Institution: Queen Mary University of London		
Unit of Assessment: 16 Economics and Econometrics		
Title of case study: Modelling interest rates after the financial crisis		
Period when the underpinning research was undertaken: 2011-2018		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Andrea Carriero	**Role(s) (e.g. job title):** Professor of Economics	**Period(s) employed:** Sept 2006-Present
Period when the impact occurred: 2014-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Professor Carriero's research on monetary policy, term structure models and forecasting has led to the development of monetary policy tools that inform policy makers in the UK and France in an environment of low inflation and near zero interest rates, such as the one prevailing in advanced economies after the 2008 financial crisis and during the COVID-19 pandemic. Research by Carriero has informed the operational practices of HM Treasury's Debt Management Office (DMO) in the areas of macroeconomic forecasting and bond pricing in an environment with near zero interest rates and has been used by the Banque de France (BDF) to measure its monetary policy stance.

2. Underpinning research

Carriero produced an influential body of research on macroeconomic forecasting ([3.3], [3.4], [3.5], [3.7]). The econometric methods developed in these papers allow a rigorous assessment of the uncertainty involved in alternative macroeconomic scenarios. Carriero's major contribution consists in developing methods for the estimation of time-varying vector autoregressions with large data sets.

In a related stream of research, Carriero established a link between the forecasting performance of vector autoregressions and term structure models ([3.1], [3.2]). Term structure models use economic theory to explain the relationship among interest rates at different maturities.

Conventional term structure models, however, became increasingly ineffective in the aftermath of the 2008 financial crisis. Central banks worldwide implemented expansionary monetary policies in an attempt to revive their economies, but this led to an unprecedented situation in which interest rates became so low that they arguably could not go any lower. The ability of central banks to cut interest rates further was constrained by the zero lower bound: if government bonds paid negative interest rates, investors could earn higher (i.e. zero) returns by holding cash instead. This also meant that the compensation for holding short-term government bonds until maturity (term premia) became negative. Conventional interest rate and monetary policy models were inconsistent with such a situation, since they invariably assumed that interest rates can fluctuate freely.

In collaboration with researchers at the DMO (Vangelista) and the BDF (Mouabbi, previously a PhD student at Queen Mary), and based on his expertise in macroeconomic forecasting and term structure models, Carriero developed an innovative joint nominal-real interest rate model with a zero lower bound [3.6].

The first key innovation of [3.6] is that it incorporates the zero lower bound restriction in a model including both real and nominal interest rates simultaneously. This makes it possible to price government bonds of different maturities, regardless of whether they are indexed or not indexed to inflation, while ensuring absence of arbitrage (i.e. making a profit without risk by exploiting a mis-pricing of some assets) and enforcing the zero lower bound on nominal interest rates.

The second key innovation of the model presented in [3.6] is that it estimates a 'shadow interest rate'. This is the policy rate that would prevail in absence of the zero lower bound and it can go below zero, unlike the actual policy rate. Importantly, the shadow interest rate can be interpreted

as a measure of a central bank's monetary policy stance in periods in which the actual rate is at the zero lower bound.

3. References to the research

[3.1] Carriero, A. (2011). Forecasting the yield curve using priors from no-arbitrage affine term structure models. *International Economic Review*, *52*(2), 425-459. doi.org/10.1111/j.1468-2354.2011.00634.x
[3.2] Carriero, A., & Giacomini, R. (2011). How useful are no-arbitrage restrictions for forecasting the term structure of interest rates? *Journal of Econometrics, 164*(1), 21-34. doi.org/10.1016/j.jeconom.2011.02.010
[3.3] Carriero, A., Clark, T., & Marcellino, M. (2015). Bayesian VARs: specification choices and forecast accuracy. *Journal of Applied Econometrics, 30*(1), 46-73. doi.org/10.1002/jae.2315
[3.4] Carriero, A., Clark, T., & Marcellino, M. (2016). Common Drifting Volatility in Large Bayesian VARs. *Journal of Business and Economics Statistics, 34*(3), 375-390. doi.org/10.1080/07350015.2015.1040116
[3.5] Carriero, A., Clark, T., & Marcellino, M. (2018). Measuring uncertainty and its impact on the economy. *The Review of Economics and Statistics, 100*(5), 799-815. doi.org/10.1162/rest_a_00693
[3.6] Carriero, A., Mouabbi, S., & Vangelista, E. (2018). UK term structure decompositions at the zero-lower bound. *Journal of Applied Econometrics, 33*(5), 643–661. doi.org/10.1002/jae.2635
[3.7] Carriero, A., Clark, T., & Marcellino, M. (2019). Large Vector Autoregressions with stochastic volatility and non-conjugate priors. *Journal of Econometrics*, *212*(1), 137-154. doi.org/10.1016/j.jeconom.2019.04.024

Evidence of the quality of research
[EQR.3.6] is an academic paper which is directly linked to the new no – arbitrage model developed for the DMO.
[EQR.3.3; 3.4; 3.5] were supported by research grant, Carriero [PI]. Economic Forecasting under Macroeconomic Uncertainty [ES.K010611.1]. *ESRC*. GBP323,311.67.
http://researchcatalogue.esrc.ac.uk/grants/ES.K010611.1/read

4. Details of the impact

Informing the operational practices of the Debt Management Office in the area of macroeconomic forecasting in relation to its bond issuance strategy

The Debt Management Office (DBO) decides annually on how the Treasury will finance government spending through issuing bonds in accordance with the debt management objective as well as the debt management framework and wider policy considerations. To do this, the government assesses the costs and risks of issuing government bonds (debt securities issued to finance government spending) by maturity and type (i.e. indexed to inflation or not). This requires accurate forecast models to understand the risks, costs and benefits involved under the alternative financing scenarios and alternative macroeconomic developments.

The DMO approached Carriero to develop a model to produce forecasts of future macroeconomic developments and their effects on government bond yields and their levels of risk. The model developed by Carriero based on his body of research [3.3-3.5 & 3.7] has been routinely used by the DMO over the period 2014-2020. Crucially, this model allows for a proper evaluation of the uncertainty around the forecasts in the form of a fan chart that shows visually the likelihood of alternative future scenarios.

James Warren – a Senior Research Economist at the DMO – stated:

> 'The forecasts produced by this model were inputs for the portfolio simulation tool, which is used in providing advice and evidence in setting the next year's financing remit. Charts B4 and B5 in the Debt Management Report were generated using inputs created from the VAR, specifically the distribution of the likely future paths for RPI [Retail Price Index]' [5.1].

For example, in the Debt Management Report 2019-2020 the portfolio simulation tool projected debt service costs for the year 2023-2024 at between GBP45-60,000,000,000. This projection is based on (among other inputs) the forecasting VAR model developed by Carriero. The DMO produces and publishes such projections annually [5.4-5.6].

Further evidence of the use of the forecasting model is provided in the 2017 Office for Budget Responsibility's Fiscal risks report [5.7]. Over the last year, the forecasting VAR model developed by Carriero has been expanded by the DMO to allow use of larger data sets.

Informing the Debt Management Office's bond pricing activity in an environment with near zero interest rates

Between 2014-2020 the DMO has routinely estimated the joint nominal-real interest rates model with a zero lower bound, developed in [3.6], to produce reliable and theoretically sound estimates of the term premia and inflation premia. The estimated term premia are typically displayed in chart B2 of the annual Debt Management Report [5.4-5.6]. These estimates are then used to inform the choice of a particular issuance strategy – i.e. what kind of bonds to issue with what maturity dates.

The Senior Research Economist at DMO explains:

> 'This model is used in the evidence process for the annual Debt Management Report (chart B2). This model is broadly used to provide an indication, through the term premia, to understand whether or not there is any evidence to favour any particular issuance strategy' [5.1].

For example, in the Debt Management Report 2019-2020 [5.6], the model shows that term premia on medium and long-term gilts have been negative since 2015, which indicates that conventional (i.e. not indexed to inflation) bonds are more cost-effective than has historically been the case. The estimates of the inflation premia instead indicate that – assuming that the Retail Price Index (RPI) remains constant at 3% – index-linked gilts could offer better value to the government than equivalent maturity conventional gilts, with savings ranging from GBP2,000,000 to GBP10,000,000 for every 1,000,000,000 of gilts reopened. However, most of these savings would be wiped out if the RPI index were to go above 3.5%.

Influencing the Banque de France's approach to measuring its monetary policy stance

The Banque de France (BDF) and other central banks typically measure their monetary policy stance (whether the policy is tight, neutral or loose relative to their objectives) on the basis of the central bank interest rate (policy rate). Since in the aftermath of the crisis the policy rate could not go below the zero lower bound, conventional monetary policy was no longer viable. Indeed, central banks worldwide resorted to alternative policy instruments such as Quantitative Easing and therefore the policy rate became much less informative. In such a low interest rates environment, a new measure of monetary policy stance was needed.

The joint nominal-real interest rates model with a zero lower bound, developed in [3.6], provides a no-arbitrage measure of the shadow interest rate that can be reliably used by a central bank to evaluate its monetary policy stance. For this reason, it has been used by the BDF since 2015.

The Head of the Financial Economics Research Division at the Banque De France stated:

> 'This framework served as a basis for building a shadow-rate model for European Overnight Index Swap interest rates at the Banque de France. The model allows the estimation of a synthetic measure, known as the shadow interest rate, which can be used as a proxy of the monetary policy stance in the euro area.
> The euro-area shadow rate estimate is currently updated every month and is part of the tools that are used to brief the Governor of the Banque de France, in preparation of the Governing Council at the European Central Bank' [5.2].

The BDF has used Carriero's research [3.6] to measure its monetary policy stance, as reflected in the policy notes of the various departments of the Banque de France [5.8], [5.9], [5.10]. The policy

note [5.10] in particular states that the model is 'used to build a shadow-rate model for French zero-coupon government bonds'.

In summary, by providing advanced technical tools for macroeconomic forecasting and interest rates modelling, particularly in near zero rate environments, Carriero's research has supported and informed the decision-making process of monetary policy institutions in the UK and France.

5. Sources to corroborate the impact

[5.1] [Testimonial] Debt Management Office, Senior Research Economist. [Corroborator 1]
[5.2] [Testimonial] Head of Division –Financial Economics Research Division at the Banque de France. [Corroborator 2]
[5.3] [Testimonial] HM Treasury, formerly at Debt Management Office [Corroborator 3]
[5.4] [Report] HM Treasury, *Debt Management Report 2017-2018*, paras B10-B13, Chart B2. Paras B22-B26, Charts B4 and B5. File: debt_management_report_2017.pdf. Available at: https://www.gov.uk/government/publications/debt-management-report-2017-to-2018
[5.5] [Report] HM Treasury, *Debt Management Report 2018-2019*, paras B8-B11, Chart B2. Paras B21-B25, Charts B4 and B5. File: debt_management_report_2018.pdf. Available at: https://www.gov.uk/government/publications/debt-management-report-2018-to-2019
[5.6] [Report] HM Treasury, *Debt Management Report 2019-2020*, Paras B8-B11, Chart B2. Paras B22-B26, Chart B4. File: debt_management_report_2019.pdf. Available at: https://www.gov.uk/government/publications/debt-management-report-2019-to-2020
[5.7] [Report] Office for Budget Responsibility, *Fiscal risk report*: See pt 8.32 and Chart 8.9, p. 252. File: July_2017_Fiscal_risks.pdf, Available at: https://obr.uk/frr/fiscal-risk-report-july-2017/
[5.8] [Report] Policy note of the Financial Team (Recfin), Recfin_2015_031: A policy note on term structure decompositions, comparing Gaussian and shadow estimates. The model from the paper 'UK Term Structure Decompositions at the zero-lower bound' is mentioned. File Recfin_2015_031.pdf
[5.9] [Report] Policy note Recfin_2016_045: A policy note containing the description of an indicator built for the Banque de France: A shadow-rate for France. This explicitly acknowledges the use of the model from the paper 'UK Term Structure Decompositions at the zero-lower bound'. File Recfin_2016_045.pdf
[5.10] [Report] Policy note Recfin_2016_067: A policy note listing all internal indicators used by the Banque de France, the shadow-rate based on the model from the paper 'UK Term Structure Decompositions at the zero-lower bound' is the 4th indicator listed. File Recfin_2016_067.pdf