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# A robust data-driven macro-socioeconomic-energy model

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ABSTRACT

In a resource-constrained world with growing population and demand for energy, goods, and services with commensurate environmental impacts, we need to understand how these trends relate to aspects of economic activity. We present a computational model that links energy demand through to final economic consumption, illustrated by application to UK data. Our model fits within a whole-economy framework which harmonises multiple national accounting procedures. Our model minimises both the number of exogenous aspects and tuning factors by using historical data to calibrate relationships. We divide economic activity into a number of distinct but interdependent outputs that are non-substitutable in the short-term. The dynamic aspects assume that supply follows demand, but are constrained in the short-term by physical infrastructure. At the same time, capital formation grows the physical infrastructure. Our model regenerates historical data dynamically as a basis for projecting forward scenarios to discuss pathways to a lower carbon future.

*Keywords:* Employment; Energy modelling; Feedback control; Fixed capital formation; GDP; Intermediate consumption



## 1. Introduction

In developed nations, economic activity leads to significant GHG emissions. Such activity is enabled and mediated by various infrastructures for energy, water, and power distribution, residential and commercial buildings, manufacturing, transport of people and goods, and information and communications networks. Such national-scale infrastructure (capital stock) tends to need large dedicated investment programmes which are short-lived compared to the asset lifetime, and can lead to lock-in of indirect and induced GHG emissions which are difficult to mitigate (LeCoq and Shalizi, 2014). The projected levels of investment required for a nation to transition to a low carbon economy are difficult to estimate. It is not clear what counts as 'low carbon' and governments are generous in estimating what sums might be raised and spent. There is renewal of transport infrastructure ready for a more electric future, electrification of heating, deployment of renewables, smart grid infrastructure, and refurbishment of the housing stock.

The UK Government aspires to spend over £100 bn between 2010–2020 with £375 bn in the longer-term pipeline (HM Treasury, 2013). These demands compete for investment and resources within and across nations. The key question is how much investment can an economy afford? It is desirable to maintain an active broad-based economy and to ensure

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**Software availability**

Name of software 7see-GB
Contact Dr. Simon H. Roberts (corresponding author)
Programming environment Vensim
Availability Freely available as a Vensim Reader version. The full model is also freely available from the corresponding author.
Download URL http://dx.doi.org/10.7488/ds/231
Year first available 2015
Hardware required 2.0 GHz processor with 2 Gb memory
Software required Windows (XP/Vista/7/8/8.1) or Macintosh OSX (10.4+)
Program size 10 Mb

*Abbreviations*

| | |
|---|---|
| *agri* | agriculture industry |
| *cnstr* | construction industry |
| *dwlg* | dwellings |
| *extr* | extraction industry |
| *manu* | manufacturing industry |
| *serv IR* | service industry, including rental |
| *serv LR* | service industry, less rental |
| *util* | utility industry |

*Acronyms*

| | |
|---|---|
| AFC | actual final consumption |
| BoP | balance of payments |
| CCGT | combined cycle gas turbine |
| CFC | consumption of fixed capital |
| CGE | computable general equilibrium |
| CPC | Central Product Classification |
| FC | fixed capital |
| FCF | fixed capital formation |
| GDP | gross domestic product |
| GFCF | gross fixed capital formation |
| GHG | greenhouse gases |
| GVA | gross value added |
| IC | intermediate consumption |
| IO | input–output |
| IOT | input–output table |
| ISIC | International Standard Industrial Classification |
| NPISH | non-profit institutions serving households |
| p | production of a unique output from fixed capital |
| SNA | System of National Accounts |
| SUT | Supply and Use Tables |
| TTM | transport and trade margins |

*Nomenclature*

| | |
|---|---|
| *CFC* | flow of consumption of fixed capital of infrastructure |
| **e** | vector representing the set of exogenous demand |
| $f$ | final supply of industry output, at purchasers' prices |
| FC | stock of fixed capital of infrastructure such as for an industry or of power stations |
| **FC** | vector representing the set of FC |
| *FCF* | flow of fixed capital formation of infrastructure |
| $g$ | final demand of industry output, at purchasers' prices |
| $j, k$ | index numbers for type of infrastructure |
| $M$ | imports |
| $n$ | total number of types of infrastructure in a 7see model |
| $p$ | production of a unique output, which from an industry is classified by type of industry, at basic prices |
| **p_sup** | vector representing the set of output from the set of FC |
| $q$ | supply of $p$ from an industry rearranged for classification by products, at basic prices |
| $r$ | supply of industrial products in their form directly following intermediate consumption, at basic prices |
| s | supply of $r$ after transfer from services of transport and trade margins, at basic prices |
| t | time |
| V | total modelled-demand for investment (GFCF) |
| $V'$ | damped total modelled-demand for investment (GFCF) |
| X | exports |

that levels of employment remain high, but there are trade-offs with resource availability.

Multi-sectoral economic modelling techniques are well established. Input–Output (IO) is the most widely used, partly because of the simplicity of its structure (Allan et al., 2012). It exploits intermediate consumption data from national accounts to derive direct and indirect changes in supply resulting from demand induced disturbance. Technical and production coefficients do not change since an IO model is typically for just one year, thus modelling the potential effects of policy changes requires other methods (McGregor et al., 2008). Furthermore, either spare production capacity is presumed, or that there are no constraints on capital because it is free to increase as producers are paid more. For the study of energy and resource use in economies, IO models have been used recently for GHG emissions due to consumption (Barrett et al., 2013; Duarte et al., 2013), supply chain life cycle assessment (Chang et al., 2014), and waste analysis (Lenzen and Reynolds, 2014).

The limitations of an IO model of supply simply following demand are addressed in computable general equilibrium (CGE) models. Both supply and demand are modelled systematically and simultaneously (Shoven and Whalley, 1992). Supply is disaggregated, such as into factors of production. Elasticities of substitution determine how far producers substitute between inputs in response to changes in relative prices. Calibration of static CGE models typically depends on data for a single year, and as such they represent structural transitions poorly, but this can be overcome by a dynamic CGE framework (Harrison et al., 2000; Lecca et al., 2013). A sequence of single-period equilibria can be linked through stock-flow relationships so that computed equilibria vary over time as the value for the model's stock variables adjust, thus endogenising growth (Dixon and Rimmer, 2002). But this brings the disadvantage that dynamic models are complex and more difficult to solve. Another limitation is that the elasticities of substitution cannot be directly derived from the same data, but depend on modellers' judgement or the need to use estimates from secondary sources. As with IO