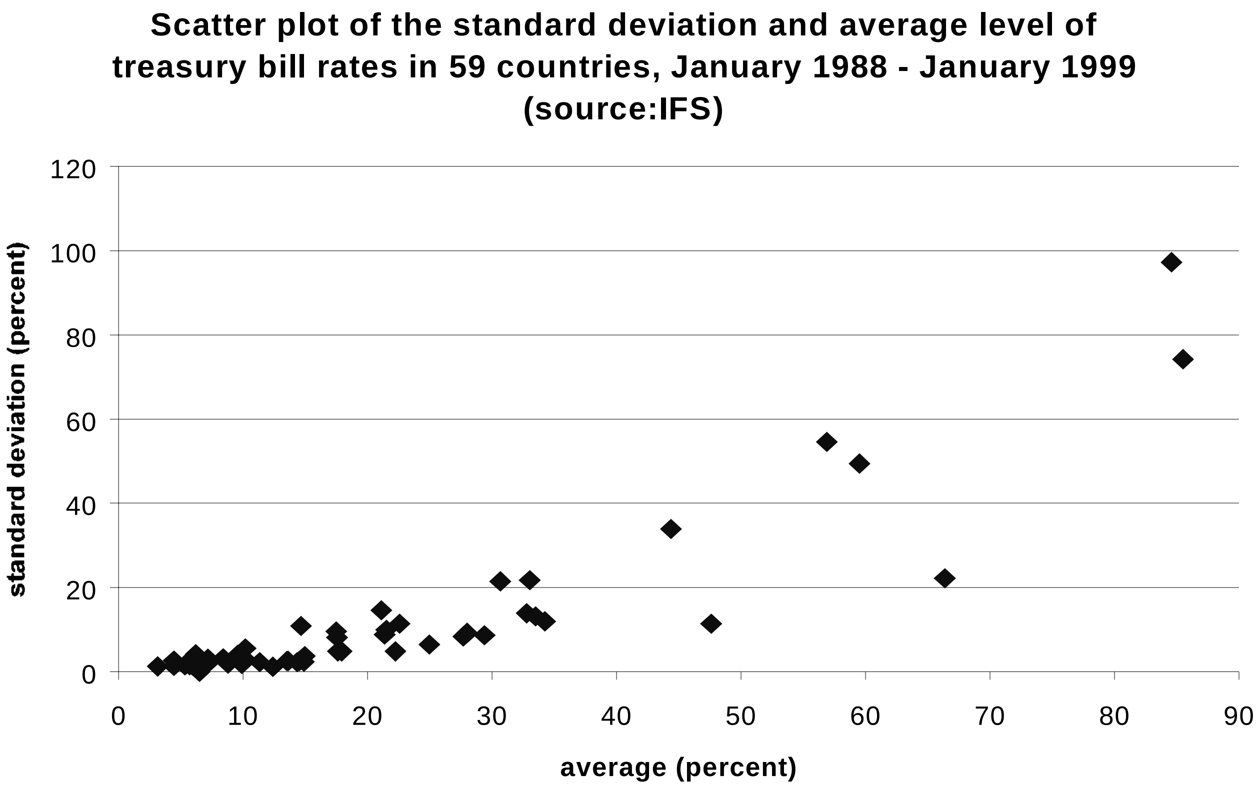


Table 5

Correlation: 0.89