NAVIGATING COMPLEXITY IN FORESIGHT: LESSONS FROM THE UK FUTURE OF MANUFACTURING PROJECT

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Abstract

As the role of manufacturing within national economies is re-evaluated in countries around the world, manufacturing foresight is becoming increasingly relevant in the policy agenda. There is increased recognition among policy makers of the need for a better understanding of the forces influencing the future of manufacturing, the consequences for national manufacturing competitiveness, and the implications for policies to support manufacturing-based economic growth. However, manufacturing foresight is becoming an increasingly complex task. Manufacturing systems are evolving rapidly and are becoming more intricate. The future of manufacturing and its role within national economies is being shaped not only by technological innovation but also by a broad spectrum of socio-economic forces such as environmental concerns and increasing global competition. Multiple units of analysis and areas of expertise are therefore potentially relevant to manufacturing foresight. Drawing from the experience of the Foresight Future of Manufacturing project conducted by the UK Government Office for Science, this paper illustrates the complexity involved in conducting manufacturing foresight, particularly in developing analysis frameworks and selecting appropriate portfolios of tools. The paper then suggests potential approaches and effective practices to navigate this complexity and concludes by discussing implications on coordination across government in areas including sector and technology strategies.

Keywords: Manufacturing, Foresight, Policy, UK

Introduction

In recent years, the role of manufacturing in national economies has received renewed attention from policy makers (Chang et. al., 2013; UNIDO, 2013; EOP, 2012). In particular, the 2008 financial crisis highlighted the need for new sources of jobs and economic growth (BIS, 2012). As new industrial strategies and manufacturing policies are designed in countries around the world (O'Sullivan et. al., 2013; Warwick, 2013), there is increasing interest in understanding the forces influencing the future of manufacturing, the consequences for national competitiveness, and the implications for policies to support manufacturing-based growth.

In this context, manufacturing foresight has become an increasingly important tool for supporting policy development. A number of national manufacturing foresight-related exercises have recently been carried out in countries around the world (Abele, 2011; Acatech, 2012; Foresight, 2013; van der Zee, 2007). And while approaches adopted vary considerably, there is increasing awareness and recognition among foresight practitioners of the increasing complexity of manufacturing and the challenges for effective foresight (O'Sullivan and Mitchell, 2013).

A number of factors make manufacturing foresight especially challenging. First, the nature of modern manufacturing-*systems* requires more than analysing individual industry sectors and technologies. Many high value manufactured products are themselves complex systems, made up of multiple technological components, produced by advanced process technologies and relying on diverse (often interdependent) supply networks (Tassey, 2010; Brecher, 2012). The high level of complexity of these systems and the diversity of forces acting on them make anticipating their future configurations, challenges and opportunities extremely challenging. Second, manufacturing innovation driven by emerging science and technology developments (e.g. additive manufacturing, the internet-of-things) have the potential to radically reshape the future of manufacturing (Dickens et. al., 2013). Third, the future of manufacturing is also being shaped by powerful social and economic drivers – e.g. climate change, energy security and aging populations (Abele, 2011; Lopez-Gomez et. al., 2013) – and relies on the availability and combination of production factors relevant to the entire economy – e.g. labour, knowledge, resources, capital (O'Sullivan et. al., 2013). Consequently manufacturing foresight and policies need to account for multiple (often competing) stakeholder agendas, political priorities and policy levers.

This paper aims to contribute to the literature on future-oriented technology analysis by exploring the complexity of manufacturing foresight and suggesting approaches for navigating this complexity. It draws from academic literature and a review of recent international foresight exercises, as well as from the authors' participation in the UK *Foresight Future of Manufacturing* project. While our focus is on manufacturing, the implications are relevant to foresight analysis of other complex dynamic systems.

Methodological approach

The methodology of this paper is as follows: We first briefly explore how manufacturing systems are characterised in the academic literature and international foresight in terms of system elements, linkages, actors and drivers of change, paying special attention to policy-related perspectives. Based on this discussion of what makes manufacturing as a subject theme different, we then explore implications to four tasks in the foresight process: defining *objectives*, setting the *scope*, selecting foresight *tools*, and synthesising *outputs*. We then use this structure to describe the recent UK Foresight Future of Manufacturing project from a manufacturing-*systems* perspective, contrasting it with international approaches and discussing lessons learned and effective practices. Finally, we draw conclusions about managing the complexity of manufacturing foresight (and foresight of complex systems more generally), offer suggestions for research opportunities, and make some practical policy recommendations for enhancing future manufacturing foresight analyses.

Characterisation of manufacturing

In this section we explore how manufacturing systems are characterised in the academic literature and international foresight, in terms of: (a) different system elements and structures, (b) manufacturing actors and their linkages, and (c) drivers of change in the system.

In characterising manufacturing system *elements and structures* relevant for advanced manufacturing strategies and policies several authors distinguish between (1) complex system products which require sophisticated manufacturing integration (Tassey, 2010), (2) advanced production systems and tools (Jovane et. al., 2009) (3) 'smart' manufacturing and distribution systems (Brecher, 2012), (4) complex networks for supply and value-adding

activities (Sturgeon, 2001) and (5) emerging science and technologies with the potential to disrupt the nature and configuration of the other manufacturing elements (IDA, 2012).

Critical to the effective analysis of manufacturing systems is an understanding of how different *actors* are configured within 'production networks' (Sturgeon, 2010; Gereffi, 2005). Authors make efforts to distinguish between lead firms, 'turn-key' manufacturers and suppliers (Sturgeon, 2002). Others distinguish between the roles and incentives of final product industries and factory suppliers (Jovan et. al., 2009). While others point to the importance of (clusters of) firms supplying an 'industrial commons' of enabling engineering tools, infrastructure and services (Pisano and Shih, 2009).

In addition to changes in manufacturing resulting from technical and/or operational developments, manufacturing systems are being shaped by powerful social and economic *drivers*, e.g. climate change, energy security, globalisation, etc. (O'Sullivan et. al., 2013). These global challenges and trends drive competing agendas regarding what will need to produced, where and how.

The high level of complexity of manufacturing systems and the diversity of system elements and structures, manufacturing actors and linkages, and drivers of change, have implications for the design of a foresight process. We explore these implications across key tasks in the foresight process in the following sections.

Defining objectives

Owing to the complexity of manufacturing systems outlined earlier, the use of foresight as a "systematic, participatory, future-intelligence-gathering and medium-to long-term vision-building process aimed at present-day decisions and mobilising joint actions" (Gavigan et.al., 2001, p.V) requires prioritising among many possible objectives.

Beyond the analysis of particular manufacturing sectors and technologies, manufacturing foresight can be used to reveal cross-cutting patterns. In particular, it can be used to explore themes relevant to national competitiveness, including: interdependence of manufacturing and innovation; requirements for manufacturing in high wage economies; sustainability trade-offs; and the evolving global distribution of value added.

Because no single government department or agency will be able to implement action items and therefore a number of potential policy 'customer' needs may need to be considered, manufacturing foresight may address a number of policy functions, including:

- developing consensus vision(s)
- revealing competing vision(s)
- setting R&D priorities
- stakeholder networking/coordination/awareness/alignment
- benchmarking

Setting the scope

In designing any foresight study, it is important to identify the elements and boundaries of the system being studied, before defining key units of analysis and the scope of inquiry. This is especially important for manufacturing where the definition of 'manufacturing' itself has evolved in recent years and varies between stakeholders. The definition adopted influences choices of foresight scope, in terms of relevant analysis themes, stakeholder perspectives, time-frames and geographies.

Although different international manufacturing strategies and foresight exercises have addressed the issues outlined above in a variety of ways, certain themes and elements appear regularly in frameworks used for manufacturing strategy development and foresight:

advanced products (requiring high value, hard-to-replicate manufacturing technologies) (PCAST, 2011), advanced production technologies (which can achieve significant economies of scope and planning) (Acatech, 2010), 'smart' manufacturing systems and supply chains (PCAST, 2011), and manufacturing-related S&T developments (especially those with the potential to radically reshape manufacturing systems, e.g. advanced materials, additive-manufacturing and the 'internet-of-things') (IDA, 2012).

One striking aspect of several manufacturing foresight-related exercises is the effort to distinguish between different categories of firms. Recent exercises in Germany take care to gather stakeholder input from the SME community and not just large MNCs (Abele, 2010. Other exercises highlight the distinction between manufacturing firms (and associated value chains) producing commodity-based 'consumer' products and those firms which produce capital equipment- and tool-based products and services for factories (Jovane et. al., 2009). Further distinctions are drawn between firms providing manufacturing solutions for *established* sectors and *emerging* sectors.

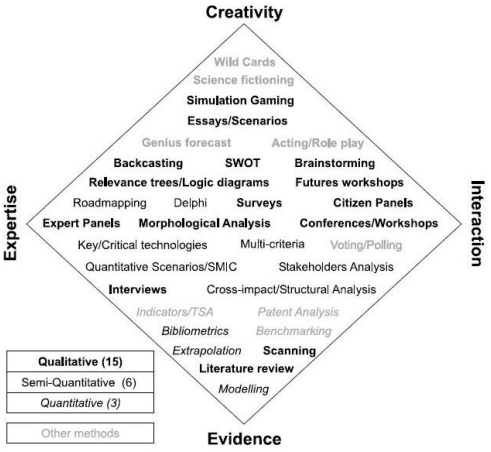
Most recent international manufacturing foresight-related exercises identify a common set of 'mega-trends' shaping the future of manufacturing. These include phenomena affecting industrial activity at the global and national levels: the increasingly complex and globalized nature of manufacturing; the drastic reduction in manufacturing timescales and associated acceleration of technological innovation; and the growing need for sustainable, resource efficient production (Lopez-Gomez, 2013; O'Sullivan and Mitchell, 2013).

Selecting foresight tools

The portfolio of tools used in a foresight exercise also needs to be defined with the system of analysis in mind. The type of evidence and level of detail that the selected tools are able to provide need to be commensurate with the objectives and scope defined, and may need to be deployed in a phased manner to act upon

Popper (2008) proposes a characterisation of foresight tools (the 'foresight diamond', see Figure 1) according to two 'fundamental attributes': *nature* and *capabilities*. In terms of their nature, methods can be characterised as qualitative, quantitative or semi-quantitative. Popper's (2008) second attribute refers to the *capabilities* of methods to gather or process information based on evidence, expertise, interaction or creativity.

Figure 1. Popper's 'Foresight Diamond'



Source: Popper (2008)

Many international foresight studies used a mix of tools, combining engagement with key experts with broader interactions with manufacturing stakeholder communities, backed up by

'desk research' analysis of the existing evidence base (O'Sullivan, 2013; Popper, 2008). This reflects a variety of factors, such as: the scale and geographical scope of study; the dominant manufacturing sectors; the time horizon; the missions and perspectives of the study sponsors; the national innovation strengths and R&D intensity (O'Sullivan, 2013).

Synthesising outputs

From a policy perspective, there are a variety of 'framework conditions' and related 'policy levers' capable of influencing manufacturing systems, e.g.: intellectual property regimes, regulations, STEM education, immigration policies, technical standards, demographics, availability of financial capital (Warwick, 2013). Not only do these factors need to be accounted for in manufacturing foresight frameworks, but foresight outputs need to be synthesised to usefully inform relevant policy actions.

Similarly, the results of manufacturing foresight need to be presented in a way that meets requirements of a variety of 'policy customers' in terms of their specific evidence needs (anticipated and unanticipated), useful level of detail and accessible language. Such customers may include government departments and agencies in charge of a wide range of issues: science and technology, skills, environment, economic development, investment promotion, and international trade. The visions developed also need to inform academia and industry.

Results, Discussion and Implications

The UK approach

Policy context

Since the 2008 global financial crisis, there has been widespread economic and political acceptance, even among many of the traditional proponents of a finance-led service economy (Chang et. al., 2013) that the role of manufacturing in the UK economy needs to be reappraised and given greater priority (Cable, 2012). A resurgence of interest in the sector has also been generated by ongoing declines in the relative share of manufacturing in the UK economy, from 30% in the early 1970s to 10% in 2013 (Hay et. at., 2013), in the face of competition from developing economies and faster growth in the service sector. This trend has also been seen in other developed economies including the US and France, and has been accompanied with the loss of manufacturing facilities, capacity, capabilities and jobs.

The policy response in the UK has been for a call to rebalance the economy (BIS, 2012) to place manufacturing at the heart of a healthy UK economy (Cable, 2012). The Government's Industrial Strategy (BIS, 2014) provides a framework for the whole of government to work in partnership with industry to set out and deliver long-term plans to secure jobs and growth. This policy response was developed from 2011 onwards, contemporaneously with the Foresight Future of Manufacturing Project. The Government's Industrial Strategy focuses on five themes of strong relevance to the manufacturing sector including sector partnerships, technologies, skills, access to finance and procurement.

The UK government also introduced a number of manufacturing focused policy measures, aligned to the wider programme of Industrial Strategy, to strengthen the UK's manufacturing capability. These include the measures below, designed to encourage businesses to:

- Innovate and invest in new technologies, including establishing the 'High Value Manufacturing Catapult', a new national technology and innovation centre, in 2011.

- Build supply chains including introduction of an Advanced Manufacturing Supply Chain Initiative, a funding competition.
- Improve skills, with investment in the Employer Ownership and STEM capital teaching funds.
- Increase manufacturing exports, for example with UK Trade & Investment (UKTI) providing expert trade advice and practical support to companies.

Government agencies also responded; for example the Engineering and Physical Sciences Research Council (EPSRC) established a specific 'Manufacturing the Future' strategy, and the Technology Strategy Board (now Innovate UK) developed its a High Value Manufacturing Strategy 2012-15 informed by a wide ranging Future Landscape Study. All of these manufacturing stakeholder initiatives harnessed specific information about manufacturing that the foresight exercise drew upon to complement its own analysis.

The UK Foresight Programme

The Foresight Programme, based in the UK Government Office for Science under the leadership of the UK Government Chief Scientific Adviser, specialises in using "the latest scientific evidence and futures analysis to address complex issues and provide strategic options for policy makers" (GO-Science, 2014). Foresight projects typically examine either an important public policy issue where science might be part of the solution, or a scientific topic where potential applications and technologies are yet to be realised.

Project process and governance

As set out in Figure 2, the Project was structured using a framework which involved the development of formal governance arrangements; time bound phases; specific activities; and managed outputs. These are discussed further below.

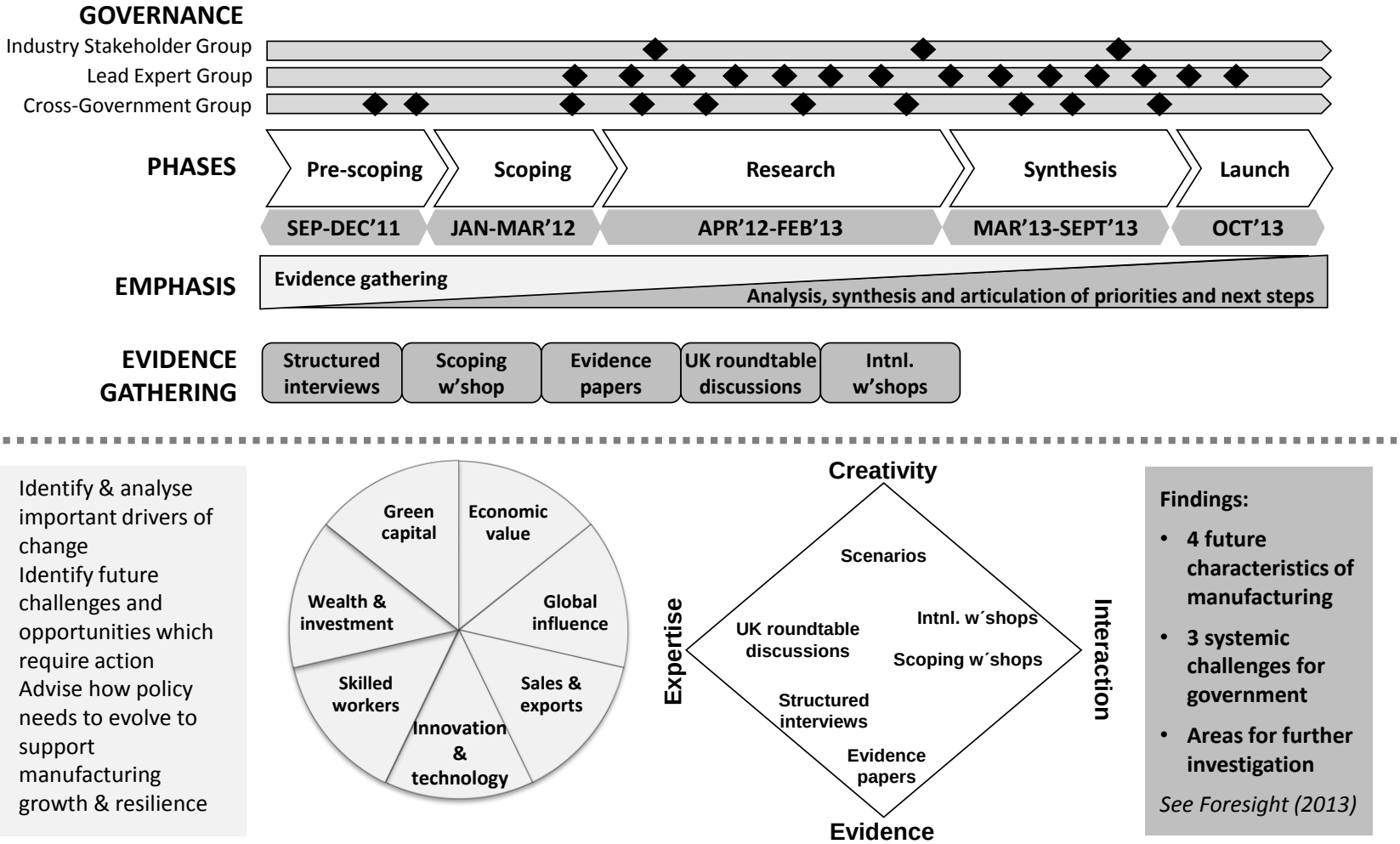
The 2-year Project was run by the Foresight Programme in the UK Government Office for Science, under the personal direction of the Government Chief Scientific Adviser. The Project involved over 300 industry and academic experts, business leaders and stakeholders, from 25 countries. This input supported the development of 37 peer-reviewed technical evidence papers and provided a wide range of insights and advice. Valuable international perspectives were provided at workshops held in Asia, Europe and the US.

Formal governance arrangements included an Industry High Level Stakeholder Group chaired by the Secretary of State for Business, Innovation and Skills, which provided strategic advice; a multi-disciplinary Lead Expert Group drawn from business and academia, chaired by a senior industrialist, which provided technical advice; and a cross-Government Project Advisory Group, which provided ongoing policy advice.

Project objectives

The project objective was to take a strategic look at manufacturing out to 2050, in order to "identify and analyse important drivers of change affecting the UK manufacturing sector; identify the challenges and opportunities that lie ahead and which require action by Government and firms; and advise how Government policy needs to evolve so that it is better positioned to support the growth and resilience of UK manufacturing over coming decades" (Foresight, 2013). The findings and underpinning evidence were primarily aimed at decision makers in Government however were also of direct interest to businesses.

Figure 2: UK Foresight Future of Manufacturing Project: Framework and Governance



Scope and definitions

The UK Foresight Future of Manufacturing project used as its starting point an analysis of the evolution of manufacturing, from a production process in which raw materials are transformed into physical products, to a more recent understanding of production as a critical part of a wider manufacturing value chain, which includes complementary pre-production and post-production activities (Foresight, 2013). The project used this broader definition of manufacturing to build evidence that analysed elements of the wider manufacturing system, which informed the units of analysis and research tools used.

The reports adopted a broad systems-based perspective to deliver insights into the drivers of change likely to affect manufacturing and the environment in which it operates over the decades ahead up to 2050. In doing so, the work also considers the cross-cutting interdependencies which exist between science and innovation, technology and sector specific policy measures.

Selection of foresight tools & methods

The Foresight project utilised a range of specific tools to deliver relevant findings and insight, based on expertise, evidence, interaction or creativity based. The tools used included:

- A *scoping workshop* to define potential objectives;
- *Expert panels*, including the multi-disciplinary Lead Expert Group, which provided insight into the complex and interconnected nature of manufacturing systems;
- *37 peer-reviewed evidence papers* examining sociological, technological, economic, environmental and political drivers of change of relevance to manufacturing, some of which also included quantitative scenario analysis or economic forecasting;
- *UK roundtable discussions* examining specific changes in further detail with leading experts, such as changing approaches to industrial strategy;
- *Structured interviews* to draw on the experience and skills of leading UK and international academic experts and industry leaders;
- *International workshops* held in Asia, Europe and the US to test early findings in an interactive and creative environment; and
- *Scenario writing* to consider the potential implications of interactions between drivers of change on manufacturing systems.

The research was conducted in an iterative manner, with evidence papers commissioned in stages to allow for later pieces of research to reflect and test the findings of earlier evidence papers. Workshops and expert panels were also arranged to support this iterative approach and support ongoing synthesis of findings.

Output and expected impact of the process

All of the foresight tools detailed above produced findings which were subsequently used to inform the final project report, with the exception of the scenario writing tool which produced less robust results, a point which is considered further in the discussion section. In parallel to the application of foresight tools, an ongoing literature review considered relevant manufacturing related publications to provide regular additional evidence and insights, whilst ongoing interaction with the manufacturing policy community provided regular opportunities to ensure that the foresight tools being applied would produce evidence and insights of use to policy makers.

The findings of the project can be categorised into three groupings. Firstly, the Project provided findings relating to the changing nature of UK manufacturing activities and their role in creating value. Secondly, the Project provided findings relating to important long-term changes affecting UK manufacturing which are presented as four future characteristics of

manufacturing. Thirdly, the Project provided findings relating to new approaches that policy makers will need to utilise as manufacturing evolves, to ensure that the UK is a place where it also increasingly thrives.

The Project identified four future characteristics of manufacturing, which is likely to become faster, more responsive and closer to customers; exposed to new market opportunities; more sustainable; and increasingly dependent on highly skilled workers, and recommended that the UK Government develops specific policies which help the UK adapt to these changes. The Project also recommended that the UK Government acts in three systemic areas to:

- Exploit new forms of intelligence to gain sharper insights into the sector and value creation;
- Take a more targeted approach to supporting manufacturers, based on a system-wide understanding of science, technology, innovation and industrial policies; and
- Adapt and build innovative new institutional capability for the future.

The Secretary of State for Business, Innovation and Skills, described the report as "unique in Europe, if not globally" in terms of the strategic view it provides of the future of manufacturing as far ahead as 2050, and called the work a "big contribution to long term industrial strategy" (RAE, 2013). The work was also welcomed by industry leaders from organisations including the Nissan Motor Co Ltd, GSK plc, BAE Systems plc, Siemens AG, and GKN plc (Foresight, 2013). Overall, the project recommended action in 76 policy areas relating to the four future characteristics of manufacturing and the three systemic challenges facing policy makers. 75 of these 76 recommendations were accepted by the UK Government (The Manufacturer, 2014), with evidence set out in the Foresight report now being used to inform policy development in these areas.

Discussion

A key challenge for manufacturing foresight is to ensure that the perspectives of the different relevant actors are appropriately considered. In the UK Foresight project this challenge was addressed by establishing a clear governance structure that ensured an ongoing involvement of stakeholders and provided the communication channels to inform them regularly of the progress the work was making.

A further challenge gathering, analysing and acting upon a wide breadth of evidence in a flexible manner. In order to address this challenge, the UK Foresight project was conceived as an iterative and phased over a two-year period. Commissioning evidence papers was particularly effective as it allowed further investigation of emerging findings, addressing perceived knowledge gaps as they emerged.

Because manufacturing represents a global system, there appeared to be significant value in hosting internationally-based workshops. However, not all of the work commissioned was ultimately robust enough to inform the final project findings. This included a scenario writing exercise, which did not anticipate the full complexity of manufacturing systems and, as a result, did not provide suitable evidence and was ultimately not developed further.

In the future, as other policy initiatives develop, a clear area for opportunity is the coordination and integration of manufacturing foresight analyses with other relevant policy analyses. In the UK, relevant analyses include evidence papers of 'Great Technologies', 'Sector Strategies', other), as well as foresight exercises in related themes.

In particular, with the development of sector strategies, more sector-specific detail can be drawn upon and the foresight agenda should be shaped to address the evidence needs of

these strategies. For example, sector strategies can provide key manufacturing capability challenges identified by particular sector communities. The need to recognise variations across manufacturing sectors is particularly important – for example, the 'smile curve' of value distribution presented in the UK manufacturing foresight was a generalisation of value distribution across sectors which can hide future high-value manufacturing opportunities.

And while the exercise commissioned a number of papers looking at international experiences (Chang et. al., 2013; O'Sullivan, 2013) there were opportunities for using the findings to more carefully define the units of analysis and methodologies selected for the study. Finally, while the report reflected on the implications of the vision developed for areas of government action, it did not explicitly discussed implications for the role of the private sector.

Conclusions

The high level of complexity of manufacturing systems and the diversity of forces acting on them make anticipating their future configurations, challenges and opportunities particularly difficult. Manufacturing foresight needs to deal with multiple units of analysis, assimilate a variety of evidence at different levels of disaggregation from a variety of sources, and integrate diverse stakeholder perspectives.

Manufacturing foresight provides an opportunity to address themes (challenges, opportunities, strengths, weaknesses) which cannot be fully revealed by analysing individual technologies or particular industry sectors alone. For example, it can provide a better understanding of sector-specific implications of cross-cutting trends and the extent to which concerns and opportunities are shared across sectors. In particular, manufacturing foresight can be used to explore themes relevant to national competitiveness, including: interdependence of manufacturing and innovation; requirements for manufacturing in high wage economies; sustainability trade-offs; and the evolving global distribution of value added.

In order to do this, however, manufacturing foresight exercises need to adopt a broader systems perspective – addressing different manufacturing system elements and structures, actors and linkages, and drivers of change in the system. This implies a recognition of themes that are relevant to the manufacturing 'ecosystem' to which manufacturing, sectors and technologies all belong.

Given the multiplicity of units of analysis involved, manufacturing foresight needs to reflect upon existing analyses of individual elements of the system (including sector- and technology-specific studies). Opportunities exist to coordinate the evidence base across such analyses and foresight, using gathered evidence, accumulated know-how and institutional capabilities. All this has implications for inter-agency collaboration and structure, sequencing of initiatives, and efficiency of information sharing.

From a practical point of view, practitioners have the opportunity to build on previous manufacturing foresight analyses nationally and internationally - drawing on lessons learned, effective practices as well as key findings.

Finally, the outputs of manufacturing foresight need to be presented in a way that meets the requirements of a variety of 'policy customers' in terms of their specific evidence needs, useful level of detail and accessible language. This means that it is necessary to make sure that outputs are relevant for government but also that the visions developed are useful to academia and industry.

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