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INPUT OUTPUT ANALYSIS: A PILOT STUDY ASSESSING THE FLOWS OF NPL'S IMPACT INTO FINAL DEMAND

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Input Output analysis: A pilot study assessing the flows of NPL's impact into final demand.

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ABSTRACT

The document describes a pilot study using Input-Output (IO) analysis to track the National Physical Laboratory's (NPL) support to businesses in terms of income and Gross Value Added (GVA) growth. It employs IO tables to account for interdependencies in the economy. The study identifies end-users of NPL's support as the broader economy, mapping its impact on final demand/use/GDP. It notes that injections into the economy, like investment and net exports facilitated by NPL, lead to real GDP growth. Additionally, it explores indirect benefits, such as those resulting from the dissemination of calibration knowledge. The analysis reveals that NPL's impact is particularly significant in boosting exports, with exports of goods to the EU and rest of the world being 2.69 and 2.75 times higher than the UK economy as a whole and suggests variations in impact across different NPL subdivisions. Moreover, it observes a decoupling between productivity growth and emissions, with economic impact increasing by 11.6% while emissions decreasing by 11.4% between 2016-2021. The study proposes further analysis, including a market analysis of NPL's supported firms and an investigation into its impact on trade. It acknowledges the limitations of the pilot study and the need for future research to address missing aspects such as health-based benefits and policy influences.

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EXECUTIVE SUMMARY

This document details a pilot study using Input-Output (IO) analysis to track NPL's support/input to businesses, in the form of competitively won income and the Gross Value Added (GVA) growth seen by its Regularly Supported firms (RSFs) as it flows through the economy. Given that nearly all the sectors of an economy are interdependent, the inputs aren't only flowing through them and their end-users. For example, energy is both consumed by producers and by end-users (households). Therefore, these flows need to be accounted for, to find the total spread of NPL's benefits. This is done using IO tables, which tracks these interdependencies.

Once the interdependencies have been accounted for, the ultimate purpose of NPL's support can be mapped. This purpose is the impact on the broader economy, as represented in final demand/use/GDP (Consumption, Investment, Net Exports). It should be noted that Investment and Net Exports are an injection into the economy, increasing the flow of money, while consumption merely represents the flow of money between consumers and businesses. Injections in the economy lead to real GDP growth, meaning if they are facilitated, broader economic growth would follow.

It should be noted that the GVA growth and income account for direct benefits, but there are also indirect benefits, which affect firms who don't work with NPL directly. This is due to the importance of fan-out, which accounts for the flow of measurement knowledge through the economy without IP controls. This is a market failure, providing rationale for the National Measurement System, from which NPL receives the majority of funding. The indirect benefits are accounted for in three main ways; 1) Comparing the indirect benefits generated by subtracting the direct benefits (inputs) from the total benefits, comparing the direct and indirect final demand ratios. 2) by looking at the sectors that disseminate calibrations, 3) tracking the Measurement Services (MS) income.

Having assessed the Final Demand breakdown, with both direct and indirect measures, export benefits of NPL's work were identified. Using quotients, NPL's impact is clearly channelled through exports to a much greater extent than the rest of the UK economy, with exports of goods to the EU and rest of the world seeing a proportion of benefits that are respectively 2.69 and 2.75 times higher than the UK economy as a whole. This shows a secondary effect to the initial productivity gains companies see by working with us. These gains also appear to differ by NPL's sub-divisions, called sectors, with areas such as Digital & Quantum impact on the export of services being 1.72 times higher than NPL more broadly. This suggests a "one-size-fits-all" approach doesn't work when trying to assess the sectors given their varying impacts on final demand. Another interesting effect that is seen is that the productivity growth generated by NPL's work appears to have been "decoupled" from the expected increase in emissions, with economic impact increasing by 11.6% while emissions decreasing by 11.4%. This could be due to general decarbonisation or the make-up of NPL's support shifting towards more environmentally friendly sectors.

One major extension would be a broader market analysis into NPL's supported firms to better understand what NPL's services provide. This would help understand (for example) why NPL's end-users are far more export-focused than the rest of the UK economy. Other potential extensions include the use of the UK innovation survey's results to determine innovation focuses, a conversion from the one-year analysis done in this study to a time-series approach and a broad trade analysis to determine the impact of NPL's work on trade.

1 INTRODUCTION

This document details a pilot study into the implementation of Input-Output (IO) analysis using NPL's competitively won income and the Gross Value Added (GVA[1]) growth seen by its Regularly Supported firms, as described in Dias & King (2022). That report developed a metric based on the findings detailed in Nayak et al (2023), which determined that firms who either paid for a service or collaborated with NPL in five years out of a six-year window saw net-additional wage and employment growth. What previous studies didn't detail is where that GVA growth went subsequently. This section will set up some of the background, then provide context on input-output analysis more generally.

Inputs into an economy: As detailed in Nayak et al (2023), NPL's work with customers led to significant GVA growth, initially in the form of wage and employment growth. However, what wasn't assessed was where this GVA growth subsequently went. This value is effectively a net-additional input that is circulated through the economy, but in order to estimate the end-destination of the input within the economy, there must be an understanding of how different sectors work to produce their products (goods or services). Another way to assess NPL’s input is by looking at the income generated from customers (from both the public and private sectors), using willingness-to-pay to represent the value of the services.

Interdependencies within an economy: Complexity begins to arise in the production process. In the simplest world, each economic sector – Finance, Manufacturing, etc. – would be insular (only working with itself, not requiring any outside support). In this instance, the sector-level input would equal the sector-level output. But this does not happen in the real world. The most obvious sector of the economy that has major crossovers is the energy sector. Energy is required in all sectors to produce goods & services, be it the manufacture of furniture to financial services, while inputs into this sector include areas such as steel manufacturing, engineering services and fossil fuel production. Due to these interdependencies, statistical tools must account for the flow of inputs into the production process - otherwise known as intermediate consumption.

Destination of Products: Once produced, products have an end-point - the point at which they are used up - Final use/demand. There are four main aspects of Final Demand:

- Spending/Household Consumption (C)
- Investment (I)
- Government Consumption (G)
- Net Exports (NX)

It should be noted that Final Demand = Aggregate Demand = Gross Domestic Product (GDP). It should be noted that these aspects of Final Demand aren't all made equal. Firstly, the proportions of GDP they each respectively account for are very different. Household consumption accounts for 62.7% of GDP, while Investment accounts for 18.9% of GDP[2]. Also, growth in certain aspects of Final Demand also affect the scale of it in different ways. This is self-evident in the circular flow of money model. This model details how money flows from "producers to workers as wages and flows back to producers as payment for products" in the simplest form. But this doesn’t account for other aspects of final demand. An example of this model is detailed below[3]:

1 https://www.ons.gov.uk/economy/grossvalueaddedgva
2 https://www.ceicdata.com/en/country/united-kingdom
3 https://www.economicsonline.co.uk/managing_the_economy/the_circular_flow_of_income.html/

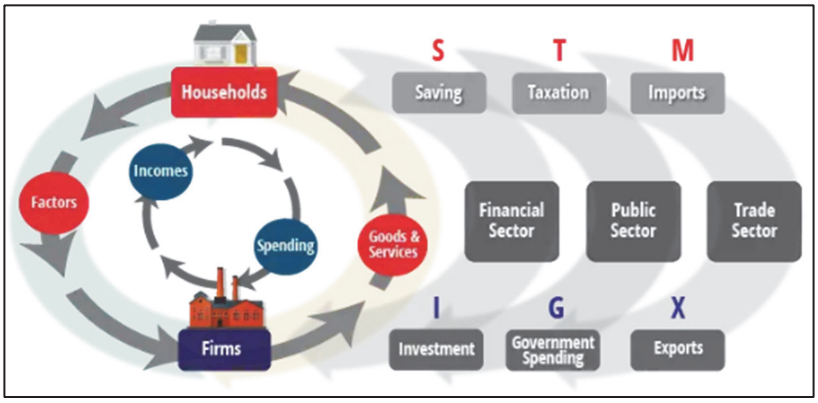


Figure 1

Here we see the incomes generated by firms which are provided to the households in exchange for their factor of production (labour/human capital), who in turn spend (consume) that income on goods & services. However, beyond this circular motion, there are injections and withdrawals, which increase and decrease the flow of money within the circular system respectively - effectively, the net scores between injections and withdrawals are the aspects of final demand, not including consumption. But unlike consumption, which is a function of the circular flow, the other three aspect are exogenous - i.e., the remaining aspect of final demand are a way to increasing the flow of income. Therefore, if NPL's work leads to greater injections into the economy, then it can be argued that there is a secondary effect to the initial wage and employment growth.

Beyond direct impact: As detailed in Dias & King (2023), the GVA growth is an example of direct impact, which is channelled through our customers and collaborators. However, the IO framework also allows for an assessment of where the income flows to, beyond the initial customers. This allows for indirect impact to be revealed, but this has been done in three ways. The first looks at the ratio between direct and indirect benefit as calculated within the IO framework, subtracting the direct from the total benefit, assessing which aspects of final demand are more affected by direct and indirect impact. The second looks at industries that link to fan-out and provide traceability across the economy. The third way looks at NPL's measurement services income, as they provide the top of the calibration chain. Outside of these methods, there are two non-private sector methods to track benefits from NPL's work.

Non-Private Sector benefits: Outside of the benefits detailed above, there were two other benefits that can be tracked. The first tracks NPL's public sector income, which shows the public benefits that can be attributed to NPL. The other looks at the emissions generated by NPL's benefits. Generally speaking, economic growth would lead to an increase of emissions[4], which is by nature a negative consequence of economic growth. The scale of this increase could be measured using emissions factors. By using a time-series, an assessment of emissions generated by productivity growth caused by NPL work can be seen.

Operational uses: As detailed before, if NPL's benefits are flowing to non-consumption aspects of final demand, there could be further analysis to determine whether there is a secondary impact to NPL's GVA growth. Another extension is using some of the indirect measures as a proxy to count indirect impact as a whole, while the emissions proxy could be used to assess environmental impact over time. Furthermore, the data can be segmented into NPL’s subdivisions, allows for a more granular analysis of NPL’s work.

This paper will progress as follows: Section 2 details the context of Input-Output analysis, providing background, prior examples of its implementation and a summary of the tables used. Section 3 details a small-scale, theoretical 2-sector model to detail how the analysis will be done. Section 4 converts the

4 https://www.iea.org/commentaries/the-relationship-between-growth-in-gdp-and-co2-has-loosened-it-needs-to-be-cut-completely

"parts" detailed in the 2-sector model for the broader UK economy. Section 5 looks at the results of the analysis, both providing an NPL top-line result and assessments of NPL's indirect benefits and environmental impact. Section 6 details potential extensions of the analysis, with section 7 detailing an early example of an extension, looking at the NPL sector splits in Regularly Supported firms and their final demand impacts.

2 CONTEXT

2.1 BACKGROUND

The purpose of IO analysis is to assess the interdependencies between different sectors of the economy using IO tables[5]. The columns and rows within these tables represent the sectors that make up the economy as a whole, with the data within the table represents the level of inputs into production – otherwise known as intermediate consumption[6]. Its original purpose was for informing a central planner on the impact of shocks on the broader economy in a given sector(s) – be it positive or negative. Though not initially applied in neoclassical economics and broader policy circles in the West, it's a tool used by a range of public bodies[7], such as the UK government (with the Office of National Statistics' Blue Book building IO tables to produces the National Accounts for a given year), the World Bank, the United Nations, and the U.S. Department of Commerce.

Their construction requires three main features[8]:

1. Harmonization of data – This includes matching years, transforming the data into a uniform valuation system accounting for valuations, adjusting for statistical treatments such as dummy sectors and *Financial Intermediation Services Indirectly Measured*, and classifying sectors to a common format (e.g., SIC codes)
2. Accounting for imports – This includes the construction of a cost, insurance and freight (CIF) import matrix, which requires harmonising the treatment of CIF and Free On Board (FOB)[9],splitting it into matrices by country of origins, then converting them from CIF to basic prices.
3. Linking and balancing the domestic and import matrices - join the classifications between the uniform and national input-output classifications, apply RAS algorithm[10] to establish row-column balances and then a consistency check.

Once constructed[11], IO tables allow for the assessment of three types of economic impact: direct, indirect, and final, which can otherwise be seen as initial, secondary, and tertiary impacts that ripple throughout the economy when a change is made to a given input level, operationalising those mentioned in section 1. The use of IO models allows for "economists [to] estimate the change in output across industries due to a change in inputs in one or more specific industries". Using a bridge construction example, the direct, indirect and final impact is as follows:

1. The direct impact of an economic shock is an initial change in expenditures. For example, building a bridge would require spending on cement, steel, construction equipment, labour, and other inputs.
2. The indirect, or secondary, impact would be due to the suppliers of the inputs hiring workers to meet demand.
3. The Final impact/demand would result from the investment benefits, which range from workers of suppliers purchasing more goods and services for personal consumption to reduced travel times, encouraging economic growth in the region.

5 https://www.investopedia.com/terms/i/input-output-analysis.asp
6 https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Intermediate_consumption
7 https://www.investopedia.com/terms/w/wassily-leontief.asp
8 https://www.cepal.org/sites/default/files/events/files/presentation_satoshi_inomata_ide_jetro.pdf
9 https://www.investopedia.com/ask/answers/020215/what-difference-between-cif-and-fob.asp
10 https://www.wikiwand.com/en/Iterative_proportional_fitting
11 https://www.investopedia.com/terms/i/input-output-analysis.asp

2.2 LITERATURE REVIEW

The origin of Input-Output analysis is detailed in Leontief (1936), detailing a method to understand the interdependencies of various sectors within an economy. Leontief developed a model that quantified how changes in one sector of the economy wou ld affect others. This was designed as a more advanced, US version of the Tableau Economique designed by Frederic Quesnay in 1758[12]. The IO analysis pioneered by Leontief led to a new field of analysis concerning the assessment of complex systems within an economy. In time, this field expanded into a variety of theoretical and applied fields, with environmental, trade and stochastic IO fields as a few examples. Books such as Leontief (1986), Miernyk (1965), ten Raa (2006) and Miller & Blair (2009) all detail the background and fundamentals of IO analysis.

Within this field, there have been a range of applications of IO analysis in recent time. ten Raa and Wolff's (2000) paper uses IO analysis to determine the main drivers of Total Factor Productivity[13] (TFP) growth in the US economy, detailing 10 "engines of growth", which required IO tables to detangle the interdependencies. Gregory & Greenhalgh (1997) uses IO analysis to determine the effect of trade patterns on the structure of the UK economy, particularly its industrial sectors, and subsequently influence the demand for labour. Lave (1995) looks at utilising IO analysis to assess the impact of economic growth on the environment, particularly focusing on environmental pollutants. This was done by multiplying the total sectoral outputs (post IO analysis) by the sectoral discharge coefficients (amount of discharge by change in sector output) to see the overall effect. The total output detailed before is another expression that must be broken down. As detailed in Lenzen et al (2003), the use of IO allows for indirect effects to be accounted for, with this case study revealing that "total impacts are considerably higher than the on-site impacts". In this instance, the on-site impacts refer to direct ones, with IO analysis used to calculate the indirect impacts, leading to the total being the sum of both. IO analysis uses a range of different tables, but the one primarily used in this analysis is the Leontief inverse matrix. This matrix, as detailed explicitly in Dobrescu et al (2010), "allows for a wide variety of analytical and predictive simulations", with this paper using the matrix to determine the effect of a "change in final demand can have on the overall output". This is the reverse of the method used in this report, where we look at the impact of output on Final Demand.

It should be noted that this study is not the first time IO analysis has been conducted on NPL. As seen in PA consulting (1999), IO analysis was used to assess the effect of measurement capital per £million of Final Demand. That study found that measurement capital largely affects investment and exports, notably investment not including construction. This study will be building on the work done in that previous report in several ways. There will be different measures in input into the economy used, greater explanation of the methods and most importantly, the data will be much more up to date. Despite these differences, that study showed the feasibility of IO analysis with regards to the NMS and therefore, NPL.

2.3 TABLES TO USE

As detailed above, the base IO table merely shows the inputs required to generate the output for a respective sector. By itself, this table is informative but not useful as an analytical tool. What is interesting is the assessment of the per-firm inputs requirements for all producers to generate one unit of output, which concerns the flow of input through the economy as a whole. The first step in this transformation is by dividing the IO table by the total sector output. This produces the **A** table – Matrix of Coefficients: Direct input requirements per unit of output.

Once this has been constructed, an expression for the whole economy can be found using **A,** total output **X** and Final Demand **D** in the following form: X = AX – D. This is rearranged as follows: $X = AX - D \rightarrow D = X - AX \rightarrow D = X(I - A) \rightarrow \boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{D}$,

- Where $\boldsymbol{I}$ is an identity matrix = $\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$

12 https://www.wikiwand.com/en/Tableau_%C3%A9conomique
13 https://agridata.ec.europa.eu/Qlik_Downloads/InfoSheetSectorial/infoC27.html

X and D remain but a new term has been created which will be called $L = (\mathrm{I} - \mathrm{A})^{-1}$. L is the Type I Leontief Inverse (Product by Product) - Total input requirements per unit of final use – which is used for assessing the flow of input through intermediate demand into final demand. The calculation of the economy-wide L table is difficult to present due to its scale, but a smaller, 2-sector version of the economy should enlighten and demystify the full analysis.

3 SIMPLE 2-SECTOR MODEL

3.1 INTERMEDIATE CONSUMPTION – L MATRIX

Take a 2-sector economy producing x_i (i = 1,2) units of a single homogenous good. In order to produce x_i units of its goods, each sector would need a_{ij} units of input to provide the output. This example will use dummy numbers, with the units being £million. Assuming this to be true, we can also incorporate final output (the final output by each respective sector) as d_i. In this simple model, x_i would equal:

$$x_1 = a_{11}x_1 + a_{12}x_2 + d_1 \;\&\; x_2 = a_{21}x_1 + a_{22}x_2 + d_2$$

In this example, the following IO table (The a_{ij}s) was used:

Input-Output table	Production	Services
Production	100	50
Services	25	50

Table 1 – Basic IO table

Once we have the IO table, there is a 2-stage transformation conducted as detailed before. One thing to note is that the columns of the IO table + each sectors primary input (GVA growth into the economy) = Aggregate supply

Step One – divide the IO table and Primary Input (GVA – more on this in the input section below) through by Total use (= Aggregate Supply = Aggregate Demand):

Input-Output table	Production	Services
Production	100	50
Services	25	50
Primary Input (GVA)	200	150
Aggregate Supply	325	250

→

A matrix (Intermediate)	Production	Services
Production	0.308	0.200
Services	0.077	0.200

Table 2 – Calculating the A matrix

Step Two – having created the A table, the following equation can be used to generate the Leontief table: $\boldsymbol{L} = (\boldsymbol{I} - \boldsymbol{A})^{-1}$. This leads to the following:

A matrix (Intermediate)	Production	Services
Production	0.308	0.200
Services	0.077	0.200

→

Leontief Inverse	Production	Services
Production	1.486	0.371
Services	0.143	1.286

Table 3 – Calculating the Leontief Inverse

3.2 FINAL DEMAND – D MATRIX

We now have the analytical table to be used as part of the analysis, but we must also see how these goods are consumed. In this simplified model, a closed economy is assumed (no imports or exports), with the final demand **D** comprised of Consumptions and investment:

Final Demand	
Consumption	Investment
75	100
120	55

Table 4 – Final Demand Allocation

Quality check – making sure this all adds up.

In order to confirm that this model works, multiplying the Leontief Inverse by the Final Demand should return X (= $(\boldsymbol{I}-\boldsymbol{A})^{-1}\boldsymbol{D}$). This calculation is seen as follows:

			Final Demand				
Leontief Inverse	Production	Services	Consumption	Investment	Output of Multiplication		Total Use
Production	1.486	0.371	75	100	156	169	325
Services	0.143	1.286	120	55	165	85	250

Table 5 – Quality Check of the 2-sector model

Here we see the output of Multiplication adds up to Total Use for both Sectors, signifying the correct representation of the economy.

3.3 SHOCK/INPUT – Z MATRIX

As detailed in section 2.1, the focus of IO analysis is to assess shocks to the economy. In this analysis, the shock used is the planner input into an economy. This is described as a shock as it is net-additional to Gross Value Added (or GVA), which represents the Primary Input into the economy (As highlighted in blue in section 2.1), which is the same final demand/use at purchasers' prices minus Taxes less subsidies on products and use of imported products in intermediate demand.

As this input is net-additional to the primary input, it provides a boost to the 2 sectors, with the extent of the boost represented in the Z matrix. However, the extent of that boost each sector receives is dependent on how the 2 sectors interact with one another.

For this model, it is represented as follows:

	Production	Services
Planner input	10	10

Table 6 – Subsidy to the economy

However, the raw value of the input must be scaled to account for the size of the sector receiving it. For example, a sector worth £500 billion receiving £1 billion would notice that input far less than a sector worth £50 billion receiving that same £1 billion. To scale this, the input is divided through by Total Use, leaving the following Direct Planner Input Intensities:

	Production	Services
Direct Planner input intensity	0.031	0.020

Table 7 – Intensity of Direct Planner Input by sector

3.4 CONVERTING DIRECT TO TOTAL PLANNER INPUT

The initial division shows the direct effect of planner input, but the IO table and Leontief inverse show that there isn't a one-to-one relationship between input and output. If the off diagonals in the IO table = 0, it would suggest there would be no difference between input and output at a sector level (Economy Level would always add back up). As the off diagonals don't equal 0, this suggests that the input doesn't all go to the sector it's been directed to.

Therefore, one must pass the direct planner input intensity through the Leontief inverse to assess the Total flow:

		Production	Services
	Direct Planner input intensity	0.031	0.02
Leontief Inverse	Production	1.486	0.371
	Services	0.143	1.286
	Total Planner input Intensity	0.049	0.037

Table 8 – Calculation of Total Planner Input Intensity by Sector

3.5 SCALING FOR FINAL DEMAND

Once the total input intensity has been calculated, it must be scaled to account for Final Demand, the final use of these goods. In this model, it can either be consumed or invested. After multiplying Total Planner Input Intensity by final demand, you get the following:

	Consumption	Investment	Total Planner Input
Effect of Input on Final Demand	11.4	8.6	20
% Effect of Input on Final Demand	57%	43%	N/A

Table 9 – Final Demand calculations

What is seen is an asymmetric allocation to the aspects of Final Demand. Equal input in both Production and Services would lead to slightly higher levels of Consumption over Investment. This output would have several impacts for a planner. The most obvious one is that if a planner wished to increase investment, there would need to be an imbalanced division of input between the two main sectors.

4 ECONOMY-WIDE MODEL

4.1 BASIC LOGIC

In the simplified world, when inputs increase in sector x within the economy, this would lead to an increase in final demand. But the question is whether the increase of inputs in sector x solely affects sector x. If there were no overlaps between the sectors of the economy, it would assume that increasing GVA growth in one part of the economy wouldn't affect any other sector within the economy, which would be identified by the IO table being an identity matrix. However, there is a relationship between the various sectors of the economy due to much overlap and the relationship between primary, secondary and tertiary goods. Constructing this graphically:

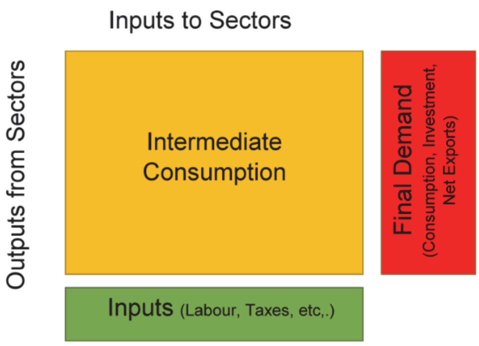


Figure 2 – Graphical construction of the IO model

This graphical structure is the basis of the analysis and should be kept in mind when considering the conversion from the simple model described before to the current one. The basic structure remains the same, but the parts themselves are now expanded to better account for the complexity of the real world. For the analysis, the 2019 Leontief matrix and final demand matrix were used, while the input data from NPL's sources all comes from 2021, unless stated otherwise.

4.2 LEONTIEF MATRIX – 105 SECTORS

The Leontief matrix remains but much more expanded, both in definition and scale to account for the complexity of the broader economy. They are constructed by a range of national and supra-national bodies, with the ones used here coming from the UK's Office of National Statistics. They are used to help calculate the UK National Accounts: Blue Book, which "record and describe economic activity in the UK and are used to support the formulation and monitoring of economic and social policies."[14] This data is compiled without political interference and are the best set of accounts for the UK economy.

Another change between the initial 2-sector economy and the expanded version is the products produced by each sector. In the simplified version, we assume homogenous products in each sector, but this isn't possible in the real world. Initially, the tables assess industry-by-product flows of capital across them. However, at an industry-by-product, the numbers won't add up due to the complexity of heterogenous products/services being produced. Therefore, the model is simplified by assuming and converting to product-by-product, allowing for the columns and rows to add back up. This adjustment is done by reallocating secondary production. Considering the product-by-product case, an industry's consumption of products is transformed to the production processes of products.

It should be noted that the supply and use tables (from which the IO tables are derived) measure the inputs used by an industry (using bakery as an example, even if a firm doesn't not produce bakery products); the IO tables show the inputs used to make bakery products (whoever creates them). This uses something called the hybrid technology assumption. The approach prefers the product technology assumption, that a product is produced using the same inputs, whoever produces it. This is the default. However, this can create negatives, and in these cases, the industry technology assumption is used – that an industry uses the same inputs regardless of the product produced. Applying the hybrid technology assumption transforms the domestic use table in basic prices, detailed in step 2 of section 2.1, into a product-by-product input output table.

This would effectively account for the Intermediate consumption of the domestic economy at basic prices, at a Product-by-Product level. In terms of scale, there are a much larger number of sectors, going from 2 to 105. The industries are categorised using 2 digit SIC codes and the SIC categories[15], detailing as follows:

14 https://www.ons.gov.uk/economy/grossdomesticproductgdp/compendium/unitedkingdomnationalaccountstheblu ebook/2022/anintroductiontotheuknationalaccounts

15 https://resources.companieshouse.gov.uk/sic/

A01	Crop And Animal Production, Hunting And Related Service Activities	E37	Sewerage
A02	Forestry And Logging	E38	Waste Collection, Treatment And Disposal Activities; Materials Recovery
A03	Fishing And Aquaculture	E39	Remediation Activities And Other Waste Management Services
B05	Mining Of Coal And Lignite	F41, F42 & F43	Construction
B06 & B07	Extraction Of Crude Petroleum And Natural Gas & Mining Of Metal Ores	G45	Wholesale And Retail Trade And Repair Of Motor Vehicles And Motorcycles
B08	Other Mining And Quarrying	G46	Wholesale Trade, Except Of Motor Vehicles And Motorcycles
B09	Mining Support Service Activities	G47	Retail Trade, Except Of Motor Vehicles And Motorcycles
C101	Processing and preserving of meat and production of meat products	H491_2	Rail transport
C102_3	Processing and preserving of fish, crustaceans, molluscs, fruit and vegetables	H493T495	Land transport services and transport services via pipelines, excluding rail transport
C104	Manufacture of vegetable and animal oils and fats	H50	Water Transport
C105	Manufacture of dairy products	H51	Air Transport
C106	Manufacture of grain mill products, starches and starch products	H52	Warehousing And Support Activities For Transportation
C107	Manufacture of bakery and farinaceous products	H53	Postal And Courier Activities
C108	Manufacture of other food products	I55	Accommodation
C109	Manufacture of prepared animal feeds	I56	Food And Beverage Service Activities
C1101T1106 & C12	Manufacture of alcoholic beverages & Tobacco Products	J58	Publishing Activities
C1107	Manufacture of soft drinks; production of mineral waters and other bottled waters	J59 & J60	Motion Picture, Video & TV Programme Production, Sound Recording & Music Publishing Activities & Programming And Broadcasting Activities
C13	Manufacture Of Textiles	J61	Telecommunications
C14	Manufacture Of Wearing Apparel	J62	Computer Programming, Consultancy And Related Activities
C15	Manufacture Of Leather And Related Products	J63	Information Service Activities
C16	Manufacture Of Wood & Products Of Wood & Cork, Except Furniture; Manuf. Of Articles Of Straw	K64	Financial Service Activities, Except Insurance And Pension Funding
C17	Manufacture Of Paper And Paper Products	K65.1-2 & K65.3	Insurance, reinsurance and pension funding services, except compulsory social security
C18	Printing And Reproduction Of Recorded Media	K66	Activities Auxiliary To Financial Services And Insurance Activities
C19	Manufacture Of Coke And Refined Petroleum Products	L683	Real estate services on a fee or contract basis
C203	Manufacture of paints, varnishes and similar coatings, printing ink and mastics	L68A	Owner-Occupiers' Housing
C204	Manufacture of soap & detergents, cleaning & polishing, perfumes & toilet preparations	L68BXL683	Buying and selling, renting and operating of own or leased real estate, excluding imputed rent
C205	Manufacture of other chemical products	M691	Legal activities
C20A	Manufacture of industrial gases, inorganics and fertilisers (inorganic chemicals) - 20.11/13/15	M692	Accounting, bookkeeping and auditing activities; tax consultancy
C20B	Manufacture of petrochemicals - 20.14/16/17/60	M70	Activities Of Head Offices; Management Consultancy Activities
C20C	Manufacture of dyestuffs, agro-chemicals - 20.12/20	M71	Architectural And Engineering Activities; Technical Testing And Analysis
C21	Manufacture Of Basic Pharmaceutical Products And Pharmaceutical Preparations	M72	Scientific Research And Development
C22	Manufacture Of Rubber And Plastic Products	M73	Advertising And Market Research
C235_6	Manufacture of cement, lime, plaster and articles of concrete, cement and plaster	M74	Other Professional, Scientific And Technical Activities
C23OTHER	Manufacture of glass, refractory, clay, porcelain, ceramic, stone products - 23.1-4/7-9	M75	Veterinary Activities
C241T243	Manufacture of basic iron and steel	N77	Rental And Leasing Activities
C244_5	Manufacture of other basic metals and casting	N78	Employment Activities
C254	Manufacture of weapons and ammunition	N79	Travel Agency, Tour Operator And Other Reservation Service And Related Activities
C25OTHER	Manufacture of fabricated metal products, excluding weapons & ammunition - 25.1-3/5-9	N80	Security And Investigation Activities
C26	Manufacture Of Computer, Electronic And Optical Products	N81	Services To Buildings And Landscape Activities
C27	Manufacture Of Electrical Equipment	N82	Office Administrative, Office Support And Other Business Support Activities
C28	Manufacture Of Machinery And Equipment N.E.C.	O84	Public Administration And Defence; Compulsory Social Security
C29	Manufacture Of Motor Vehicles, Trailers And Semi-Trailers	P85	Education
C301	Building of ships and boats	Q86	Human Health Activities
C303	Manufacture of air and spacecraft and related machinery	Q87 & Q88	Residential Care & Social Work Activities
C30OTHER	Manufacture of other transport equipment - 30.2/4/9	R90	Creative, Arts And Entertainment Activities
C31	Manufacture Of Furniture	R91	Libraries, Archives, Museums And Other Cultural Activities
C32	Other Manufacturing	R92	Gambling And Betting Activities
C3315	Repair and maintenance of ships and boats	R93	Sports Activities And Amusement And Recreation Activities
C3316	Repair and maintenance of aircraft and spacecraft	S94	Activities Of Membership Organisations
C33OTHER	Rest of repair; Installation - 33.11-14/17/19/20	S95	Repair Of Computers And Personal And Household Goods
D351	Electric power generation, transmission and distribution	S96	Other Personal Service Activities
D352_3	Manufacture of gas; distribution of gaseous fuels through mains; steam and aircon supply	T97	Activities Of Households As Employers Of Domestic Personnel
E36	Water Collection, Treatment And Supply		

Table 10 – The 105 sectors used in the UK's IO table

4.3 FINAL DEMAND

Beyond the simplified version of the D matrix, the closed economy assumption is relaxed, with Exports included and each category broken down into three subparts, detailed below:

- Consumption – by **Households**, **Government** and **Non-profit organisations serving households (NPISH)**. It should be noted that the vast majority of Government spending is consumption. This includes things such as benefits (state pension, universal credit etc,.) and defense spending. The only area that isn't is Investment in Capital, of which there are two kinds: Human Capital - Childcare, Healthcare, Education and Physical Capital – Roads, Trains, Energy.
- Investment – **Gross fixed capital formation (GFCF)**, **Acquisitions less disposals of valuables** and **Changes in inventories**. For the graphs and analysis, the components of investment outside of GFCF aren't used as they are much smaller (~99% of the UK's GVA growth that is channelled through Investment is GFCF).
- Exports – **Goods to the EU**, **Goods to Rest of the World (ROW)** and **Services.**

This data also comes from the ONS, which calculates this within the IO framework. A unique attribute that exists within the IO structure is how Imports are accounted for. Final Demand normally accounts for net exports rather than gross, with imports being subtracted from exports. As the UK hasn't had a trade surplus since 1997 (excluding 2020 due to covid), this number should be negative to return the correct value of Final Demand. This correction is done in the inputs line, where Imports (and Taxes) are subtracted from inputs to account for the correct Final Demand calculation.

Public Sector wrinkles to Final Demand

Given NPL's role as a public sector research establishment (PSREs), cutting across a variety of different social interests, it felt necessary to account for potential public sector impact of NPL's work. In order to assess this, columns were created so that the multiplication process would account for these sectors as if they were a part of final demand. Using a new, created column in the final demand matrix (e.g. Health & Social Care) and the totals of the relevant sectors (human health services and residential and social work), the health column was set equal to the totals of those sectors, then setting the rest of the row and column = 0. The pictures below display the changes:

	Industry	Final consumption expenditure by government	Final consumption expenditure by households	Final consumption expenditure by non-profit organisations serving households (NPISH)	Gross fixed capital formation	Changes in inventories	Acquisitions less disposals of valuables	Exports of goods to EU	Exports of goods to rest of the world	Exports of Services
M691	Legal activities	0	588	596	4,343	-581	0	0	0	6,727
M692	Accounting, bookkeeping and auditing activities; tax consultancy	0	142	1	130	0	0	1	1	5,768
M70	Activities Of Head Offices; Management Consultancy Activities	119	986	64	1,163	0	0	93	84	22,088
M71	Architectural And Engineering Activities; Technical Testing And Analysis	4	932	24	8,538	-493	0	159	145	13,240
M72	Scientific Research And Development	359	1,463	330	13,223	-17	0	424	384	5,385
M73	Advertising And Market Research	43	489	13	323	0	0	56	51	5,584
M74	Other Professional, Scientific And Technical Activities	3	1,107	4	202	0	0	96	75	3,395
M75	Veterinary Activities	0	3,622	1,075	16	0	0	10	9	14
N77	Rental And Leasing Activities	0	9,204	6	322	0	0	56	51	4,946
N78	Employment Activities	7	539	7	153	-1	0	1	1	4,035
N79	Travel Agency, Tour Operator And Other Reservation Service And Related Activities	0	18,130	3	61	0	0	50	45	204
N80	Security And Investigation Activities	0	203	1	73	0	0	3	3	366
N81	Services To Buildings And Landscape Activities	0	1,512	554	92	1	0	31	28	522
N82	Office Administrative, Office Support And Other Business Support Activities	8	1,492	10	441	-1	0	338	307	25,292
O84	Public Administration And Defence; Compulsory Social Security	138,155	5,088	19	2,417	0	0	0	0	2,293
P85	Education	58,783	24,848	28,673	6,113	2	0	7	6	11,222
Q86	Human Health Activities	140,250	14,065	2,814	1,095	0	0	80	73	549
Q87 & Q88	Residential Care & Social Work Activities	34,854	17,095	10,161	146	1	0	27	25	186
R90	Creative, Arts And Entertainment Activities	200	4,296	1,998	368	0	-804	11	3,805	360
R91	Libraries, Archives, Museums And Other Cultural Activities	1,077	334	157	27	0	519	14	751	464
R92	Gambling And Betting Activities	0	10,774	1	403	1	0	2	2	319
R93	Sports Activities And Amusement And Recreation Activities	2,325	13,906	588	336	1	-2	29	34	1,164
S94	Activities Of Membership Organisations	0	7,858	4,387	56	0	0	11	10	163
S95	Repair Of Computers And Personal And Household Goods	0	1,610	0	98	0	0	68	63	525
S96	Other Personal Service Activities	0	24,245	2	188	3	0	100	89	243
T97	Activities Of Households As Employers Of Domestic Personnel	0	3,582	0	0	0	0	0	0	23

	Industry	Final consumption expenditure by government	Final consumption expenditure by households	Final consumption expenditure by non-profit organisations serving households (NPISH)	Health & Social Care	Scientific Research	Security	Gross fixed capital formation	Changes in inventories	Acquisitions less disposals of valuables	Exports of goods to EU	Exports of goods to rest of the world	Exports of Services
M692	Accounting, bookkeeping and auditing activities; tax consultancy	0	142	1	0	0	0	130	0	0	1	1	5,768
M70	Activities Of Head Offices; Management Consultancy Activities	119	986	64	0	0	0	1,163	0	0	93	84	22,088
M71	Architectural And Engineering Activities; Technical Testing And Analysis	4	932	24	0	0	0	8,538	-493	0	159	145	13,240
M72	Scientific Research And Development	0	0	0	0	21,551	0	0	0	0	0	0	0
M73	Advertising And Market Research	43	489	13	0	0	0	323	0	0	56	51	5,584
M74	Other Professional, Scientific And Technical Activities	3	1,107	4	0	0	0	202	0	0	96	75	3,395
M75	Veterinary Activities	0	3,622	1,075	0	0	0	16	0	0	10	9	14
N77	Rental And Leasing Activities	0	9,204	6	0	0	0	322	0	0	56	51	4,946
N78	Employment Activities	7	539	7	0	0	0	153	-1	0	1	1	4,035
N79	Travel Agency, Tour Operator And Other Reservation Service And Related Activities	0	18,130	3	0	0	0	61	0	0	50	45	204
N80	Security And Investigation Activities	0	0	0	0	0	649.81	0	0	0	0	0	0
N81	Services To Buildings And Landscape Activities	0	1,512	554	0	0	0	92	1	0	31	28	522
N82	Office Administrative, Office Support And Other Business Support Activities	8	1,492	10	0	0	0	441	-1	0	338	307	25,292
O84	Public Administration And Defence; Compulsory Social Security	0	0	0	0	0	147972	0	0	0	0	0	0
P85	Education	58,783	24,848	28,673	0	0	0	6,113	2	0	7	6	11,222
Q86	Human Health Activities	0	0	0	158925.92	0	0	0	0	0	0	0	0
Q87 & Q88	Residential Care & Social Work Activities	0	0	0	62495.75	0	0	0	0	0	0	0	0
R90	Creative, Arts And Entertainment Activities	200	4,296	1,998	0	0	0	368	0	-804	11	3,805	360
R91	Libraries, Archives, Museums And Other Cultural Activities	1,077	334	157	0	0	0	27	0	519	14	751	464
R92	Gambling And Betting Activities	0	10,774	1	0	0	0	403	1	0	2	2	319
R93	Sports Activities And Amusement And Recreation Activities	2,325	13,906	588	0	0	0	336	1	-2	29	34	1,164
S94	Activities Of Membership Organisations	0	7,858	4,387	0	0	0	56	0	0	11	10	163
S95	Repair Of Computers And Personal And Household Goods	0	1,610	0	0	0	0	98	0	0	68	63	525
S96	Other Personal Service Activities	0	24,245	2	0	0	0	188	3	0	100	89	243
T97	Activities Of Households As Employers Of Domestic Personnel	0	3,582	0	0	0	0	0	0	0	0	0	23

Table 11 – Creating Public Sector Impact aspects of final demand

In total, three new aspects of final demand were created from the following Product Codes:

- Health and Social care:
  - Q86 - Human Health Activities
  - Q87 & Q88 - Residential Care & Social Work activities
- Scientific Research:
  - M72 - Scientific Research and Development
- Security:
  - C254 - Manufacture of Weapons and Ammunition
  - C303 - Manufacture of air and spacecraft and related machinery
  - J61 - Telecommunications
  - N80 - Security and Investigation services
  - O84 - Public Administration and Defence; Compulsory Social Security

It should be noted that these choices are, by nature, judgement calls. This means there is always a discussion on what should count as being relevant, with the aforementioned definitions open to debate in the future.

4.4 Z MATRIX - INPUT INTENSITIES

As detailed in section 3.3, a shock is required to be introduced as an input into the model. In this instance, the shock will be NPL's impact on its supported firms. Much like the 2-sector economy, the input is scaled by all output and represents the direct planner input intensity. Unlike the 2-sector model and PA consulting (1999), this study will use two different measures; NPL's competitively-won income and GVA growth seen in NPL's Regularly Supported Firms. In both instances, the values would always be x/P1 per sector, with x being either Income or GVA in £s per £million. The baseline used to compare NPL is the UK's primary input – GVA growth across the UK economy, indexed by sector.

The first method indicates the customer's willingness-to-pay and therefore, can be assumed to be the value of the private benefit of the good/service in question[16]. This method is simple as all that is required is deflated income data available from internal sources. The second uses NPL's regularly supported firms each year, which requires further description. Details for the data sitting behind this is detailed in the annex for Dias & King (2023).[17] It should be noted that NPL's impact on regularly supported firms is net-additional to the economy and can be viewed an an exogenous shock, which is detailed below:

NPL's GVA growth – Regularly Supported Firms

As detailed in a 2014 report by Haskel, Hughes and Bascavusoglu-Moreau, the quantifiable economic impact of public R&D is channelled through businesses with whom they are working. Therefore, to calculate the direct economic benefits channelled through the private sector, there needs to be an assessment on which firms see an effect from NPL's support when compared to a control group of firms who haven't received it.

As detailed in the analysis from Nayak et al (2022)[18], we see the following concerning support and the impact it has on those supported:

- "Support" is defined as either collaborating with NPL through R&D or payment for NPL's services.
- The "Regularly Supported firms" (RSFs) are those who were supported for at least five years within a six-year period.

16 https://www.wikiwand.com/en/Willingness_to_pay
17 https://eprintspublications.npl.co.uk/9634/2/Supplementary%20Information%20-%20User%20Data%20Analysis%20note.pdf
18 https://eprintspublications.npl.co.uk/9682/1/IEA17.pdf

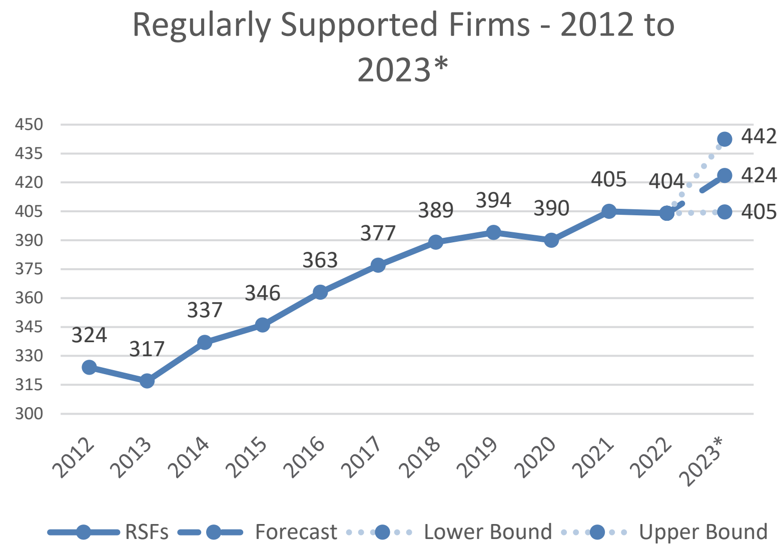
During 2022, NPL had 404 regularly supported UK-based firms. These firms grew by ~6.3 employees each year to support, with the employees who switch to one of these jobs see their annual wage increase by £4,080. These benefits last for around 6 years – discounted to 5.12 due to time preference. Using the above numbers, the overall benefit can be calculated in the following manner:

$$\text{"Extra Wages"} = \underbrace{404}_{\text{No. of Regularly Supported Firms}} \times \underbrace{6.3}_{\text{Employment Growth at Regularly Supported firm}} \times \underbrace{5.12}_{\text{Lifetime of benefits (discounted)}} \times \underbrace{£4{,}080}_{\text{Wage Premium for job switchers}}$$

Equation 1 – NPL's Wage Equation

1. The "Extra Wages" benefits are only one part of three elements that comprise a firm's Gross Value Added (GVA), with the other being profits for investors (capital) and taxes paid to HMRC – These add up **to ~£53.2 million** per annum.
2. As the taxpayer and investors see the same amount of benefit as workers, implying a flow of benefits amounting to **~£160 million**.
3. Indirect benefits from the diffusion of technological knowledge are typically twice that of the direct benefit to the original innovator. A lower bound for the total benefit (direct plus indirect) is **~£480 million**.

The only number that changes each year is the No. of RSFs, with each firm seeing an average effect of the subsequent three parameters. Therefore, it can be assumed that each firm sees an impact of approximately £1.2 million. As most firms is tagged to a 2-digit siccode, we can calculate the amount of GVA each sector receives from NPL's support. Below is the RSFs curve and a forecast for 2023's numbers, based on the previous year's dynamics:



Graph 1

What is notable is the changes in the rate of growth of RSFs over the time-period:

- 2015-2018: Median year-on-year growth of <u>**13**</u> RSFs
- 2019-2022: Median year-on-year growth of <u>**2**</u> RSFs

Here we see a considerable slowdown in the number of RSFs between the two windows, with the rate of growth reducing by 85%. There are both external and internal reasons for this. Internally, needed reform was undertaken, involving a portfolio-rebalancing exercise. It is possible that this process may have had a short-term effect on RSFs, though NPL only left a few areas. Externally, there are two main reasons. First, the Higher Education Institutions budget flat-lined between 2010 - 2017 (after accounting for inflation). This likely impacted the broader science base for several years, both during and following this period of fixed funding. Second, the COVID pandemic in 2020 compounded the aforementioned effect, leading to the first year of decline in RSFs since 2013. It should be noted that there is a prediction of growth in 2023, following a change in trend of the previous few years

It should be noted that there have been significant updates to the underlying data, which mean that this curve is significantly different to the curve in Dias & King (2023)[19]. The cause of this is twofold. Data on the grants/collaboration NPL does/did is pulled from Dimensions data. This process began in 2018, but the data wasn't backdated to previous years, leading to an incomplete time-series which misrepresent the level of collaborations at the time. Once the data was backdated, a new filter was introduced in the data-cleaning to best represent the full extent of NPL's collaborators. Firms that conducted Research Council Projects had to have a GRID id (a research-intensity identifier) to count as a proper collaborator. Innovate-UK and A4I-esque project collaborators don't require this filter. The purpose of this filter is to remove organisations that don't conduct R&D but would only look to be involve after the innovation has been completed.

Full details concerning this update will be detailed in the associated annex.

4.5 SUMMARY OF METHODS

As detailed in the simple 2-sector model, there are only two main steps for the analysis. Most of the tables are pre-prepared. The Direct Input Intensity is generated using the RSFs values as detailed before, tagged by sic code sectors detailed in section 4.2. The input would be divided through by the total output of a sector. Following the previous method as before, There are two sets of matrix multiplication. Step 1 is the 1st Matrix Multiplication - Direct Intensity is passed through IO to find total intensity. Step 2 is the 2nd Matrix Multiplication - Total Intensity is passed through the final demand matrix. This assesses how each industry's products are consumed, which is summed to assess the overall effect of NPL's input on Final Demand.

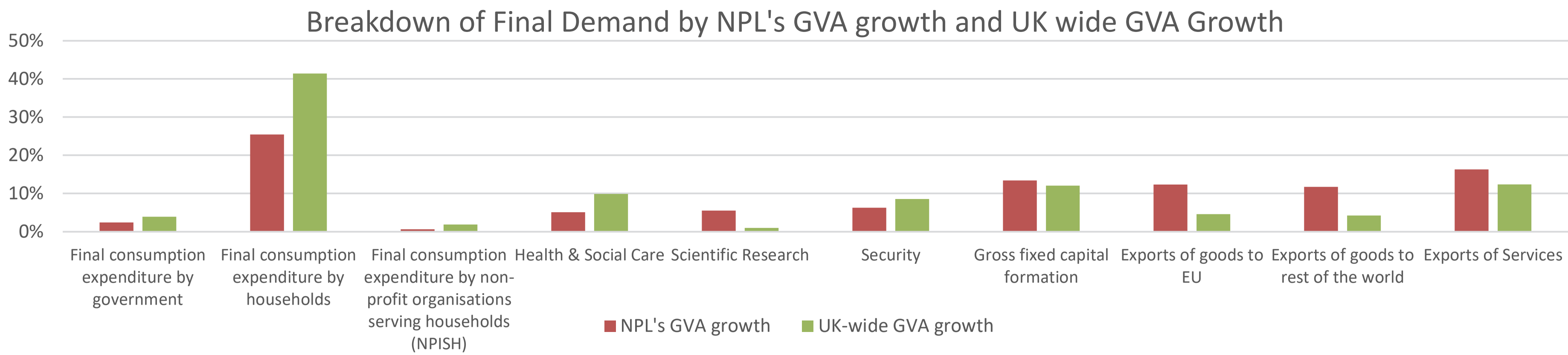
The other addition is that there needs to be a way to compare NPL to the UK as a whole (given that UK's primary input is used as a baseline). In order to do this, like Dias & King (2022) and (2023), location quotients are used. These are traditionally used in Economic Analysis to compare "a region's industrial specialization relative to a larger geographic unit" - effectively, it allows for an analysis that compares the subparts of a system to the system. In this context, this allows for a comparison of different metrics to a benchmark – with the benchmark being UK GVA growth, with the values produced representing the following:

- If the Quotient = 1, the aspect of Final Demand is **in-line** with UK GVA growth
- If the Quotient < 1, the aspect of Final Demand is **less concentrated** than UK GVA growth
- If the Quotient > 1, the aspect of Final Demand is **more concentrated** than UK GVA growth

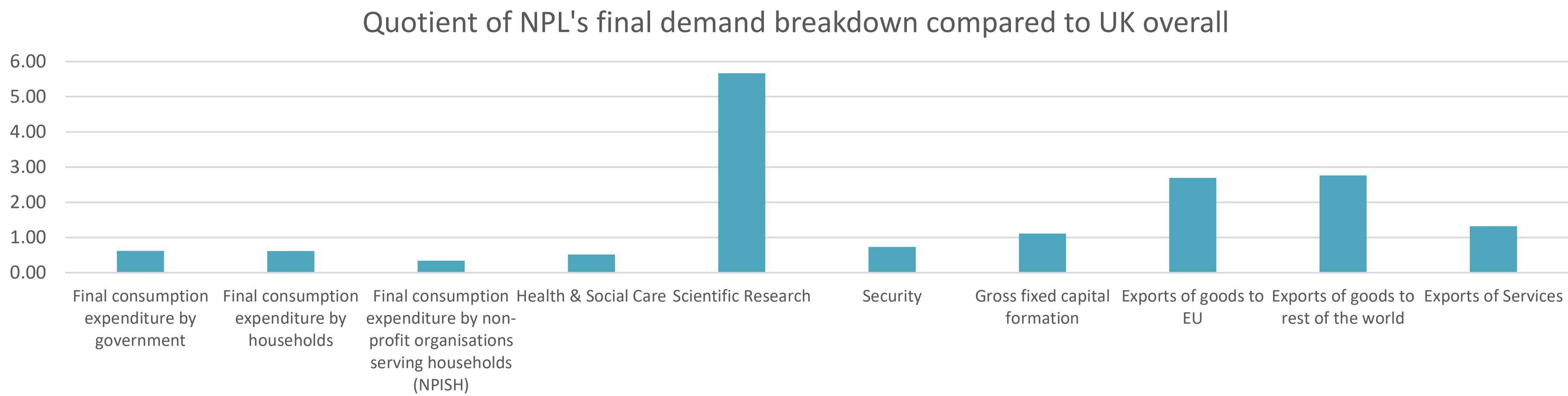
19 https://eprintspublications.npl.co.uk/9634/1/IEA13.pdf

5 RESULTS

5.1 NPL HEADLINES



Graph 2



Graph 3

When assessing the Quotients, there are two areas where NPL engages with Final Demand far more so than the UK – One of these is self-explanatory, the other isn't. The obvious one is Scientific Research – given NPL's research functions, it makes sense that NPL directly contributes to this area far more than the UK as a whole. It'd be deeply surprising if NPL wasn't contributing significantly to this area. The area that is more surprising is the link to Trade in Goods – While less than scientific research, Export of Goods appears to be greatly affected. This could be to help exporters meet foreign standards better, but would require further exploration to understand more fully.

5.2 INDIRECT & PUBLIC BENEFITS

The initial assessment looks at the flow of total benefits through Final Demand from NPL's work, but the same method can be applied to look at more specific aspects of NPL's impact, be it indirect, public or environmental. For example, the indirect benefits can be assessed using three main methods. Before detailing these methods, it is important that the term **fan-out** is properly defined – as it is heavily linked to NPL indirect benefits.

An aside on Fanout

Fan-out describes the flow of knowledge when NPL works with calibration labs to disseminate measurement standards. Calibration labs like Trescal and Keysight would have their instrumentation calibrated by NPL, who would then look to calibrate instrumentation for third parties and so on. This process allows for a traceable calibration chain to be constructed, where final products are known to be accurate as the instruments that measure them can be traced back to the national standards held by National Measurement Institutes, like NPL.

Now, once calibration labs have had their instruments calibrated by NPL, they can calibrate their customers instruments without having to pay royalties to NPL for any further work that they do. The reasons that there is a lack of copyright enforcement are twofold. Firstly, if it were possible, it would damage economic growth given the extra operating costs to pay for accurate measurements on an individual level. Secondly, and more importantly, it is effectively impossible to enforce copyrights on calibrations. Most calibrations are both non-divisible and non-rivalrous, key factors in the definition of a public/information goods. Once these forms of goods are in the economy, it is effectively impossible for the original creator to monetise any further resale of their good. An extreme example of this is the time signal disseminated by NPL, as one clock receiving the time signal doesn't remove the ability of another clock to receive that signal. The monetisation of the time signal is dependent on meeting regulatory standards, such as MIFID II's requirement for time-stamping of high frequency trading requiring high levels of granularity.

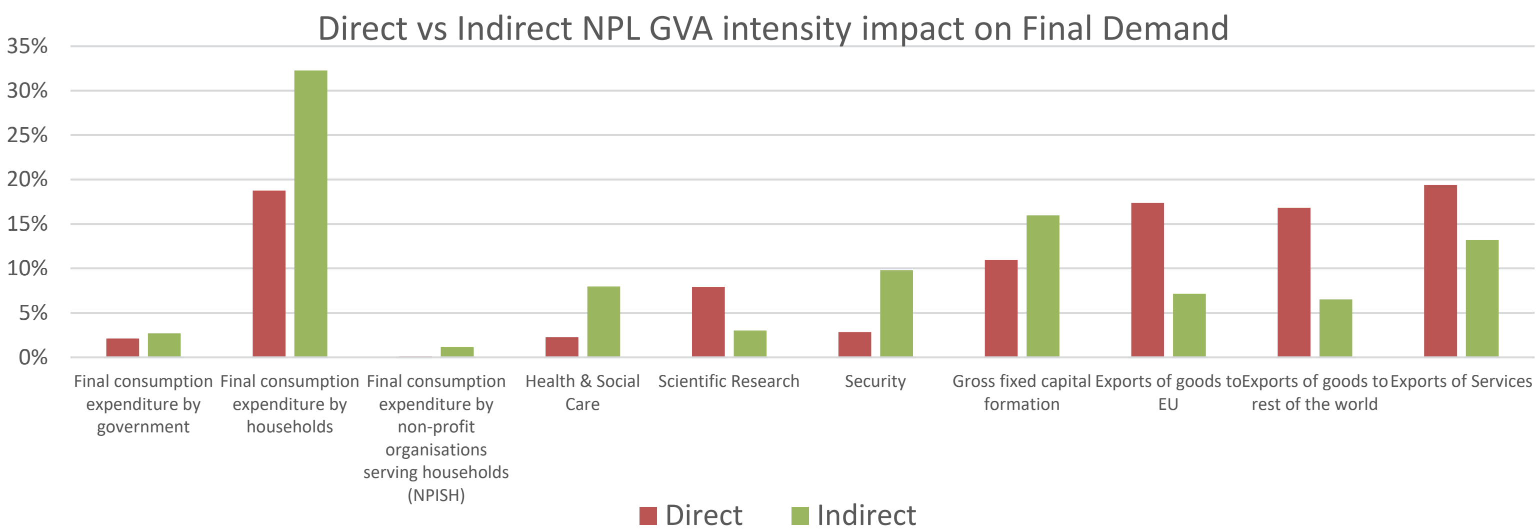
Where NPL does make revenue is on the constant improvement of its services. NPL's scientists are constantly improving the accuracy of its measurement services. These services, once established, are sold to calibration labs detailed above, who then serve the rest of the calibration chain. Due to their public good nature, NPL cannot make money in the provision of the same services.

Methods to assess indirect benefits

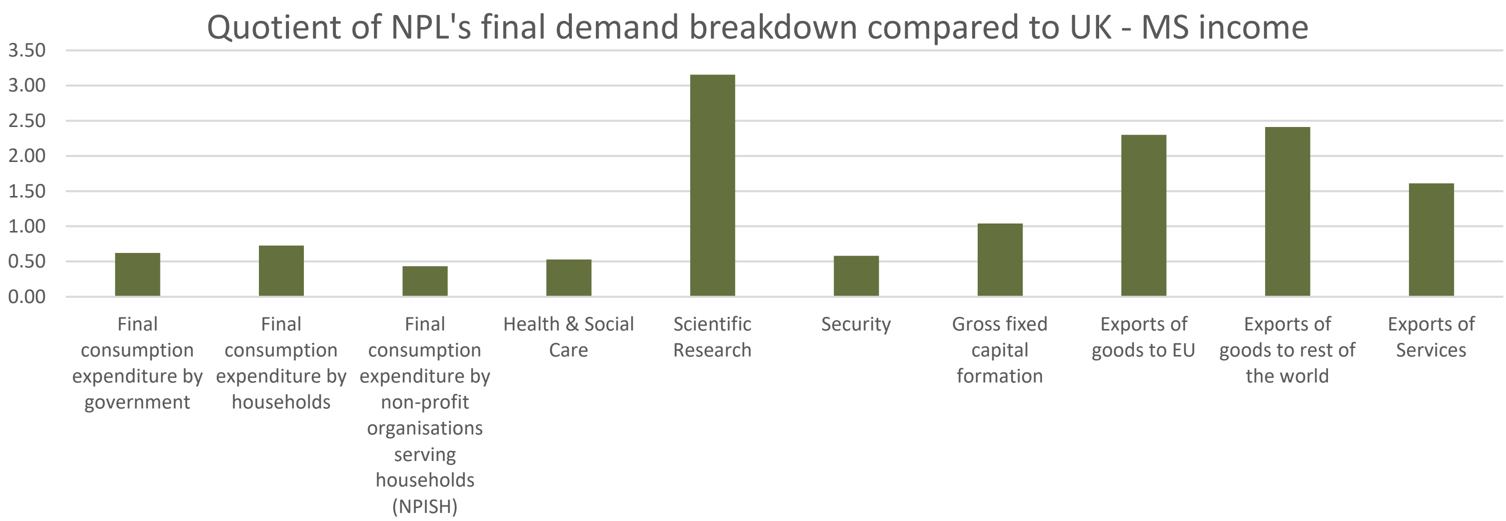
Having now defined fanout, we can use the tools at hand to better assess both it and indirect benefits more broadly. The first method focuses on indirect benefits as detailed in section 1.1. By the very nature of the IO tables, NPL's impact flows from those it has directly worked with to those that it hasn't. Therefore, we should be able to assess the scale of NPL's indirect benefit when assessing impact across the economy. The direct impact is determined the GVA intensities detailed before, while the total intensity is the allocation of GVA once the matrix multiplication has been passed through. Therefore, by subtracting the direct intensity from the total, we should be able to determine the total This in turn may allow NPL to determine the **extent of its fanout** – effectively how much of its impact is passed down the "Calibration Chain" and how far does it reach across the economy.
A second way is a derivative of the above method, but using specific sectors related to calibration and instrumentation. These are the methods through which traceability is accounted for down the calibration chain. The sectors that have been used for this are as follows: *C26 Manufacture Of*

Computer, Electronic And Optical Products, *M71 Architectural And Engineering Activities; Technical Testing And Analysis*, and *M74 Other Professional, Scientific And Technical Activities.* These choices are believed to best represent those disseminate calibrations down the calibration chain, though they are subjective choices that are open to interpretation

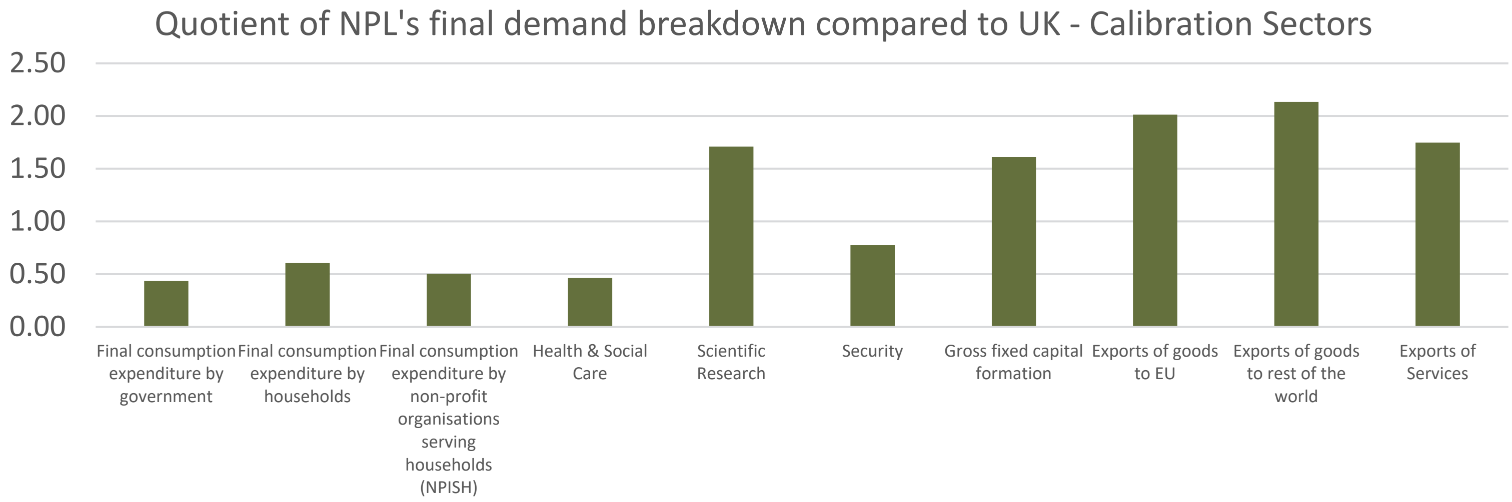
The third way of assessing fanout is by looking at the MS income, tagged by siccode. The Measurement Services provided by NPL are used to calibrate instruments at the "top of the calibration chain" which are then, in turn, used to calibrate all other instruments. The structure of this "chain" allows for all traceability to be tracked back to NPL's standards. Now, the IO table won't capture the entire chain, but would capture the top part, determining which sectors are most reliant on the granularity of NPL's measurements. This in turn can allow us to see which parts of Final Demand NPL's calibration services contribute to the most. It should be noted that this version doesn't capture the collaborative work. Below are the results from each of the methods, but it should be noted that this study is agnostic about which measure to use:



Graph 5



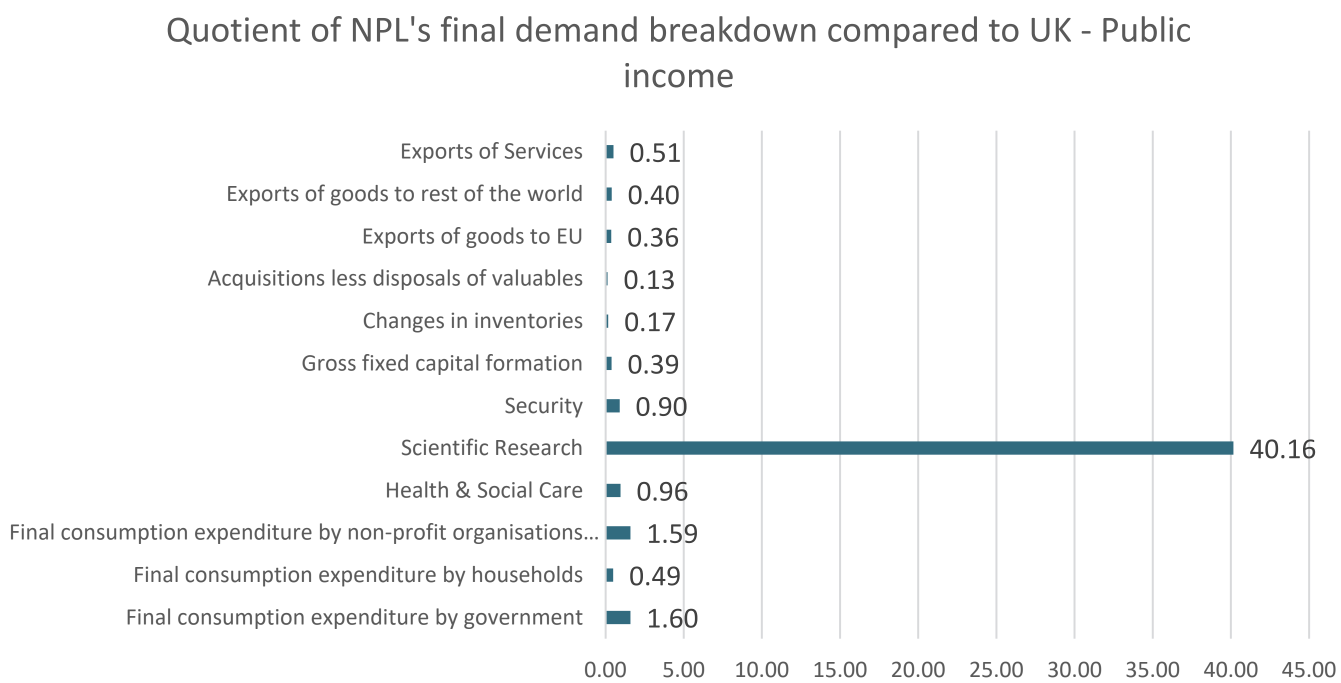
Graph 4



Graph 6

When looking at all three measures of Indirect benefits, a similar story is seen when compared to the total benefits numbers. When comparing the direct to the indirect, Scientific Research and Exports are significantly higher in a direct manner than the indirect. The remaining aspects of final demand are affected in an indirect manner, particularly Household Consumption and Gross Fixed Capital Formation. Looking at the calibration sector – Scientific Research, Gross Fixed Capital Formation and Exports are significantly affected by calibration. This is likely driven by these sectors requiring high levels of accuracy for their activities. Research needs accurate results, GFCF needs accuracy to assure that investments are being made correct and exports often require meeting foreign standards – this in turn requires measurement to meet those standards. Measurement services income is in-line with the calibration sector, apart from GFCF which is in-line to the UK economy.

The other segment of income to assess is the public income, which NPL receives from a range of different sources, which flows to the following segments of Final Demand:



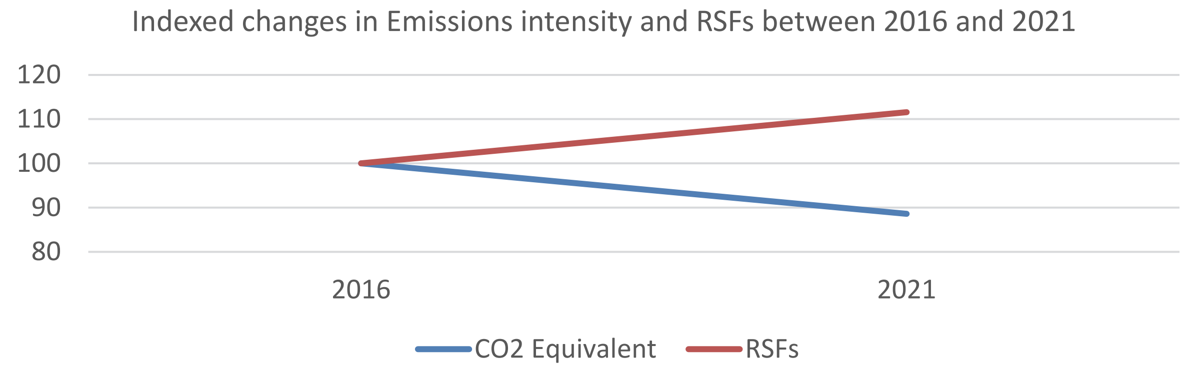
Graph 7

The public income is primarily channelled through the scientific research sectors, likely due to the public income generated from the University sector. It should also be noted that Consumption by NGOs and Government is also greater than 1. This could be driven by both PSREs and direct government spending on NPL's services. An example of this is the Heavy Metals Network, which NPL has run on behalf of DEFRA for several years. It should also be noted that PSRE spend on NPL could be captured in both consumption and Scientific Research.

Emissions Factors – GVA growth vs Carbon Equivalent emissions

The previous analyses all assess different forms of economic and social impact, but this tool can also be used to assess the impact of economic growth on the environment as well. This has been previously done in Lave (1995). This version uses a similar method, but with a different method to account for environmental damage. Rather than looking at toxic discharges, environmental damage is accounted for using emissions intensities, which accounts for the "emission rate of a given pollutant relative to the intensity of a given pollutant relative to the intensity of a specific activity". In this instance, the measure entails the ratio of greenhouse emissions produced relative to GDP - the exact measure being "Thousand tonnes CO2 equivalent/£ million". It should be noted that equivalent is used as CO2 is only one of many GHG gases, which include Nitrous Oxide, Ozone and Methane, along with CO2. These gases often have a higher greenhouse effect (Methane is 28 times stronger than CO220), so this allows for them to be standardised.

In this analysis, the factors are multiplied by the intensities to generate the amount of emissions generated by NPL's impact:



Graph 8

What is clearly seen here is that while NPL's RSFs have consistently grown between 2016 and 2021, the CO2 equivalent emitted has declined, running contrary to the expected effect seen over the past 150 years (more economic growth leads to more emissions). It should be noted that this decoupling is being seen across the world21. There are two potential drivers of this. First, it could be that the make-up of NPL's RSFs have changed. As the UK de-industrialises, the high polluting industries are the ones declining. This, in-turn, could reduce the number of NPL's RSFs from high carbon industries. Second, it could be that the economy more broadly has de-carbonised, leading to a decoupling of economic growth and emissions more broadly. It should be noted that the overall UK emissions factors have declined by 17% between 2016 to 2021, while the decline in emissions resulting from

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20 https://energy.ec.europa.eu/topics/oil-gas-and-coal/methane-emissions_en#:~:text=On%20a%20100%2Dyear%20timescale,on%20a%2020%2Dyear%20timescale.

21 https://www.iea.org/commentaries/the-relationship-between-growth-in-gdp-and-co2-has-loosened-it-needs-to-be-cut-completely#:~:text=As%20a%20result%2C%20economic%20growth,relationship%2C%20however%2C%20is%20changing.

NPL's impact is 11.4%, suggesting the NPL's customer base is decarbonising at a slower rate than the rest of the UK. This could mean that the latter hypothesis detailed above could be true but would require further investigation. Most likely, a balance of both of these factors likely sit behind this decoupling.

6 EXTENSIONS

The pilot study, in its current form, has allowed for a broad assessment of a range of different factors, assess total, indirect and public flows into Final Demand. But there are things that it has uncovered, such as a potential trade link between NPL's income and the UK's trade patterns. Given the strong link between exports and NPL's regularly supported firms, there should be further investigation of the drivers. This could be linked to NPL's foreign income, which could help to reduce trading barriers, as it could be argued that the foreign income helps to assure that UK imports are accurate. This could be done by using the research done by the Observatory of Economic Complexity[22], assessing the flows of trade and see if there is a correlation/causal relationship between NPL's income and trade flows. This would help to strengthen the economic case that NPL can make, given the current model doesn't account for foreign income or trade benefits. Another area for analysis that could be mined is due to the fact that the IO tables can be linked to the UK Innovation Survey. This in turn could be used to assess the impact of NPL's work on innovation outcomes, be it product/process innovation, scale of innovation, innovation factors and a range of other measures.

Another set of extensions that could be done is by increasing the granularity of IO analyses, covering a greater area than is done so far. The first way this could be done is by converting the analysis from a cross-sectional analysis to a time-series one, to see the changes in the various metrics over the years. This would be tricky as IO tables are updated yearly with a 4-year lag – so knowing which to use for each year is difficult. Potentially, the most recent one could be used, updated each year, but this is just speculation and can be decided at a future time. **BUT** by using a time-series, metrics could be developed to assess NPL emissions impact and fan-out (as initial examples). On the emissions part, there could be further investigation into why the decoupling between emissions and GVA growth has occurred. This could take the form of a market analysis, which assesses NPL's body of supported firms over time to see what it is made up of and how/if it has changed over time. The third way would be looking at segments of NPL. Thanks to the granularity of the data, equivalent analyses, as seen above, could also be done for the NPL sub-divisions. This has initially been done at an NPL sector level, which groups together a few different (but related) scientific areas.

7 SECTORAL ANALYSIS

NPL as currently constructed has four sectors:

- Advanced Manufacturing
- Digital & Quantum technologies
- Health & Life Sciences
- Energy & Environment

These are defined operationally**,** by looking at the sub-parts of NPL that are accounted for by each sector. The operational parts of NPL are the *Departments,* representing specific, scientific areas of expertise and will be listed in the sectoral allocations. It should be noted that some departments overlap different sectors. The groups sitting within a department can be/are amended to fit the research focuses with each department at the time. If just the department is listed, it is wholly represented by the respective sector. Further details of these sub-parts can be found in Yildiran (2024).

These are detailed in the table below:

22 https://oec.world/en

Advanced Manufacturing:
• Engineering
• Chemical & Biological Sciences
    • Surface Technology
• Data Science
    • Digital Manufacturing
• Materials & Mechanical Metrology
• Electromagnetic & Electrochemical technologies
    • Electronic and Magnetic Materials
    • Electrochemistry
• Thermal & Radiometric Metrology
    • Temperature & Humidity
	Life Sciences & Health:
	• Chemical & Biological Sciences
	    • Biometrology
	    • National Centre of Excellence in Mass Spectrometry Imaging
	    • Surface Technology
	• Medical, Marine & Nuclear
	    • Medical Physics, Radiotherapy, Nuclear Medicine

Energy & Environment:
• Atmospheric Environmental Science
• Medical, Marine & Nuclear
    • Underwater acoustics
    • Nuclear Energy
• Electromagnetic & Electrochemical technologies
    • Electrochemistry
    • Electromagnetic Technologies
• Thermal & Radiometric Metrology
    • Optical Radiometric Metrology
    • Climate & Earth Observation
	Digital & Quantum:
	• Data Science
	    • Data Analytics & Modelling
	    • Informatics
	• Electromagnetic & Electrochemical technologies
	    • Electromagnetic Measurements
	    • Electromagnetic Technologies
	• Quantum Technologies
	• Time & Frequency

Table 12 – Operational Definitions of the Sectors

7.1 PRIOR ANALYSIS OF THE SECTORS: CASE STUDY META-ANALYSIS

Dias & King (2022) details a prior analysis of the sectors, which entailed a meta-analysis of a corpus of case studies which stretch back 25 years. This intended to see where the sectors have been in the past, with the case studies undergoing a "kind of 'survey'. This is based on the belief that the sectors have pre-set "personalities" (Impact Profiles), which are quasi-fixed and can only be changed through evolution of the respective sector." "Each impact profile is unique and there is no preference between them from the perspective of Analysis & Evaluation. To reveal this "personality", each case study underwent a standardised coding procedure, where it was 'asked' a set of questions by reviewers and coded according to its 'answers'. Every case study was analysed independently of each other, and then segmented according to sector". The following graph was produced, detailing where the sector had sat with regards to direct, indirect and future impact:

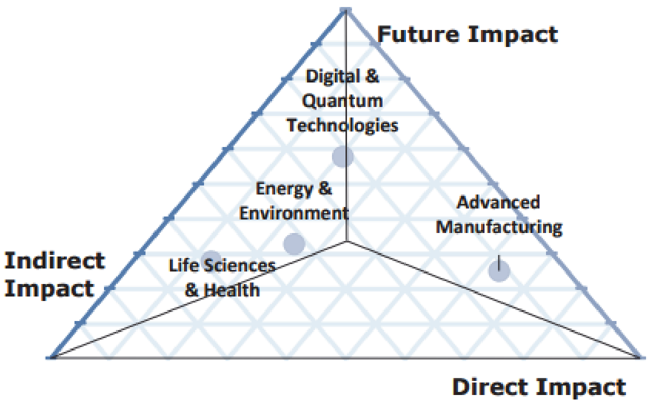


Figure 3 – Impact Profiles of the Sectors

It should be noted that this analysis goes through what has happened in the past, with the Digital & Quantum Technologies weighted towards Future Impact, Advanced Manufacturing weighted towards Direct Impact, Life Sciences & Health and Energy & Environment weighted towards Indirect Impact

7.2 METHODS USED TO COUNT SECTOR-LEVEL RSFS

To assess the RSFs at a sector level, there are two sets of methodological differences which look to account for the cross-overs between the sectors:

- Individual vs team/counterfactual differences
- Specific vs dependent firms

The first methodological difference concerning the calculation of the sectors. Using a football analogy, it's like assessing the performance of a player in isolation vs assessing what happens to the overall team's performance without that player in the starting lineup. A player may not have the highest statistical output (goals, assists, tackles etc.), but their role within the team may still be invaluable. This role can be better uncovered with advanced stats, but a simple way of assessing this would be to remove that player and assess overall team performance. This is the difference between the individual and team-based analysis.

Effectively, the player-based analysis treats each sector as a quasi-NPL, calculating their performance in isolation to the rest of NPL. The team-based performance removes the relevant support interactions tagged to a respective sector, then recalculates the RSFs, subtracting this new, lower RSFs number from the NPL headline to generate the sectoral counts. It should be noted that the team-based calculation is similar to how HM Treasury calculates the value of a programme. As detailed within the Green Book[23], HM Treasury uses counter-factuals, which effectively represents a baseline scenario

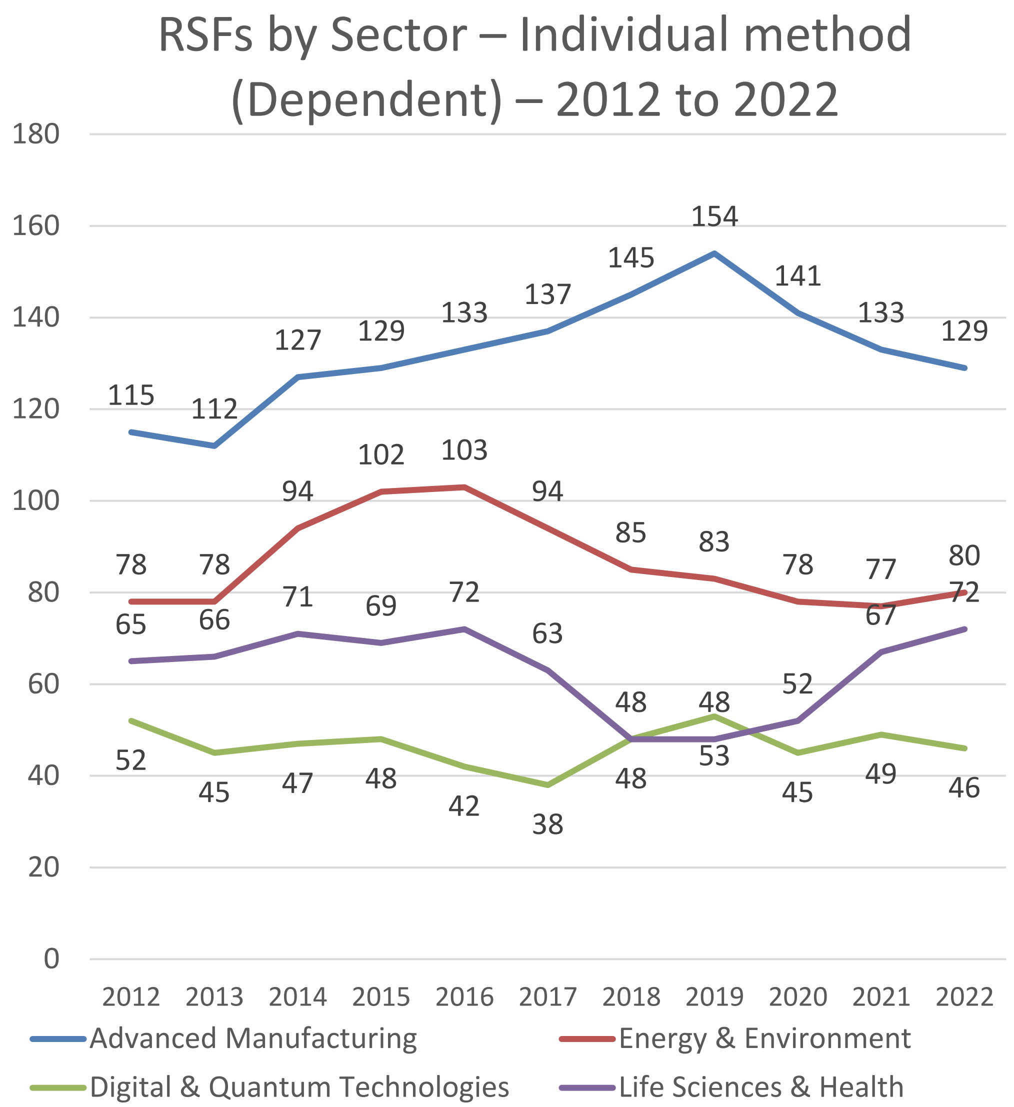
23 https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-government/the-green-book-2020

within which the outcomes are assessed in a world where the programme isn't funded and looks to calculate the loss of impact. These are typically constructed using statisical methods, with social sciences (like economics) tending to use tools like linear regression, but this sophistication prevents yearly repeatability. This means that generating a metric can be tricky, which is why the method detailed for the counter-factual method was used; it allows for a form of counter-factual which can be measured. It should be noted that this doesn't account for underlying factors, such as external and internal shocks. Rather, it acts as a scoreboard, much like the player-based analysis does but in a different manner.

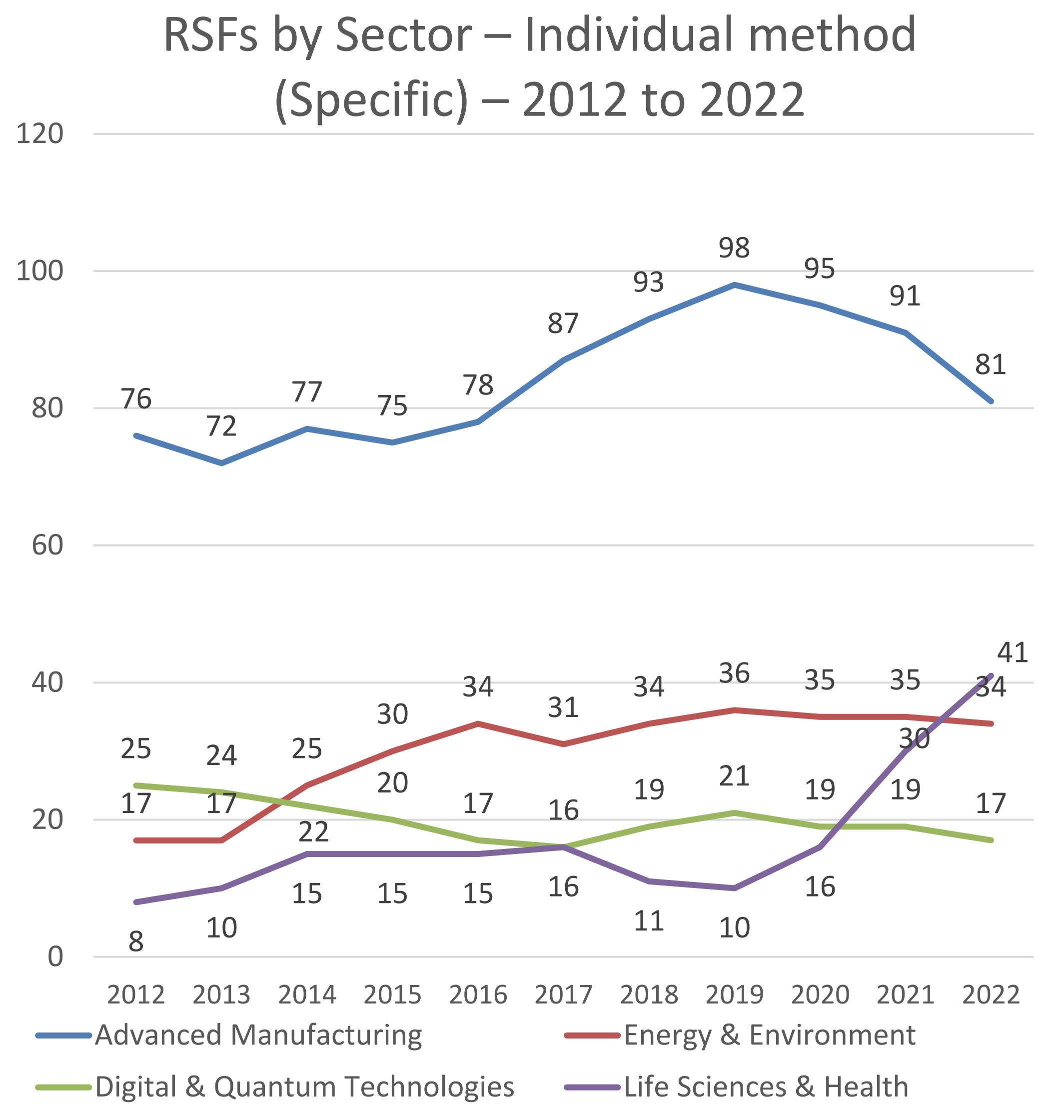
Each of these methods can be described as different windows into the same room. They provide different perspectives into the impact of each of the sectors. Each of these numbers could be used in different ways. Given the counter-factual method maps neatly onto the Green Book framework, it could be better suited for use during spending reviews and business cases, which relies on developing counterfactual scenarios if programmes weren't funded. The individual method could be better for internal monitoring and evaluation, properly assessing how the sectors are doing with regards to themselves. At the end of the day, these numbers are two manifestations of the same thing and there is no preference between either.

It can't be assumed that the team-based calculation is the correct estimation of how many RSFs would be lost if NPL were to lose a respective sector. Due to the cross-over, many RSFs work with significant sub-parts of NPL and knowing which part of NPL is their focus is impossible with the data at hand. This is why there is a second methodological difference within the data: Specific vs Dependent firms. **Specific** firms are ones that only work with one sector, they are "specific" to their respective sectors. **Dependent** firms work with a range of different sectors, they are "dependent" on sectors but not doing specific work with a sector.

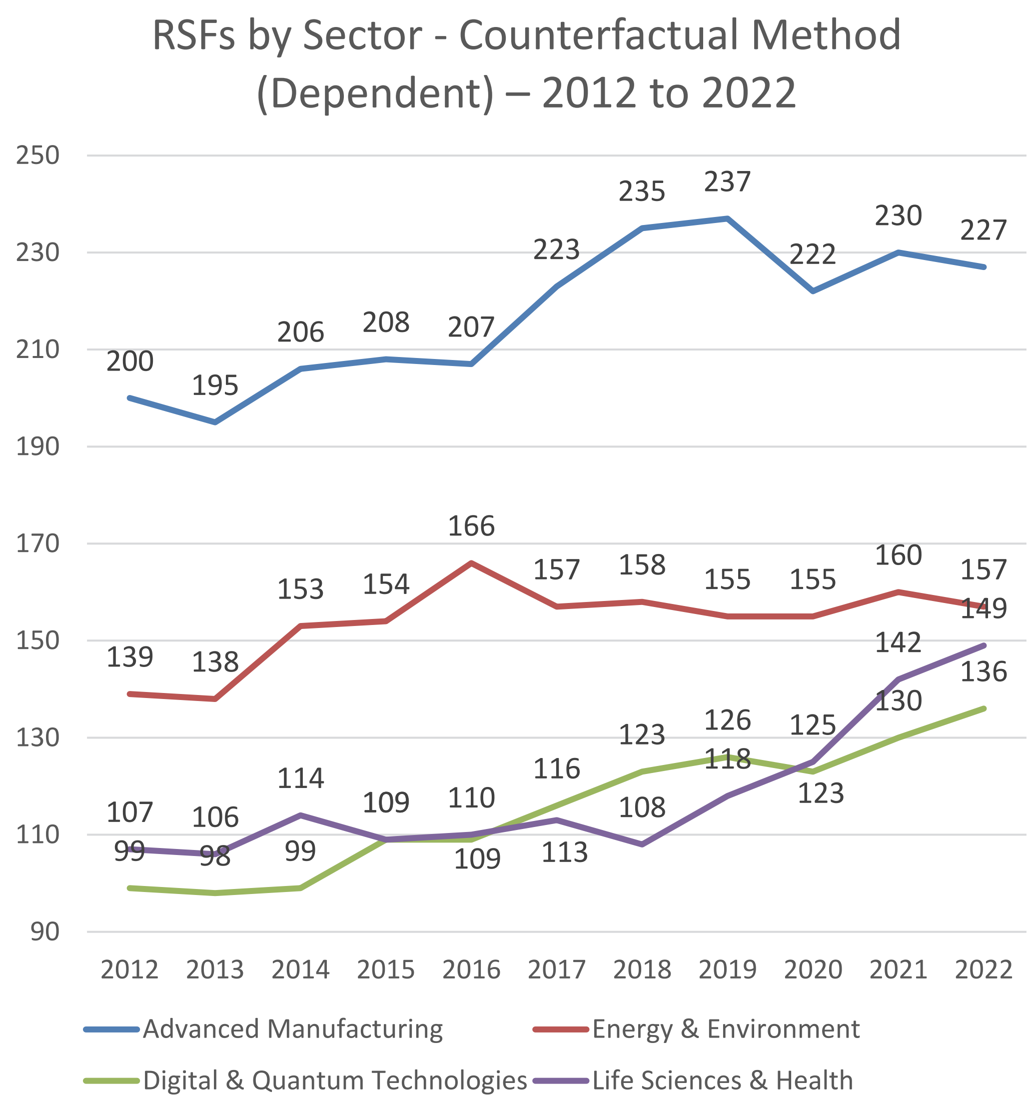
This different working relationship could be for different reasons. There are several operational departments within NPL that sit between multiple sectors (e.g. Medical, Marine and Nuclear sits between Life Sciences & Health and Energy & Environment), while some firms (often larger) work with multiple sectors. In order to simplify the structure, it is assumed that these working relationships are randomly distributed (i.e. there isn't a relationship between a sector and its firms' working relationships). As detailed above, the groups are able to re-shaped to best fit research areas, so the departments are the smallest structure that analysis can be done on, despite the complexity required when accounting for the NPL sectors. Examples of department level analysis can be found in Nayak et al (2024) and y could be utilised in further studies. Presentation-wise, the individual numbers will be presented, followed by the counterfactual ones (both with Dependent and Specific):



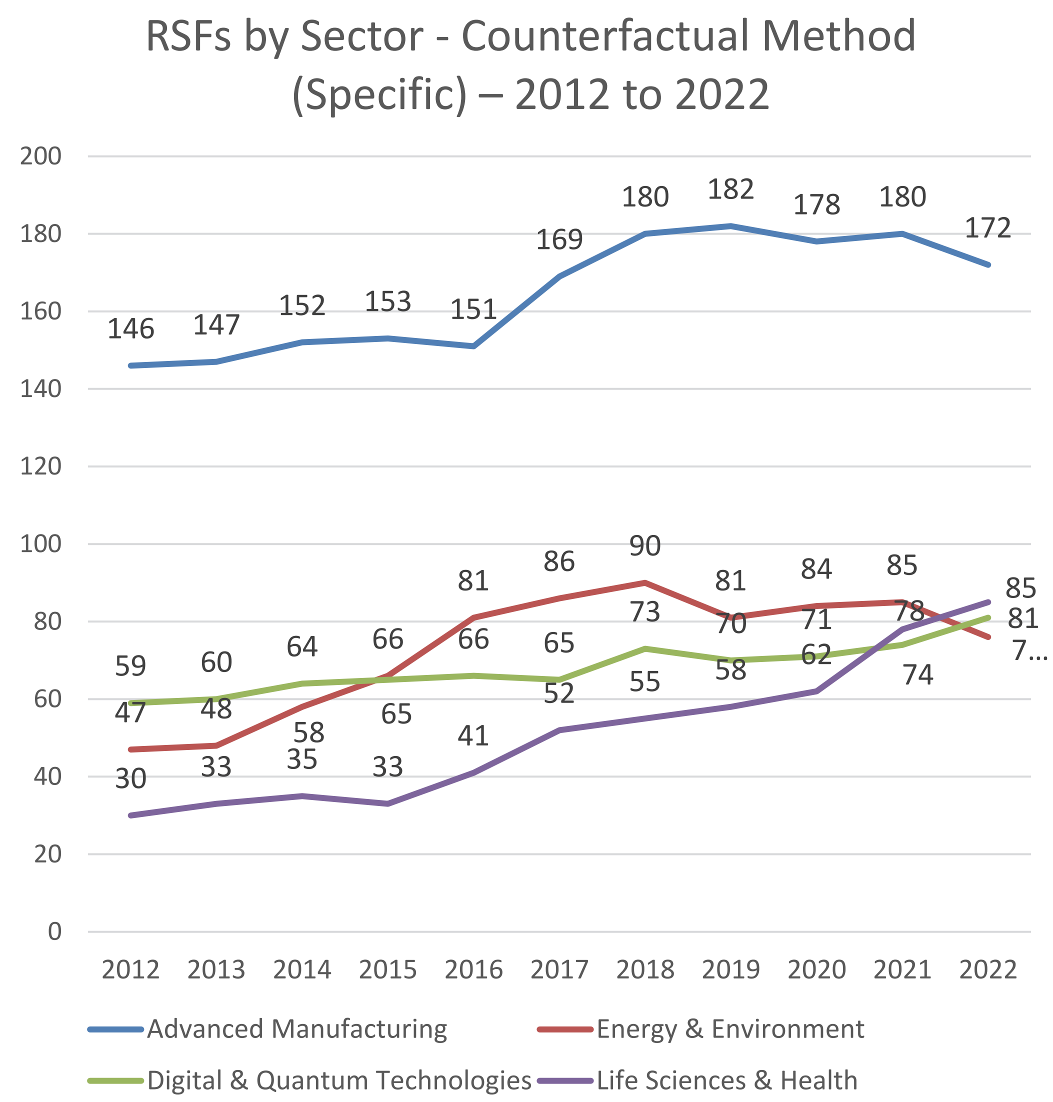
Graph 9



Graph 10



Graph 11



Graph 12

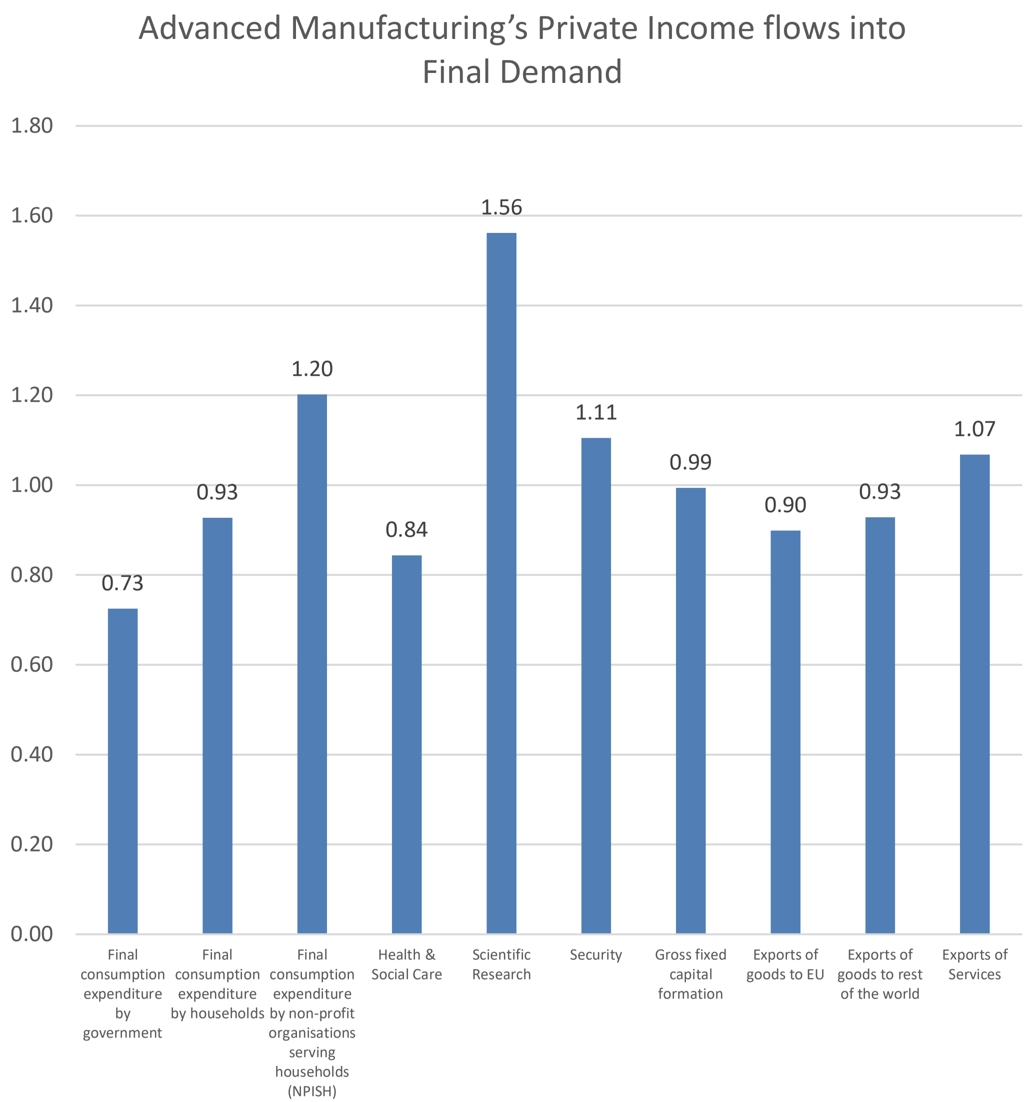
When assessing both methods, there are some fundamental similarities. Advanced Manufacturing is always set above the others, which makes sense given that its primary focus is facilitating economic growth. It saw consistent increase up to 2019, then a decline. This is timed with COVID and subsequent external effects, such as the cost-of-living crisis. However, the other three curves do differ:

Individual method: Energy & Environment sees its dependent firms peak in 2016, then decline subsequently, while its specific firms effectively flatline from 2016. This suggests its increase in dependent firms was driven by the increase in specific firms, showing a greater prioritisation of Energy & Environment-only firms. Life Sciences shows two different stories between the dependent and specific curves. The dependent curve saw a decline and recovery over the period, while the specific curve just saw the increase from 2019. This suggests that Life Sciences has been able to establish a unique set of firms that only works with them, which is much more robust than just relying on dependent firms. Digital and Quantum RSFs numbers effectively flat-lined over the period.

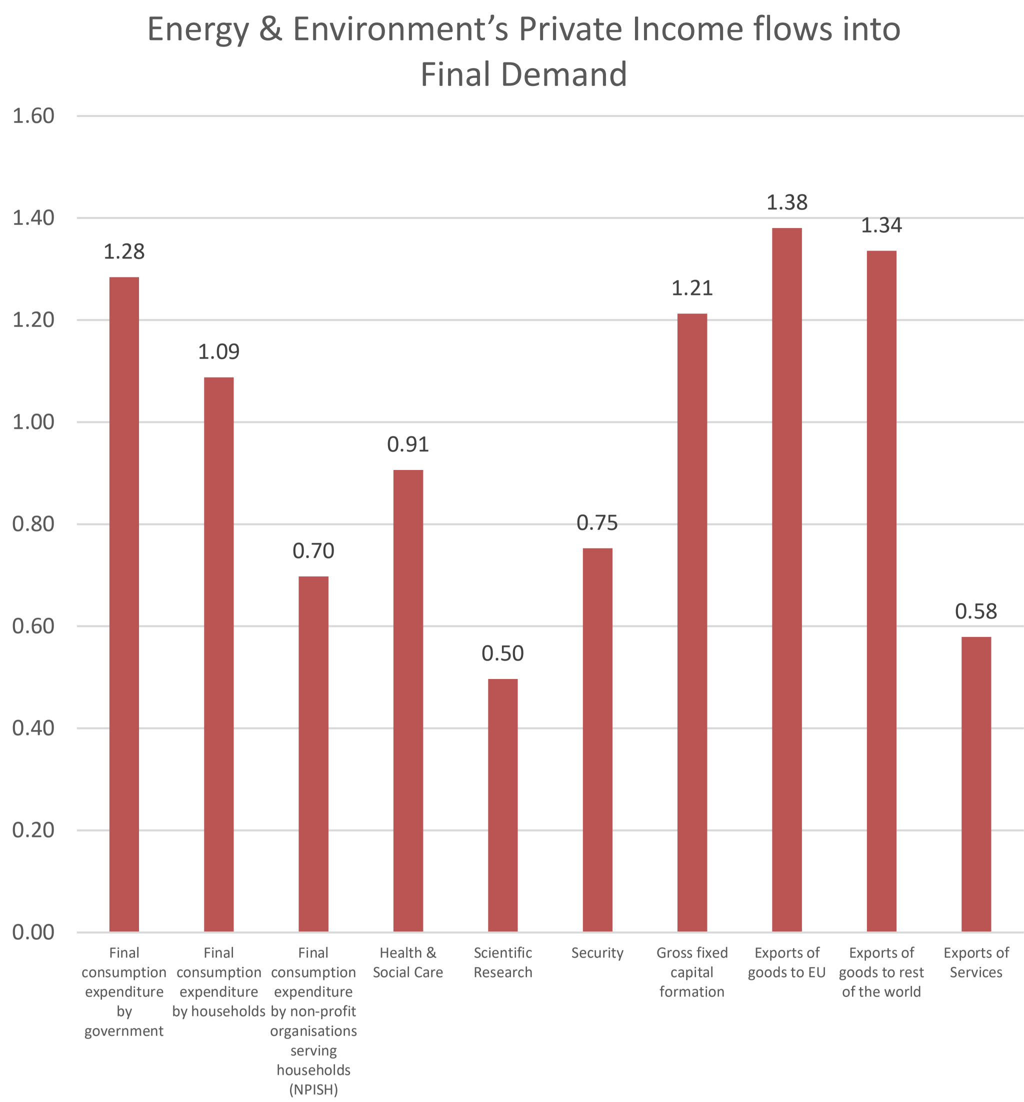
Counter-factual method: The three sectors appear to be tending towards each other, particularly on the specific firms' measures. Energy & Environment has flatlined since 2016, while the other two have seen different levels of growth. Concerning dependent firms, Digital & Quantum and Life Sciences saw increases at similar levels over the period, though Life Sciences has seen much higher growth in recent years. Concerning specific firms, Digital & Quantum saw slower increases when compared to Life Sciences, with Life Sciences overtaking all sectors other than Advanced Manufacturing in 2022.

7.3 INPUT-OUTPUT SECTORAL ANALYSIS

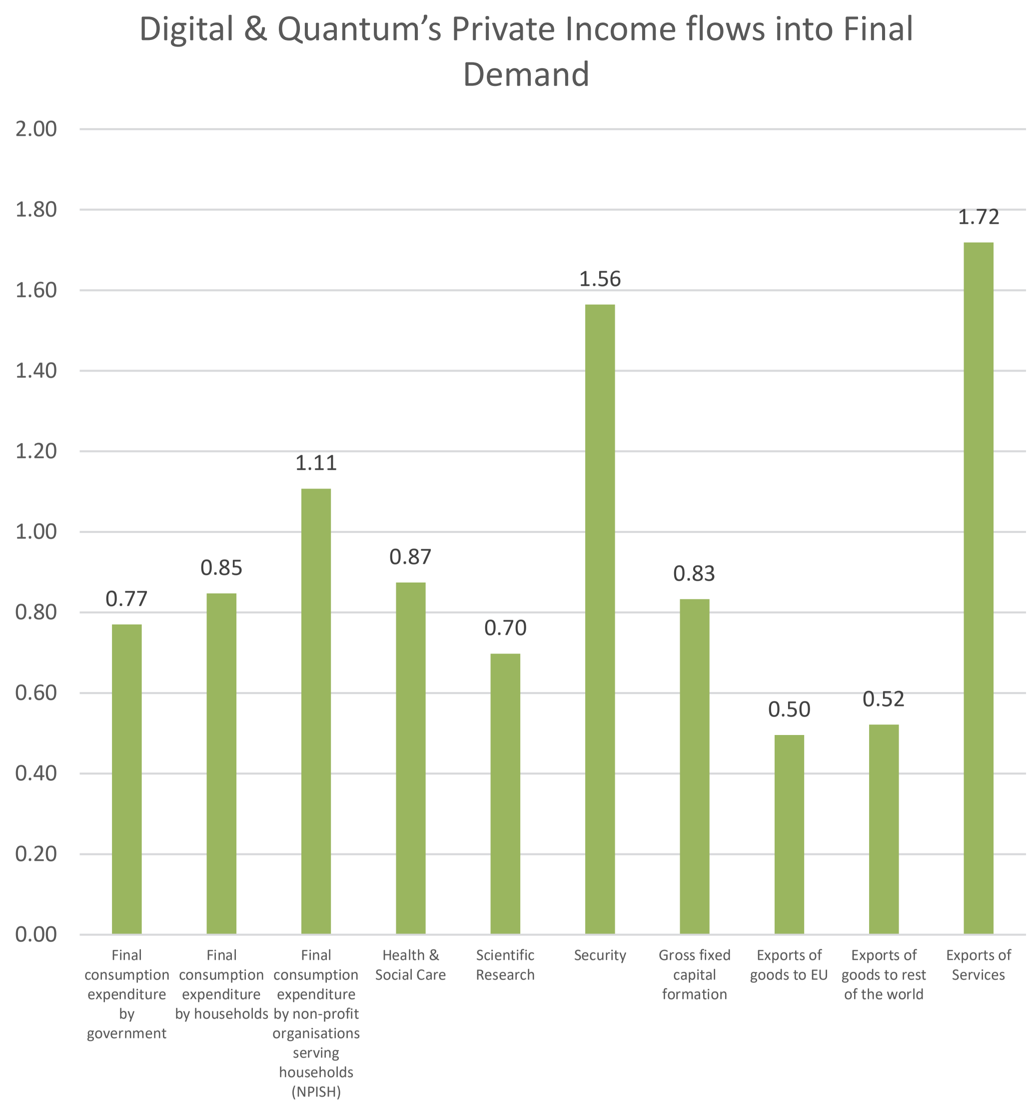
Given that the data is segmented into sectors, an IO analysis can be done in order to see which aspects of final demand are affected by each sector. Given the variation in scientific areas that the sectors work in, it can be assumed that there are different effects on final demand. A single year analysis was done for the four sectors, with 2021's income data used to determine the aspects of final demand that are affected by each respective sector. Both the Private and Public income was used in this analysis. In time, this could be done with the RSFs but this was unfeasible at the time of the analysis. Quotients have again been used, but this time the sectors aren't being compared to UK GVA growth, rather the base category is NPL's income. This provides a more sensible benchmark given that the sectors are the sub-parts that NPL is comprised of.



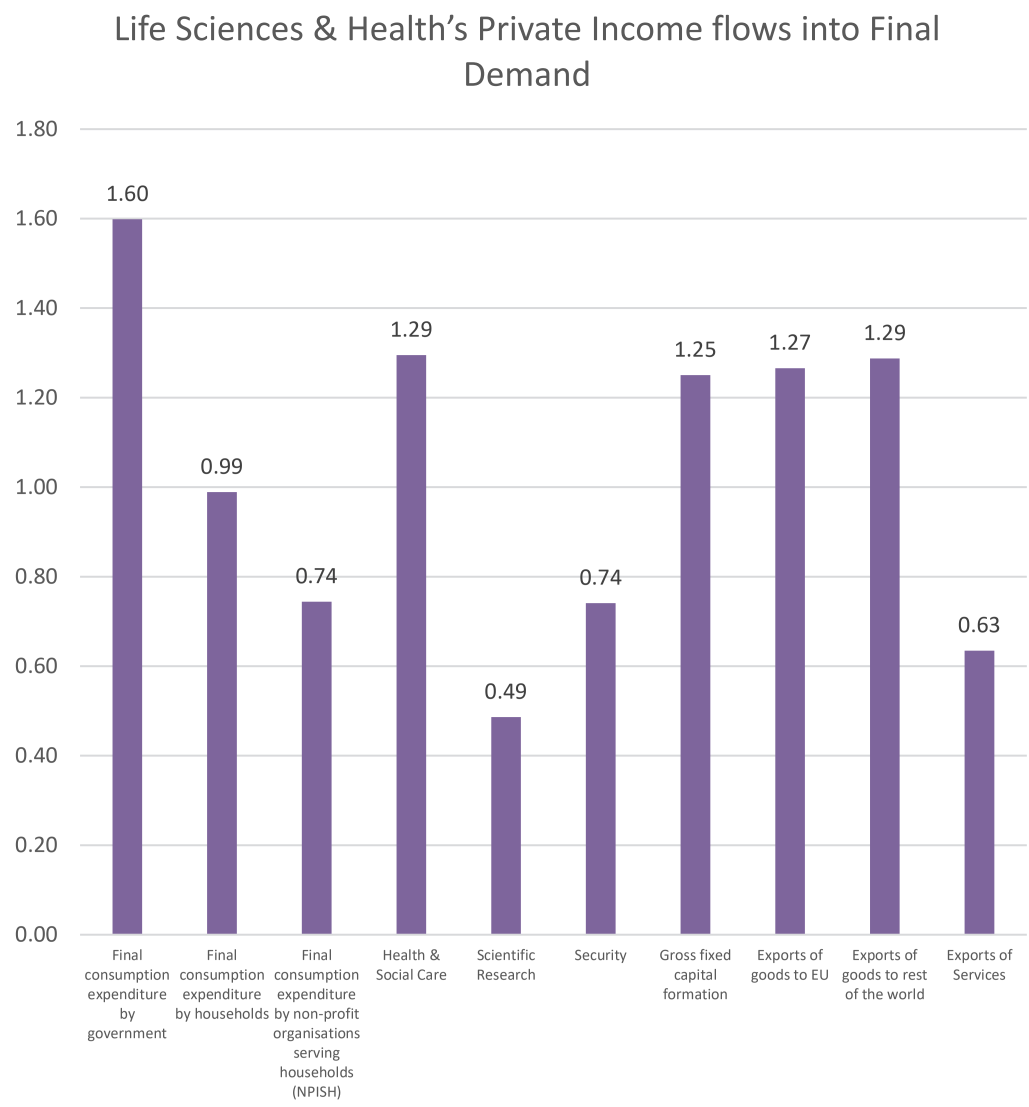
Graph 13



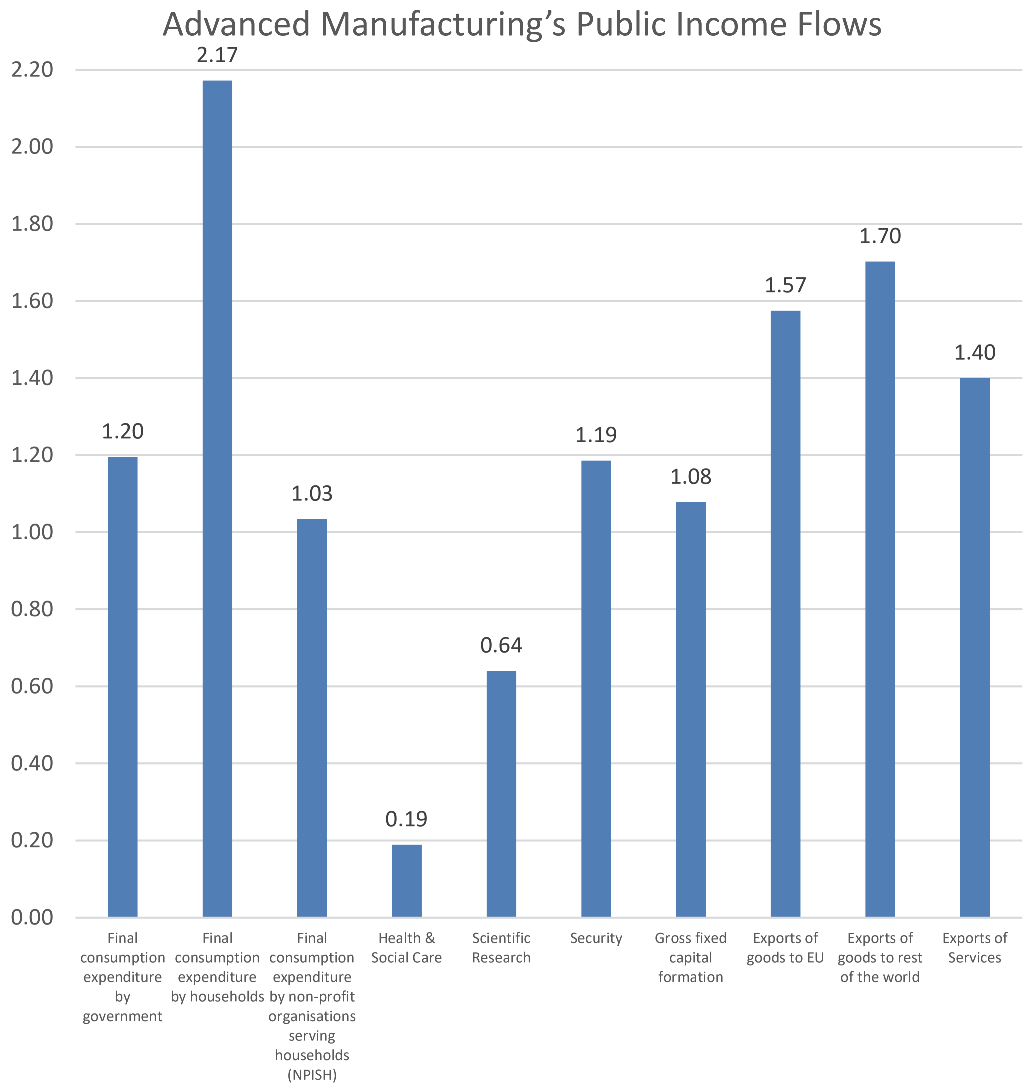
Graph 14



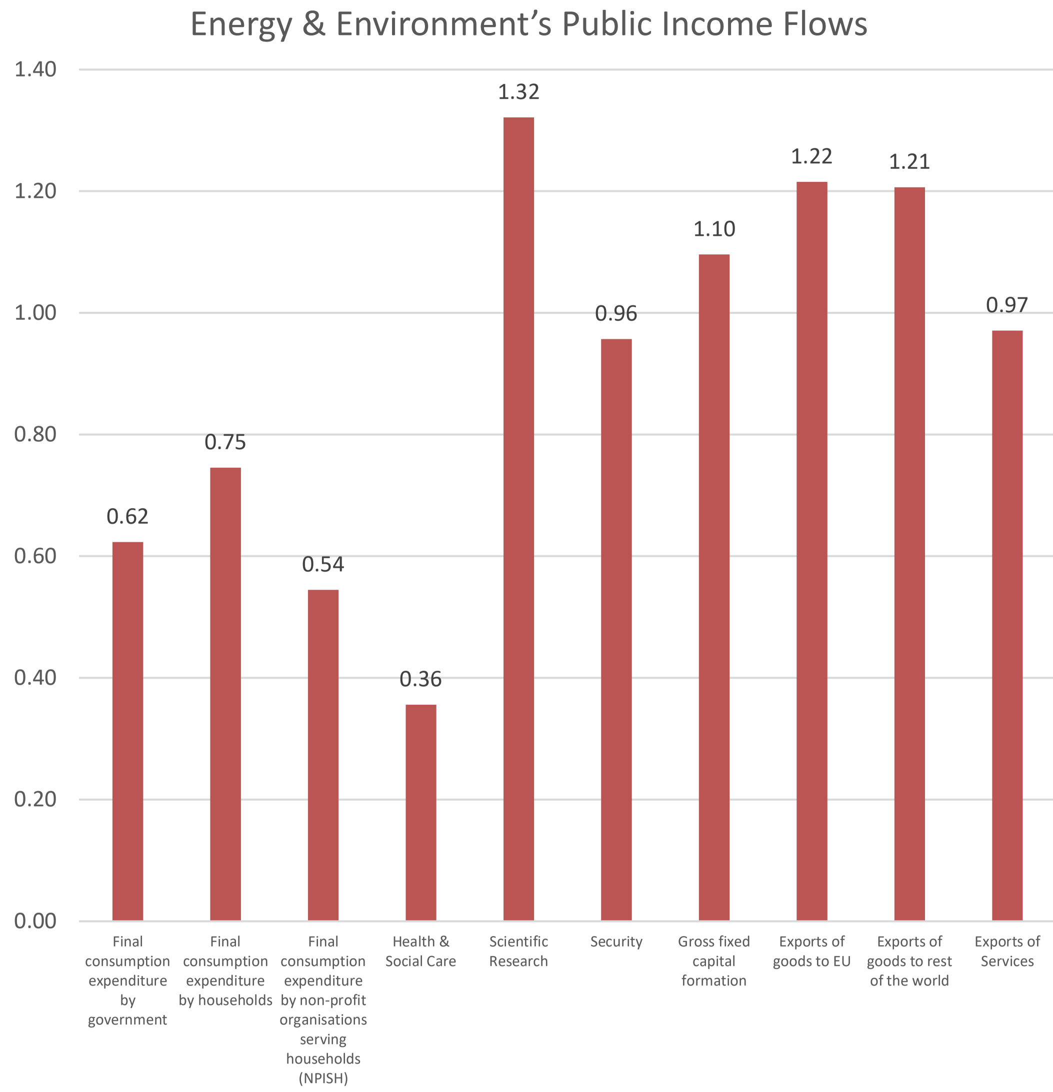
Graph 15



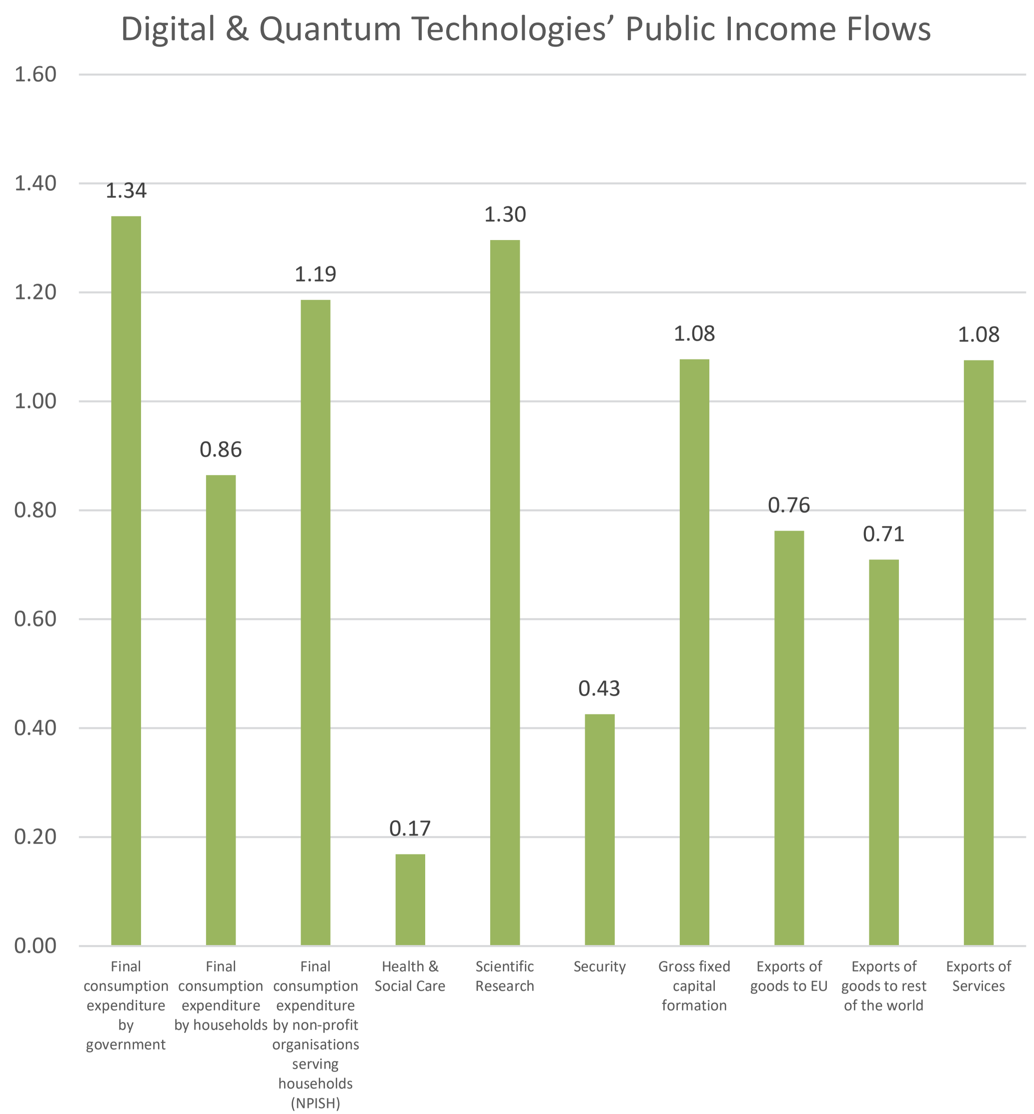
Graph 16



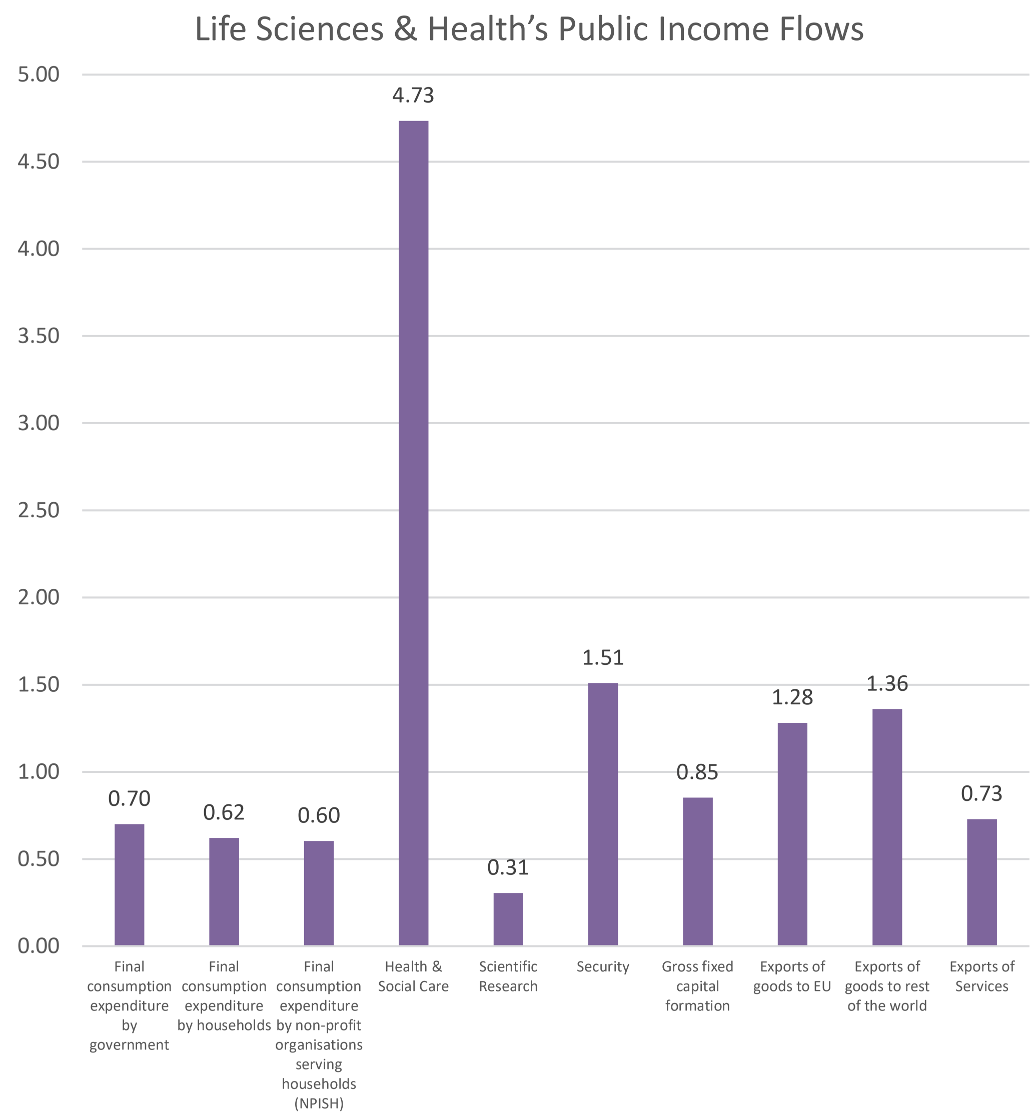
Graph 17



Graph 18



Graph 19



Graph 20

There are several notable aspects when comparing the **private income** of the sectors, particularly the different aspects of Final Demand that are targeted by each sector. Advanced Manufacturing sees its Private Income flows channelled through Non-Profit organisations (domestic NGOs) and Scientific research, with little going to government consumption. Facilitating research makes sense, both of the universities and NGOs (Which could include PSREs), given the fact that many of the major SI units sit within this area (Length, Mass, Temperature). Digital & Quantum is channelled through security and the export of services, with most other channels being lower than NPL overall. Given the security applications of Digital and Quantum, that channel of final demand makes sense. The export of services is an interesting one though, given its prominence. It could be linked to services such as NPLTime[24], which helps financial companies adhere to European regulation such as MIFID II[25]. This, in turn, would facilitate greater exports to the rest of Europe. Foreign countries may also want to be assured that telecommunications are secure, with tools such as quantum key distribution as another example where services exports are bolstered[26]. Life sciences & health is channelled through government consumption, Health & Social Care, (like Energy & Environment) GFCF and exports of goods, while Energy & Environment is channelled through government consumption, GFCF and the exports of goods, with little going to NGOs, Scientific Research, Security and the export of services. Life Sciences & Health's and Energy & Environment's similarities suggest similar customers, who are investment-heavy, working with the government to help solve societal issues such as healthcare and environmental management and helping exporters assure foreign customers that their goods are high quality and meet their nations' standards.

For the **public income**, we see the following. Advanced Manufacturing is channelled through government and household consumption, security and exports, with little scientific research and health. This could be linked to the National Quality Infrastructure[27] (or NQI), which looks to "ensure that when businesses and consumers buy something, they get exactly what they expect". This would include conformity testing, standardisation and accreditation, all of which requires strong measurement infrastructure. Energy & Environment is channelled through Scientific Research and the export of goods with little consumption of goods. With the need to minimise emissions and reach net-zero, it makes sense that a large portion of public money is dedicated towards scientific research, particularly by universities. Digital & Quantum is channelled through government consumption, NGO consumption and the scientific research, with health & social care, security and the exports of goods being notably lower. With Digital & Quantum often having security-focused applications within its area, it makes sense that the government sees significantly more impact from this sector when compared to NPL as a whole. Life sciences & health is channelled primarily through Health & Social Care, with security and the exports of goods being high (though at much lower standing than health). Given NPL's strong health links, particularly to cancer care and radiotherapy, this follows that lead[28].

Generally speaking, when accounting for both public and private income, the differences between the sectors are clear and obvious. Most notable difference is seen when looking at the private income flows, with Advanced Manufacturing having little impact on GFCF and exports, while the other three each affect either GFCF or a version of exports. This suggests that the non-advanced manufacturing sectors see a greater secondary productivity benefits given the impact they have on the injections detailed in section 1, despite having lower RSF counts. The scale of this secondary impact could be investigated in a trade-based analysis following this study.

24 https://www.npl.co.uk/npltime
25 https://safran-navigation-timing.com/mifid-ii-clock-sync-requirements/
26 https://www.npl.co.uk/quantum-programme/quantum-communications-hub
27 https://www.gov.uk/guidance/the-uks-national-quality-infrastructure
28 https://www.npl.co.uk/case-studies/helping-deliver-world-class-cancer-care

8 CONCLUSION

To conclude, NPL's impact does appear to have a secondary effect on the UK economy, beyond the initial GVA boost detailed in Nayak et al (2023). As mentioned in section 1, boosts provided to exports acts as an injection into the UK economy, increasing the flow of income. Given the fact that NPL's paying customers and regularly supported firms' impact is (at least) twice as likely to flow through export of goods, it can be assumed that NPL has a trade effect given that exports were impacted across all the different private benefit measures, both direct and indirect.

It should also be noted that these benefits do differ at an NPL-sector level. Certain sectors appear to focus on different aspects of final demand while the private and public income differences are also notable. Two examples of this include Digital & Quantum's private income flowing into the exports of services and Life Sciences & Health's public income flowing into Health, which is unlike any other sector.

Furthermore, the sectors have differing trajectories with regards to their RSFs curves, with Advanced Manufacturing seeing a decline across all versions of the metric, while the others are either flat or increasing over the last few years. Beyond economic impacts, the use of emissions factors also allows for an understanding of NPL's impact on the environment. Initial findings suggest a decoupling between economic growth and further emissions, with GVA growth of 11.6% occurring while emissions decreased by 11.4%. This could be due to general decarbonisation or the make-up of NPL's support shifting towards more environmentally friendly sectors, but this does require more in-depth analysis to truly assess NPL's environmental effects.

This is just one area of potential further work that could lead on from this study. One area of note that has been least explored is the trade aspect of NPL's work. At this point in time, no assessment of NPL's impact on trade has been conducted at time of publication. This area of analysis is one that could open up new evidence concerning NPL's impact and the broader impact of measurement on trade, with work such as Blind (2001) as a start point for where the analysis could go.

It should be noted that this study builds on and does many things that Dias & King (2023) wasn't able to do, but that doesn't mean the whole picture has been accounted for. The future benefits detailed in Dias & King (2022) aren't accounted for here, which would require a very different form of analysis, due to the probabilistic nature of this type of impact. Health-based benefits aren't accounted for here as well, along with policy influences and standards. In spite of the missing aspects of NPL's impact, the study does help improve areas of weakness within the broad evidence base that NPL currently have.

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