# A no-arbitrage structural vector autoregressive model of the UK yield curve

### Summary of Working Paper no. 357 Iryna Kaminska

Monetary policy makers control short-term interest rates. But long-term rates are no less important, since they influence borrowing costs and aggregate demand in the economy. Thus understanding the behaviour of the whole spectrum of interest rates (the 'yield curve') is crucial.

While yield curve dynamics have been extensively studied in statistics and finance, these studies abstract from the macroeconomic drivers of yield curve movements. The contribution of this paper is to link the term structure of nominal interest rates to the wider economy, by assuming that all risks affecting the pricing behaviour of agents are related to the underlying ('structural') macroeconomic shocks. This approach allows us to enrich financial models of the yield curve with macroeconomic theory, and thus to narrow the existing gap between financial and macroeconomic models.

Thus the paper builds upon and extends two strands of research: previous work on the finance approach to yield curves; and empirical macroeconomic modelling. At the nexus of these two strands, a yield curve model is presented that relates fundamental macroeconomic shocks identified from a macroeconometric model to the bond pricing behaviour of the economic agents. This is in contrast to standard finance models, in which agents are concerned with non-structural risks, which are not directly interpretable. The combination of the macroeconometric and financial models helps us to achieve several goals. Primarily, we are able to model the yield curve across maturities and across time jointly with the macroeconomic dynamics, explaining 'term premia' which describe how rates at longer maturities are related to short rates. Additionally, replacing purely statistical factors by macroeconomic variables simplifies the estimation of highly parametrised financial models.

As an application, three underlying shocks to the UK economy are studied, and their roles in determining the term structure of UK nominal interest rates examined. The approach has two steps. First, aggregate supply, aggregate demand and monetary policy shocks are identified from a three-variable model based on the output gap, inflation and short-term interest rate. Second, the shocks' effects on the nominal yield curve are analysed with the help of a term structure model of interest rates.

The results can be summarised as follows. Demand and supply shocks have different effects on the yield curve. Both supply and demand shocks drive short-term interest rates, whereas demand shocks dominate long-term interest rates. Both demand and supply shocks affect the slope of the yield curve positively on impact. This result confirms previous findings that the slope of the yield curve and economic activity are linked. Finally, the monetary policy shock affects the whole yield curve, with the effect decreasing with maturity.

The results are broadly consistent with the dynamics of yields implied by previous work in empirical macroeconomics. The advantage of the approach is that we are able to decompose long-term interest rates into expected short-term rates and term premia. The results show that the short end of the yield curve moves due to changes in expectations, while movements in the long end are due to the term premia dynamics.

Although the model performs well overall, it does not fit the long end of the yield curve well over the most recent sample, which suggests that including additional macroeconomic variables and shocks might improve the simple model.

# Understanding the real rate conundrum: an application of no-arbitrage finance models to the UK real yield curve

### Summary of Working Paper no. 358 Michael Joyce, Iryna Kaminska and Peter Lildholdt

Long-term interest rates in the major international bond markets fell sharply during 2004 and 2005, at the same time as US policy rates were rising. This phenomenon was famously described as a 'conundrum' by Alan Greenspan the Federal Reserve Chairman at the time. But it was arguably the decline in international real rates (interest rates adjusted for inflation) which was more unusual. And by the end of 2007, although real (and nominal) rates had recovered slightly in the United States and euro area, long real rates in the United Kingdom remained at recent historical lows.

Understanding the causes of low long real rates matters for monetary policy makers, not least because different explanations have correspondingly different implications for monetary conditions. If, for example, low real rates are due to lower investor risk aversion, the response of monetary policy may differ from the scenario where they reflect expectations of weaker long-term growth. There are also implications regarding the risks of long rates reverting to more normal, higher levels. For example, if low long real rates reflect a temporary rather than a permanent shock, there is a greater risk of a sharp upward adjustment in borrowing rates, which would be disruptive for the real economy.

A large number of potential explanations for the conundrum have been put forward. Some have emphasised the role of saving and investment: either high global saving (the so-called Asian 'saving glut') or low investment (particularly in the industrialised countries). Others have focused on looser monetary policy or 'excess liquidity'. Other explanations have related the conundrum to lower risk premia (the amount by which the market rewards the holders of more risky assets). This may have reflected perceptions of greater macroeconomic stability, or the so-called 'search for yield', which could have driven up the demand for riskier but higher yielding assets. And search for yield itself has been seen by some as a possible consequence of excess liquidity, which has depressed nominal risk-free rates and increased investors' demand for risky assets to meet their nominal return aspirations. Finally, other explanations have focused on the role of imbalances between market demand and supply, arising from either large portfolio inflows into bonds from Asian central banks or strong demand from pension funds. Each of

these explanations has some plausibility and it is probably fair to say that no firm consensus has yet emerged on which was the most important. But the fact that the fall in long nominal interest rates during the conundrum period mainly reflected a decline in long real rates, as opposed to lower inflation compensation, suggests that understanding the behaviour of real rates may be particularly fruitful.

In this paper, we try to shed light on what accounts for the phenomenon of low long real rates, by estimating several empirical models of the term structure of real interest rates, derived from UK government index-linked bonds. We adopt a standard 'finance' approach to modelling the real term structure, based on the assumption that there are no risk-free profits to be made by trading between different government bonds (in other words, there are no arbitrage opportunities). Importantly, the assumption of no arbitrage enables us to decompose forward real rates into expectations of future short (ie risk-free) real rates and forward real term premia in a theoretically consistent way.

Although we find some evidence that long-horizon risk-free real rates of interest have declined, the results from the models we examine suggest that reductions in term premia played the more important role in explaining the decline in UK long real rates over the 2004–05 period. This could be consistent with both the search for yield/excess liquidity explanation of the conundrum or heavy demand for index-linked bonds by institutional investors and central banks, although the global nature of the conundrum inclines us to put more weight on the former explanation. More recently, however, it seems likely that real rates have been depressed by a 'flight to quality' from risky assets triggered by the sub-prime crisis in the United States. Taking our results at face value would suggest that there are risks that real rates may rise in the future, as they currently remain below the long-run equilibrium levels implied by our models. But it should be borne in mind that there are a number of caveats with our analysis. In particular, the model set-up does not directly allow for structural changes in the level of the long-run equilibrium real interest rate, and the estimates themselves may be less reliable as a result of the relatively short data sample available.

## Globalisation, import prices and inflation dynamics

### Summary of Working Paper no. 359 Chris Peacock and Ursel Baumann

The past two decades saw a marked fall in inflation across the globe, also associated with a rise in stability more generally. This stability is currently less obvious, as the major economies are experiencing a set of shocks that may mean that this benign period will eventually be judged to be one of only temporary respite from a more normal level of macroeconomic volatility. Whether this is the case or not, there may be important lessons to be learned from recent experience, and this paper examines the role that globalisation, and in particular rising imports and competition from low-cost countries, may have played in exerting downward pressure on global prices over that period of stability (specifically, we examine the periods from 1965 and 1985 until early 2007).

While theory tells us that the level of inflation is ultimately determined by monetary policy and its effectiveness in anchoring long-term inflation expectations, globalisation has certainly engendered a marked decline in the relative price of imported to domestically produced goods. In the short run, this may also have had an impact on inflation by lowering production costs, if firms were able to substitute between domestic and imported inputs to production. Stronger competitive pressures may also have had an impact on dampening inflation by making it harder for firms to raise their prices in the face of increased cost pressures. Explaining the dynamics of inflation in the light of increased global integration is thus high up on the agenda of policymakers.

Several recent papers have sought directly to analyse the impact of an increase in import openness or competitive pressures on inflation in an empirical framework by employing a 'reduced-form' approach, which conflates separate,

fundamental, relationships into a single empirical vehicle. This approach has two main drawbacks. First, it is difficult to link back the finding of lower relative prices in more-open sectors to aggregate inflation. Second, the estimates cannot tell us which underlying economic mechanisms are driving the relationship between globalisation and inflation. Consequently, in this paper a structural model of inflation dynamics — a New Keynesian Phillips Curve (NKPC) — is employed which allows us better to examine the impact of globalisation on inflation. The role of globalisation is modelled via the inclusion of intermediate imports in firms' production functions, and the results compared to those from a simpler closed-economy version of the model. This framework provides evidence on two questions. First, does the inclusion of import prices in firms' marginal costs (the cost of producing an extra unit of output) provide a relatively better in-sample fit of post-war inflation dynamics in the United Kingdom, United States and Japan than a model where marginal costs reflect labour costs alone? Second, is the weight on import prices in marginal costs now larger than it was prior to the most recent period of globalisation that has been evident since the mid-1980s?

Overall, the results suggest that import prices do help explain movements in inflation. In particular, NKPC models that allow for import prices to enter into firms' costs outperform closed-economy models in sample. However, they also suggest that the influence of import prices has generally remained constant across the whole sample period, with perhaps only the United Kingdom providing some evidence that import prices have become more important in firms' marginal costs.

## Extracting inflation expectations and inflation risk premia from the term structure: a joint model of the UK nominal and real yield curves

Summary of Working Paper no. 360 Michael Joyce, Peter Lildholdt and Steffen Sorensen

The nominal and real interest rates implied by government conventional and index-linked bonds of different maturities (ie the term structure of nominal and real interest rates) can potentially provide monetary policy makers with a great deal of information about financial market expectations of both future interest rates and inflation. The nominal and real term structures embody market expectations of future nominal and real interest rates respectively, while the difference between the two — the inflation term structure — embodies information about inflation expectations. Extracting this information, however, is complicated by the fact that the interest rate term structure may also reflect inflation risk premia (the compensation investors require for holding nominal bonds given the risk of unexpected inflation) and real term premia (the compensation investors require for the risk of unexpected future real interest rate movements).

In this paper we formulate and estimate a joint model of the UK nominal and real term structures, which enables us to decompose nominal forward interest rates into expected real policy (risk-free) rates, expected inflation, real term premia and inflation risk premia. The model is based on the assumption of no arbitrage, which implies that there are no risk-free profits to be made by trading combinations of nominal or real bonds. A necessary condition for this assumption to hold is that investors price nominal and real bonds consistently, so that for example the real interest rate priced into nominal bonds is the same as the real rate priced into index-linked bonds. To help identify inflation expectations, we also incorporate survey expectations of longer-term inflation, although the structure does not constrain model expectations to equal the survey expectations period by period. The model is estimated using monthly data since October 1992, to enable us to analyse the dynamics of the term structure over the period that the UK monetary authorities have had an explicit inflation target.

Our analysis suggests there has been a marked fall in both expected longer-term inflation and inflation risk premia since the Bank of England was granted operational independence for setting interest rates. Moreover, in May 1997 — the month that independence was announced — we find a significant fall in both, suggesting that this institutional change was important relative to other influences. More recently, we find that the unusually low level of long real forward interest rates since 2004 (the bond yield 'conundrum') reflects a decline in real term premia, although a significant proportion remains unexplained. The relative inability of the model to fit long-dated real forwards during much of the recent period may reflect strong pension fund demand for index-linked bonds. And our analysis suggests that these special factors affecting the index-linked market may also partly explain the increase in long-term inflation forward rates since the middle of 2005, with long-term inflation expectations changing only modestly over this period, according to the model.

While more structural models are needed to analyse more carefully the economics behind the determinants of term premia and expected risk-free interest rates, our model-implied decompositions nevertheless add insights on which components have accounted for changes in short, medium and long-term forward interest rates since 1992.

# Why do risk premia vary over time? A theoretical investigation under habit formation

## Summary of Working Paper no. 361 Bianca De Paoli and Pawel Zabczyk

Risky assets, such as stocks, tend to yield higher returns than safer assets, such as bonds. This difference in returns reflects the fact that investors require extra compensation (or a 'premium') for bearing risk. Evidence suggests that the size of this risk premium depends on whether the economy is in a period of stagnation or prosperity. In particular, investors require higher premia during economic slowdowns than during booms. This empirical regularity has been termed 'premium countercyclicality', and accounting for it in a theoretical framework is the focus of this paper.

We assume that investors form 'consumption habits'. That is, they get used to a certain reference level of consumption, which, much like real-life habits, is allowed to change over time. Allowing for habits has two main implications. First, it means that good times correspond to periods when actual consumption is high *relative* to this reference level. Second, it implies that in those good times, agents tend to be less averse to bearing risk (ie risk aversion is countercyclical). Our first, somewhat surprising, finding is that it is possible for more risk-averse agents to demand lower compensation for bearing risk. The remainder of the paper then analyses why this is the case and highlights conditions which guarantee that risk premia fall in good times and increase in bad times — as found in the data.

We first demonstrate that investors' assessment of future prospects is crucial in determining the behaviour of premia. We then show how the interplay of different model parameters, such as the speed with which investors change their habits or the persistence of shocks affecting the economy, jointly influence investors' assessment of the future. We prove that, in our simple model, to generate countercyclical risk premia, shocks to economic conditions have to be long-lasting, and consumption habits have to adjust slowly to these shocks.

To understand the intuition behind this result, consider a bad shock which pushes down the level of consumption. If the shock is temporary and households very quickly change their habits, then next period they will be used to a lower level of consumption, while actual consumption will tend to revert back to its previous (higher) level. Hence, households hit by the negative shock have every reason to expect consumption next period to be high relative to the benchmark.

Accordingly, even though risk aversion increases as a result of the bad shock, prospects of *good times* ahead make agents take on more risk and actually lead to a compression of premia. This is why temporary shocks and quickly adjusting habits translate into procyclical risk premia.

We then extend our analysis and investigate the likely behaviour of risk premia given more complicated dynamics of consumption, similar to those that might arise in modern macroeconomic models (and, arguably, in the data which they attempt to fit). A typical feature of these models is that they produce a 'hump-shaped' response of consumption to shocks. That is, following a bad shock, consumption will initially be expected to fall before recovering. As a result, bad shocks can lead to a reduction in risk-taking and an increase in risk premia, even if habits adjust quickly. Thus, under this specification, the conditions for countercyclical premia become less stringent. This result suggests that features which help generate humpshaped consumption responses are likely to generate more realistic risk premium behaviour.

## Output costs of sovereign crises: some empirical estimates

### Summary of Working Paper no. 362 Bianca De Paoli, Glenn Hoggarth and Victoria Saporta

There have been many financial crises over the past 30 years especially in emerging market economies (EMEs). Crises have either hit the banking sector, the currency, the government or all three. This has spawned a large volume of empirical studies that have attempted to predict these types of crises. In recent years, there have also been a number of studies that have quantified the costs associated with banking and currency crises but there have been very few on the costs of sovereign debt crises. This is surprising especially given that some debt crises have had a broader impact on the global financial system such as the Latin American debt crisis in the early 1980s and the more recent Russian sovereign debt crisis ten years ago which culminated in the bail out of LTCM. This paper seeks to help fill this gap by assessing the impact on output of 40 sovereign debt crises since the 1970s.

In order to calculate the impact on output during periods of debt crises an estimate of what output would have been in the absence of crisis is needed. Two methods are adopted to measure this output counterfactual. The first method uses a relatively simple (Hodrick-Prescott) time trend of the country's GDP growth before the crisis. The second method involves estimating a model that, aside from the debt crisis itself, explains output growth (per head) by the ratio of investment to GDP, the ratio of government consumption to GDP, inflation, the degree of trade openness and a measure of political stability. This procedure should give a more precise measure of the counterfactual growth rate, since it controls for other factors that may affect output growth during the period of the sovereign crisis. As a check on the robustness of the results, the path of output during these sovereign crisis periods was compared to that for similar countries that at the time did not have sovereign crises. Nonetheless, given the difficulty in distinguishing between the loss in output due to the sovereign crisis itself — the cost of sovereign crisis — from the loss caused by the economic event that triggered the crisis in the first place, perhaps more weight should be attached to the relative costs of different types of crises.

The results suggest that, on all methods, debt crisis periods are associated with large output losses — falls in output relative to the counterfactual — of at least 5% per annum — and last a long time — on average for about ten years. Sovereign crises also rarely occur in isolation. More often than not they are associated with banking and/or currency crises. Moreover, it is the potent cocktail of triple crises that are found to have the biggest output losses.

Given that governments in EMEs, unlike in developed countries, have in the past often defaulted at relatively low levels of external debt these results emphasise the importance for EMEs of adopting sound macroeconomic policies and structural reforms to avoid unsustainable debt positions in the first place. In fact, since the new millennium, many EMEs have improved their policy frameworks and made progress in reducing the amount of government debt owed to foreigners while also lengthening the maturity of their debts. But total government debt, including that owed to domestic residents, remains high in a number of EMEs. Governments are also often reliant for debt financing on their domestic banks. This makes some EME banks vulnerable to sovereign weakness and potentially vice versa if governments bail out weak banking systems. Moreover, improvements in debt positions over the past decade were helped by the unusually benign external conditions including strong world GDP growth, low inflation and interest rates. The external environment is now significantly less favourable and so it is important that EMEs do not allow their fiscal positions to deteriorate markedly.

Once in a crisis, annual output losses are found to increase the longer that countries stay in arrears or take to restructure their debts. There is also some evidence that countries that restructure their debts face lower output losses than those that do not. This is consistent with the recent policy emphasis on the importance of market-based policy initiatives aimed at improving the speed and efficiency of debtor-creditor restructuring.