SPRU
Science Policy Research Unit
Working Paper Series
SWPS 2018-20 (October)

A Co-Evolutionary, Long-Term, Macro-Economic Forecast for the UK Using Demographic Projections

Nick Jagger

UNIVERSITY
OF SUSSEX

SPRU Working Paper Series (ISSN 2057-6668)

The SPRU Working Paper Series aims to accelerate the public availability of the research undertaken by SPRU-associated people, and other research that is of considerable interest within SPRU, providing access to early copies of SPRU research.

Guidelines for authors

Papers should be submitted to swps@sussex.ac.uk as a PDF or Word file. The first page should include: title, abstract, keywords, and authors' names and affiliations. The paper will be considered for publication by an Associate Editor, who may ask two referees to provide a light review. We aim to send referee reports within three weeks from submission. Authors may be requested to submit a revised version of the paper with a reply to the referees' comments to swps@sussex.ac.uk. The Editors make the final decision on the inclusion of the paper in the series. When submitting, the authors should indicate if the paper has already undergone peer-review (in other series, journals, or books), in which case the Editors may decide to skip the review process. Once the paper is included in the SWPS, the authors maintain the copyright.

Websites

UoS: www.sussex.ac.uk/spru/research/swps

SSRN: http://www.ssrn.com/link/SPRU-RES.html

IDEAS: ideas.repec.org/s/sru/ssewps.html

Research Gate: www.researchgate.net/journal/2057-6668_SPRU_Working_Paper_Series

A co-evolutionary, long-term, macro-economic forecast for the UK using demographic projections

Nick Jagger[*][†]

Abstract

This paper is based around outlining and illustrating the use of a co-evolutionary method for long-term macro-economic forecasting. The paper includes economic forecasts for the UK to 2060 using a novel approach based on Multichannel Singular Spectral Analysis (MSSA). The forecasts are based on projections of the working-age population and their educational attainment, as well as building on the historic trends of these variables. The variables forecasted are Gross Domestic Product (GDP), investment and productivity, based on historic time-series dating back to 1856, and their interactions with the projected variables. Other long-term forecasts for the UK are examined and the important impact of demographic change and plateauing educational attainment is assessed. Additionally, the power of the new MSSA forecasting technique proposed here is illustrated.

Keywords

Co-evolutionary forecasting; Multichannel Singular Spectral Analysis; Demographics; Educational Attainment; Long-term macro-economic forecasting

JEL: B15; B22; C14; C53; J11

---

[*] Science Policy Research Unit (SPRU), University of Sussex, Brighton, BN1 9SL, UK
n.s.jagger@sussex.ac.uk
[†] Green Growth Platform, University of Brighton, BN2 4GJ
n.s.jagger@brighton.ac.uk

1 Introduction

An OECD consensus study foresees continued global economic growth to 2060, but at a lower rate than before 2007, due to a range of headwinds, including demographics (Braconier et al., 2014). However, these economic forecasts are controversial, with many scientists believing that growth must slow more, or stop, if the target of keeping global temperatures below 2°C are to be met (Drews and van den Bergh, 2017). Equally, it is argued that declining natural resources are also putting a cap on the level of economic growth (Heinberg, 2011). This paper aims to expand upon, and explore the consequences of, a long-term forecasting methodology which predicts that demographic slowdowns and, reductions in the working-age population in some countries, will lead to reduced economic activity and innovation. The goal is to provide an empirical ecological and co-evolutionary macroeconomic forecast model to add to the growing body of models which show how economies might respond to ecological limits (Hardt and O'Neill, 2017). The paper starts by examining existing long-term, economic forecasting methods and their critics. The most important criticism of the existing methods is that they inadequately take account of changing demographics, with advanced economies having low fertility rates which lead to stabilising or declining working-age populations. The paper then explores a novel forecasting approach using Multichannel Singular Spectral Analysis (MSSA), a non-parametric based method, and its links to evolutionary and co-evolutionary economic approaches. The paper then presents long-term forecasts for the UK, with differing demographic projections. These projections cover different migration assumptions. For example, one of the assumed consequences of Brexit might be reduced migration into the UK and this is examined. One of the advantages of the MSSA approach is that it allows the potential demographic consequences of Brexit to be examined, in the absence of any trade impacts.

2 Existing long-term forecasting methodologies

There are a range of existing methodologies for forecasting either long-term growth or the UK’s long-term GDP. These are outlined here in order to locate the MSSA methodology and to allow the relative advantages and disadvantages of these approaches to be explored.

Most of the current forecasts are based on computable general equilibrium (CGE) models, sometimes combined with expert judgement. This combined approach is used by the OECD to produce their long-term forecasts. However, their forecast for the UK rapidly settles down to a straight line (OECD, 2014a). Such a straight line is debatable given the history of business cycles and external pressures which influence the economy. A more sophisticated CGE model, also from the OECD, incorporating indicators for energy use and urbanisation, as well as a range of other additional factors (Chateau et al., 2014), still ultimately also produced a straight-line result (OECD, 2012).

Other consultancies (for example: PriceWaterhouseCoopers, 2017) and other international bodies produce similar straight line, long-term forecasts. In part, because of the equilibrium assumptions implicit in the CGE modelling method these forecasts, almost inevitably, rapidly settle down into a straight-line growth pattern. Given the variables usually included in these models, the size of the workforce does not influence the outcomes. However, the economy is facing major demographic change and has historically been subject to boom and bust business cycles. Therefore, these CGE based forecasting techniques, which do not incorporate demographic change or reflect business cycles, may have more limited use in the future when demographic changes become more apparent. In the past, it is possible that the CGE based models were able to ignore this aspect of the economy when there was a continually growing workforce.

Another approach, and one explicitly aimed at climate change issues, is the series of economic forecasts produced as part of the Shared Socio-economic Pathways (SSP) (Leimbach et al., 2017). The SSP are designed to support the development of a series of emissions scenarios

(Riahi et al., 2017), which inform the deliberations of the Intergovernmental Panel on Climate Change (IPCC) and, as such, they lead into global policy making processes. Importantly, the SPP approach explicitly incorporated demographic developments at the national level and also incorporated expert opinions. Another set of SSP long-term growth projections (Dellink et al., 2017), use a set of shared storylines (O'Neill et al., 2014) as the basis for developing a range of alternative global economic forecasts. A feature of these SSP forecasts is that, in practice, they are sets of forecasts reflecting a range of parameterisations and differing assumptions about future growth patterns. In practical terms this range of forecasts is less useful than a single forecast with implicit parameterisation.

This paper proposes a new forecasting methodology to better take into account changing demographics, with stabilisation of working-age populations and, in places, reductions in working-age populations, allowing a constrained number of forecasts. The proposed method also avoids the need to provide parameters, as these are effectively derived from the analysis of historic data. Before introducing this novel approach, the implications of the demographic changes are explored in more detail in the following section.

3 Impact of demographics and attainment

Despite the importance of the effects of the current slowing of population growth in advanced economies, there is surprisingly little analysis or quantification of the impact of projected population changes on the economy. The analyses that have occurred focus on the impact of an ageing population and the savings rates (for example: Kim and Lee, 2008). Interestingly, as part of the SSP process, there is a study which looks at the relationship between demographic growth and carbon emissions (O'Neill et al., 2010), but this does not examine the linkage between demographics and the economy.

The impact of demographics on economic growth is usually discussed in terms of the demographic dividend, when reduced female fertility allows more women to enter the workforce for longer producing greater growth (Bloom et al., 2009). However, increasingly, the discussion has moved onto the second demographic transition, where the population ages and the workforce begins to shrink (Lesthaeghe, 2014). The eventual longer-term impact of reduced fertility, a reduced workforce, is usually discussed in terms of the impact of an ageing population (Aksoy et al., 2017; Bloom et al., 2010). However, it is argued that the demographic dividend will turn into a demographic burden as the working-age populations of Europe decline (Van der Gaag and de Beer, 2015). However, this literature does not explore the economic impact of this second demographic transition.

Recently, the link between demographics and real interest rates has become a focus of interest (Ikeda and Saito, 2014; Carvalho et al., 2016; Lisack et al., 2017). These low, real interest rates, combined with a continued desire for high rates of returns by investors, is likely to produce unstable economies prone to booms and bust (Williams, 2016).

The educational attainment of the workforce, often described as human capital, has been long linked to economic growth (Becker, 1964). However, Barro and Lee (2015) has shown that in many developed countries the level of attainment, especially at the critical tertiary level, has begun to plateau. The national systems of education are reflected in the differing percentages of the workforce with tertiary level qualifications at which each country appears to be plateauing.

Overall, declining population growth is increasingly being seen as the driver of lower growth (Gagnon, 2016) and what is sometimes known as secular stagnation (Summers, 2015; Eggertsson et al., 2017). However, when the impact of demographics on the broader economy is modelled, usually using an approach known as ‘overlapping generations models’ (Bloom et al., 2007; Karras, 2009; Gagnon et al., 2016; Caballero et al., 2017), it has proved difficult to obtain a clear picture. Essentially, the limited period in which a declining workforce has been recorded in relatively few countries means that it is difficult, as yet, to get a quantified assessment of the impact. This, in turn, means that a parameterised forecasting approach is virtually impossible until a longer time series is available. However, it is clear that the impact is greater than simply that produced by fewer workers, there is an impact on interest rates, investments, productivity and adoption of innovations.

Given that there is a much longer history where the impact of rising workforces produce growth, this paper aims to introduce a novel methodology that extracts trend and cyclic patterns from time-series and then takes account of the historic interactions between the various time-series included. The extraction of the underlying cyclic patterns is based on minimising any residual white noise in the time-series. The approach assumes that the business cycle is largely endogenous with exogenous factors, such as natural disasters, creating random white noise on top of the basic cyclic pattern (Hallegatte and Ghil, 2008).

A useful feature of demographics is that change, in the absence of pandemics, is relatively slow. The bulk of the 2050 workforce has already been born and future populations are driven by birth rates, death rates and migration. Currently, the changes in death rates are in terms of longevity and do not greatly impact the working age population. Migration remains an uncertain component of future working age populations. However, current levels of migration, despite concerns, do not change the working age populations of most countries significantly.

Similarly, the educational attainment of the working age population is largely determined by the attainment levels of labour market entrants. In developing countries attainment levels are increasing, but in many advanced economies attainment shows signs of plateauing. As such, it is relatively easy to project attainment levels into the future.

This suggests that the size of the working age population and the educational attainment of this population provide a relatively reliable basis for forecasting the state of national economies. The rest of the paper outlines an appropriate non-parametric approach to this forecasting and provides a forecast for the UK. The methodology is explored in more detail in the next section.

4 The MSSA methodology and evolutionary economics

The Multivariate Singular Spectral Analysis (MSSA) approach is an extension of Singular Spectral Analysis (SSA). The SSA method takes time series data and decomposes it into cyclic components and trends, as well as a residual random white noise (Golyandina and Zhigljavasky, 2013). The forecasts are then based on combining the trends and cyclic components and rolling them forward. The method has been used to analyse and forecast a wide range of time series and, when tested, has proved to produce more accurate forecasts than conventional methods such as ARIMA and regression-based techniques (Rodeigues and Mahmoudvand, 2018). The method has more successfully forecast: sea ice extent (Jevrejeva and Moore, 2001); accidental deaths in the US (Hassani, 2007); mortality rates (Mahmoudvand et al., 2013); a range of Latvian data (Polukoshko and Hofmanis, 2009) and; EU energy data (Beneki and Silva, 2013). Importantly, the SSA method has also be used to forecast economic data, with it used to examine: GDP business cycles (Sella et al., 2013; Groth et al., 2015); forecast European industrial output (Hassani et al., 2009); and US business cycles (deCarvalho et al., 2012). A review of the use of SSA methods in many additional fields showed the method’s versatility and effectiveness (Golyandina et al., 2001). An important feature of many of the occasions when SSA has been used is that it had greater predictive power than the conventional methods.

The MSSA approach extends the SSA approach and uses a large ‘hankel matrix’ and ‘eigen triples’ to determine the interactions between more than one-time series, which have been decomposed into cyclic and trend components. These historic interactions are then used to influence the forecasts that are made from reconstructing the data. Importantly, for the forecasting method proposed here, it is also possible to incorporate independent time series which can be used to improve the forecast. This provides greater explanatory power of MSSA over SSA and provides better forecasts (Rodeigues and Mahmoudvand, 2018).

MSSA has a similar, if slightly shorter, history of usage for forecasting: re-examining mortality statistics (Mahmoudvand et al. 2017); temperature cycles in the equatorial pacific (Jiang et al., 1999); and more recently, steel prices (Kapl and Müller, 2010); Italian business cycles (Sella and Marchionatti, 2012); nowcasting the US output gap (de Carvalho and Rua, 2017), and; US inflation rates (Hassani et al., 2013). In each case, MSSA was found to be better at forecasting than SSA and conventional methods. In practice, the project will use the Rssa package (Korobeynikov et al., 2013) within the R language (R Core Team, 2015) and the multivariate extension within the Rssa package (Golyandina et al., 2014).

The MSSA forecasting model employed here, has five basic indicators that, between them, allow the characterisation of a Solow (Solow, 1956) model of economic growth. These variables are the size of the workforce, the quality of the workforce, capital investment and Solow's residual Total Factor Productivity. The variables are also like those used in evolutionary macro-economic forecasts in the past by Nelson and Winter (1982) and Verspagen (2002) and others. The MSSA approach argues that these variables can be used to explain growth as with these previous evolutionary growth models. However, unlike other evolutionary growth models the MSSA approach is not based micro foundations using a simulation to produce the macro outcomes (Silverberg and Verspagen, 1998). In contrast, this approach recognises the importance of these variables for economic growth and simply examines their historic trends, cyclic patterns and interactions using these to produce a forecast. This non-parametric approach means that the variables can be considered as coevolving with any interactions produced by historic patterns rather than a parameterised Historically, the SSA approach was used to smooth time series by extracting the cyclic components and leaving behind the trend (Alonso et al., 2005). The degree to which the cyclic components are retained and included in forecasts is determined by the 'window length' selected. For some forecasting purposes it is important to remove the cyclic components and leave the underlying trend. This is achieved by using a long window length (Hassani et al., 2011). However, given the importance of business cycles for growth dynamics, it was felt appropriate to retain the cyclic component in the forecasts shown in this paper and a shorter 10-year window was used (Jagger, 2017; Wang et al., 2015) in the UK forecast here.

The MSSA approach treats each time series as an independent system, with its own internal cyclic dynamics, and then examines the historical interactions between these time series to produce the final forecast. This means that the MSSA forecasting method has the features considered essential for a co-evolving system, independent systems which then coevolve (Kallis, 2007). Other features of an evolutionary economic approach include the absence of parameterisation, with the forecasts being based solely on historic data and trends. This is also consistent with the idea that business cycles are endogenous (Dosi et al., 2006; Dosi et al., 2008; Foster, 2015). Indeed, a MSSA based analysis showed that equivalent external shocks had different impacts on the economy depending on the stage of the business cycle which suggests that the cycle is endogenous (Hallegatte and Ghil, 2008). Beyond these little cameos of what an evolutionary macroeconomic forecasting method might look like there is little detailed empirical forecasting. Evolutionary economics focuses on firm behaviours and patterns of technical change (Dosi and Nelson, 1994). This reflects the origins of evolutionary economics, within an understanding of individual and corporate skills and capabilities, allowing responses to economic developments. This is despite the seminal Nelson and Winter (1982) work containing an economic growth model. However, this model is effectively parameterised and derives these parameters from non-evolutionary economics.

The next section provides a novel forecast of economic growth which retains many features of the original Nelson and Winter model but uses MSSA.

The MSSA method is totally data driven and avoids econometric modelling and parameterisation, this has advantages and disadvantages compared with traditional forecasting methods. The advantages are that no theoretical models or assumptions are imposed on the data, no over or under parameterisation can occur, while cyclic patterns can be revealed. The disadvantages are that currently there are few diagnostics or ways to assess the reliability of a MSSA forecast. Equally, without parameters it is more difficult to link the forecast to policy options or to model the impact of policy interventions. Many of the models used for economic forecasting have inbuilt assumptions of equilibria and only use data from after the second-world-war with constantly growing working-age populations and growing educational attainment. This MSSA forecast makes no assumptions, incorporates a much longer time series than usual and actively incorporates the declining working-age population and attainment. This combined with the greater short-term forecasting success of the MSSA technique suggests that it may produce a plausible long-term forecast.

5 UK forecasts with differing migration assumptions.

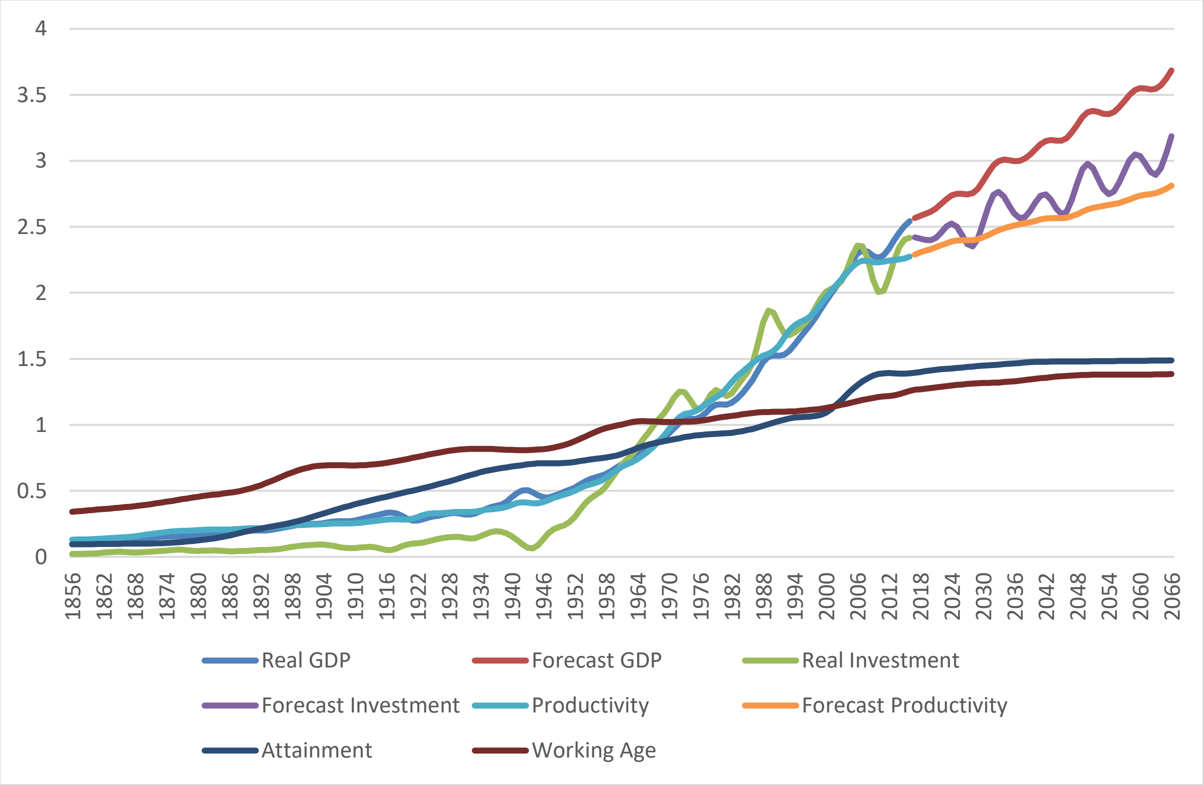
Like most forecasting techniques with the MSSA approach the longer the historic time-series the more reliable the forecast. This is perhaps even more the case with MSSA as the method relies on detecting and then rolling forward the underlying cyclical patterns in the timeseries. This represents the simpler SSA approach, in addition the MSSA approach examines the historic interactions between the time-series and uses these to modify the forecast. Further, in the approach used the more easily projected size of the working-age population and its educational attainment are used as predictors to help forecast the more complex economic variables. Two different sets of working-age projections are used reflecting differing migration assumptions. Annex A of this paper contains the R code used, a downloadable file contains the raw data, the transformed or normalised data as well as the smoothed and forecast data.

The economic time-series data are largely extracted from the Bank of England Millennium data which represents version 3.6 of a long-term data collection originally documented in Hills et al, (2010) as part of a three centuries of macroeconomic data project by the bank. In practice, the productivity data is only available from 1856, so this is taken as the baseline for the data up to 2014. The early data on working-age population is taken from a series of UK population censuses and interpolated between the ten-year intervals, then from 1941 to 2014 the annual data comes from an Office of National Statistics publication. The working-age projections from 2015 to 2060 come from the 2016 Eurostat Population Projections. The tertiary attainment figures come from the data associated with Barrow and Lee’s (2015) book with their projections that run from 1870 to 2040. As the other data was available from 1856 to 2060 the Barro and Lee data was extended using the available population data and the attendance data from Lee and Lee (2016) combined with the data for 15 to 24-year-olds in Barrow and Lee (2015).

Figure 1 shows the results of the MSSA forecasting technique using Eurostat's baseline population projections. The data, up until 2014, comes from the Bank of England and the other historic sources. The time-series were normalised before forecasting in order to reduce any impact of different scales. The normalisation process maintains the growth rates but it is easier to see linkages between the series with a common scaling.

The forecasted real GDP is shown as continuing to grow in a cyclic pattern, but at an overall lower average rate than the post second world war period. The pattern of investment similarly shows a slowing of growth, but with a more exaggerated cyclic pattern and productivity also shows a slower rate of growth than before.

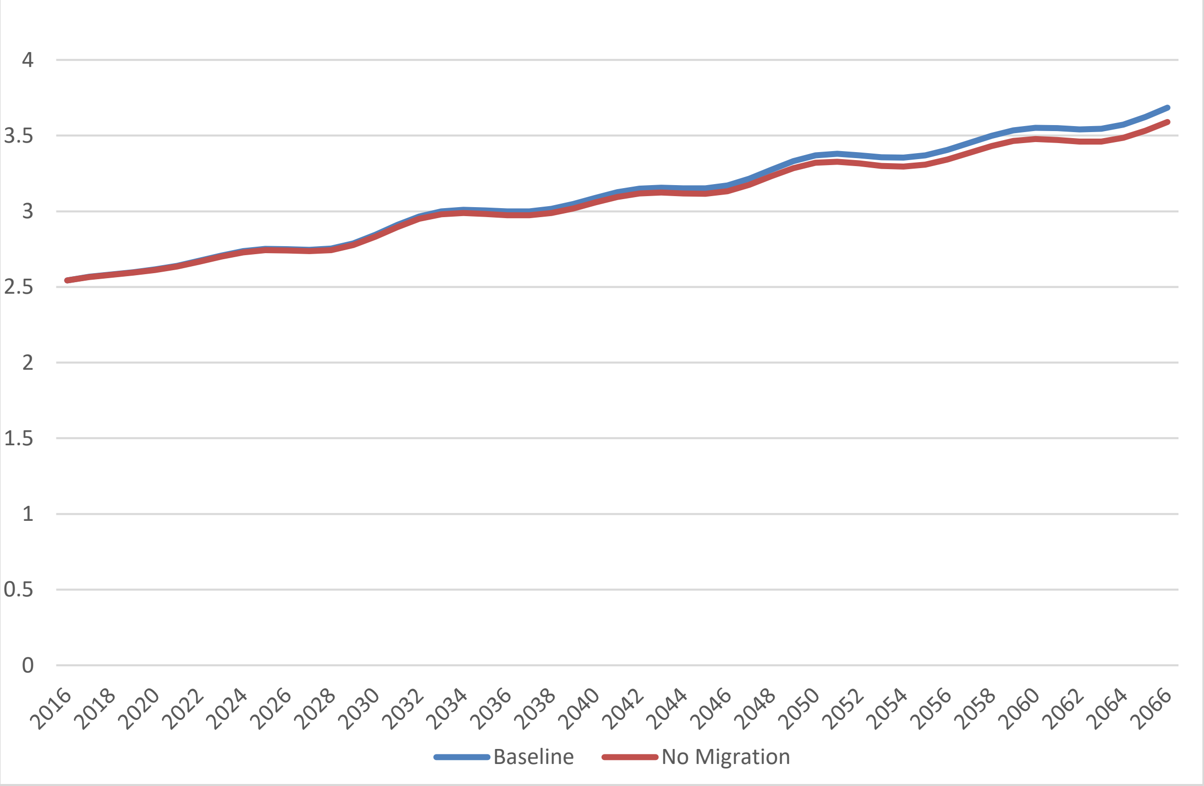
Figure 1: Baseline forecast of real GDP, investment and productivity



Source: Own MSSA analysis Bank of England, ONS and Eurostat

Figure 2 shows the impact on GDP growth of different assumptions about the size of the workforce as a result of different levels of migration. The impact of projected changes to migration is examined as this is the one way in which the size of the working age population can be influenced by policy. One of the suggested outcomes of the Brexit process might be a significant reduction in the level of migration into and out of the UK. Eurostat produced a series of population projections with a range of migration assumptions. These population projection variants were used to create different working-age population projections. The most extreme migration option is the no migration projection and this is adopted to examine the potential range of impacts. Overall, the impact of no migration compared with the baseline projection using the MSSA method is to show a minor impact on real GDP. This is not to say that there might be major impacts in specific sectors and that many Europeans settled in the UK might leave, which would have a more significant impact. Finally, this forecast simply shows the possible impact of a reduced workforce and not the impact of changes to trading patterns.

Figure 2: GDP resulting from a baseline and a no migration working-age population



Source: Own MSSA analysis Bank of England, ONS and Eurostat

An important implication of the MSSA forecasting is that the results suggest that future GDP growth is impacted not only by the reduction in the growth of the working age population, but equally by reduced productivity and investment. This is explored in the next section and possible explanations are sought.

6 Lower productivity and investment

A smaller workforce would need to perform with even greater levels of productivity to maintain growth and GDP. However, the MSSA based UK forecast here, suggests that reduced working-age population growth and plateauing attainment is associated with lower productivity growth and lower investment. A possible explanation of these patterns follows. Less growth in the workforce could mean that there is a lower requirement for new capital as existing capital, (without premature retirement) covers the capital needs of a larger proportion of the workforce. This could mean that, as a consequence, a smaller proportion of the current capital stock is new. Therefore, the average age of capital increases which, could lead to an overall relative productivity decline, even with some very high-tech investments. This could also produce a growing split between a highly productive frontier and a bigger, less productive tail, as has been observed in the UK (Andrews et al., 2015) and elsewhere (Andrews et al., 2016). Another argument is that the rate of innovation adoption is slackening. It is not that new inventions are not being made, the problem is that, for a range of reasons, it appears that there is less investment in new technologies (Gordon 2012; Gordon 2016).

Alternatively, higher levels of new capital investments could necessarily require more early retirement of older capital assets. This earlier than necessary retirement could also have negative implications for returns on capital and Total Factor Productivity. This could mean that the responses to a declining working-age population, either in terms of reduced investment or earlier retirement of existing investments, could lead to lower productivity and lower growth. In practice, the actual response of the economy might potentially be a combination of the two, with reduced investment leaving an older stock of capital and an increased early retirement of this older capital. Importantly, these productivity effects of demographic decline are in addition to the basic lower output from a smaller workforce. The explanation of low productivity and low growth outlined above could also explain the puzzling lack of investment and productivity before and after the economic crisis in the UK (Tenreyro, 2018) and elsewhere (Adler et al., 2017).

Equally, lower growth is also often associated with lower profitability and this incentivises capital to look elsewhere for more profitable investments. Lower requirements for investment and lower proclivity to invest, both lead to reduced growth and lower productivity. There is evidence that an economy with more elderly people, or an ageing economy, shows no negative impacts (Acemoglu and Restrepo, 2017). As a reducing workforce is not necessarily linked to an ageing economy, this might not be relevant. However, others explicitly argue that declining workforces are driving secular stagnation (Sharma, 2016; Prime and Kulkarni, 2017).

7 Conclusions

The MSSA approach appears to be capable of forecasting in a manner which is consistent with core evolutionary economic ideas. The technique has been proven for short-term economic forecasting, and the variables used in the UK forecast reported here are consistent with previous evolutionary growth models. Inevitably, over the 35 years of the forecast, policy and governance changes could mean that any forecast might become less useful. However, given the incorporation of trends and cyclic patterns as well as interactions between variables the resulting forecast can be considered a plausible business as usual forecast. Importantly, the method does not have externally applied parameters and any parameters are derived endogenously from the included timeseries. The use of working age projections and projections of educational attainment allow this important economic driver to be incorporated into the economic forecast. This means that the forecast also provides for the first time an assessment of the economic impact of the current demographic changes on the UK economy. Evolutionary economics suggests that: the economy develops endogenously (Nelson, 2008); based on path-dependence (Dosi and Nelson, 1994); with evolving sub-systems that then co-evolve to produce the overall pattern (Kallis, 2007); with largely endogenously determined business cycles (Dosi et al., 2006); with the pace of growth determined by the adoption of new technologies (Nelson et al., 1976) and the educational attainment of the workforce (David et al., 2012). These features are incorporated into the forecasts produced by the MSSA method using the size and attainment of the workforce as predictors. This in turn suggests that the MSSA forecast could be consistent with the evolutionary economic body of theory. Although, an evolutionary macroeconomics has yet to be fully theorised (Foster, 2011), in part because there is limited agreement about what evolutionary economics is (Witt, 2008), these elements are consistent with at least some evolutionary economics and could be considered as the basis for such an evolutionary macroeconomic forecast.

The MSSA forecast indicates that a declining working age population over the next 30 years will lead to a declining real GDP growth and declining investments and productivity. Standard models suggest that investments and productivity will continue to grow in line with long-term trends. However, the MSSA forecast reinforces the view that labour is critical for growth and without a growing workforce growth is reduced. This finding has global implications, given the second demographic transition, where a less than replacement fertility rate is spreading from the more developed countries. The MSSA forecast suggests that UK economic activity will decline faster than that simply suggested by a declining workforce (Cervellati et al, 2017). In addition, the forecast suggests that a declining workforce is associated with lower levels of capital investment and lower productivity levels. In the past higher levels of economic growth have been associated with higher levels of energy use and emissions production (Foxon, 2018). This suggests that if lower than expected levels of growth are repeated globally then lower emissions may be expected and it might be easier to meet the 1.5° C increase in temperatures established as part of the Paris Agreement.

Acknowledgements

I wish to acknowledge my doctoral supervisors Parimal Patel and Mariana Mazzucato who suggested that a long-term evolutionary economic forecast was needed. I also thank Tomaso Ciarli who provided vital comments on an early draft of this paper. Additionally, I am very grateful for the two SPRU anonymous reviewers who made major improvements to the paper. As always, the good bits are due to the reviewers and any remaining bad bits are my responsibility.

Ethical Statement

This study is based on secondary data sources and no conflicts of interest exist.

References

Acemoglu D, Restrepo P (2017) Secular Stagnation? The Effect of Aging on Economic Growth in the Age of Automation. Am Econ Rev 107(5):174–179

Adler G, Duval, R, Furceri D, Kiliç Çelik S, Poplawski-Ribeiro M (2017) Gone with the Headwinds: Global Productivity, IMF Staff Discussion Note. SND/17/04, International Monetary Fund (IMF), Washington DC

Aksoy Y, Basso HS, Smith RP (2017) Medium-Run Implications of Changing Demographic Structures for the Macro-Economy. Nat Inst Econ Rev 241(1):58–64

Alonso FJ, Del Castillo JM, Pintado P (2005) Application of singular spectrum analysis to the smoothing of raw kinematic signals. J Biomech 38(5):1085–1092

Andrews D, Criscuolo C, Gal PN (2016) The Best versus the Rest: The Global Productivity Slowdown, Divergence across Firms and the Role of Public Policy. OECD Productivity Working Papers, No. 05, OECD Paris

Andrews D, Criscuolo C, Pilat D (2015) The future of productivity: Improving the diffusion of technology and knowledge. Digiworld Econ. J. 100(4):85

Becker GS (1964) *Human Capital*. Chicago, University of Chicago Press.

Beneki C, Silva ES (2013) Analysing and Forecasting European Union Energy Data. Int J Energy Stat 1(2):127–141

Bloom DE, Canning D, Fink G (2010) Implications of population ageing for economic growth. Oxf Rev Econ Policy 26(4):583–612

Bloom DE, Canning D, Fink G, Finlay JE (2007) Does age structure forecast economic growth? Int J Forecast 23(4):569–585

Bloom DE, Canning D, Fink G, Finlay JE (2009) Fertility, female labor force participation, and the demographic dividend. J. Econ Growth 14(2):79–101

Braconier H, Nicoletti G, Westmore B (2014) Policy Challenges for the Next 50 Years. OECD Economic Policy Paper No. 9, OECD Paris

Caballero RJ, Farhi E, Gourinchas PO (2017) Rents, technical change, and risk premia accounting for secular trends in interest rates, returns on capital, earning yields, and factor shares. Am Econ Rev 107(5):614–620

Carvalho C, Ferrero A, Nechio F (2016) Demographics and real interest rates: Inspecting the mechanism. Eur Econ Rev 88:208–226

Cervellati M, Sunde U, Zimmermann KF (2017) Demographic dynamics and long-run development: insights for the secular stagnation debate, J Popul Econ 30:401-432

Chateau J, Dellink R, Lanzi E (2014) An Overview of the OECD ENV-Linkages Model: Version 3. OECD Environment Working Papers 65, OECD Paris

Dawid H, Gemkow S, Harting P, Neugart M (2012) Labor market integration policies and the convergence of regions: The role of skills and technology diffusion. J Evol Econ. 22(3):543–562

de Carvalho M, Rodrigues PC, Rua A (2012) Tracking the US business cycle with a singular spectrum analysis. Econ Lett 114(1):32–35

de Carvalho M, Rua A (2017) Real-time nowcasting the US output gap: Singular spectrum analysis at work. Int J Forecast 33(1):185–198

Dellink R, Chateau J, Lanzi, E, Magné B (2017) Long-term economic growth projections in the Shared Socioeconomic Pathways. Glob Environ Chang 42:200-214

Dosi G, Fagiol, G, Roventini A (2006) An Evolutionary Model of Endogenous Business Cycles. Computational Econ 27 (1): 3–34

Dosi G, Nelson RR (1994) Evolutionary Economics An introduction to evolutionary theories in economics. J Evol Econ 4:153–172Drews S, van den Bergh JCJM (2017) Scientists' views on economic growth versus the environment: a questionnaire survey among economists and non-economists. Glob Environ Chang 46:88–103

Eggertsson GB, Mehrotra NR, Robbins JA (2017) A Model of Secular Stagnation: Theory and Quantitative Evaluation. NBER Working Paper 22299, National Bureau of Economic Research, (NBER), Cambridge MA

Farmer REA (2012) *The Evolution of Endogenous Business Cycles*. NBER Working Paper No. 18284, NBER, Cambridge MAFoster J (2011) Evolutionary Macroeconomics: A Research Agenda. In: Andreas Pyka & M da Graca Derengowski Fonseca (eds.). Catching Up, Spillovers and Innovation Networks in a Schumpeterian Perspective. Berlin Heidelberg, Springer-Verlag. pp. 119–145

Foster J (2015) Joseph Schumpeter and Simon Kuznets: comparing their evolutionary economic approaches to business cycles and economic growth. J Evol Econ 25(1):163–172 Foxon TJ (2018) Energy and Economic Growth: Why we need a new pathway to prosperity, Abingdon and New York, Routledge Studies in Energy Transitions

Gagnon E, Johannsen BK, Lopez-Salido D (2016) Understanding the New Normal: The Role of Demographics. Federal Reserve Board Finance and Economics Discussion Series, Board of Governors of the Federal Reserve System, Washington DC

Golyandina N, Nekrutkin V, Zhigljavsky A (2001) Analysis of Time Series Structure: SSA and Related Techniques. Chapman&Hall/CRC, Boca Raton

Golyandina N, Korobeynikov A, Shlemov A, Usevich K (2014) Multivariate and 2D Extensions of Singular Spectrum Analysis with the Rssa Package. J Stat Softw 67(2):1–78

Golyandina N, Zhigljavsky A (2013) Singular Spectrum Analysis for Time Series. Springer Briefs in Statistics, Heidelberg Dordrecht London New York

Goodridge P, Haskel J, Wallis G (2013) Can Intangible Investment Explain the UK Productivity Puzzle? Nat Inst Econ Rev 224(1):R48–R58

Gordon RJ (2012) Is U.S. Economic Growth Over? Faltering Innovation Confronts the Six Headwinds. NBER Working Paper No. 18315, NBER Cambridge MA

Gordon RJ (2016) The Rise and Fall of American Growth: The U.S. standard of living since the civil war. Princetown University Press, Princeton NJ

Groth A, Ghil M, Hallegatte S, Dumas P (2015) The role of oscillatory modes in US business cycles. J Bus Cycle Meas Anal 2015(1):63–81

Hallegatte S, Ghil M (2008) Natural Disasters Impacting a Macroeconomic Model with Endogenous Dynamics. Ecol Econ 68(1-2):582-592

Hardt L, O'Neill DW (2017) Ecological Macroeconomic Models: Assessing Current Developments. Ecol Econ 134:198–211

Hassani H (2007) Singular Spectrum Analysis: Methodology and Comparison. J Data Sci 5:239–257

Hassani H, Heravi, S., Zhigljavsky, A. (2009) Forecasting European industrial production with singular spectrum analysis. Int J Fore 25(1):103–118

Hassani H, Mahmoudvand R, Zokaei M (2011) Separability and window length in singular spectrum analysis. Comptes Rendus Math 349(17–18):987–990

Hassani H, Soofi AS, Zhigljavsky A (2013) Predicting inflation dynamics with singular spectrum analysis. J R Stat Soc A 176(3):743–760

Heinberg R (2011) The End of Growth: Adapting to Our New Economic Reality. Clairview Books, Forest Row, UK

Hills S, Thomas R, Dimsdale N (2010) The UK recession in context — what do three centuries of data tell us? Bank of England Quarterly Bulletin Q4: 277–291.

Ikeda D, Saito M (2014) The effects of demographic changes on the real interest rate in Japan. Jpn World Econ 32:37–48

Jagger N (2017) Skill Requirements of the Low Carbon Transition. PhD Dissertation, University of Sussex

Jevrejeva S, Moore JC (2001) Singular spectrum analysis of Baltic Sea ice conditions and large-scale atmospheric patterns since 1708. Geophys Res Lett 28(23):4503–4506

Jiang N, Neelin JD, Ghil M (1999) Quasi-quadrennial and Quasi-Biennial Variability in the Equatorial Pacific. Climate Dynamics 12(1):101–112

Kallis G (2007) When is it coevolution? Ecol Econ 62(1):1–6

Kapl M, Müller WG (2010) Prediction of steel prices: A comparison between a conventional regression model and MSSA. Stat Interface 3(3):369–375

Karras G (2009) Demographic Change and the Current Account: Theory and Empirical Evidence. J Econ Asymmetries 6(1):1–14

Kim S, Lee JW (2008) Demographic changes, saving, and current account: An analysis based on a panel VAR model. Jpn World Econ 20(2)236–256

Korobeynikov A, Shlemov A, Usevich K, Golyandina N (2013) Package ‘Rssa’, R Documentation for the Rssa package

Lee J-W, Lee H (2016) Human capital in the long run. J Devel Econ 122:147–169.

Leimbach M, Kriegler E, Roming N, Schwanitz J (2017) Future growth patterns of world regions – A GDP scenario approach. Glob Environ Chang 42:215–225

Lesthaeghe R (2014) The second demographic transition: A concise overview of its development. Proc Nat Acad Sci 111(51):18112–18115

Lisack N, Sajedi R, Thwaites G (2017) Demographic trends and the real interest rate. Bank of England Staff Working Paper No. 701, Bank of England, London

Mahmoudvand R, Alehosseini F, Zokaei M (2013) Feasibility of Singular Spectrum Analysis in the Field of Forecasting Mortality Rate. J Data Sci 11:851–866

Mahmoudvand R, Konstantinides D, Rodrigues PC (2017) Forecasting mortality rate by multivariate singular spectrum analysis. App Stochastic Model Busi Ind 33(6):717–732

Malmaeus JM, Alfredsson EC (2017) Potential Consequences on the Economy of Low or No Growth - Short and Long-Term Perspectives. Ecol Econ 134:57–64

Nelson RR (2008) Economic Development from the Perspective of Evolutionary Economic Theory. Oxford Development Studies. 36(1):9–21Nelson RR, Winter SG (1982) An Evolutionary Theory of Economic Change. Harvard University Press, Cambridge MA

Nelson RR, Winter SG, Schuette HL (1976) Technical Change in an Evolutionary Model. Quart J Econ 90(1): 90–118

O’Neill BC, Dalton M, Fuchs R, Jiang L, et al. (2010) Global demographic trends and future carbon emissions. Proc Nati AcadSci 107(41):17521–17526

O’Neill BC, Kriegler E, Riahi K, Ebi KL, et al. (2014) A new scenario framework for climate change research: The concept of shared socioeconomic pathways. Clim Chang 122(3):387–400

OECD (2012) OECD Environmental Outlook to 2050: The Consequences of Inaction, OECD Paris

OECD (2014) OECD Economic Outlook No. 95 (Edition 2014/1), OECD Economic Outlook Statistics and Projections (Database), OECD Paris

Polukoshko S, Hofmanis J (2009) Use of ‘Caterpillar’ - SSA Method for Analysis and Forecasting of Industrial and Economic Indicators. Proceedings of the 7th International Scientific and Practical Conference. II 241–248

Price Waterhouse Coopers (2017) The Long View: How will the global economic order change by 2050. Price Waterhouse Coopers, London

Prime, P.B. & Kulkarni, K.G. (2017) Who Will Lead Global Growth? Slowing Trends are the ‘New Normal’. Glob Busi Rev 20(3):1–22

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna

Riahi K, Van Vuuren DP, Kriegler E, Edmonds J, et al. (2017) The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. Glob Environ Chang 42:153–168

Rodeigues PC, Mahmoudvand R (2018) The benefits of multivariate singular spectrum analysis over the univariate version. J Franklin Inst 355(1):544-564

Schuette HL (1994) Vintage capital, market structure and productivity in an evolutionary model of industry growth. J Evol Econ 4(3):173–184Sella L, Marchionatti R (2012) On the cyclical variability of economic growth in Italy, 1881–1913: a critical note. Cliometrica 6(3):307–328

Sella L, Vivaldo G, Ghil M, Hallegatte S (2013) Economic cycles and their synchronization: A Survey of Spectral Properties. Fondazione Eni Enrico Mattei, Nota di Lavoro 105.2013

Sharma R (2016) The Demographics of Stagnation: Why People Matter for Economic Growth. Foreign Aff 95(2):18–23

Solow RM (1956) A Contribution to the Theory of Economic Growth. Q J Econ 70(1):65–94

Summers L (2015) Demand Side Secular Stagnation. Am Econ Rev 105(5):60-65

Tenreyro S (2018) The fall in productivity growth: causes and implications. Bank of England External MPC Member Speech (January 15th), Bank of England, London

Van Der Gaag N, de Beer J (2015) From Demographic Dividend to Demographic Burden: The Impact of Population Ageing on Economic Growth in Europe. Tijdschr Econ Soc Geog 106(1):94–109

van Ruijven BJ, O'Neill BC, Chateau J (2015) Methods for including income distribution in global CGE models for long-term climate change research. Energy Econ 51:530–543

Wang R, Ma HG, Liu GQ, Zuo DG (2015) Selection of window length for singular spectrum analysis. J Franklin Inst 352(4):1541–1560

Williams JC (2016) Monetary Policy in a Low R-star World. Federal Reserve Bank San Francisco Economic Letter No. 2016–23, San Francisco

Witt U (2008) What is specific about evolutionary economics? J Evol Econ 18(5):547–575

Annex A

Summary data

Table 1 provides summary data on average annual growth rates of the key variables over a range of periods from 1856 to 2060. This shows that growth has been variable over time and no simple relationship appears to be at work. In different eras GDP growth appears to have been due to growth in attainment, the size of the working age population or investment and productivity. However, the forecast shows that future reduced rates of working age population growth, as with post World War I, and reduced attainment growth will lead to reduced GDP, investment and productivity growth. More details are available from the supplementary data.

Table 1: Actual and Forecast Average Annual Growth for Various Periods

	Tertiary Attainment Average Annual Growth	Working age population Average Annual Growth	Real GDP Average Annual Growth	Real Investment Average Annual Growth	Real Productivity Average Annual Growth
1857-1881	1.263%	1.202%	2.259%	3.155%	1.340%
1882-1913	3.810%	1.314%	1.829%	1.737%	0.756%
1920-1937	1.806%	0.593%	1.264%	5.339%	0.923%
1948-1973	0.951%	0.859%	3.282%	7.867%	2.988%
1974-1990	0.677%	0.416%	2.292%	2.435%	1.617%
1991-2014	1.314%	0.451%	2.014%	1.150%	1.425%
2017-2040	0.252%	0.208%	0.809%	0.473%	0.460%
2041-2060	0.030%	0.259%	0.704%	0.643%	0.360%

Sources: As documented above

R Code

```r
# load the Rssa package
library("Rssa")
# Read the data from fileprint with data labels
mydata <- read.table("dataforR.csv", header = TRUE, sep =",")
# Normalise the data so larger units do not have undue influence while leaving growth rates
k <- nrow(mydata)
j <- ncol(mydata)
ndata <- scale(mydata, center = FALSE)
# Make it a time series to add the years to the data
sdata <- ts(data = ndata, start = 1856, end = 2080, frequency = 1)
# First set the Window Length L set to 10 to allow business cycles to be apparent
L <- 10
# Run the SSA decomposition to detect underlying cycles and trends through smoothing
# using the MSSA variant which takes account of the interactions between variables
specdata <- ssa(sdata, L = L, kind = "mssa")
plot(specdata)
parestimate(specdata, method = "esprit-ls")
# Reconstruct the series
r.spec <- reconstruct(specdata, groups = list(Trend = c(1, 1)))
plot(r.spec, add.residuals = FALSE, plot.method = "xyplot",
    superpose = TRUE, auto.key = list(colums = 1))
print(r.spec)
# Forecast the series for the next fifty years
f.spec <- rforecast(specdata, groups = list(1, 1:4), len = 50, only.new = FALSE)
print(f.spec)
```

Recent papers in the SPRU Working Paper Series:

October

How Can Intermediaries Promote Business Model Innovation: The Case of 'Energiesprong' Whole-House Retrofits in the United Kingdom (UK) and the Netherlands. Donal Brown, Paula Kivimaa and Steven Sorrell

Climate Resilience Pathways of Rural Households. Evidence from Ethiopia. Solomon Asfaw, Giuseppe Maggio and Alessandro Palma

Public Procurement and Reputation: An Agent-Based Model. Nadia Fiorino, Emma Galli, Ilde Rizzo and Marco Valente

September

Mapping Socio-Technical Change in Mobility Regimes: The Case of Kolkata. Bipashyee Ghosh and Johan Schot

The Limitations of the Conceptual Framework of the Heterogeneous Engineer for Leadership in Megascience Projects. David Eggleton

August

Prices of Value Added and Competitiveness in Global Value Chains. Maciej J. Grodzicki

Interdependencies Between Civil and Military Nuclear Infrastructures. Andy Stirling and Phil Johnstone

July

The Relation between Research Priorities and Societal Demands: The Case of Rice. Tommaso Ciarli and Ismael Ràfols

April

Knowledge Sources and Impacts on Subsequent Inventions: Do Green Technologies Differ from Non-Green Ones? Nicolò Barbieri, Alberto Marzucchi and Ugo Rizzo

Suggested citation:
Nick Jagger (2018). *A Co-Evolutionary, Long-Term, Macro-Economic Forecast for the UK Using Demographic Projections*. SPRU Working Paper Series (SWPS), 2018-20:1-23. ISSN 2057-6668. Available at: www.sussex.ac.uk/spru/swps2018-20

SPRU – Science Policy Research Unit
University of Sussex
Falmer, Brighton, BN1 9SL,United Kingdom
SWPS Website: www.sussex.ac.uk/spru/research/swps
SPRU Website: www.sussex.ac.uk/spru
SPRU Twitter: @SPRU