# INSIDE THE BLACK BOX OF MANUFACTURING:

## CONCEPTUALISING AND COUNTING MANUFACTURING IN THE ECONOMY

A report prepared for the UK Department for Business, Energy and Industrial Strategy

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# INSIDE THE BLACK BOX OF MANUFACTURING:

## CONCEPTUALISING AND COUNTING MANUFACTURING IN THE ECONOMY

# FOREWORD

Manufacturing makes a vital contribution to the UK economy. As measured in the national accounts, manufacturing provides over 2.7 million jobs; makes up 49% of UK exports; and contributes 66% of all UK R&D business expenditure (Office for National Statistics, 2018). As impressive as these statistics are, manufacturing's contribution to the UK economy – about 9% of GDP – may seem dwarfed by services, which make up 70% of UK GDP. However, these official statistics fail to fully incorporate the role of UK manufacturing in supporting national economic competitiveness and growth. In particular, the official manufacturing statistics do not include the additional value added or jobs generated by services across manufacturing value chains. Many of these services would not thrive, or even exist, without UK-based manufacturing. In fact, many of these services, in particular technical and professional ones, require deep knowledge and sophisticated capabilities related to the manufacturing activities they support.

It is important, therefore, that policy makers understand this bigger picture and the dependencies between recorded manufacturing activity, industrial services and capabilities so we can develop policies and programmes that will support long term UK industrial competitiveness and growth. The UK Department for Business, Energy and Industrial Strategy welcomes this report that helps to further our understanding.

Department for Business, Energy & Industrial Strategy

**CLARE PORTER**
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# KEY MESSAGES

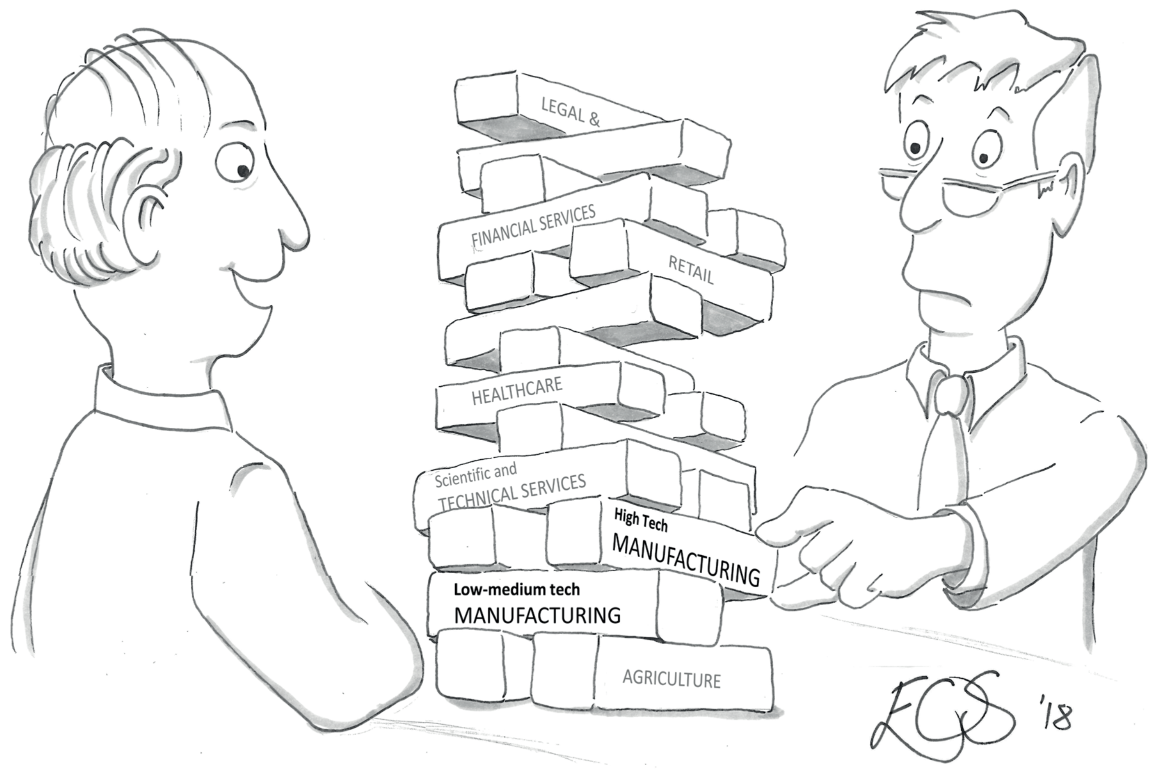
- The economic value of manufactured goods increasingly depends on activities that are officially categorised as belonging to other sectors of the economy.
- For the purpose of industrial strategy, most advanced economies (including the UK) are therefore not counting manufacturing the right way: in the system of national accounts, categories of activities do not reflect how firms self-organise into their 'industry' communities. For example, a range of manufacturing-related services are excluded from the manufacturing category.
- These manufacturing-related services are most importantly technical services that require sector-specific technical knowhow, like R&D, industrial design, analysis, and testing. Additionally, professional services, like regulatory services, intellectual property services, investment services, and consultancy services, are increasingly tailoring their needs to specific manufacturing industries. We argue that many of these services should 'belong' to the manufacturing sector for the purpose of industrial strategy (at least the technical services).
- This gives us good reason to believe that in the UK, manufacturing activity as share of the economy is significantly higher than the 10 per cent labelled as 'manufacturing' in the national accounts., although unlikely to be higher than 20 per cent.
- Digital technologies are becoming more pervasive in manufacturing processes. As industrial digitalisation enhances the speed and level of communication between different parts of industrial value networks, we hypothesise that this could strengthen the coupling between actors in value networks (e.g. between product designers and factories). This reinforces the argument for developing policies in a way that reflects how firms actually organize themselves into categories of productive capabilities.

We believe that in the UK, manufacturing activity as share of the economy is significantly higher than the 10 per cent labelled as 'manufacturing' in the national accounts.

# KEY POLICY RECOMMENDATIONS

- For the purpose of industrial strategy, firms should be associated with those sectors of the economy to which their productive capabilities contribute. This means that, for example, Arm, which is a UK semiconductor and software design company, should not be simply classified as a 'services' activity, but should be identifiable as a critical part of the UK manufacturing industry ecosystem.

- If the way manufacturing is counted does not change, the implications could be severe. First, industrial strategy will fail to target all those firms that should be targeted. Second, if manufacturing does not appear to be important for the economy, it could mean that industrial strategy will become neglected on the government's policy agenda. We, of course, argue that a well-designed industrial strategy is vital for the prosperity of the UK economy.




*"Go on... manufacturing is only 10% of the economy..."*

# 1 | INTRODUCTION

Manufacturing is changing. New technologies, business models and value chain structures are radically altering not only how we make things, but how we innovate and how nations capture value from manufacturing-related industries. As manufacturing evolves, so too do definitions of manufacturing and industrial systems. And so too do the evidence needs of policymakers.

A key challenge for policymakers and national economic statisticians is that the economic value of many manufactured goods increasingly depends on activities other than factory-based production. In particular, industrial activities which are 'upstream' of the factory (e.g. R&D and design) and 'downstream' (e.g. after-sales-services and marketing), as well as non-physical inputs integrated within the factory (e.g. embedded software), can add significant economic value. Furthermore, the competitiveness of national manufacturing sectors may depend on a range of industrial capabilities, some of which are officially categorised as belonging to other sectors.

In this context, the dynamics of competitive advantage between national manufacturing systems cannot be fully explained by examining individual manufacturing industries (as they are conventionally defined and measured) alone. Many products are in fact highly complex systems, and their manufacture relies on a range of industries contributing and integrating components, application subsystems, production systems and a variety of specialist services. Furthermore, modern manufacturing systems are constructed around value chains which may interact in highly complex ways. This complex and interdependent systems-nature of modern manufacturing value chains makes it difficult for policy makers to gather the right evidence to design policies intended to enhance manufacturing-related productivity, competitiveness and employment.

In this paper, we take a dive into the black box of manufacturing to uncover what manufacturing actually is and how we should conceptualise and count it in the economy.

Section 2 addresses the first point: what is manufacturing? We do not conclude with a definite answer to the question. Rather, our aim is to highlight the systems-nature of manufacturing. Think about the functioning of a manufacturing system like the functioning of a complex organism, like the human body. The functioning of the human body relies on cooperation between interdependent biological sub-systems — like the circulatory system, the digestive system, the immune system, the nervous system, the muscular system, the respiratory system, and so on. Just like the human body, the functioning of a manufacturing system relies on cooperation between interdependent sub-systems as well. The central value chain, which consists of R&D, design, production, distribution, and after-sale services, needs timely provision of technical services, like analysis, testing, and logistics. It also needs timely provision of specialist professional services, like regulatory services, intellectual property services, investments services, and consultancy services. And it needs supply of materials, components, and other manufactured inputs, like machinery, equipment, and tools.

Building on this discussion, section 3 critically investigates how most economies count manufacturing, and if this needs to be challenged. We make four important arguments: 1) There has been less de-industrialisation in most advanced economies than what their national accounts reveal. 2) Many manufacturing-related services are not counted as manufacturing in the national accounts. If we count these as manufacturing, the manufacturing sector increases significantly in size. 3) Manufacturing stimulates the growth of services more than the other way around. 4) The national accounts system aggregates firms which manufacture similar final products, or parts for similar final products, but may have few, if any, other industrial commonalities. From an industrial strategy perspective, it would be more useful to group together those firms that share industrial commonalities.

Hopefully this report can serve as a useful contribution to policy makers, economic statisticians, and students who want to understand how to 'properly' conceptualise and count manufacturing in the economy.

> The dynamics of competitive advantage between national manufacturing systems cannot be fully explained by examining individual manufacturing industries alone

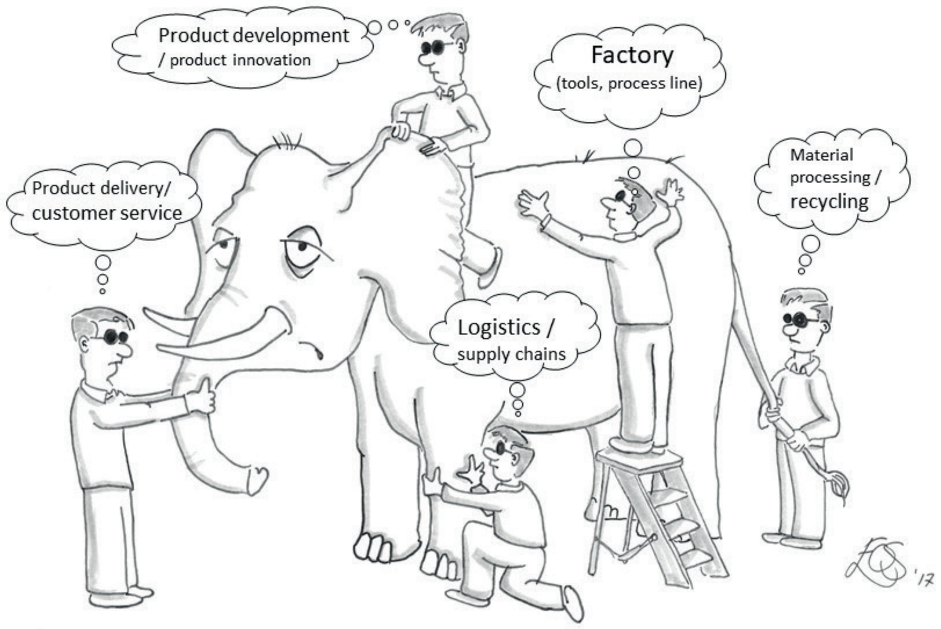
# 2 | WHAT IS MANUFACTURING?

In this section, we review different definitions and frameworks used to describe manufacturing and related concepts. In particular, we review definitions which have been designed to highlight different value-adding industrial activities 'upstream' and 'downstream' of the factory, and which endeavour to capture different aspects of the system-nature of modern manufacturing value networks.

We contrast traditional definitions of manufacturing (and manufacturing sectors) used by government statistics agencies with different conceptualisations of manufacturing designed to better reflect how firms self-organise into manufacturing-related value chains. In this context, we review a range of definitions and conceptualisations of manufacturing which are framed in terms of different industrial activity 'value streams' flowing in and out of factories. In particular, we highlight definitions which distinguish between the different sequences of industrial activities involved in:

- The transformation of materials into a new product
- The translation of a product idea into a new product
- The delivery of the new product to the customer
- The assembly of production capabilities required to manufacturing the new product (i.e. the acquisition, development and integration of the required equipment, tools and systems within the factory)

*Defining manufacturing*



## 2.1 CONCEPTUALISING MANUFACTURING WITHIN NATIONAL ECONOMIC STATISTICS

National manufacturing activity, as normally reported within the national accounts, is measured by counting the output of firms whose main industrial activity involves the transformation of materials or components into new products, and/or the assembly of components or subsystems into new products.

The sub-sectors designated as manufacturing sub-sectors (e.g. machinery and equipment manufacturing; electrical and optical equipment manufacturing; chemicals manufacturing) are those which have final products which have been fabricated or assembled from materials or components, with these production activities typically taking place within plants or factories. Industrial activity within individual manufacturing sub-sectors is calculated by classifying the manufactured outputs according to categories defined in standardised classification systems. In the UK, this system is known as the Standard Industrial Classification (SIC) system[1]. Most other countries also apply some version of this classification system. North American countries, including the US, use the North American Industry Classification System (NAICS).Here is how these two systems define the  manufacturing sector:

> *The physical or chemical transformation of materials of components into new products, whether the work is performed by power- driven machines or by hand, whether it is done in a factory or in the worker's home, and whether the products are sold at wholesale or retail. Included are assembly of component parts of manufactured products and recycling of waste materials.*

International Standard Industrial Classification (ISIC), Rev 3, 2002

> *The manufacturing sector comprises establishments engaged in the mechanical or chemical transformation of materials substances, or components into new products.*
>
> *Establishments in the manufacturing sector are often described as plants, factories, or mills and characteristically use power-driven machines and materials-handling equipment... Manufacturing establishments may process materials or may contract with other establishments to process their materials for them. Both types of establishments are included in manufacturing.*

North American Industry Classification System, 2007

As mentioned above, however, these definitions and categorisations (and the associated economic statistics) can have significant limitations in terms of helping policy makers understand how manufacturing firms create and capture economic value. This, in turn, means the statistics have limitations in terms of accurately revealing trends in sectoral productivity and international competitiveness.

In particular, the economic value of a manufactured product may depend on activities other than factory-based material transformation or assembly. In particular, industrial activities 'upstream' and 'downstream' of the factory, as well as non-physical inputs integrated into the product within the factory, may also add significant value, for example:

- Upstream activities such as research and development or design may add a functionality, usability or desirability to a product that makes it more competitive in the marketplace and/or enable the good to command a higher price.
- Nonphysical inputs such as embedded software may also add valuable functionality.
- Downstream activities such as customer delivery logistics, marketing and after-sales services.

These 'upstream' and 'downstream' activities may happen within the manufacturing firm itself or may be carried out by firms within other sectors. Not only can manufacturers have significant levels of industrial value-adding activity which is not factory-based production, but they can also outsource significant fractions of the physical transformation and/or assembly process itself.

Within the national accounts, the manufacturing of specialised components and specialised subsystems of equipment is, typically, categorised within the same class as the product or equipment for which the components or subsystems are intended. By contrast, however, specialized production equipment intended for deployment in a particular sector is not systematically classified as part of the sector for which it is intended. Similarly, specialised sector-specific upstream services, such as R&D and industrial design, are typically not classified as part of the intended sector, even when industrial capabilities in those upstream services are a critical element underpinning national competitiveness in the relevant manufacturing sector.

## 2.2 DIFFERENT DEFINITIONS OF MANUFACTURING: THE TRANSFORMATION OF RAW MATERIALS OR THE TRANSLATION OF AN IDEA INTO A PRODUCT?

Traditionally, manufacturing has typically been defined in terms of the process of transforming materials into finished goods. The term 'manufacturing' (by contrast with 'making') often comes with connotation of being made in large volumes using machinery, as per most dictionary definitions.

> *Manufacture [/manjʊˈfaktʃə/, noun]: The making of articles on a large scale using machinery.*
>
> Oxford English Dictionary

As discussed above, this conceptualisation of manufacturing is still at the heart of definitions within national statistics, but is also used by a variety of other national institutions and stakeholders.

> *Manufacturing: The process of converting materials into usable products through human skill and knowledge.*
>
> Working definition for the National Academy of Engineering's, Making Value Workshop, June 2012

The journey from raw materials (i.e. materials from natural sources such as minerals from mines, wood from forests, etc.) into final products has, however, changed significantly since the earliest definitions of manufacturing. For example, De Weck and Reed (2014) highlight new types of factory input, production stages and industrial processes involved in the material transformation activities of 21st century advanced manufacturing, in particular:

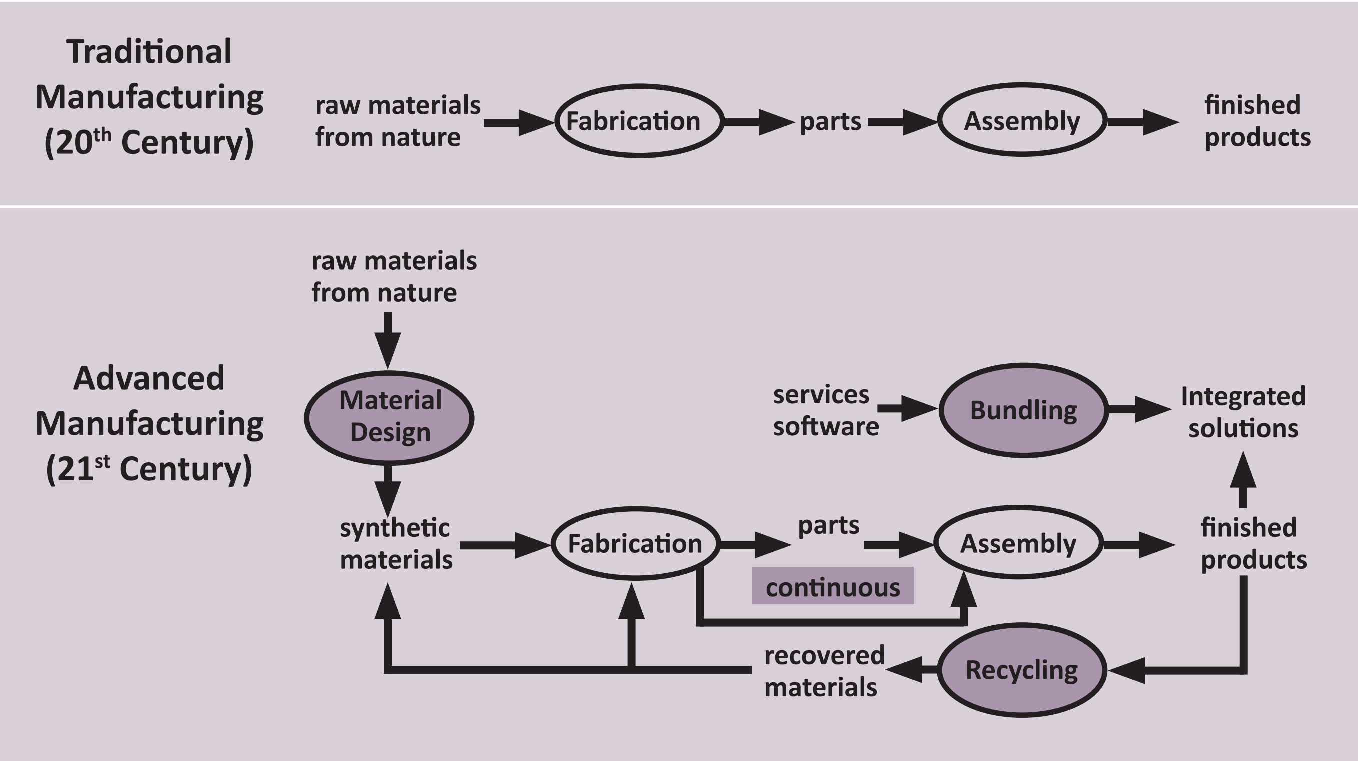



**FIGURE 1:** Definition of advanced manufacturing (bottom) as an expansion of traditional manufacturing (top) (De Weck and Reed, 2014).

- The bundling of the product with embedded software and services software to produce the integrated 'solutions' that many customers increasingly demand
- The design of synthetic materials with particular engineered functional properties that underpin/enhance the performance of the final product (to meet customer demand)
- The recycling and reuse of materials to enhance resource efficiency, productivity and/or the demand by customers for more environmentally friendly and sustainable products

As discussed below, the capabilities to underpin these value-adding activities may be carried out within the factory (and the manufacturing sector associated with the final product) or may be provided or supported by manufacturing or technical services firms in different sectors.

Such definitions are sometimes designed to highlight the different ways that value can be added, both upstream and downstream of factory-based activities. These different stages of the manufacturing process are often represented in terms of a simple 'value chain' of activities.

*Manufacturing: '[often perceived as merely production – the process of transforming raw materials and semi-finished products either into new more complex goods or for final sale to consumers… production is often only one aspect of the manufacturing process or…]*

*[the] value chain comprising [production and] a number of other vitally important functions: research, design & development of products and services, production, logistics & distribution, sales & marketing, after sales services.*

UK Department of Business, Innovation & Skills (2010

This definition of manufacturing is often represented schematically in diagrams such as the one reproduced in Figure 2 (below).

## WHAT IS MANUFACTURING?


*Note: Within this value chain some elements are repeated many times, for example as components come together to build a complex product. There are also feedback loops which may vary for different sub-sectors.*

**FIGURE 2:** Schematic representing simplified model of the manufacturing value chain (GO Science, 2013)

Similar definitions include additional engineering management activities (e.g. materials design and selection, product quality assurance, etc.) or highlight that manufacturing often takes place within a complex system of interacting supply chains and other relationships, and that new manufacturing enterprise models and networks are emerging. These variations in perspective typically reflect the nature of the stakeholders involved (engineering and factory managers versus supply chain and business managers), for example:

*Manufacturing: a series of inter-related activities and operations involving the design, materials selection, planning, manufacturing production, quality assurance, management and marketing of the products of the manufacturing industries.*

International institution for Production Engineering Research (CIRP), 1983

*'...a business system encompassing all activities required to deliver products that meet customer needs... extends from R&D, design, engineering, to production, finance, sales, marketing, and after-sales service... extends beyond any single enterprise, across increasingly global supply chains and business networks'*

Canadian Manufacturers & Exporters (2005)

We have so far outlined the dominant views on how to understand and define manufacturing. In Table 1, we have compiled a range of additional definitions. Some of these are similar to the definitions we have already discussed, some are different. None of the definitions are wrong — each one is referencing particular things that matter to the stakeholder that is defining them.

However, the message we want to convey through this exposé of definitions is clear: manufacturing is not a single cog in the economy, but an industrial system comprising of many interrelated cogs and activities. As an idea is translated into a product, all these cogs have to work together: R&D, design, production, distribution, and after-sales services. For the cogs to run smoothly, timely provision technical services, like analysis, testing, and logistics, are integral. So too is the supply of materials, components, and other manufacturing products, like machinery, equipment, and tools. And so too are specialist professional services, like regulatory services, intellectual property services, investment services, and consultancy services.

**TABLE 1:** Different definitions of manufacturing

| MANUFACTURING-RELATED LABEL | DESCRIPTION | SOURCE |
|---|---|---|
| **Manufacturing** | Manufacturing: The process of converting materials into usable products through human skill and knowledge. | Working definition for the National Academy of Engineering's, Making Value Workshop (2012) |
| **Manufacturing** | A series of inter-related activities and operations involving the design, materials selection, planning, manufacturing production, quality assurance, management and marketing of the products of the manufacturing industries. | International institution for Production Engineering Research (CIRP) (1983) |
| **Manufacturing** | ...a system designed to perform activities required to deliver end-product to the customer and meet their needs, from design to finance, production to sales, marketing, after-sales service... | US Department of Commerce (2004) |
| **Manufacturing** | [often perceived as merely production – the process of transforming raw materials and semi-finished products either into new more complex goods or for final sale to consumers... production is often only one aspect of the manufacturing process or...]<br>value chain comprising [production and] a number of other vitally important functions: research, design & development of products and services, production, logistics & distribution, sales & marketing, after sales services. | UK Department of Business, Innovation & Skills (BIS) (2010) |
| **Manufacturing** | Value chain of activities including the stages: research and development, product and service development, supplier management, production, route to market, after sales services, consumption, and disposal (including reuse, remanufacturing, recycling and recovery). | UK Government Office of Science (2013) |
| **Manufacturing** | An integrated system that includes the whole cycle of creation, production, distribution and end-of-life treatment of goods and product/services, realising a customer/user driven innovation system. | ManuFuture (2004) |
| **Manufacturing** | ...a business system encompassing all activities required to deliver products that meet customer needs... extends from R&D, design, engineering, to production, finance, sales, marketing, and after-sales service... extends beyond any single enterprise, across increasingly global supply chains and business networks. | Canadian Manufacturers & Exporters (2005) |
| **Manufacturing** | The physical or chemical transformation of materials of components into new products, whether the work is performed by power- driven machines or by hand, whether it is done in a factory or in the worker's home, and whether the products are sold at wholesale or retail. Included are assembly of component parts of manufactured products and recycling of waste materials. | United Nations (1990) |
| **Manufacturing** | Encompassing from products and services, to processes sustaining their life cycles, to companies and business models. | Jovane et al. (2009) |
| **Manufacturing** | Producing on a large scale and by a continuous process, transportable goods. | Clark (1940) |
| **Traditional manufacturing** | Traditional manufacturing is essentially the step-wise transformation of raw materials (coming from mainly natural sources such as underground mines, forests and so forth) into finished goods. | De Weck and Reed (2014) |
| **Advanced manufacturing** | Advanced Manufacturing is the creation of integrated solutions that require the production of physical artifacts coupled with valued-added services and software, while exploiting custom-designed and recycled materials and using ultra-efficient processes. | De Weck and Reed (2014) |
| **Advanced manufacturing** | The family of activities that (a) depend on the use and coordination of information, automation, computation, software, sensing, and networking, and/or (b) make use of cutting edge materials and emerging capabilities enabled by the physical / biological sciences, e.g. nanotechnology, chemistry, and biology. This involves both new ways to manufacture existing products, and especially the manufacture of new products emerging from new advanced technologies. | US President's Council of Advisors on Science & Technology (PCAST) (2011) |

## WHAT IS MANUFACTURING?

| | | |
|---|---|---|
| **Manufacturing sector** | The manufacturing sector comprises establishments engaged in the mechanical or chemical transformation of materials substances, or components into new products.<br>Establishments in the manufacturing sector are often described as plants, factories, or mills and characteristically use power-driven machines and materials-handling equipment… Manufacturing establishments may process materials or may contract with other establishments to process their materials for them. Both types of establishments are included in manufacturing. | North American Industry Classification Systems Definition (NAICS) (2007) |
| **Manufacturing sector** | The manufacturing sector comprises [the Statistical Industry Classification (SIC) code sectors]: Food, beverage and tobacco products; textiles and textile products; wood and wood products; pulp, paper and paper products; publishing and printing; coke, petroleum products and nuclear fuel; chemicals, chemical products and man-made fibres; rubber and plastic products; other non-metallic mineral products; basic metals and fabricated metal products; other machinery and equipment; electrical and optical equipment; transport equipment; other manufacturing. | UK Standard Industry Classification Codes (2007) |
| **Manufacturing system** | Coordination of production engineering research with a series of activities of design, programming, control system, machine, and fabrication. | Merchant (1961) |
| **Manufacturing systems** | Manufacturing systems are comprised of products, equipment, people, information, control and support functions for the economical and competitive development, production, delivery and total life cycle of products to satisfy market and societal needs. | Journal of Manufacturing Systems |
| **Manufacturing system engineering** | Manufacturing systems engineering is the design and operation of factories. | Gershwin (2017) |
| **Production** | To create utility or increase the measure of value of economic goods-either tangible (products) or intangible (services) which are outputs generated through activities of conversion from inputs called 'factors of production'.<br>Conversion (or transformation) processes are purely technological and are called 'production processes'. We can now define 'production' as 'the process of producing economic goods, including tangible products and intangible services, from factors of production, thus creating utility by increasing value added<br>• The above definition is concerned with two aspects:<br>• Technical production: a conversion process using means of production to give products/services.<br>• Economic production: creation of a product more highly valued than the original input elements. | Hitomi (1972, 1990) |
| **Production** | Production is an activity carried out under the control and responsibility of an institutional unit that uses inputs of labour, capital, and goods and services to produce outputs of goods or services. | System of National Accounts (2008) |
| **Production** | Production is an activity resulting in a product. It is used with reference to the whole range of economic activities. The term is not reserved for the agricultural, mining or manufacturing sectors. It is also used in relation to the service sector. More specific terms may be used to denote production: provision of services, processing, manufacturing, etc., depending on the branch of activity. Production may be measured in various ways either in physical terms or according to value. | European System of National and Regional Accounts (1995) |
| **Industrial production** | Industrial production comprises the output of industrial establishments, covering: mining and quarrying; manufacturing; and electricity, gas and water supply. | United Nations (1983) |
| **Production process** | Three levels of activity] (i) task identification and task arrangement; (ii) fund factor analysis (the bundling and utilisation of capabilities); (iii) material transformation and the organisation of materials-in-process flows. | Landesmann and Scazzieri (2009) |

# 3 | COUNTING MANUFACTURING IN THE ECONOMY

The most common way to count manufacturing's contribution to the economy is to look at manufacturing's contribution to total GDP. In the UK, the share of manufacturing in GDP — more precisely, the gross value added of manufacturing in GDP — has declined from 17 percent in 1990 to 9 percent in 2017. This clearly indicates that the UK is going through a process of deindustrialisation. The trend of deindustrialisation is quite consistent among all industrialised countries, but the UK is among those countries that has deindustrialised the most (see Figure 3).

The trend of deindustrialisation in the UK and other high-income countries has spurred a discourse which claims that services, not manufacturing, is where the future potential for innovation and productivity growth lies (e.g. Ghani and O'Connel, 2014; Haskel and Westlake, 2017; International Monetary Fund, 2018; Romer, 2012). A problem with this discourse is that it relies on evidence of deindustrialisation, which again relies on a certain way of counting manufacturing.

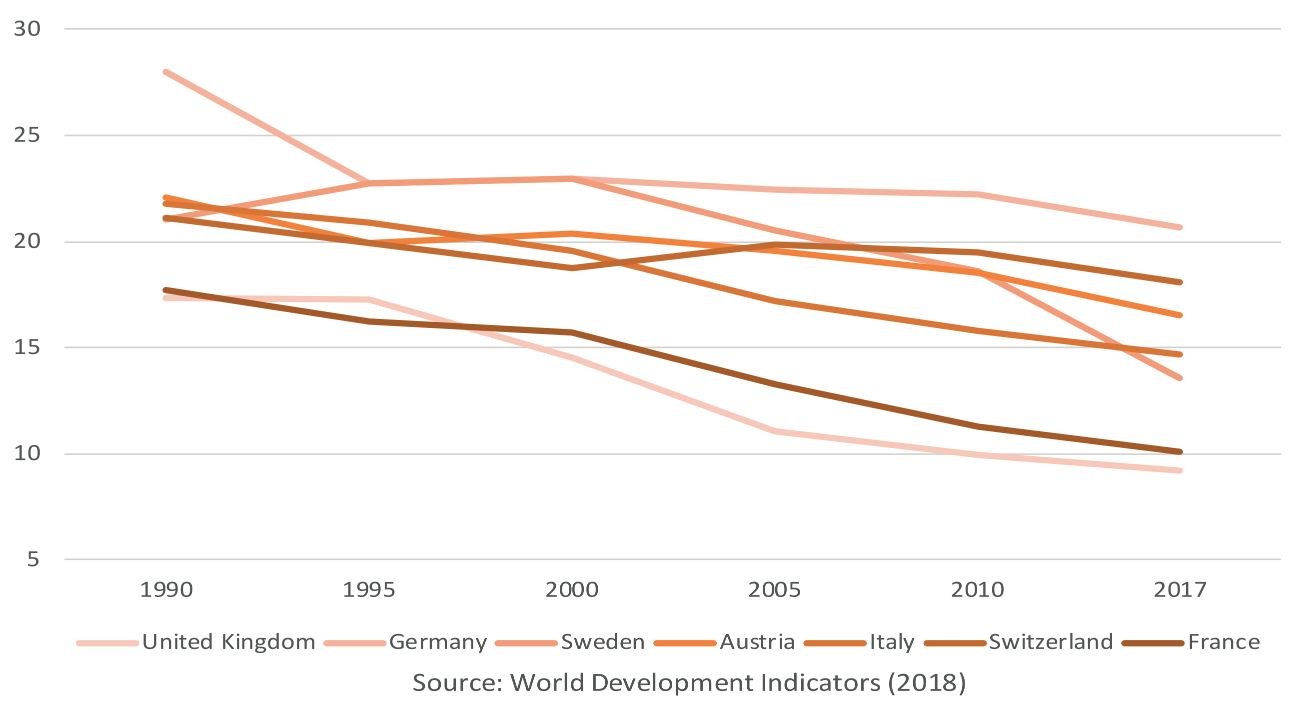



**FIGURE 3:** Manufacturing value added as % of GDP in selected European countries

This way of counting manufacturing deserves more scrutiny. In practically all national accounts databases, the value added of manufacturing is based on aggregating manufacturing activities in national industry classification codes. Increasingly, this system has come under criticism for not properly reflecting the way industries are really organised. With reference to the American industry classification system, NAICS, Dalziel (2007, p. 1561) states that the "firms classified in a given category are no more likely to have relationships with the firms in the neighbouring categories, than they are to have relationships with firms in other sectors." Similarly, Donofrio and Whitefoot (2015) argue that industry classification systems do not account for the system of activities along value chains, which would allow for a representation of the economy that reflects the ways companies organise themselves into clusters and sectors. Whitefoot et al. (2015) suggest that policies and initiatives to promote manufacturing should take a value chain perspective — economic statistics should include pre-production services, like R&D and design, and post-production services, like repair and sales.

In this section, we will show how the current system of counting manufacturing is flawed, both in terms technical counting and in terms of considering the importance of 'non-manufacturing activities' to manufacturing, particularly services. While we will not assert that deindustrialisation in high-income countries, like the UK, is not happening, our conclusion is that the manufacturing ecosystem is larger than what the industry classifications data on manufacturing reveal. Towards the end of the section, we will look at an additional problem with national accounting classifications: limitations that arise from the aggregation of firms which manufacture similar final products, or parts for similar final products, but have few, if any, other industrial commonalities. From a manufacturing policy / industrial strategy perspective, it would be more useful to group together firms which share industrial commonalities as they are therefore more likely to respond to policies in a broadly coherent and consistent way.

## 3.1 THE CLASSIFICATION (AND COUNTING) OF MANUFACTURING: ILLUSIONS OF THE MANUFACTURING DECLINE

The previous section showed that there are many different understandings of manufacturing in the academic and policy literature. Most countries rely on their national statistics offices to count manufacturing. In the list of economic activities in the standard industry classification (SIC) codes made by the office for national statistics in the UK, companies are classified to the activity in which their largest number of employees is engaged. This means that a company that both makes and delivers a product will be classified into either manufacturing or services, not both, depending on the number of people working in each category. Manufacturing Metrics Expert Group (2015) uses the example of 'ABC Computers Ltd', a company that employs 35 people, 20 of whom are employed to make computers and 15 of whom are employed to deliver computers. This company ends up being classified in the manufacturing category even though it employs almost half of its workforce in a non-manufacturing activity.

However, if ABC Computers Ltd. outsources the delivery of its products to a delivery company in the same country, there is suddenly an increase in services as share of the economy without this actually being the case. This outsourcing has actually been happening on a large scale in many countries in the last few years: a lot of supporting services that used to be provided in-house in manufacturing firms (e.g. delivery, catering, security guards, design, programming, marketing, analytics, etc.) are now supplied by independent services companies

(Chang, 2014, chapter 7; Kuan, 2016). Because of developments in information and communication technology and massive increases in the size of firms, economies of scale can more easily be achieved in a range of services (Hallward-Driemeier and Nayyar, 2018, chapter 5), making it more profitable to procure some services from specialist providers rather than produce them within a manufacturing firm (Nayyar, 2013, chapter 6).

Additionally, some manufacturing companies that have not started outsourcing their service activities have instead applied to be reclassified as services firms, even though they still conduct some manufacturing. This is mainly because the manufacturing share in their total output is falling. A UK government report estimates that up to 10 per cent of the fall in manufacturing employment between 1998 and 2006 in the UK may be due to this reclassification effect (Chang, 2014, chapter 7). Why is the manufacturing share in these companies' total output falling relative to services though? Looking at countries going through a deindustrialisation process in the 1980s and the 1990s, Rowthorn and Ramaswamy (1999) argue that the main explanation for this trend is not that manufacturing has become less important, but rather that productivity in manufacturing grows faster than that of services, resulting in a falling labour share of manufacturing. A more recent study by Tregenna (2009) similarly shows that the trend of deindustrialisation in some countries is happening because the labour-intensity of manufacturing declines more rapidly over time compared to services — i.e. manufacturing has higher productivity.

As a result of this greater productivity potential of manufacturing, prices of manufactured goods have declined relative to that of services, resulting in a falling share of manufacturing in total economic output. This is an important observation:

Part of the manufacturing decline can be explained by the fact that manufacturing has higher productivity potential than services, not because it is 'less important'

We should also note that the relative price decline of manufactured goods is a result of price increases of services as well. Because the services sector has lower potential for productivity growth, income growth in advanced economies, combined with the fact that many services are not tradable, has led to higher wages and prices in the services sector (see Baumol (1967) for the original explanation of this. Nayyar (2013) explains this phenomenon with reference to more recent trends), as well as an increased employment share (Rowthorn and Wells, 1987).

When this relative price effect is taken into account and the shares of different sectors are recalculated in constant prices, as opposed to current prices, the share of manufacturing has in fact not fallen very much in most high-income countries. In some of them, like the US, Switzerland, Finland and Sweden, when calculated in constant prices, it has actually increased (Chang, 2014, chapter 7).

In conclusion, with the current way of counting and classifying manufacturing, part of the manufacturing decline of the economy is an illusion. First, many services that used to be provided in-house in manufacturing firms have been outsourced to independent firms. This has resulted in an increasing share of services in the economy without this actually being the case. Second, part of the manufacturing decline can be explained by the fact that manufacturing has higher productivity potential than services, not because it is 'less important'.

## 3.2 MORE DIFFICULTIES WITH COUNTING: THE 'SERVITISATION' OF MANUFACTURING

If we use the traditional way of counting manufacturing's contribution to the economy, many important services that are 'embedded' in the manufacturing process are neglected. Most importantly, these include manufacturing R&D and product design — services that add significant value to a product value chain.

Berger (2015) shows that in some industries, the R&D and manufacturing process are close to inseparable. For example, in solar power, the most promising R&D and innovation involves cheaper and more efficient ways of manufacturing photovoltaics. The innovation is in the manufacturing. Similarly, Pisano and Shih (2012) argue that it does not make sense to separate manufacturing from many of the services that are embedded in the manufacturing process. They propose that we should talk about the 'industrial commons' instead, which they define as "The R&D and manufacturing infrastructure, know-how, process-development skills, and engineering capabilities embedded in firms, universities, and other organizations that provide the foundation for growth and innovation in a wide range of industries" (Pisano and Shih, 2012, p.2). Through various industry case studies, they show how the United States has lost much of its innovation infrastructure to competitor countries in East Asia because the United States initially outsourced manufacturing operations to these countries but failed to realise how closely innovation and design services were linked to the manufacturing process.

We highlight R&D services not only because they are in many instances linked to manufacturing, but also because R&D services is playing an increasingly important role in innovation. On a global scale, R&D expenditure in services increased from an annual average of 6.7 percent of total business R&D during 1990-1995 to 17 percent during 2005-2010[2] (World Trade Organisation, 2013).

R&D and design services are only part of the spectrum of services that are embedded in the manufacturing process. Hallward-Driemeier and Nayyar (2018, chapter 5) lists several such additional services: those related to marketing, distribution, logistics and e-commerce. While it could and should be debated what a finite list of services embedded in manufacturing would look like, studies have made it abundantly clear that they play an increasingly important part in manufacturing production. Falk and Jarocinska (2010) shows that between 1995 and 2007, intermediate services demand generated from €1 of manufacturing output increased from €0.42 to €0.61. According to Bamber et al. (2017), globally, more than one-third of the value of gross-manufacturers' exports come from the value added of embodied services, with distribution and business services making the largest contribution. The EU tops the list of 'servitisation' of manufacturing, where embodied services accounted for 40 percent of gross manufacturers exports in 2011.

In the introduction, we mentioned how Whitefoot et. al. (2015) suggest that policies and initiatives to promote manufacturing should take a value chain perspective that incorporates pre-production services, like R&D and design, and post-production services, like repair and sales. Examining employment in US manufacturing, they find that in 2002, manufacturing narrowly defined had about 15.2 million workers, but that the entire value chain, which includes these services, employed nearly 37.2 million workers. By 2010, employment had dropped to 11.5 million in production and to 32.9 million across the value chain — meaning that there was deindustrialisation, but barely in the services segments of the value chain. Actually, some services saw an increase in employment in this time period: it expanded 26 per cent for market analysis, 13 per cent for R&D, and 23 per cent for design and technical services.

A similar study has recently been carried out in the UK by Oxford Economics, a consultancy firm. Arguing that manufacturers' purchases from suppliers generate indirect impacts which ripple out across all sectors of the economy, they look at purchases that UK-based manufactures make from UK-based suppliers. Once these indirect impacts are included in calculations for estimating the size of the manufacturing sector, they find that manufacturing in the UK generated £301 billion (15 per cent of the UK economy) and supported five million jobs (15 per cent of total employment) in 2016 (Oxford Economics, 2018).

The smiling curve is a useful illustration to understand these value chain perspectives and to demonstrate the value of services embedded in the manufacturing process (see Figure 4). Coined by Stan Shih, Acer's CEO in the early 1990s, it is an illustration of the value adding potentials at different stages of a production value chain. It suggests that services such as R&D, product design (the left side of the smile), branding, advertising, and retail (the right side of the smile) constitute a larger share of value added than the manufacturing and assembly process (the bottom part of the smile).

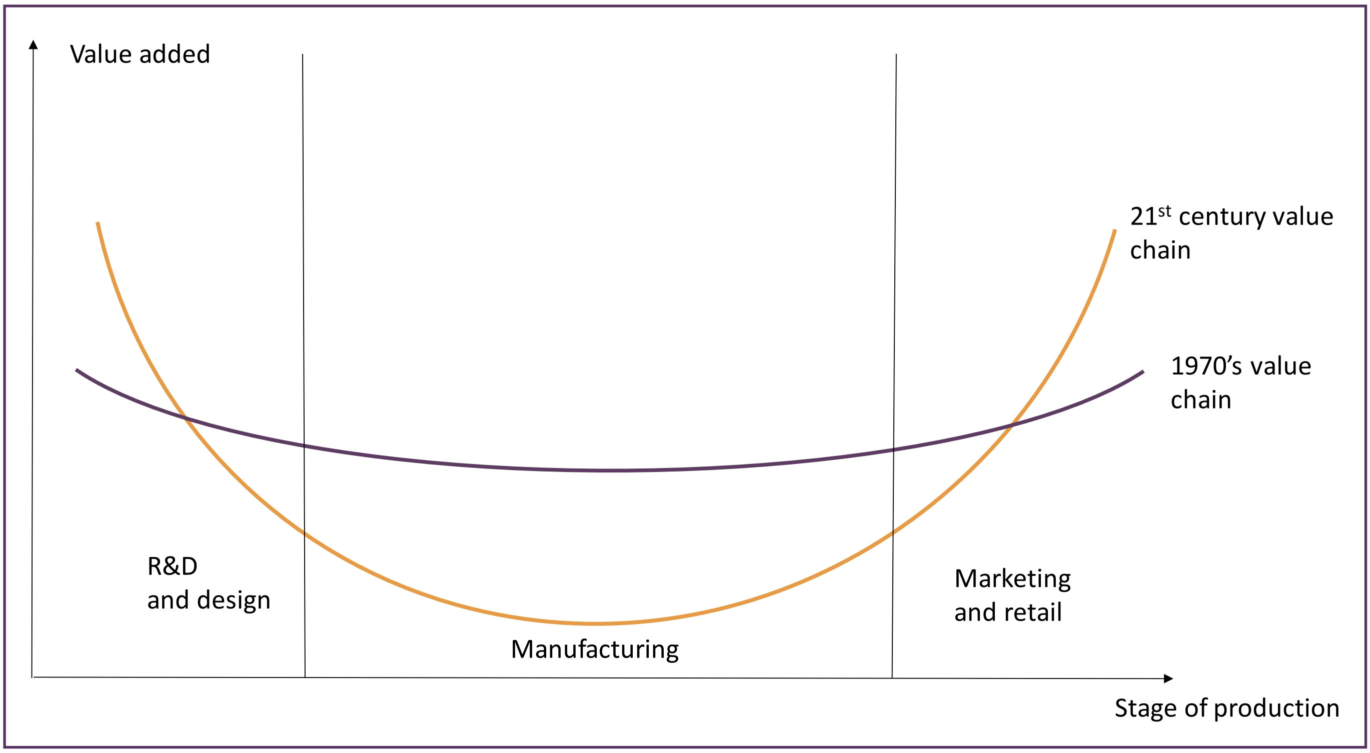



**FIGURE 4:** The growing smile of value chains

For example, Ali-Yrkko et al. (2011) found that only one-third of the value of a Nokia N95 phone comes from manufacturing: making the parts (33 percent) — processors, memory chips, integrated circuits, displays and cameras — and assembling the phone (2 percent). Two-thirds of the value comes from services, such as support services (30 percent), licences (4 percent), distribution (4 percent), retailing (11 percent) and operating profit (16 percent). Since the 1970s, the smile on the smiling curve has grown (WPI, 2017), suggesting that the manufacturing segments of a value chain is becoming less profitable and that the services segments of a value chain are becoming more profitable.

The smiling curve as an illustration of value capture in a value chain has shortcomings though. First, some manufacturing activities are high-value and does therefore not fit into this typology. Examples would be the manufacture of high-precision machine tools, lasers, medical imaging systems, and aircraft propulsion systems. A 'toothy' smiling curve (see Figure 5) might therefore be a better illustration of how some of today's value chains work. This smiling curve accounts for the fact that certain manufacturing activities spike up in value. Think about the manufacture of high pressure chamber blades or fans in aircraft propulsion systems. These are certainly not low-value manufacturing activities. Most of the toothy manufacturing activities are carried out in advanced economies though. Thus, the smooth 21st century smiling curve is more fitting to describe manufacturing value capture in developing countries rather than advanced economies.

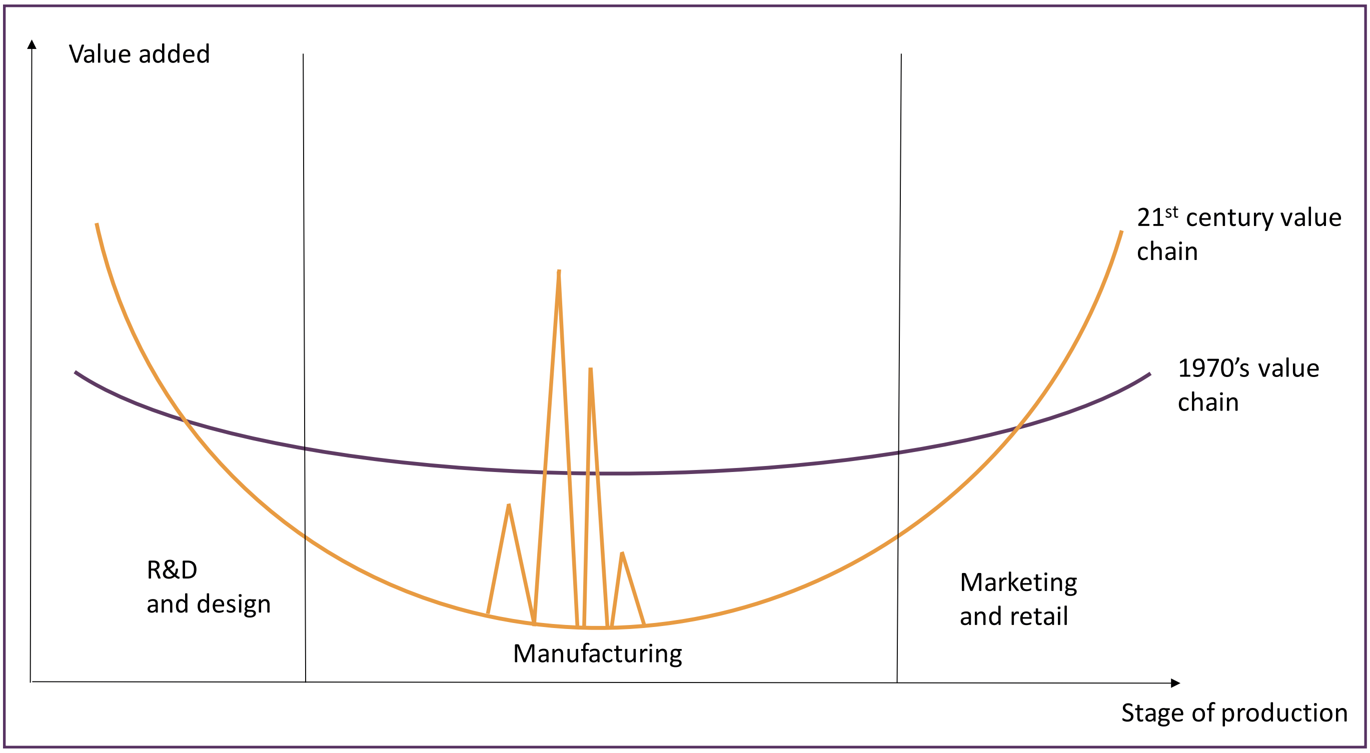



**FIGURE 5:** The growing smile of value chains (but with 'toothy' parts)

Second, the labels for stages of production have severe implications in terms of what the framework suggests for value adding potential. In the figures depicted above, manufacturing is labelled at the bottom of the smile. However, this depiction is not universally agreed upon. For example, in technology management theory and business management theory, as opposed to political economy, the bottom of the smile often depicts manufacturing assembly, which indeed is a low-value part of manufacturing. And the left part of the smile often incorporates some component manufacturing that is high value. In that sense, some versions of the smiling curve reflect a deeper level of understanding the manufacturing process.

Third, it is debatable whether services that depend on engineering know-how, like R&D and industrial design, should be understood as value propositions separate from manufacturing, as we already have discussed extensively.

### 3.2.1 THE 'SERVITISATION' OF MANUFACTURING — OFFICE FOR LIFE SCIENCES CASE STUDY

The Office for Life Sciences (OLS) in the UK has made a very useful exercise of mapping the landscape of the UK life science industry (medical technology and biopharmaceutical sectors) in a way includes all the range of services that are linked to the manufacturing process (OLS, 2016). The OLS explains that part of the motivation for carrying out such an exercise is that SIC codes 'box' activities of the industry in widely different categories (OLS, 2016, p. 46) — i.e. the categories of SIC codes do not fully reflect the way the industry is really organised, especially the way manufacturing and service activities are linked to each other.

We looked at all the data gathered by the OLS at the firm level, and highlighted the most revenue-generating categories of activities as classified in the SIC codes. We reached these categories of activities by using a threshold of minimum revenue generated by each activity, and thereby singled out 31 activities from a total of 111. Our results are shown in Table 2. As seen, manufacturing is important, but only part of the industry. A significant share of the industry's value is generated by information and communication services; professional, scientific and technical services; administrative and support services; and wholesale and retail trade services.

According to OLS (2016, p. 47), manufacturing activities in the life science industry as counted by the SIC codes generate £20.1bn in turnover and employ 81,900 people. However, the entire life science industry, which most importantly include all the activities in Table 2, generate 63.5bn in annual turnover and employ 233,000 people. If we assume that the 'ecosystem' of other industries self-organise like the life science industry, neglecting the services embedded in manufacturing gives us an estimate of roughly one-third of the 'real' size of a manufacturing sector.

**TABLE 2:** Activities in the life science industry that generate the most revenue, using SIC categories. Includes both manufacturing and services. 31 activities in total, 16 of which generate exceptionally high revenue **(marked in bold)**

| | |
|---|---|
| Manufacturing | • **Manufacture of basic pharmaceutical products**<br>• **Manufacture of pharmaceutical preparations**<br>• **Manufacture of dental instruments and supplies**<br>• **Other manufacturing not elsewhere classified**<br>• Manufacture of electronic measuring and testing equipment<br>• Manufacture of other chemical products<br>• Manufacture of other plastic products<br>• Manufacture of other fabricated metal products<br>• Manufacture of other special purpose machinery |
| Information and communication services | • **Business and domestic software development**<br>• **Other information technology services**<br>• Information technology consultancy services<br>• Data processing, hosting and related activities |
| Professional, scientific and technical services | • **Research and experimental development on biotechnology**<br>• **Other research and experimental development on natural sciences and engineering**<br>• **Management consultancy activities other than financial management**<br>• **Other professional, scientific and technical activities not elsewhere classified**<br>• Activities of head offices<br>• Solicitors<br>• Technical testing and analysis |
| Administrative and support services | • **Other business support services activities**<br>• Temporary employment agency activities |
| Human health and social work services | • **Other human health activities**<br>• Hospital activities |
| Other service activities | • **Other services activities not elsewhere classified** |
| Wholesale and retail trade services | • **Wholesale of pharmaceutical goods**<br>• **Retail sale of medical and orthopaedic goods in specialised stores**<br>• **Non-specialised wholesale trade**<br>• Agents specialised in the trade of particular products<br>• Other retails sale not in stores, stalls or markets<br>• Wholesale of other machinery and equipment |

## 3.3 THE MULTIPLICATION OF MANUFACTURING

A third problem with the way we count manufacturing's contribution to the economy is the neglect of all the value added arising from activities that manufacturing stimulates. This is related to the above point, but it encompasses more than manufacturing-related services. Hirschman (1958) made and important contribution for understanding the spillovers from the manufacturing sector to other sectors of the economy. He argued that all sectors are linked to one another through backward and forward linkages, but that the manufacturing sector is characterised by stronger backward and forward linkages than other sectors of the economy, thus acting as the main engine of economic development.

Daniel J. Meckstroth's recent paper, The Manufacturing Value Chain is Much Bigger Than You Think!, illustrates Hirschman's point in a useful way (Meckstroth, 2016). Meckstroth has attempted to calculate manufacturing's footprint in the United States by including the all the upstream and downstream activities that are part of a manufacturing value chain. The upstream supply chain includes activities that delivers the raw materials, processed inputs and services required by the downstream sales chain. An example of an upstream supply chain would be corporate and contract R&D facilities, outsourced professional services for manufacturers and distributors, fuel used for transporting manufactured goods to wholesale and retail, transport costs for shipping, imports of inputs used in production, domestic mining activities, and electricity, water and gas used by manufacturing distribution facilities. The downstream sales chain includes the transport, wholesale and retail trade margins. This would include transport of goods from factory/port to market, wholesale and warehousing operations, retail activities, and aftermarket maintenance and repair services.

Based on the inclusion of all these economic activities, Meckstroth calculates a domestic value added multiplier of 3.6. This means that for every dollar of domestic manufacturing value-added destined for manufactured goods for final demand, another $3.60 of value-added is generated elsewhere. He also concludes that for each full-time equivalent job in manufacturing dedicated to producing value for final demand, there are 3.4 full-time equivalent jobs created in non-manufacturing industries.

Meckstroth's study has some weaknesses though. Every economic activity stimulates another economic activity, so one can also make a case for a large multiplier for service activities or agriculture. Another important point is that some of the abovementioned activities could be provided domestically without a domestic manufacturing core. This is different from the argument we made in the above section, where we made a case for inclusion of services 'embedded' in manufacturing production. We did not make a case for including activities like the mining of metals, manufacturing of inputs needed in production of another manufacturing product, fuel consumption, and utilities consumption.

However, Meckstroth is right in that the size of the manufacturing sector is much larger than what industry classifications data reveals. And while each economic activity stimulates another economic activity, manufacturing tends to have the largest multiplication effect. Early work by Galenson (1963) highlighted that growth of manufacturing employment generated more employment in services than vice versa. Another influential study on this was conducted by Park and Chan (1989), who found that the manufacturing sector generates two to three times more output in the rest of the economy than the services sector does. More recent studies also confirm that manufacturing has the largest multiplication effect. Pilat and Wolfl (2005) estimate that 29 per cent of the manufacturing workforce in France contribute indirectly to the production of non-manufacturing output, whereas only 13 per cent of the services workforce contribute indirectly to the production of non-services output. Kuan (2017) shows that in Singapore, the manufacturing sector has stronger value-added spillovers to the services sector than vice versa: every 100 new manufacturing jobs were associated with 27 new non-manufacturing jobs. By contrast, every 100 new services jobs were associated with only 3 additional manufacturing jobs.

### 3.4 ADDITIONAL CLASSIFICATION PROBLEMS WITH ACTIVITIES ALREADY COUNTED AS MANUFACTURING: UNDER WHAT CIRCUMSTANCES SHOULD MANUFACTURING SUB-SECTORS BE REASSIGNED?

Limitations in the national accounts are not only about what industrial activities are omitted from manufacturing. Limitations can also arise from aggregating firms which manufacture similar final products, or parts for similar final products, but have few, if any, other industrial commonalities.

There are instances where industry classification codes group together manufacturing firms with very different market trends and drivers, research and innovation priorities, workforce capability needs, supply chain structures, infrastructural requirements, energy and resource costs, etc. From an industrial strategy perspective, it would be more useful to group together firms which are likely to respond to policies in a broadly coherent and consistent way.

The ‘electronic and other electrical equipment sector’ (SIC Code 36 in the UK) offers a useful illustrative example of this. For historical reasons, the sector contains an eclectic mix of industrial, consumer and infrastructural sub-categories, including: electric transmission /distribution equipment; electrical industrial appliances; household appliances; electrical lighting/wiring equipment; household audio/video equipment; communications equipment; electronic components /accessories, as well as ‘miscellaneous electrical machinery, equipment & supplies’. It is not obvious that products as varied as transmission equipment for the electricity grid, domestic vacuum cleaners, fibre optic cables, home video projectors, etc. will have significant commonalities in terms of research and innovation priorities, and workforce capability needs. At the same time, understanding national strengths and capabilities in for example high performance batteries or graphene-based industrial products may be of critical importance in developing strategies for important emerging technologies and industries in entirely different ‘sectors’ (e.g. automotive or telecommunications); and/or in addressing important socio-economic grand challenges (e.g. low carbon transport).

The point we want to get across is that there is an implicit assumption that there is some level of interconnectedness between firms in the same ‘sector’ — an interconnectedness based on a collective set of capabilities to address common sectoral opportunities and challenges. But if industrial data is not organised in a way reflects these commonalities, policy makers will be limited in their ability to develop effective evidence-based policies to address particular sectoral needs.

## 3.5 FUTURE TRENDS: WILL INDUSTRIAL DIGITALISATION CHANGE THE WAY WE SHOULD COUNT AND UNDERSTAND MANUFACTURING IN THE ECONOMY?

Digital technologies, such as artificial intelligence, additive manufacturing, and the industrial internet of things, are becoming more pervasive in manufacturing processes. Evidence of the impact of how these technologies are affecting manufacturing is scant, which signals a need for research to devote more attention to digitalisation. Below, we pose a few open-ended questions to point out possible avenues for future research on if and how industrial digitalisation will impact the way we should conceptualise and count manufacturing.

First, as industrial digitalisation enhances the speed and level of communication between different parts of industrial value networks, will this strengthen the coherence/coupling between actors in value networks? Does this mean that different elements of the system will be increasingly impacted by policies targeting other elements? For example, if digitalisation enables faster feedback/alignment between factories and product designers, do policies addressing designer skills and training have a greater impact on national factory productivity? Will this, in turn, reinforce the argument for developing policies (and structuring and gathering related industrial economic data) in a way that reflects how firms actually organize themselves into value network structures?

Second, as industrial digitalisation drives further codification and standardisation of manufacturing activities, will this lead to activities traditionally carried out by vertically integrated manufacturing firms becoming modularised and outsourced (to specialist engineering services firms, contract manufacturing/R&D firms, etc)? Will it result in an acceleration of the transfer of specialised industrial activities from manufacturing sectors to technical services subsectors? Will industrial digitalisation lead to the development of entirely new categories of technical services which will grow to a level that merits the creation of new subsector codes?

Third, as the as the digitalisation of manufacturing systems (of supply chains, factories, and product development) becomes more pervasive and standardised, will this mean that there will be a reduced burden on firms in terms of responding to national accounts/governmental business surveys? Will this improve the sampling and accuracy of national industrial data? What new opportunities might this open up?

# 4 | CONCLUSION

In this report we investigated the black box of manufacturing — critically discussing existing methods for conceptualising and counting manufacturing in the economy.

In section 2, we reviewed definitions and understandings of manufacturing. Is manufacturing the transformation of raw materials or the translation of an idea into a product? Our aim was not to conclude with 'wrong' and 'right' definitions but rather highlight the systems nature of manufacturing. We used the analogy of a complex organism, like the human body, to explain how a manufacturing system works. The functioning of the human body relies on cooperation between interdependent biological sub-systems — like the circulatory system, the digestive system, the immune system, the nervous system, the muscular system, the respiratory system, and so on. Just like the human body, the functioning of a manufacturing system relies on cooperation between interdependent sub-systems as well. The central value chain, which consists of R&D, design, production, distribution, and after-sale services, needs timely provision of technical services, like analysis, testing, and logistics. It also needs timely provision of specialist professional services, like regulatory services, intellectual property services, investments services, and consultancy services. And it needs supply of materials, components, and other manufactured inputs, like machinery, equipment, and tools.

In section 3, we analysed how most economies count manufacturing's contribution to the economy. We highlighted that while most advanced economies have experienced deindustrialisation in the past 10-40 years, there has been less deindustrialisation than what their national accounts reveal. One reason for this is that more and more services are counted as separate from manufacturing in the national accounts, without there actually being a change in the production structure of the economy that fully reflects this change in counting.

Another point that challenges the notion of deindustrialisation is that even manufacturing-related services, like R&D, industrial design, and other technical and specialised business services, are not counted as manufacturing in the national accounts. In section 3.2 we presented studies that have looked at the contribution of manufacturing in the economy through perspectives that include manufacturing–related services. All these studies conclude that manufacturing's contribution to the economy, both as measured through value added and employment, is significantly larger than what industry classification codes reveal.

We also highlighted an additional problem with national accounting classifications in section 3: limitations that arise from the aggregation of firms which manufacture similar final products, or parts for similar final products, but have few, if any, other industrial commonalities. From a manufacturing policy / industrial strategy perspective, it would be more useful to group together firms which share industrial commonalities as they are therefore more likely to respond to policies in a broadly coherent and consistent way.

We hope that policy practitioners and national economic statisticians take our findings into account. Essentially, we are arguing for a system of analysis that is more useful for policymakers than the existing system of industry classification codes. We are arguing for a system of analysis where firms have self-organised around a common economic value proposition.

Policy therefore needs to have a more holistic sense of the system. Industrial strategy should be designed with not only manufacturing firms in mind (those currently counted as manufacturing firms in the industry classification system), but also all the services firms that are part of and serve industrial systems. Those countries that wish to retain a strong manufacturing base need to invite these services firms to the table when they conceptualise their national industrial strategy. Moreover, we hope that this report has given enough reason for policy practitioners and national economic statisticians to believe that manufacturing still is and will keep being an integral driver of technological development, productivity growth and economic prosperity.

Policy needs to have a more holistic sense of the system. Industrial strategy should be designed with not only manufacturing firms in mind, but also all the services firms that are part of and serve industrial systems.

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# ENDNOTES

*[1]The categories of manufacturing sector contained within the SIC system include: Food, beverage and tobacco products; textiles and textile products; wood and wood products; pulp, paper and paper products; publishing and printing; coke, petroleum products and nuclear fuel; chemicals, chemical products and man-made fibres; rubber and plastic products; other non-metallic mineral products; basic metals and fabricated metal products; other machinery and equipment; electrical and optical equipment; transport equipment; other manufacturing [SIC, 2007].*

*[2]However, some of this increase in services' share of R&D is most likely attributable to outsourcing of R&D to specialised laboratories that are now being reclassified from manufacturing to services — as mentioned in the previous section — and better measurement of R&D in services (Hallward-Driemeier and Nayyar, 2018).*

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The IfM is part of the University of Cambridge's Department of Engineering. It brings together expertise in management, technology and policy to address the full spectrum of issues which can help industry and governments create sustainable economic growth.

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