Institution: University of York		
Unit of Assessment: 16 - Economics and Econometrics		
Title of case study: Quantitative tools for global modelling and forecast evaluation to support policy analysis and forward-looking decision making		
Period when the underpinning research was undertaken: 2003-2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Laura Coroneo	Senior Lecturer	2012-present
L. Vanessa Smith	Senior Lecturer	2013-present
Period when the claimed impact occurred: 2014-2020		
Is this case study continued from a case study submitted in 2014? No		

1. Summary of the impact (indicative maximum 100 words)

Research undertaken at the University of York has developed quantitative tools for global economic modelling that account for the complex interdependencies existing across markets and countries, and for reliably assessing the accuracy of economic forecasts. These tools have been influential in informing and guiding policy analysis and risk management practices, and in aiding forward-looking policy-making under conditions of uncertainty. Together, they have supported monetary policy development and financial decisions across a large number of international organisations, central banks and commercial businesses, including the European Central Bank, the International Monetary Fund, the Bank of England, the Central Bank of Ireland, Citi, and the National Bank of Belgium.

2. Underpinning research (indicative maximum 500 words)

Research in the Department of Economics and Related Studies, via two distinctive projects, has led to the development of quantitative tools for global modelling, forecast evaluation, and risk management, designed to support accurate and informed economic decision making at national and supra-national levels. This recognises that a global perspective and accurate forecasts are required in order to support policy analysis and forward-looking decision making, whilst accounting for the increasingly complex interdependencies that exist across markets and countries.

(1) A key contribution is the **GVAR Toolbox 2.0** (the toolbox) **[A]** and related research. The toolbox was designed for the purpose of Global Vector Autoregressive (GVAR) modelling, specifically the modelling of a large number of countries and variables within a framework that accounts for a rich set of spatiotemporal dynamics and cross-country interdependencies. It consists of a collection of codes and procedures, with a user-friendly interface, developed with a view to freely offering interested parties access to an easy-to-use package that can be employed for the purposes of informing and guiding policy analysis, forecasting, and risk assessment. It is supplied with a simple but comprehensive manual that guides users in developing, estimating, and analysing GVAR models.

This work was developed via an ESRC grant ('Cross Section Dependence in Panel Data Models: Analysis of Short T Panels and Tests of Weak and Strong Cross Section Dependence', ES/I031626/1, 2011-14) held by L. Vanessa Smith (Co-I) initially at the University of Cambridge (Department of Economics), where version 1.0 was developed. The toolbox represents a considerable advance over its predecessor, and contains a number of technical innovations:

- greater flexibility in specifying global variables, such as commodity prices, which can now be determined outside specific country models, allowing for possible feedback effects from the rest of the world
- the option to use differential weights in the construction of country-specific foreign variables to capture cross-country interdependencies more realistically; for example, country–specific trade weights can be applied to macro variables and financial weights to financial variables
- a decomposition analysis of the GVAR model, that can be used for a more structural approach to global modelling, where, for example, the effect of global demand, supply, and monetary policy shocks can be assessed (based on **[B]**)

- an optimal shrinkage technique that improves estimation of global modelling involving many countries and variables (covered in **[C]**)
- the possibility of computing forecasts conditional on selected information of relevance; for example, recent research has used forecasts conditional on GDP trajectories to assess the impact of the shock to the global economy from COVID-19 on global fossil fuel consumption and CO_2 emissions. This culminated in a recent working paper 'Assessing the Impact of COVID-19 on Global Fossil Fuel Consumption and CO2 Emissions' (available at SSRN).

(2) A second key contribution is the development of **reliable forecast evaluation tests** that allow users to select the most accurate competing forecasts. This work was developed under an ESRC grant ('Modelling government bonds: macroeconomic, financial and international linkages', ES/K001345/1, 2013-16) held by Laura Coroneo (PI). The research was developed in collaboration with Dr Fabrizio Iacone (University of York, 2005-17; University of Milan, 2017-present).

Coroneo's research on improving the accuracy of forecast evaluation tests stems from the significant shortcomings of standard tests in reliably comparing the predictive accuracy of two competing forecasts in the small sample sizes typically encountered in macroeconomics. The methodological contribution of **[E]** is to apply fixed-smoothing asymptotics, as opposed to standard asymptotics, to forecast evaluation tests, thus obtaining reliable tests for predictive accuracy even in small samples. This substantially widens the applicability of forecasting evaluation tests for macroeconomic policy makers, and beyond. For example, in recent research, this methodology was used to assist healthcare authorities in selecting the most accurate forecasts of the number of COVID-19 fatalities on which to base public health intervention decisions **[F]**. In addition, a recent methodological extension of this research, in collaboration with an ESRC-funded PhD studentship at York, considered the case of testing for equal density forecast accuracy **[D]**. Density forecasts provide a wider understanding of the uncertainty associated with a prediction, and it is therefore important to be able to compare their predictive ability using tests that are accurate in small samples.

3. References to the research (indicative maximum of six references)

[A] **Smith, L.V.** & Galesi, A. (2014). "GVAR Toolbox 2.0" Software and accompanying 200 page guide: https://sites.google.com/site/gvarmodelling/gvar-toolbox/download

[B] Dees, S., Pesaran, M.H., **Smith, L.V.** & Smith, R.P. (2014). "Constructing multi-country rational expectations models". Oxford Bulletin of Economics and Statistics 76(6) pp.812-840 https://doi.org/10.1111/obes.12046

[C] Bailey, N., Pesaran, M.H. & **Smith, L.V.** (2019). "A multiple testing approach to the regularisation of large sample correlation matrices". Journal of Econometrics 208(2) pp.507–534 https://doi.org/10.1016/j.jeconom.2018.10.006

[D] **Coroneo, L.**, Iacone, F. & Profumo, F. (2019). "A Real-time Density Forecast Evaluation of the ECB Survey of Professional Forecasters". Discussion Papers 19/14, Department of Economics, University of York https://ideas.repec.org/p/yor/yorken/19-14.html

[E] **Coroneo, L.** & Iacone, F. (2020). "Comparing predictive accuracy in small samples". Journal of Applied Econometrics, 35(4) pp.391–405 https://doi.org/10.1002/jae.2756

[F] **Coroneo, L.**, Iacone, F., Paccagnini, A. & Santos Monteiro, P. (2020). "Testing the predictive accuracy of COVID-19 forecasts". Discussion Papers 20/10, Department of Economics, University of York https://ideas.repec.org/p/yor/yorken/20-10.html

[B][C] & **[E]** are peer reviewed publications; **[B]** & **[D]** had external funding (ECB/ESRC PhD scholarship); **[C]** & **[E]** are returned to REF2021; **[B]** was returned to REF2014. Code for **[E]** is available on the Journal of Applied Econometrics Data Archive and also from LC's personal webpage (Matlab code, R code).

4. Details of the impact (indicative maximum 750 words)

These quantitative tools have had an impact within four broad areas, benefiting a wide range of national and international institutions (covering organisations, banks, and commercial operators working across the public and private sectors).

(i) Informing an understanding and assessment of the impact of global shocks to a country's or group of countries' economic resilience, thus supporting monetary policy decision making

The toolbox has supported the European Central Bank (ECB) in the understanding and assessment of the impact of oil price changes on economic activity, spillovers of equity prices from the US to other economies, and the rising impact over time of economic shocks from China to the rest of the world. The findings of these studies contributed to the information set available to the President and other Executive Board members when making monetary policy decisions **[1a]**.

The toolbox has also supported the International Monetary Fund, with their Division Chief, Western Hemisphere Department, noting that *"in particular, the model* [was] *extremely helpful to provide insights for the 2016 and 2018 regional consultations for the Eastern Caribbean Currency Union countries (ECCU)... We hope you can continue your excellent work providing public access tools that contribute to advances in our field"* **[1b]**. This was achieved through an assessment of the extent to which the slowdown of the economic growth of Trinidad and Tobago, instigated by an oil price decline, resulted in negative spillovers for other ECCU countries **[2a]**; as well as the impact of the normalisation of US monetary policy on ECCU countries **[2b][2c]**.

At the Bank of England (BoE), the toolbox is regularly used in putting together their world forecast, which feeds into the UK forecast, both of which are key inputs to the decisions of the Monetary Policy Committee. The Head of International Directorate confirmed that *"compared to other tool kit that we use, the GVAR Toolbox allows us to investigate the spillover of shocks for a large number of countries. Also, the accompanying user guide was very helpful at the early stages of our use"* **[1c]**. Furthermore, it has informed assessment of the impact of the Chinese economy on the UK, as documented in BoE Quarterly Bulletins **[2d][2e]**, and has supported speeches by the Governor - for instance in his speech 'Pull, Push, Pipes: Sustainable Capital Flows for a New World Order', where the toolbox informed assessment of the 'spillbacks' from emerging economies to advanced economies **[2f]**.

For the Central Bank of Ireland *"the GVAR Toolbox 2.0 is a welcome addition to the economic modelling toolkit at the Bank and has been useful for a range of policy relevant topics such as Brexit, a slowdown in the Chinese economy, oil price shocks, and changes to the US policy interest rate"* **[1d]**. For example, scenario results obtained from the toolbox on the potential impact of Brexit on the Irish economy featured in the Bank's Technical Paper **[2g]** and were communicated to a public audience through the Bank's Quarterly Bulletin **[2h]**. The Reserve Bank of New Zealand, has *"used GVAR scenarios obtained using the toolbox to cross check our international forecasts, and highlight the potential impact on the New Zealand economy of emerging global risks"* **[1e][2i][2j]**. For example, a speech given by a former Reserve Bank Governor attested to the value of the toolbox in informing understanding of the impact of US fiscal expansion on the New Zealand economy **[2k]**.

The Institute for Privatization and Management Research Center used the toolbox to assess the impact of a drop in the oil price and a fall in Russian and global GDP, in order to inform policy making at the National Bank of the Republic of Belarus **[1f][2l][2m]**. At the King Abdullah Petroleum Studies and Research Center (KAPSARC: Saudi Arabia), the toolbox contributed to their mission to *"advance the understanding of energy economics and to act as a catalyst for dialogue, charting a path to better welfare for societies, locally and globally"* **[1g]**, by informing an understanding of the impact of shocks to world oil and inventory markets, and gauging the effect of the 2018 trade disputes (imposition of trade sanctions by the US and China on each other, and escalation of the US threats to withdraw from the World Trade Organisation) on crude oil prices, production, and inventories **[2n][2o]**. Related findings were presented at the KAPSARC workshop, 'The Stability of World Oil Markets, and the Potential for Oil Shocks' (Feb. 2020) and *"the results ignited discussions among participating practitioners from around the world"* **[1g]**.

(ii) Informing supervisors of the resilience of a country's financial system, thus supporting financial policy decision making, and contributing to the design of risk management tools for making financial institutions more resilient to environmental risk

In relation to risk management, the toolbox has supported the decisions of the Financial Policy Committee of the BoE, *"used in regular Bank of England outputs like Inflation Reports (now Monetary Policy Reports) and the Annual Cyclical Stress Test to decompose the impact of foreign events on the UK macro-financial outlook"* **[1c] [4a]**. It has assisted the Monetary Authority of Singapore in evaluating the resilience of Singapore's financial system to adverse shocks, through their industry-wide stress testing exercises **[3a][4b][4c]**. At the ECB, it *"was used in the calibration of international spillovers of a rise in US long-term interest rates. These spillovers formed part of the set of macro-financial shocks that were used to assess for 51 European banks how their Tier 1 capital ratios react if the stress scenario were to materialise"* **[1a][4d][4e][4f]**. At Risk Management Solutions, the toolbox was *"invaluable"* in the work coordinated by the United Nations Environment Program Finance Initiative in making financial institutions more resilient to environmental risks, through the provision of a stress-testing tool that can be used by corporate lending institutions to test their lending portfolios against major drought events. As a Senior Consultant attests: *"The GVAR Toolbox 2.0 supported the macroeconomic modeling component of the project, and supported the comprehensive conclusions critical to our project partners...we were able to produce impactful results that served as a key data source for the Drought Stress Testing Tool"* **[3b]**. Additionally, the toolbox informed understanding of how droughts would affect the macroeconomic environment in which companies operate, which in turn could change the likelihood of corporate default **[4g]**.

(iii) Supporting the operations and decision-making processes of a number of private sector financial services

At Bancolombia the toolbox has informed and guided their decision-making processes relating to the setting of interest rates for their commercial banking products **[5a][6a]**. It has supported the operations of the Spanish multinational financial services company, Banco Bilbao Vizcaya Argentaria, through the provision of the macroeconomic analysis and scenarios used for the bank's planning and management processes (including budget and risk) **[5b][6b]**. It has informed and guided the investment decisions of a foreign global institutional investor who manages pension and insurance plans, assisting them in the assessment of how their portfolio of emerging market sovereign bonds might be impacted by the initial spread of COVID-19 beyond China. They have confirmed that: *"the general insights from the model's outputs enriched our portfolio positioning discussions during the risk-off mood brought about by the pandemics."* Specifically, results from the toolbox contributed to a decision to increase their exposure to certain countries whose yields had materially increased **[5c]**. The toolbox was used by Citi Research to simulate the impact of shocks to economic or financial variables that might carry global or regional importance, such as changes in GDP growth, credit growth, or bond yields in large economies, or changes in global commodity prices, for the purpose of informing and guiding discussion around scenario planning and forecasting **[5d]**. It also informed Citi's analysis of the impact upon the global economy of China's decline in GDP growth, supporting the results of their separately constructed 'China vulnerability index' **[6c]**.

(iv) Providing institutions with a reliable tool to select and develop accurate projections for monitoring macroeconomic outlooks

The National Bank of Belgium (NBB) included the forecast evaluation test developed by Laura Coroneo in **[E],** which *"makes the evaluation more realistic in* [their] *daily work"* and that *"can potentially improve the quality of all* [their] *products",* in the "Nowcasting" plug-in of JDemetra+ (the software officially recommended for conducting seasonal adjustment of official statistics within the European Statistical System and the European System of Central Banks) **[8a-d]**. The plug-in can be downloaded from the NBB official website (under the tab `Other time series resources'), from the European Commission official website, or directly from the GitHub platform. The NBB regularly employs this approach to produce forecasts of economic activity for both the euro area and Belgium **[8e]**, the latter of which are officially published in the NBB's Business Cycle Monitor. These forecasts are used in two ways: firstly, to inform the ECB, which makes

use of them as part of the decision-making process and implementation of the Eurosystem's monetary policy **[7a]**; secondly, to internally monitor the macroeconomic outlook at the NBB in order to ensure financial stability. The testing methodology has also been used by the Austrian Institute for Economic Research (WIFO) to better understand differences in competing forecasts produced by national institutions and international organisations. This established that forecasts published by the former tended to be more accurate than those published by the latter. A Senior Economist at WIFO confirms that *"this exercise was of interest to our stakeholders and regular users of our forecasts, the key institutional user being Austrian Ministry of Finance that uses the forecast in the fiscal planning and surveillance framework of the European Commission"* **[7b]**.

5. Sources to corroborate the impact (indicative maximum of 10 references)

[1] Testimonials: **(a)** Head of External Developments Division, European Central Bank (ECB) (10/09/20); **(b)** Division Chief Western Hemisphere Department, International Monetary Fund (IMF) (10/09/20); **(c)** Head of the International Directorate, Bank of England (BoE) (17/09/20); **(d)** Head of Research and Economic Modelling, Central Bank of Ireland (CBI) (21/08/20); **(e)** Manager of Central Banking Analytics, Reserve Bank of New Zealand (RBNZ) (10/10/20); **(f)** Chairman of the Supervisory Council, IPM Research Center (Belarus) (7/8/20); **(g)** Program Director, Markets and Industrial Development, King Abdullah Petroleum Studies and Research Center (KAPSARC, Saudi Arabia) (30/10/20)

[2] Documents: (a) IMF reports IMF Country Report No. 19/62 (see Annex III) **(b)** IMF Country Report No. 16/333 (see, Annex V); **(c)** IMF Working Paper 19/256; **(d)** BoE Quarterly Bulletin 2016 Q1; **(e)** BoE Quarterly Bulletin 2018Q2; **(f)** BoE Speech by the Governor (2019); **(g)** CBI Research Technical Paper (2017); **(h)** CBI Quarterly Bulletin No.4 2016; **(i)** RBNZ Analytical Notes (2019); **(j)** RBNZ Bulletin (2019); **(k)** RBNZ Speech by the Governor (2017); **(l)** IPM Research Center Policy Paper (2016a); **(m)** IPM Research Center Policy Paper (2016b); **(n)** KAPSARC Instant Insight Series (2019); **(o)** KAPSARC Publication Series (2020)

[3] Testimonials: **(a)** Executive Director Economic Analysis Department, Monetary Authority of Singapore (MAS) (15/9/20); **(b)** Senior Consultant, Risk Management Solutions (RMS) (30/11/20)

[4] Reports: **(a)** BoE Stress Test (2019) (see chart 14, p.14); **(b)** MAS Financial Stability Review (2018), pp. 35-37; **(c)** MAS Macroeconomic Review (2017), Vol. XVI(2), pp. 80-89; **(d)** European Systemic Risk Board Stress Testing; **(e)** 2016 EU Wide Stress Test Results; **(f)** ECB Working Paper Series No 1749 (2014); **(g)** United Nations Environment Programme Finance Initiative Publications (2017): Drought Stress Testing

[5] Testimonials: **(a)** Chief Treasury Officer, Bancolombia (26/8/20); **(b)** Head of Economic Analysis of BBVA Research, Banco Bilbao Vizcaya Argentaria (BBVA) (3/8/20); **(c)** Foreign global institutional investor that manages pension and insurance plans (anonymised attribution) (8/9/20); **(d)** Head of Emerging Markets Economics, Citi (29/7/20)

[6] Documents: **(a)** Documents Supplied by Bancolombia **(b)** BBVA Research Publications (2019); **(c)** Citi Global Perspectives & Solutions December 2017 (see p.43)

[7] Testimonials: **(a)** Economist, Research and Development Cell, National Bank of Belgium (NBB) (25/8/20); **(b)** Coordinator of the Research Group on Macroeconomic and European Economic Policy, Austrian Institute of Economic Research (WIFO) (21/9/20)

[8] Documents: **(a)** Technical note, NBB; **(b)** JDemetra+ Nowcasting user guide - Accuracy Test; **(c)** JDemetra+ user guide - Diebold-Mariano Test; **(d)** JDemetra+ user guide - Encompassing Test; **(e)** NBB Working Paper No. 331.