# Investigation of General Equilibrium Modelling for Domestic Sectoral Policy Analysis

#### Disclaimer

The analysis and policy proposals presented in this paper are not government policy and only represents an academic investigation into this policy area.

## Abstract

The UK, like many advanced economies subsides advanced manufacturing sector (Broadberry & Leunig, 2013), particularly if the technology associated are considered ‘Green’. For example, the USA passed the Inflation Reduction Action (IRA), (White House, 2022) and future EU investments will be made by The Green Deal Industrial Plan (GDIP), (European Commission, 2023). There are presumed to be multiply benefits to this decision, however this is a market distortion to a true free market equilibrium. The neo-classical approach (Cordato, 1980) states that without market failures the government should not intervene in the market and that it may produce worse outcomes, government failure (Grand, 2009).The government therefore must show market failures exist that it is trying to counteract and that intervening would be an economic and social benefit to the UK. The first is covered in the Five Case Model, (HM Tresury, 2018). To confirm the latter analysts must perform ex-ante modelling of its impacts (Munby, 2023).

This paper will investigate the potential introduction of General Equilibrium Modelling (GEM) to analysis interventions in advance manufacturing sectors. With a specific focus on the automotive industry due to it being the author’s area of work however there is possibility of applicability to other areas.

## Non-Technical Summary

**[1 to complete]**

## Context

### Government Departmental Changes

The Department for International Trade (DIT) was created on 14th July 2016 and became part of the Department of Business and Trade (DBT) as part of a Machinery of Government (MOG) change on 7th February 2023. DIT had a remit to complete trade policy analysis, for this remit the independent report: Trade modelling review expert panel, recommended development of Computable General Equilibrium Model (CGEM) capabilities, (Venables, 2022).

This remit for external policy focus has been combined with Department for Business, Energy & Industrial Strategy (BEIS) domestic business policy focus. Therefore, allowing government to have a join up domestic and international policy objectives to strengthen UK industry. As DBT matures this joined up policy direction will embed, a requirement for shared analytical approach across the two sides of the departments will grow. Therefore, the domestic policy analysis approach described later in Impact/Benefit justification could be expanded by considering the approach previously used for external policy analysis.

#### Collaboration

After discussing with ex-DIT trade analyst colleagues, the modelling approach investigate in this paper will be based on the work of (Böhringer, et al., 2003) and (Wing, 2004). These discussions formed the original motivation for the work.

### Policy Area - Market Failures

As stated, government needs to conclude that there are market failures before it can intervene. The following section will show there is a strong economic rationale for government intervention in this sector due to the presence of several market failures. Some market failures affect the whole sector, while others are specific to a particular stage, such as R&D investment. Current HMG assessment of different market failures is viewed through the breakdown given in Figure 1. This paper will focus on production side of the industry specifically capital investments. The example of market failures below builds on the information provide in the Green Book 2022, Section 4.23[[1]](#footnote-1).

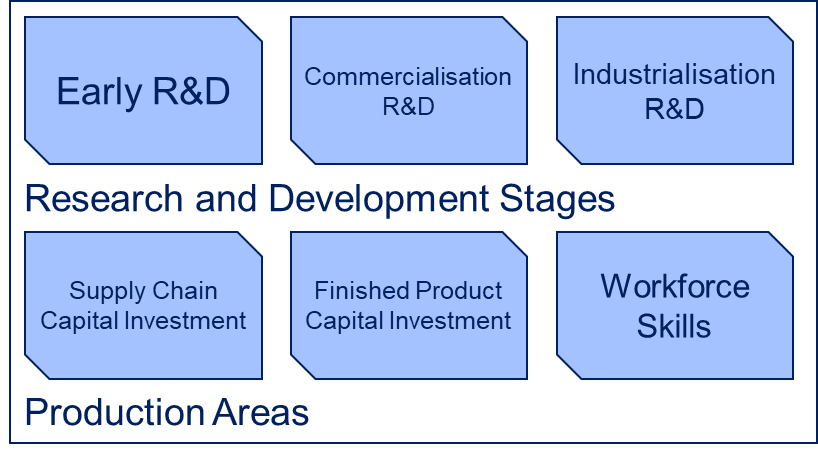


Figure Industry Sections

#### Positive Externality

The industry is current transition to the production of Electric Vehicles (EV) from traditional Internal Combustion Engine (ICEV). EV has a positive externality of reduced CO2 emission when consumed compared to ICEV (USEPA, 2023), even when including the manufacturing process (FCAB, 2021).

As the Marginal Social Benefit (MSB) is greater than the Marginal Private Benefit (MPB) there will be an under consumption and production of the good, (Pindyck & Rubinfeld, 2009). Therefore, the government can intervene to promote the consumption and production of that good.

#### Barriers to Entry and Market Power

For the market to be considered a perfect competition many firms must be present with none having high market power. This is enabled by lower barrier to entry and exit from the market. The automotive industry and its supply chain have high barriers to entry due to the very high initial fixed capital costs; for example, the new gigafactory[[2]](#footnote-2) for JLR will require investment of £4bn (BBC News, 2023).

Certain elements of the electrified supply chain are already characterised by monopolistic supply, for example over 70% of the natural graphite supply is controlled by China.[[3]](#footnote-3)

This market power can enable these Chinese firms to extract profits from European firms by charging above the equilibrium price. The well-established nature of these firms in Asia and the large amount of subsidisation they receive mean that new European firms attempting to entry the market cannot compete.

This uncompetitive international behaviour results in EV supply chain projects typically having low margins[[4]](#footnote-4) and therefore attracting low levels of investable financial especial given the scale required.

#### Information Failures

Although EV have been produced for years, this has not been at the scale required to transfer the entire new car market away from ICEV, a stated goal of the UK government (HMG, 2020) and the EU (Reid, 2023) by 2030 and 2035 respectively. There are multiple competing chemistries that an EV cell can have resulting in uncertainty in investment.

The performance and quality of an EV is driven by this chemistry and the quality of the production process. The knowledge to understand EV cells is complex and therefore the consumers of the good (motorists) will not be able to have accurate information and the market has failed (Pindyck & Rubinfeld, 2009). This can also be true for car manufactures who use the EV cells as intermediate goods in their production process.

Character of the technology (lock-in) – Vehicle technology is very capital intensive, and so exhibits slow replacement rates. This means that the industry will often keep with existing technologies and be too cautious and delay investment until proven alternatives have happened elsewhere before investing significantly into new technologies.

The lock-in nature of the technology means that the following scenario is possible. A cell or car manufacturer has invested in one specific chemistry type which may not develop as productively as other could result in large loss as they are required to retool and invest in the more productive chemistry type. This risk reduces the investment levels in the EV technologies.

### Policy Area – Intervention

The above is a summary of the market failures which were used to justify the Automotive Transformation Fund (ATF), (Munby, 2023), a capital grant fund offering a share of the total budget, valued up to £1 billion, (HMG, 2022) to intervene in the EV supply chain. The total intervention into the sector is called the programme and individual cases are the projects.

#### Impact/Benefit justification

For any grant provided by HMG an ex-ante assessment is completed including an economy appraisal. This is done in line with ‘Green Book’ (GrB) principles. The most common approach is a Cost Benefit Analysis (CBA) appraisal using the Benefit Cost Ratio (BCR) as a metric. The GrB considers the social welfare benefit of bringing advanced manufacturing to the UK as the move to more productive jobs.

This approach assumes that the economy is working at or near full employment and therefore only the wage above the next best alternative wage is a benefit. The next best alternative wage is assessed against a local alternative.

Advance manufacturing like automotive have higher average wages than alternative employment. The majority of advanced manufacturing occurs outside of London and the Southeast aligning interventionist policies with the Levelling Up[[5]](#footnote-5) agenda.

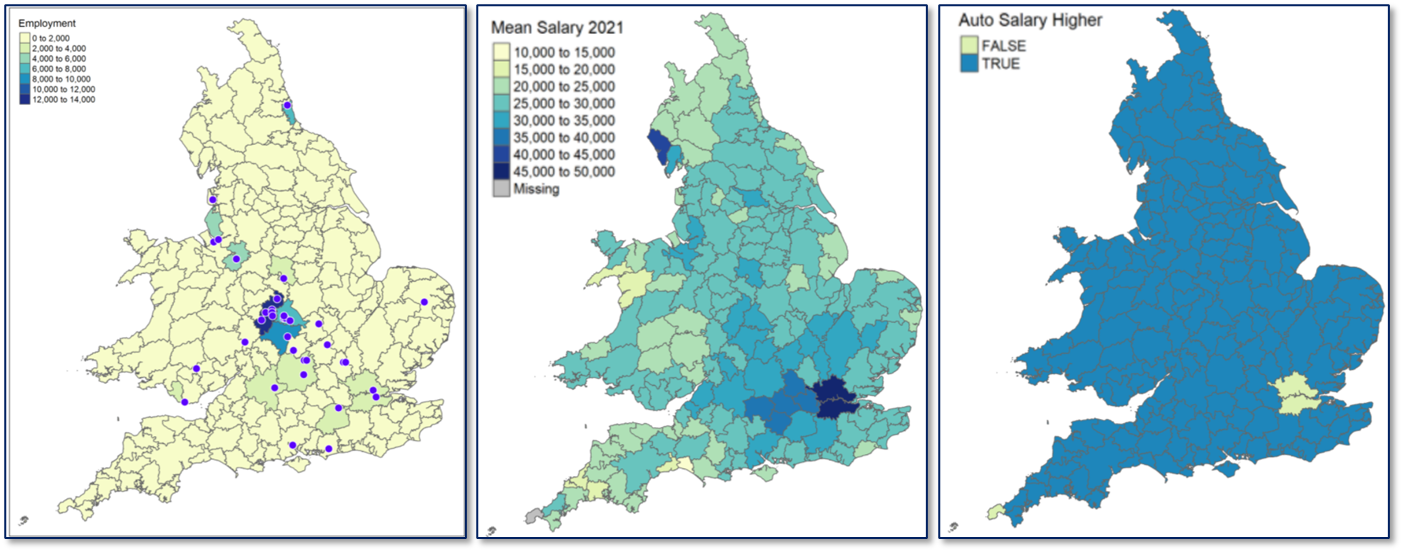


Figure Automotive Employment Maps – ONS data

The maps in Figure 2 show the location of automotive employment, the counterfactual salary, and the areas of the country in which automotive employment represents a move to a more productive employment.

These current assessments are at the project level of individual cases (funding certain OEMs, or key suppliers), but it has been used to approach the programme level intervention. This work will review the macro level of supporting the sector. **This is a live policy debate within HMG and contains commercial sensitive information. Therefore, where appropriate information has been redacted for a wider audience.**

## Methodology

### Current Methodology

The current methodology builds a model of the automotive industry in isolation to the rest of the economy. This methodology is currently in use in the appraisal of an active policy decision; **therefore, where appropriate information has been redacted for a wider audience, include the results of current modelling.** A version of the current methodology was original derived by the author for appraisal of policy of intervention into the automotive sector by HMG and was used to complete the Value for Money assessment presented on gov.uk by the then Permanent Secretary of BEIS, (Munby, 2023).

The model considers the capacity in the UK to produce vehicles, which is a capital-intensive production and is limited by the number of sites of factories. These sites are presented on the first map in Figure 2.

As a result of the change from producing ICEV to EV the new supply chain will be a further limiting factor on the production capabilities in the UK[[6]](#footnote-6). Therefore, investing in both the vehicle manufacturing and EV supply chain new levels of production and employment will be reached. The UK exports the majority (c80% annually) of the vehicles produced and demand for UK produced vehicles is exogenous in this modelling.

It is the modelling described above provides a quantitative assessment of the number of jobs in the sector with and without intervention. The difference in job numbers is multiplied by wage premium associated and is used as the benefit in the CBA. It does not specifically model what the opportunity cost of the economic activity foregone; therefore, it is not a general equilibrium model. There is no consideration given to: what sectors have a reduction in employment, potential changes in output and increases in prices and the wider social-economic impacts.

For this reason, the alternative methodology is proposed and will be investigated for usefulness in this paper.

### Alternative Methodology

The approach being reviewed is a Computable General Equilibrium Model (CGEM), which is a method of constructing a Walrasian general equilibrium in which supply and demand are equalized across all the interconnected markets in the economy, (Wing, 2004).

There is international precedent for the use of CGEM in policy formation, notably Norway and Australia, (Dixon & Jorgenson, 2013). They have been using single-country models since the 1960’s and 1975 respectively. Since the 1990’s other governments and NGOs have built and maintained CGEM to help policy assessment, including US International Trade Commission, the Organisation for Economic Cooperation and Development, and the World Bank, (Burfisher, 2011).

### Project Aims

To investigate the possibility and usefulness of developing a CGEM to analysis programme level intervention into advance manufacturing sector. The worked example will be the automotive sector and its transition from ICEV to EV production.

### Output Objectives

The output aims for a complete model would be:

* Investigate the structures presented in (Wing, 2004),
* Construct a method to establish the distribution of employment between different sectors,
  + With and without policy intervention
* The comparative salary distribution,
* Understand the distribution of wages across areas,
* Produce a framework to analysis regional equality impacts.

Motivation - Objectives

The reasons for these aims are:

* To enable the model to produce a counterfactual to compare to the intervention state to calculate the impact of the policy.
* To enable comparison of modelling results on the same primary economy benefit (wage premium).
* To assess policy impacts against wider strategy of Levelling Up.

The benefit of taking an CGEM approach would be to investigate the opportunity cost of the economic activity foregone. It would consider how the government intervention will impact the different sectors of the economy.

### Economy structure - closed circular economy

A diagram of a company

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Figure Close circular economy model

The underpinning idea in CGEM is circular flow of commodities in a closed economy. The above model diagram is an autarky version of the model present in the HMRC GEM paper, (HMRC, 2013) .

CGEM can be dynamic and track the evolution of the economy over time in response to a policy change. In the baseline, it is assumed the economy follows a steady-state growth path where all economic activities grow at a constant rate, (HMRC, 2013).

### Required Modelling Assumptions

The following are require modelling assumptions to build a working CGEM.

#### Firms Assumptions

Firms are assumed:

1. To be profit maximises,
2. To be producing homogenous products,
3. To have a homogenous production function within a single sector of the economy,
4. To be producing using labour, capital, and intermittent good as input factors,
5. To be producing with a constant return to scale,
6. To have production modellable with a Cobbs-Douglas (CD) function.

#### Households Assumptions

Households are assumed:

1. To be utility maximisers, with a define utility function,
2. To gain income from selling labour as price takers, and collecting interest on invested capital at fixed rate,
3. To save income at a fixed rate,
4. To be budget neutral in a single period; income = expenditure + savings.

#### Government Assumptions

The government is assumed:

1. To have a constant tax and spend policy throughout model expect for the policy being assessed.

### Justification and Reasoning

The reason for some of the assumptions above is such that the CGEM is a modelling a perfectly competitive market; specifically, 1, 2, 3, 7, & 8. They are as justifiable as assumption in a model as assuming that the UK economy is a perfectly competitive market is justifiable. The scope of this paper does not include discuss this whether the UK is a perfectly competitive market. The reasoning and justification for the other assumptions are given in Table 1 below.

|  |  |  |
| --- | --- | --- |
| **Assumption** | **Reasoning** | **Justification** |
| 4 | The inclusion of these three factors allows for a model which explores the topics of interest for the policy area. Labour is required to understand wage premium impacts, capital to understand how government intervention could be achieved and the intermediate goods are included to understand interaction between the different sector of the economy. | The production function is limited to 3 factors and excludes entrepreneurship and land as they would increase complexity without provide insight for the policy question. |
| 5 | This helps with analytical simplification, specifically in the regression modelling of the CD production function. | This is a widely used assumption in analysis of production (Lim & Shumway, 1992) however if not valid can lead to mistakes in output combination, one example is between risk-neutral optimising firms and those which are risk averse. However, these considerations are outside the scope of this paper therefore the paper will assume the simplifying assumption. |
| 6 | Ensure that the production function is algebraically manageable for the modelling and while enabling it to contain the necessary factors of production. | There would be limited benefits to the scope of the policy question for incorporate increase complexity. |
| 9 | Analytical simplification to make this saving rate exogenous to the model | There would be limited benefits to the scope of the policy question for incorporate increase complexity |
| 10 | Analytical simplification to reduce the modelling requirements. | There would be limited benefits to the scope of the policy question for incorporate increase complexity |
| 11 | Analytical simplification and would allow the model to be computable | There would be limited benefits to the scope of the policy question for incorporate increase complexity |

Table Modelling Assumptions - Reasoning and Justifications

## Modelling – CGEM

The data on which the CGEM were calculated with is from the ONS – Office for National Statistics. ONS produces Input-Output Analytical Tables which includes product-by-industry section derived from the annual Supply and Use Tables (SUTs) (ONS, 2023). From this the annual use of intermediate goods, labour expenditure and final output can be gathered. This data has disaggregated by SIC code as described in Annex A: Standard Industrial Classification (SIC). This classification of sectors has used at two levels, 39 sectors and 5 sectors.

This data is the appropriate set for this work as it gives the depth of disaggregation (covers a range of sectors), breadth of data points (range of years) and is relative consistent in presentation when matching across datasets.

### Model Derivation

Initial modelling derivation was built from the work presented in the MIT Joint Program on Science and Policy of Global Change report: Computable General Equilibrium Models and Their Use in Economy-Wide Policy Analysis. (Wing, 2004).

Set of commodities:

Set of industry sectors:

Set of primary factors:

Set of final demands:

For simplicity

In CGEM, the price and income elasticities of demand are crucial in determining the sectoral growth pattern and economic impact, (Hertel, 2012). For this initial model the utility function, is modelled as a Cobb-Douglas, from this function the price elasticities of demand can be calculated, this is discussed further in the Utility Function section.

It assumes that the circular economy in the model conforms to:

* Cobb-Douglas Economy
* Commodity market clearance
* Factor market clearance
* Full employment
* Zero profit

These assumptions can be formulised as in the equations below:

|  |  |
| --- | --- |
|  | Equation Commodity Market Clearance |
|  | Equation Factor Market Clearance |
|  | Equation Full Employment |
|  | Equation Zero Profit |

Where:

|  |  |
| --- | --- |
| **Variable** | **Definition** |
|  | Total output of commodity |
|  | Intermediate good required for commodity |
|  | Final good use of commodity from factor rent |
|  | Consumption of commodity |
|  | Saving of commodity |
|  | Total available primary factor |
|  | Primary factor used for sector |
|  | Total rent from all primary factors employed |

The households in this model are assumed to be utility maximises (Assumption 8) and therefore the agent problem can be defined as:

|  |  |
| --- | --- |
|  | Equation Agent Utility Maximisation |

The where the function is defined as:

|  |  |
| --- | --- |
|  | Equation Cobb-Douglas Utility Function |

This can be solved to results in the equations for

|  |  |
| --- | --- |
|  | Equation Consumption of commodity i |
|  | Equation Alpha of commodity i |

The producers in this are model are assumed to be profit maximises (Assumption 1) and therefore the producer’s problem can be defined as:

Equation Produces Profit Maximisation

Where is specified as the production function. For this model it will be an extension of the CD investigated in Equation 22 to:

Equation Produces Cobb-Douglas with Intermediate Goods

|  |  |
| --- | --- |
| Where: | Equation Constant Return to Scale |

From these equations can be derived as:

The aim is to create a benchmark within which price of each commodity and wage are set to 1. This unity of prices and wages is a modelling assumption to enable algebraic simplification without the loss of generality in the modelling. There is no loss in generality of modelling as the prices and wages are relative to the base year and consumption/output is not modelled as unity. The following are the equations used to calculate the calibration parameters:

|  |  |
| --- | --- |
|  |  |
|  |  |
|  |  |
|  |  |

Equation Calibration Equations

With the above definitions for calibration the general equilibrium equations can be reformulated as:

|  |  |
| --- | --- |
|  | Equation Benchmark Commodity Market Clearance |
|  | Equation Benchmark Factor Market Clearance |
|  | Equation Benchmark Full Employment |
|  | Equation Benchmark Zero Profit |

Rearranging Equation 13 to Equation 16 and inserting the calibration definitions from Equation 12, the following deltas can be derived:

|  |  |
| --- | --- |
|  | Equation Delta Consumption |
|  | Equation Delta Primary Factor |
|  | Equation Delta Profit |
|  | Equation Delta Factor Clearance |

This delta function can be combined into a single function of function:

|  |  |
| --- | --- |
|  | Equation Delta Function |

For a given set of calibration inputs a vector is in equilibrium

The difference of from can be interrupted as the amount the vector needs to change to move the model to equilibrium.

#### Structural Choices

There is a trade-off between the computable & producibility of the model and the complexity & number of features in the model. These options must be balanced when constructing the model. Examples of this include the number of sectors in the model, the functions deriving economic actor behaviour.

### Model 1

For the model to more computable with initial modelling the 5-sector disaggregation has been used. For this 2015 ONS Input-Output Table[[7]](#footnote-7) data was taken and a benchmark CGEM was constructed. This version of the model assumed no savings, capital, imports, exports, or government involvement.

However, this is not the case in the data from ONS which are presented in current price year opposed at a unit production level. So, the outputs had to themselves calibrated to unity price and wages, which is presented in the code: 11\_Model\_1\_Calibration.R.

The ONS data provide a unit input-output for intermediate goods which could be used for the within the model. From this a corresponding set of and . The model constructed its own (technology constant) to allow each sector to create enough output to cover both intermediate goods and final demand .

Implementing this approach, the benchmark model was able to reach general equilibrium as within the realms of computational tolerance, account for floating point errors.

This could be tested with the delta function in Equation 21.

### Model 2

For a more complex version of the model capital will be introduced as an additional required primary factor. The construction of the first began again with the ONS data, with an initial endowment of fixed capital levels in 2015 and employment figures.

The total output was scale to match a salary cost of 1 and capital cost of 0.1 (to represent an economic wide interest rate of 0.1). This model produced a set of outputs include intermediate goods required and final consumption levels for consumers which match the return on labour and capital, . However, as the initial input data is based on real world values, with the additionality complexity of two primary factors the model could not be engineered such that all the deltas were zero.

### Model 2 Next Steps

The next test for the model is varying the initial exogenous variables and so the benchmark model comes to an equilibrium. This requires the creation of an algorithm to search for the equilibrium point. The endogenous variables in Model 2 that could be altered are the vectors of price , wages , and consumption (consumption alters total output ), each of which are containing 5 elements.

This gives 15 variables which could be scaled, and table below present the relationship between the deltas and increase in the variables. When the delta is has a subscript this means the change of a delta for a different commodity.

|  |  |  |  |
| --- | --- | --- | --- |
| **Increase** in Variable |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

The literature recommends an approach similar to a Newton-type steepest-descent optimization algorithm (Kehoe, 1991). An attempt to construct an algorithm to find the equilibrium can be found in the R code: Model\_2\_Calibration.R. a flow diagram of the attempt is given in Figure 4. The function Update Values contain the Newton-type steepest-descent. However, this was unsuccessful.

A diagram of values and functions

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Figure Flow Diagram for Equilibrium search

## Modelling Weaknesses

Although the CGEM can investigate the opportunity costs of the intervention better than the previous approaches by showing which industries are impacted by incentivising the Automotive sector it does have some weaknesses. This section of the paper will discuss them and give some potential solutions where investigated.

### Weaknesses with the Benchmark Approach

The following explores the weaknesses with the Benchmark aspect of the CGEM approach.

#### Unity Prices and Wages

The methodology reviewed in the documentation readily used in DBT (ex-DIT) assumes in the benchmark year prices and wages are set to 1. This enables the algebra to construct future years relative to the first year. However, this assumption negates the main benefit that a model would be trying to predict. Therefore, an attempt to construct a version that assumes wages which are not equal to 1 was created. The code can be found in 00\_Main\_Model\_v1.R[[8]](#footnote-8). Code to find the equilibrium point was not produced for this version.

#### Production Function

The methodology presented by (Wing, 2004) and used in the modelling above calculates the CD coefficients for production from a single year of data. Depending on the sensitivity of the results to these coefficients this may lend to misleading results. A potential solution to this is approximate the CD from many years of data.

The three factor Cobb-Douglas is given as:

Where: Output, intermediate goods, capital used, labour used, technology constant.

Equation Factor CD Production Function

The would as be inferred from the ONS Input-Output tables. Linear regression modelling and an author derived data searching algorithms were used to calculate the parameters of Equation 22. Full technical detail of the approach can be found in Annex A: Technical.

The benefit of this approach is to produce more robust coefficients.

### Weaknesses with the General CGEM Approach

The following explores the weaknesses with the CGEM approach, additional to those in caused by benchmarking.

#### Data Limitations – SIC Codes

The SIC code 29 covers the production in the automotive industry, a breakdown is given in Figure 5. There is currently no split between the production of ICEV and EV which are both contained within SIC 29. A screenshot of a computer

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Figure SIC 29 Breakdown

This means that any production function derived from SIC 29 will have capitalisation levels and intermediate goods for both ICEV and EV. The UK currently produces a small percentage of EV compared to ICEV which means that it can be assumed that production function is likely representative of the current sector and for the next few years. However, as the industry transitions to produce more EV this assumption will be weakened.

Below is a proposed method to handle this is when calculating the production function by the regression given in Annex A: Technical 3. Production Function 1.

The regression model will have to incorporate a term for the percentage of the market which is EV in that year. This will try to determine how the intermediate goods and capitalisation level change as EV proportion increases.

This could allow for a model with an exogenous term of EV percentage which alerts the production function over time.

Data usefulness

#### Multiplicity of Equilibrium

It is extremely difficult to proof analytically that a given equilibrium solution is unique in real world models, especial when there is the inclusion of taxes distortion. There have been examples testing for multiplicity of equilibria in real-world CGE models. However, the complexity of doing so would means there are uncommon. (Wing, 2004).

This does provide a doubt on the solution and subsequential policy advice provided by any CGE modelling.

#### Generality of Production Function

The parameters of Equation 22 provide a more robust production function than the one used in Model 1 and 2 however the approach is more general than the one used in the current methodology. The CGEM approach is based on data which includes both the production of ICEV and EV as the data is not disaggregated between the two.

The current methodology is able to model the balance between investing in the EV supply chain and at the car manufacturing level. For this to be incorporated into the CGEM the commodities used would have to be disaggregated further. This is not possible with current data source (ONS, Input-Output Tables). The current methodology relies on specific subject matter expertise which could not be duplicated for the CGEM approach.

Therefore, the alternative methodology explored in this paper is not as accurate as the current method.

#### Utility Function

Therefore, are multiple implications of using the CD utility function discuss below that makes it not a useful representation of consumer behaviour.

The price elasticity of demand is defined as , (Mac Lean, 2011) can be calculated by differentiating Equation 7 with respect to . In model 1 and 2 described above there was assumed to be no savings which means for those models it gives:

|  |  |
| --- | --- |
|  | Equation Price elasticity for Model with no savings |

The derivate as , this implies that the demand will always decrease for increasing prices and vice versa. This means that Giffen goods cannot be included in the model.

The price elasticity of a model including savings is evaluated below, assuming is not dependent on .

Equation Price elasticity for Model with savings

The modelling assumes that the consumer budget is balanced within a single year (no borrowing), therefore Therefore the price elasticity in a model has the same behaviour, i.e., no Giffen goods.

Cross-price elasticity of demand is defined as (Pindyck & Rubinfeld, 2009)

In the model with no saving there is no cross elasticity of demand as .

The cross elasticity of a model including savings is evaluated below, assuming is not dependent on .

|  |  |
| --- | --- |
|  | Equation Cross Elasticity in Model with Savings |

As price are defined as positive at any solution to the model, Equation 25 implies that all cross elasticities are negative and therefore all goods are complementary.

Income elasticity is defined as , where is income, (Pindyck & Rubinfeld, 2009). Income elasticity is the same in a model with or without savings, if is not dependent on .

|  |  |
| --- | --- |
|  | Equation Income Elasticity |

This implies that an increase in income will always results in an increase in consumption of all goods. This implication can be tested against real world data via the ONS 'Household expenditure by gross income decile group’ dataset[[9]](#footnote-9). Comparing the total spend on each commodity group in each decile to the lower decile one (i.e., Third decile group compared to Second decile group) you can infer the income elasticity.

Reviewing the data from ONS infers that there is evidence to support a negative income elasticity at certain income levels for:

Alcoholic drinks, tobacco & narcotics,  
Housing(net)[[10]](#footnote-10), fuel & power,  
Health &  
Education[[11]](#footnote-11)

To examine the income elasticity with this data requires the assumption that firms within a commodity group are producing homogenous goods/services. This means that the prices paid for a unit of goods/service does not change. This removes the possibility that consumer will pay for a more luxury version of the same item as income increases, i.e., changing from Supermarket own brand to a premium brand food product. The inverse of this phenomenon has been seen in the post-COVID cost-of-living crisis, with 64% of consumers are switching to cheaper brands (Grocery trader, 2022) according to a Shopmium survey[[12]](#footnote-12).

The inability of the Cobb-Douglas utility function to model negative income elasticities and positive cross elasticities are the biggest weakness when comparing to the available data. Specifically, the income elasticities as the modelling objective is investigate the changes to the economy of subsiding and incentivising advance manufacturing as it has a wage premium.

### Autarky

The new methodology models the economy as an autarky excluding international trade. This was by design to enable an initial exploration of the model limiting complexity. For any complete usable version of model for real policy analysis would have to consider international trade. In the last ten years, despite the reduction in vehicle production numbers from a high in 2016, the percentage of exports has remained around 80%. This is evidenced in data presented in Figure 4[[13]](#footnote-13)

Figure UK Vehicle Production Data

This is an area that a future CGEM could be stronger than the current approach. The current approach assumes that international demand for vehicles is exogenous and will absorb any increase in UK production. A CGEM will be able to test this assumption and build in trade reactions.

An international trade CGEM will also be able to contextualise UK government policy intervention with USA IRA and EU GDIP policies. However this development option will require a considerable larger dataset and calibration.

### Black Box

Simulation models like CGEM are criticized for being ‘Black Boxes’ (Burfisher, 2011), whose results are difficult to explain by clear causal chains (Dixon & Jorgenson, 2013). This is especial true for proprietary commercial modelling, which is the reason is the reason that R an open-source coding language was attempted when creating a new CGEM.

One of the key approaches to overcome this weakness is in the presentation approach. The recommendation would be:

* Narrowing the scope of the results to key areas of interest to the audience
* Focus on understand how policy intervention impact key metrics (employment, trade ratios).

## Conclusion

This paper was an investigation into the use of CGEM as a policy analysis tool for domestic intervention into an advance manufacturing sector. Due to the weakness discussed above a satisfactory model to appraise the policy decision has not been able to be completed.

Therefore, the ongoing policy decision of intervention level into the advanced manufacturing sectors the previous analytical framework should be continued to be used. However, this does not mean that this approach could not be utilised with additional work. It would require collaboration with analysis with additional skills in programming, data science and specific trade data knowledge.

The future model structure recommendation would to be:

* Use of the multi-year Cobb-Douglas Production Function Parameters.
* Intermediate good values from ONS.
* Exogenous constant saving rate.
* Labour - primary factor costs (salary) based on ONS data.
* Incorporating a tax system, simplest being a Poll Tax or flat rate of income and cooperation tax policy.
* Government expenditure would be model as increased consumption of sector goods based on ONS Input-Output table data.
* It would require economic data of UK key trade partners at a minimum, recommended would be all trade partners.
* A presentation style appropriate for the advanced modelling would have to be adopted to mitigate the risks presented by the model’s perception as a ‘black box’.

**[3 to complete]**

**[6 to complete]**

Impact of improving CGEM modelling on bring DIT and BEIS analytical teams together

## Annex A: Technical

1. Standard Industrial Classification (SIC)

SIC was first introduced into the UK in 1948 for classifying business establishments (ONS, 2009) and can be used across multiple ONS datasets as a method of managing data disaggregated by production sector.

The classifications are in a hierarchy structure, section (letter), division (2-digit), group (3-digit), class (4-digit) and subclass (5-digit). There are 39 classifications used in parts of this report modelling, which are:

|  |  |  |
| --- | --- | --- |
| **Code** | **Description** | **New Code** |
| A01 | 01: Crop and animal production, hunting and related service activities | A |
| A02 | 02: Forestry and logging | A |
| A03 | 03: Fishing and aquaculture | A |
| B | B: MINING AND QUARRYING | A |
| C10T12 | 10-12: Manufacture of food, drink, and tobacco | B |
| C13T15 | 13-15: Manufacture of textiles, wearing apparel, leather, and leather products | C |
| C16 | 16: Manufacture of wood and of products of wood and cork | C |
| C17 | 17: Manufacture of paper and paper products | C |
| C18 | 18: Printing and reproduction of recorded media | C |
| C19 | 19: Manufacture of coke and refined petroleum products | C |
| C20 | 20: Manufacture of chemicals and chemical products | C |
| C21 | 21: Manufacture of basic pharmaceutical products and pharmaceutical preparations | C |
| C22 | 22: Manufacture of rubber and plastic products | C |
| C23 | 23: Manufacture of other non-metallic mineral products | C |
| C24 | 24: Manufacture of basic metals | C |
| C25 | 25: Manufacture of fabricated metal products, except machinery and equipment | C |
| C26 | 26: Manufacture of computer, electronic and optical products | C |
| C27 | 27: Manufacture of electrical equipment | C |
| C28 | 28: Manufacture of machinery and equipment | C |
| C29 | 29: Manufacture of motor vehicles, trailers, and semi-trailers | D |
| C30 | 30: Manufacture of other transport equipment | C |
| C31\_32 | 31-32: Manufacture of furniture and other manufacturing | C |
| C33 | 33: Repair and installation of machinery and equipment | A |
| D | D: ELECTRICITY, GAS, STEAM AND AIR CONDITIONING SUPPLY | E |
| E | E: Water supply; sewerage, waste management and remediation activities | E |
| F | F: Construction | E |
| G | G: Wholesale and retail trade; repair of motor vehicles and motorcycles | E |
| H | H: Transportation and storage | E |
| I | I: Accommodation and food service activities | E |
| J | J: Information and communication | E |
| K | K: Financial and insurance activities | E |
| L | L: Real estate activities | E |
| M | M: Professional, scientific, and technical activities | E |
| N | N: Administrative and support service activities | E |
| O | O: Public administration and defence; compulsory social security | E |
| P | P: Education | E |
| Q | Q: Human health and social work activities | E |
| R | R: Arts, entertainment, and recreation | E |
| S | S: Other service activities | E |

1. Further Reduction

When completing CGEM the following groupings of industry sectors will be used.

|  |  |
| --- | --- |
| **New Code** | **Definition** |
| **A** | Raw Materials, Manufacturing input |
| **B** | Food goods |
| **C** | Manufactured Non-Food Goods |
| **D** | Automotive Production |
| **E** | Services and Other Goods |

1. Production Function 1

This section gives the mathematical derivation of the linear regression model used to calculate the parameters of the CD production function for each section of the economy. This is an adaption of the methodology for two factor production function found in [**reference**]. This two-factor method has been replicated for SIC 29 to give:

If you assume constant return to scale, then .

Equation Multivariable Linear Regression Model of CD

The constants in this equation can be estimated by multi-variable linear regression which was complete in R. The simple linear regression used to calculate the parameters can return answer in the whole range . Therefore, for some of the sectors there may exist better estimators of the function outside the bounds of the parameters, .

#### Linear Regression Results

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sector** |  | **Alpha** | **Beta** | **Gamma** |
| A01 | 1.364 | 0.414 | 0.111 | 0.475 |
| A02 | 1.602 | 0.188 | 0.353 | 0.458 |
| B | 1.113 | 0.666 | 0.118 | 0.215 |
| C18 | 1.058 | 0.587 | 0.259 | 0.154 |
| C19 | 1.282 | 0.698 | 0.072 | 0.229 |
| C22 | 0.941 | 0.512 | 0.445 | 0.043 |
| C23 | 1.261 | 0.396 | 0.47 | 0.135 |
| C25 | 1.677 | 0.11 | 0.538 | 0.353 |
| C28 | 1.036 | 0.466 | 0.459 | 0.075 |
| C31\_32 | 0.843 | 0.754 | 0.22 | 0.026 |
| D | 0.873 | 0.752 | 0.087 | 0.162 |
| F | 1.758 | 0.571 | 0.099 | 0.331 |
| H | 1.111 | 0.314 | 0.565 | 0.121 |
| N | 0.952 | 0.597 | 0.384 | 0.02 |
| O | 1.094 | 0.138 | 0.63 | 0.232 |
| P | 1.248 | 0.319 | 0.358 | 0.323 |
| Q | 1.904 | 0.293 | 0.244 | 0.462 |

Table Linear Regression Modelling Results

1. Production Function 2

To find the parameters for the sectors that linear regression failed other techniques were required. The aim was to find the local minimum Mean Squared Error (MSE) within the parameter range. Given the level of accuracy the modelling is going to use, the first approach was to use a brute force search method. Calculate the Mean square Error (MSE) of all possible combination of at 2-digits (i.e., 0.23, 0.76, etc).

This approach would give a local minimum within the discrete search space, that would be a false local minimum of the continuous search space. i.e. it is the minimum MSE for the finite discrete set of parameter searched over.

Where the bar denotes the found estimators satisfying the equation:

,

However, this was too computationally intensive and only one result was found after 18 hours of run time. There were 22 sectors that needed finding (c16 day runtime).

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sector** | **A** | **Alpha** | **Beta** | **Gamma** |
| A03 | 0.95 | 0.8 | 0.01 | 0.199 |

1. Production Function 3

The next search method to find the local minimums was an algorithmic search based on shrinking spheres. The starting point for the algorithm is the central point, .

* The step 1 is to create new set of points are selected at random on the surface of the sphere centred at the start point.
* The radius of the sphere decreases with each iteration of the algorithm.
* The MSE of each element of the set is calculated.
* The element with the smallest MSE is the new start point, return to step 1.

The algorithm is illustrated in Figure 4. The code can be found in LM Regression 7.R, the name of the functions in Figure 4 correspond to those in the code.

A diagram of a function

Description automatically generated

Figure Flow Diagram of Search Algorithm

#### Production Function Results

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Sector** | **A** | **Alpha** | **Beta** | **Gamma** |
| A01 | 3.91 | 0.41 | 0.11 | 0.48 |
| A02 | 4.96 | 0.19 | 0.35 | 0.46 |
| A03 | 29.92 | 0.41 | 0 | 0.58 |
| B | 3.04 | 0.67 | 0.12 | 0.22 |
| C10T12 | 7.23 | 0.7 | 0.03 | 0.27 |
| C13T15 | 8.06 | 0.75 | 0.18 | 0.06 |
| C16 | 3.3 | 0.88 | 0.07 | 0.05 |
| C17 | 141.98 | 0.29 | 0.57 | 0.13 |
| C18 | 2.88 | 0.59 | 0.26 | 0.15 |
| C19 | 3.6 | 0.7 | 0.07 | 0.23 |
| C20 | 4.82 | 0.81 | 0.13 | 0.06 |
| C21 | 84.22 | 0.41 | 0.49 | 0.09 |
| C22 | 2.56 | 0.51 | 0.44 | 0.04 |
| C23 | 3.53 | 0.4 | 0.47 | 0.13 |
| C24 | 3 | 0.87 | 0.07 | 0.06 |
| C25 | 5.35 | 0.11 | 0.54 | 0.35 |
| C26 | 18.37 | 0.62 | 0.31 | 0.08 |
| C27 | 3.57 | 0.87 | 0.08 | 0.06 |
| C28 | 2.82 | 0.47 | 0.46 | 0.07 |
| C29 | 8.08 | 0.73 | 0.2 | 0.06 |
| C30 | 28.15 | 0.58 | 0.4 | 0.02 |
| C31\_32 | 2.32 | 0.75 | 0.22 | 0.03 |
| C33 | 67.14 | 0.4 | 0.43 | 0.16 |
| D | 2.39 | 0.75 | 0.09 | 0.16 |
| E | 6.48 | 0.8 | 0.14 | 0.06 |
| F | 5.8 | 0.57 | 0.1 | 0.33 |
| G | 37.54 | 0.37 | 0 | 0.63 |
| H | 3.04 | 0.31 | 0.56 | 0.12 |
| I | 5.76 | 0.81 | 0.13 | 0.06 |
| J | 16.51 | 0.66 | 0.28 | 0.06 |
| K | 162.35 | 0.32 | 0.62 | 0.07 |
| L | 289.52 | 0.15 | 0.48 | 0.37 |
| M | 60.66 | 0.43 | 0.48 | 0.09 |
| N | 2.59 | 0.6 | 0.38 | 0.02 |
| O | 2.99 | 0.14 | 0.63 | 0.23 |
| P | 3.48 | 0.32 | 0.36 | 0.32 |
| Q | 6.71 | 0.29 | 0.24 | 0.46 |
| R | 17.81 | 0.61 | 0.31 | 0.07 |
| S | 62.86 | 0.41 | 0.48 | 0.12 |

Table Linear Regression and Search Algorithm Results

These coefficients could be used in any future CGEM modelling without the bias of having a single benchmark year.

1. Household expenditure data

The groupings of commodity and services in the ONS 'Household expenditure by gross income decile group’ are:

|  |  |
| --- | --- |
| Code | Group (Description) |
| 1 | Food & non-alcoholic drinks |
| 2 | Alcoholic drinks, tobacco & narcotics |
| 3 | Clothing & footwear |
| 4 | Housing(net)[[14]](#footnote-16), fuel & power |
| 5 | Household goods & services |
| 6 | Health |
| 7 | Transport |
| 8 | Communication |
| 9 | Recreation & culture |
| 10 | Education |
| 11 | Restaurants & hotels |
| 12 | Miscellaneous goods & services |

Table ONS Household Expenditure Commodity groups

|  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | Moving from Percentile X to Y | | | | | | | | |
| Commodity Group | 10 to 20 | 20 to 30 | 30 to 40 | 40 to 50 | 50 to 60 | 60 to 70 | 70 to 80 | 80 to 90 | 90 to 100 |
| 1 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 2 | 33% | 17% | 8% | 0% | 0% | 17% | 8% | 42% | 0% |
| 3 | 0% | 0% | 0% | 0% | 8% | 8% | 0% | 0% | 0% |
| 4 | 0% | 8% | 0% | 25% | 17% | 50% | 50% | 50% | 0% |
| 5 | 8% | 0% | 17% | 17% | 0% | 25% | 25% | 8% | 0% |
| 6 | 0% | 42% | 8% | 33% | 33% | 42% | 33% | 8% | 8% |
| 7 | 0% | 0% | 0% | 0% | 0% | 8% | 0% | 0% | 0% |
| 8 | 0% | 0% | 0% | 0% | 8% | 0% | 0% | 0% | 0% |
| 9 | 0% | 0% | 0% | 0% | 0% | 8% | 0% | 0% | 0% |
| 10 | 67% | 42% | 17% | 42% | 75% | 0% | 42% | 42% | 0% |
| 11 | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% | 0% |
| 12 | 0% | 0% | 0% | 8% | 0% | 17% | 0% | 0% | 0% |

Table Result of investigating commodity groups with negative income elasticities

The percentage in Table 4 represent the percentage of years that had a negative income elasticity for the move to the higher percentile in that commodity group. This is measuring absolute spend decreases not just a proportion decrease.

## Annex B: Code Blocks

Full R code used for this project can be found at:

<https://github.com/James-Lambertcoding/Dissertation>

A qr code on a white background

Description automatically generated

## Annex C: Project Management

1. Risk Register

The below risk register is based upon the methodology used in project management within DBT and specific the programme management of the ATF. The risks are measured against likelihood and impact on a 5-level RAG (Red, Amber, Green) scale. These metrics are combined to give a RAG Rating by the risk rating matrix, any rating Amber or above requires a mitigation in place.

A chart with different colors and text

Description automatically generated with medium confidence

Figure Risk Rating Matrix

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Risk** | **Description** | **Impact** | **Likelihood** | **Rating** | **Mitigation** |
| Unavailability of data | Although the data was going to be sourced from ONS open platform there is no guarantee that the disaggregation available would be suitable | Amber/Red | Green/Amber | Amber | There are private data providers that DBT has contracts with which could be used to procure additional data sources |
| Data loss | Due to corruption of hard drives or mishandling of version control there was a loss of work either completely or sections. | Amber/Red | Green/Amber | Amber | The dissertation and code have been backed up across multiple devices and cloud platforms including, personal computer, DBT servers and Google cloud.  Version Control has been implemented using GIT hub to ensure previous states of the code are retrievable. Adds additional redundancy to stop complete data loss.  Comments used exhaustively through out to ensure doing what new parts were doing |
| Policy change | Could there be a change in strategic direction for the policy area meaning that the policy question being answer was no longer relevant. | Amber | Green | Green/ Amber | N/A This work provides additional benefits besides implications for a policy decision |
| Modelling not completable | There is no guarantee that a complete CGEM would be codable within the time of the project | Amber /Red | Amber | Amber/Red | The policy intervention will be assessed by the current methodology within the department. This ensure that the ability to provide robust analysis for policy decision is not solely dependent on this project. |
| Subject matter difficulties | Barriers to completing the work because of difficulties in using the CGEM approach | Red | Amber | Amber/ Red | The author has ensured good working relationship with subject matter experts within the department to provide guidance and |
| Time constraints | Balancing work on project, work and live. Could other commitments stop the completion of the project. | Amber/Red | Amber/Green | Amber | A project timeline was created to ensure that time was divided across all the aspects of the project.  This would ensure that blockers in one aspect of the project do not hold back reaching a suitable conclusion.  Ensure that there is flexibility to include more time/days on to the project |

Table Project Risk Register

1. Project plan

A close-up of a chart

Description automatically generated

Figure Project plan

The project plan was created to ensure that enough time remain to complete tasks and evaluate when contingency days were required to complete steps. One of the main uses was to know when a certain activity had to be stopped (particularly in the modelling) to ensure time to complete the other stages. This enable understanding the trade off between continuing coding/modelling and focusing on completing the write up.

## Annex D: KSBs

Table 5 below is taken from (Institute for Apprenticeships, 2019) as presented by Queen Mary University of London.

|  |  |  |  |
| --- | --- | --- | --- |
| **High Level** | **individual KSBs** | **Pass/Distinction** | **Mapping** |
| **Applied economic analysis** | **S1** Apply micro-economic and macro-economic theories and modelling, including econometric, to inform a range of business and policy decisions. **S2** Convert the policy or other question into a tractable appraisal, evaluation or other analysis drawing on the most appropriate analytical method, including non-market valuation methods. Analysis considers, inter alia: the counterfactual, opportunity cost, risk and uncertainty and how to estimate discount rates and costs of capital. **S3** Critically assess available information sources and judge validity and usefulness for the issue at hand; clean and manipulate data; be aware of data limitations and explain them; clearly describe and present data using data visualisation techniques; and draw out and explain policy and business implications to clients | Apply their economic knowledge to inform a range of business and/or policy decisions. | [Impact/Benefit justification](#_Impact/Benefit_justification) shows that economic knowledge has been applied to a business area and policy decision. |
| Assess and argue what an appropriate method and data sources (s) are and identifies any limitations in the policy/business situation. | The ONS data was identified as the appropriate data source for the project because of the multiple years of data and the reliability. The limitations of the data are discussed in [Data Limitations](#_Data_Limitations) |
| Give a clear explanation of the assumptions made in their analysis and argue effectively for why these are appropriate. | The desired modelling assumption for the CGEM are presented in [Desired Modelling Assumptions](#_Desired_Modelling_Assumptions) with further explanation given to explain reason and justification for them. To ensure they were presented clearly a table format was used in Table 1 |
| Choose a presentation style and data visualisation tools that effectively describe the analysis and draw out recommendations for policy/business decisions. | Multiple plots and maps have been used through the project to illustrate the analysis: particularly:  Figure 2  Figure 4  Figure 5 |
| Identifies data relevant to the issue and the limitations of that data when judging validity and usefulness | The relevant data for the project is the input output tables whose weakness are is discussed in [Data Limitations](#_Data_Limitations). Within this section there is a discussion of the data usefulness and why in the CGEM approach it should continue to be used. In the conclusion the limitations of the data are considered. |
| Evaluate how limitations in the method/data selected could be improved upon and judge what the risks are for the project’s conclusions. | The paper contains a complete section on the modelling weakness, which inform the conclusion of the paper. There is an in-depth mathematical derivation of the weakness to the CD utility function used in the initial modelling, specifically the inability for it to handle income elasticity of demand, in [Utility Function](#_Utility_Function) |
| Explore a range of ways to improve their assumptions through new analysis and create convincing arguments to support their judgements. | The weakness of the initial utility function analysis and production function assumption are explored, and alternate versions are provided. [Production Function](#_Production_Function) & [Utility Function](#_Utility_Function). |
| Make predictions of the likely impact of their recommendations on the business/policy situation | Provided a prediction on the impact of this project on the analytical working environment between ex-DBT and ex-BEIS analysts, [Conclusion](#_Conclusion) |
| **Project management and planning** | **S5** Scope areas of work identifying objectives, analytical methods, resources required and potential delivery risks.Able to recognise when complementary expertise is required e.g., scientists, other social scientists, and data specialists. | Set out a clear project scope and had the correct resources to deliver the requirements of the project | This evidence by the inclusion of [Project Aims](#_Project_Aims) and [Output Objectives](#_Output_Objectives). The resources were in place to work on the project as best could give time constraints by reaching out to Trade Analysis with Ex-DIT |
| Understood the risks to the project and set out evidence of how these were mitigated during the project. | Evidence by the Risk Register:  Table 6 Project Risk Register |
| Have, where required, drawn on other sources of expertise and opinion to inform their results and ensure maximum impact. | The initial stages of developing this work required collaborating with trade Analyst in ex-DIT who have the sources and the expertise to inform the work in the project. |
| Demonstrate how the learning they have generated during the project could be used to inform future projects and/or the wider workplace. | This is evidenced in the recommendations in the [Conclusion](#_Conclusion) |
| Devised processes for interdisciplinary working or tools to improve the effectiveness of interdisciplinary working. | The join up and buy in from trade analysts has improved interdisciplinary working and enabled a smoother transition to a joint DBT analytical working environment. |
| **Effective communication** | **S7** Clearly communicate economic principles and concepts to non-economists; present trade-offs and uncertainties and articulate these clearly; frame advice, drawing on knowledge of stakeholders' positions, for maximum impact | Communicate complex economic ideas to a non-economist audience. | This is evidenced by the [Non-Technical Summary](#_Non-Technical_Summary) |
| Explore options and trade-offs. | Exploration of options and trade-offs is given in [Structural Choices](#_Structural_Choices) and by the paper covering multiple models and different function that could be used in the approach. |
| Set out key uncertainties. | ??? |
| Frames advice showing awareness of how stakeholders will react to analysis or recommendations. | The advice in the conclusion is continue working with the ex-DIT analysts shows how to best land the advice in the project by anticipating stakeholder reactions. |
| Demonstrates that they can tailor their communication approach to the needs of different audiences. | This is evidenced by the [Non-Technical Summary](#_Non-Technical_Summary) and the language in the [Conclusion](#_Conclusion) being tailored to the non-analytical audience. There is the inclusion of maps and charts to help communicate to those who benefit from visual explanations. Evidenced by  Figure 2  Figure 4  Figure 5 |
| **Horizon scanning** | **S6** Use horizon scanning methodologies to anticipate new trends, opportunities and challenges that may influence outcomes of interest to client. | Show how trends, future opportunities and future challenges will affect their analysis. | This evidence by the inclusion of the description of Governmental Departmental Changes which has helped motivate this project. |
| Demonstrate how their conclusions are resilient to future events or represent least regret solutions. | In [Data Limitations – SIC Codes](#_Data_Limitations_–) there is a discussion of how future changes to the automotive industry will impact the modelling. It presents a method to build resilience into the modelling for these future events. |
| **Maintaining quality standards** | **S8** Design Quality Assurance processes and implement these, following organisational best practices, and drawing on sources of external expertise; critically assess economic analysis and improve it. **B1** Ethical conduct: analyst attributes sources and ideas to their originator; provides honest advice on all relevant aspects to an issue; avoids bias. **B4** Rigour: demonstrates a commitment to detail. | Devise a robust quality assurance process for their work to ensure that analysis and written outputs are accurate and error free. | When creating the code of the models in the project’s steps have been taken to allow robust quality assurance. This includes:  Proper version control by using GITHUB.  Complete comments to enable others to follow. |
| Clearly set out and reference all the sources they use, including both data sources and the source of ideas. | Referencing system has been used and [Bibliography](#_Bibliography) provided to set out clearly the sources of ideas. The sources of data are provided with links to original data sets where possible. Evidence by footnotes 1, 6, 8, and 12. There has been necessary redaction of sensitive sources. |
| Selected the appropriate level of detail necessary to achieve the required output. | The paper is presented at different levels, [Non-Technical Summary](#_Non-Technical_Summary) and [Conclusion](#_Conclusion) for policy focussed readers as well as a detailed derivation for analytical interested readers, [Model Derivation](#_Model_Derivation). This will enable the recommendation of the paper to be understood by all readers. |
| • Compare their results with results from other methods or studies to check validity of results and conclusions. | The results from the equilibrium model were checked against the delta function to test their validity. The project is looking at an alternative methodology for a policy analysis, which has been used to check the conclusion against. |
| • Describe the steps taken to ensure that their analysis is free from bias. |  |
| • Ensure that inconvenient facts or analyses that do not fit their argument are addressed. | This paper included a through exploration of the weakness of the approach and provides full details of the limitation in the author ability to complete a full complex CGEM. Therefore, show that all facts and analysis has been included |
| • Draw on new sources of expertise that are external to their organisation which substantially improve the robustness of, or insight from, findings. | The |
| • Challenge conventional wisdom and/or existing approaches in a sensitive and effective way. | This paper is its challenge the conventional wisdom of the approach to sector intervention analysis by incorporating a new approach. However, it balances the |

Table QMUL KSBs

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1. [https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\_data/file/  
   1063330/Green\_Book\_2022.pdf](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/1063330/Green_Book_2022.pdf) [↑](#footnote-ref-1)
2. Gigafactory is the term for a site making cells to go into the batteries of EVs. [↑](#footnote-ref-2)
3. Redacted internal HMG source. [↑](#footnote-ref-3)
4. Redacted internal HMG source. [↑](#footnote-ref-4)
5. https://www.gov.uk/government/publications/levelling-up-the-united-kingdom [↑](#footnote-ref-5)
6. Redacted internal HMG source and reasoning. [↑](#footnote-ref-6)
7. <https://www.ons.gov.uk/economy/nationalaccounts/supplyandusetables/datasets/ukinputoutputanalyticaltablesdetailed> [↑](#footnote-ref-7)
8. This code runs: 01\_Packages.R & 02\_read\_data\_v2.R & 02a\_Start\_point\_data.R & 03\_Calibration\_v3.R & 04\_CGE\_Functions\_v\_2.R. [↑](#footnote-ref-8)
9. [https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/expenditure/datasets/  
   householdexpenditurebygrossincomedecilegroupuktablea4](https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/expenditure/datasets/householdexpenditurebygrossincomedecilegroupuktablea4) [↑](#footnote-ref-9)
10. Excluding mortgage interest payments, council tax and Northern Ireland rates [↑](#footnote-ref-10)
11. Although the data in the Education group had gaps unlike others, so likely not significant as a result as other groups. [↑](#footnote-ref-11)
12. survey of 4,000 consumers by leading supermarket media and promotions business Shopmium. [↑](#footnote-ref-12)
13. Source: <https://my.ihs.com/> [↑](#footnote-ref-13)
14. Excluding mortgage interest payments, council tax and Northern Ireland rates [↑](#footnote-ref-16)