Industrial capabilities, innovation and place

A PAPER FOR UK RESEARCH AND INNOVATION

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1 Introductory remarks: Industrial Policy and the Economics of Production

Where do R&D and place fit into industrial strategy? More specifically, "How might UKRI develop a place-based fund that invests in local research and innovation systems in order to develop local industrial capabilities to enable significantly greater local economic benefits?"[1]

This question encapsulates the uniqueness and historical weakness of UK industrial policy. In nearly every other advanced industrialized country science and technology policy is integral to industrial policy. Industrial follower nations design industrial strategies to take advantage of the science and technology resources of leading nations. The central focus of their industrial policies is to advance the production capabilities of their business enterprises. In contrast, the integration of science and technology policy with attention to the fundamental principles of production and business organization has never been the approach taken by UK policymakers from when it was first proposed by Charles Babbage with the publication of *On the Economy of Machinery and Manufacturers* in 1832.

Perhaps Babbage's clarion call for a science-informed industrial policy was ignored precisely because of place. While economic policymaking was concentrated in London, the industrial revolution occurred in the north. Babbage's call for an economics of production was alien to the success of London as the financial and commercial centre of a rapidly growing international trading system. In this context, the economics of exchange was the language of economic discourse and has remained so through the decades. It would be hard to overstate the power of ideas to influence government policy independent of their relevance, as Keynes warned us.

The conventional wisdom is that the UK is good at invention but poor at the translation of a well-funded science and technology infrastructure into successful companies and higher national productivity levels. It comes as no surprise that a preoccupation with low productivity and industrial decline remains at the centre of the recent White Paper on industrial strategy.

UK governments have undertaken and implemented numerous industrial strategies, but they have all failed to arrest industrial decline or reduce regional imbalances. The policymaking spectrum guiding earlier strategies has been wide. One finds that examples of government ownership of production and central planning; laissez-faire; Keynesian demand management; monetarism; supply-side tax reform; and light touch regulation have all been at the centre of policymaking in at least one government over past decades. But beyond the strongly held disagreements on the efficacy of specific policy instruments, the competing perspectives share an explicit or implicit theoretical conception of the economy in which the production system, business organization, and economic governance tend to be treated as separate and unconnected issues where government has at best an extremely limited role to play. It is a policy-making environment in which systemic linkages and mutual adjustment processes are invisible and one that ignores the lessons of successful policymaking experiences elsewhere at considerable cost to economic performance.

A successful industrial strategy must answer the question from whence will come the business enterprises that are going to grow, organize new production capabilities, innovate, invest in new production facilities, train new workers and collectively create new industries and transform existing industries to achieve a step change in economic performance. The interconnectedness theme has crucial implications for the design of industrial policy. Strategies that address production capability, enterprise growth, skill formation and governance separately and in isolation will not be successful. A

[1] This is the 'key question' posed by a University of Cambridge's project in support of the UKRI's request to explore how it can play an active role in contributing to the UK Government's place agenda within the industrial strategy (March 2018).

requirement for transformative policies is that they be almost seamlessly blended into the detailed mechanics of change within private firms.

At the same time, while firms are the drivers, they are not the organizers of industrial strategies. Only the government has the legitimacy, the powers, and the resources to craft and implement an industrial strategy. The government's role is to establish the vision, the roadmap and the enabling environment to set the enterprise strategy in motion, to make it work. The goal is not to financially or otherwise support any single firm but to create the enabling conditions for whole sectors, clusters, or populations of enterprises to undertake change programs to advance their productive structures.

Perhaps it is ironic that the nation that was the first to industrialize is the last to pursue a production-centric industrial policy and yet has historically been at the forefront of scientific research and technological innovation. What distinguishes the UK is that its vaunted science and technological knowledge base has rarely served as a science and technology infrastructure to advance the performance of either the national or regional production system. In contrast, nations without a science and technology infrastructure have accessed the UK's knowledge base as an imported productive resource and an instrument of industrial policy. In this way, the UK's advanced R&D capability has served as a science and technology infrastructure but to the benefit of productive structures elsewhere and not to its own production system. The 2018 British White Paper on industrial strategy seeks, in effect, to connect the UK's research and innovation institutions into an extra-firm infrastructure integral to indigenous production capability development with particular emphasis on stranded regions.

Here, the UK is playing catchup. Other nations have operationalized inter-organizational linkages connecting science and technology institutions with production capability development. Much can be learned from best practice or by benchmarking successful 'translational research' capability by which industrial policies elsewhere have successfully connected R&D into an instrument to advance national and regional productive structures.

Conventional economics and UK economic policy practices do not address what goes on inside the business enterprise in terms of production capability development or economic transformations concerning innovation dynamics that result in rapid growth experiences. But real-world transformation experiences have many lessons for economic analysis, including the role of a national science and technology infrastructure as a component of place-informed industrial policy.

Translational research is shorthand for the mediating linkage(s) in an inter-organizational innovation process chain which connects basic, developmental, and applied research activities conducted outside the business enterprise in public and private labs with technology management, design for manufacturability, new product development, and production process capabilities undertaken within the enterprise. In multi-divisional enterprises applied and even developmental research activities can be internalized, but in most SMEs these activities are accessed via long-term consultative relationships with external suppliers. Successful linkages are mediated by networking modes of coordination rather than market or bureaucratic modes. It means going beyond one-off technology transfers to fostering translational research relationships that impact the new product development and technology management capabilities of regional clusters of enterprises. Here the industrial policy purpose is to create networking opportunities for innovating firms to drive production capability development and in the process advance a nation and/or region's productive structures.

The unique responsibility of industrial policy officers is to conduct research to characterize the interfaces and the links that are underdeveloped and thereby limiting the innovation dynamics of a region and/or nation's business enterprises. Unlocking a region's capability development potential will

depend upon organizing inter-organizational innovation process chains and increasing the flow of projects through them.

Translational research in the UK is the bottleneck to flow along the innovation process chain and limits the economic impact of science and technology funding. This means that merely increasing the science and technology budget will not increase productivity if the nation's and/or region's enterprises do not take ownership of internal capability development strategies. Research funding, alone, will not induce dynamic increasing returns, the key to transformative growth. Nor will funding enterprises that are not committed to or lack the means to move up the production capability spectrum (Best 2001: 55-56).

In this short paper we present the role of research institutions that are functionally equivalent to the UKRI in two economic 'miracles' within industrial policies enacted first in the US and second in Germany. This is followed by a UK experience of a university initiative to create a local manufacturing research center which is fostering a regional industrial resurgence and ask why this is the exception in the UK. The answer in important part is the historic lack of economic policymaking powers at the metro-government level and the dominance of stabilization over development policymaking at the national level. The following section draws upon observation-informed research conducted over several decades to derive the capability triad - an economic framework that focuses on production, enterprise, and governance - as a strategic industrial policy framework. Finally, we illustrate how a place-based industrial policy can leverage the UK's science and technology infrastructure to meet the government's climate change targets in ways that foster sustainable and inclusive growth dynamics.

2 US Arsenal of Democracy: An Interconnected Strategy

The most successful industrial policy experience in history is arguably that conducted by the US government during World War II to build the 'Arsenal of Democracy' during which national output nearly doubled in a half a decade. How was it done? The answer was to organize an organizationally interdependent innovation process chain linking basic research, developmental research and applied research with the diffusion of world class production capabilities. The American business system was transformed to harness the driving force of innovating enterprises. In the process the American production system was, in effect, reengineered to accomplish a step change in performance standards. The effect was to build an inter-organizational technology management capability.

The manufacturing process in virtually every enterprise in the US was reengineered to meet the performance standards required to meet the output targets to build the 'arsenal of democracy'. It can also be interpreted as the creation of a national translational research capability that linked 'top down' enabling agencies with 'bottom up' operational drivers. Implementation required combined efforts of a set of unified extra-firm infrastructural agencies led by the Office of Scientific Research and Development (OSRD), the War Production Board (WPB), the Manpower Development Commission (MDC), and the Defense Plant Corporation (DPC). Each was dismantled at the War's end.

The key to implementation was inter-organizational connectedness. The OSRD, led by Vannevar Bush, involved building a national science and technology 'extra-firm' infrastructure to organize, design, develop, and produce technologically advanced weapon systems. Examples, of which microwave or radar, penicillin, and synthetic rubber are only three, required marrying basic, developmental, applied research with design for manufacturability either in or with mass production facilities. The latter required reengineering the production base of the country to meet the performance standards of

cheaper, better, and faster. When adopted and extended by Japan in the post-war era, the process innovations become widely known, imitated, and diffused as JIT, TQM, and SDWTs.[2]

With twelve million Americans transferred into the armed services, the production system had to be transformed. Designing the means to undertake the transformation across the economy to meet the production targets was the task of the WPB and the MDC. For example, to meet the production target of one B-24 bomber per hour required the supply chain deliver 1.5 million parts to the factory gates per hour. The War Manpower Commission designed and operationalized the functional equivalent of a fast-track national training program to grow a labour force with the skills to achieve the production targets.

Economic statisticians played a key role. The engineering challenge by which the nation's production system was restructured was critical to implementation of the Victory Program, itself written by Simon Kuznets, chief economist at the War Production Board. He and fellow economic statisticians diligently created statistical tables on the existing and planned output of the nation's manufacturing enterprises often ingeniously located sources of data some of which came from the UK's Ministry of Industry. Kuznets, as the father of US national income and production accounts was the perfect person and perhaps the only person who could have linked the nation's production system requirements with the Allies war strategy.

No doubt, the US World War II experience was a special case. But it was special case from which much can be learned about the economics of production and 'translational' research as an infrastructural enabler of innovation dynamics and enterprise capability development. It offers a powerful negative lesson as well. With respect to both US and UK post-war policymaking, the major lesson is that economic policymaking dominated by debates over stabilization instruments and targets has, in effect, made invisible the production side of the economy. The economic statistics collected today by the Office of National Statistics reflect this invisibility, as does the failure to incorporate a detailed production side into macroeconomic models. So, too, does the dominance of the Federal Reserve Bank and the Treasury at the pinnacle of economic policymaking and the shunting of economic analyses of production into, at best, lower tier ministries.[3]

Kuznets and his team of statisticians did not have electronic computers or the sophisticated survey techniques to generate the data of today, but they constructed tables with measures of the production capacity of the nation's enterprises and estimates of the links between existing output and the potential output if investments to remove input bottlenecks and best practice enterprise change methodologies were successfully undertaken. These were necessary inputs into estimates of the nation's supply capabilities that lay behind the strategic military decision to delay the Allies invasion of western Europe until 1944. Without it, military success would have been problematic. Finally, and critically, they had the ear and confidence of the President who successfully subordinated stabilization policies to ensure consistency with the production transformation imperative. Roosevelt's leadership in articulating a vision in the form of the Arsenal of Democracy was a purpose with which everyone could identify. It was a vision with a roadmap of quantitative goals, but which had remarkably little on *how* it was to be implemented. In a market-based economy, this was a wise decision; the government did not depend upon or seek centralized authority to plan the economy as demanded by the military. It meant subordinating military authority over production planning to the economic statisticians at the WPB and subordinating technology priorities of the military authorities to the OSRD. Within the WPD,

[2] Just-in-time, total quality management, and self-directed work teams.

[3] See the Final Report of the Industrial Strategy Commission for practical proposals to move industrial strategy into the heartland of UK policymaking.

the economic statisticians, partnering with production engineers, did not seek to supplant operational decision making at the enterprise level. Instead, they devised policies including planning accounting measures to galvanize the energies of those with the requisite expertise, skills and experience to design methods and practices to make advances in production performance happen.

Although the circumstances were very different to those currently facing the British economy, the WWII "Arsenal of Democracy" experience in the USA, as well as the Cold War policy initiatives that led to Route 128 and Silicon Valley, were examples of "top-down" national strategic objectives working in a synergistic way with "bottom-up" operational capabilities. In a similar way, the German 'miracle' was a collaborative process where regional capabilities were harnessed and co-ordinated by national government, a process made easier by the federal nature of the German state. [4]

3 Germany's 'Miracle' Unpacked: the role of place

Germany provides a useful laboratory to address the challenge of "place" in national enterprise strategies. Any nation's business system is embedded within a national ecosystem made up of a unified set of extra-firm infrastructures. These need to be organized in ways that make the whole greater than the sum of the parts in a form of dynamic increasing returns at the macroeconomic level.

Tony Blair once asked Angela Merkel to explain why the German economy is so successful. She answered: "We still make things." The German post-war 'miracle', like the World War II US 'miracle', were outcomes of policy frameworks initiated, crafted, organized and undertaken by governments. In the case of Germany, strategic formulation was at the national level but customization and implementation were undertaken by local and regional governments. This fostered flexibility in formulating and shaping policy agendas to account for regionally specific legacies in engineering skills and production capabilities. The German experience may be unique in its success in organizing production capability and enterprise performance across most if not all regions of the nation. This has important implications for the introduction of place into economics and economic policymaking.

The industrial policy framework centered around fostering production and innovation capabilities within the enterprises that constituted the prewar *mittelstand* business system. These business units are largely family-owned SMEs but lack the scale to engage internally the range of activities necessary to do the production and new product development required to anticipate and respond to changes in technology and markets.

Germany's enterprise-focused policy framework leveraged its renowned engineering legacy but combined it with a production engineering culture, with extra-firm infrastructures that are seamlessly blended to establish regional industrial ecosystems in which *mittelstand* SMEs thrive. When unified, they serve as functional equivalents to the range of activities internalized in large innovative enterprises. These included:

- Dual vocational education system
- R&D services
- Development capital
- Machine, tooling, instrument and equipment making sub-sectors
- Multi-level governance

[4] See Best, 2018 (*How Growth Really Happens*), Chapters 2 and 3 for detailed accounts of the US experiences and chapter 5 for the German experience.

These functions complement, but are beyond, the scale of SMEs acting individually. While many countries have such infrastructures in name, the focus of the German economic policy framework on cumulatively and collectively advancing the production capabilities of the nation's business enterprises is what makes it work. In this it is an exemplar of capability triad thinking at work (more on this below). Change methodologies at the firm level are inter-connected with the focused range of activities for targeting and advancing the productive structures of the economy, region by region. In this the German and the American economic 'miracles' had much in common although the institutional features were very different.

The German case is an enterprise strategy that fostered new product development and technology management capabilities of existing enterprises as the core of open innovation systems at the regional level. The policy framework enabled enterprises to focus on a core capability and partner for complementary capabilities which fostered networks and networks, in turn, created new opportunities for differentiation and specialization amongst both existing and new business enterprises. The policy target was not clusters of firms in the same sector. Rather, it was networked groups of firms that create niches, innovation opportunities, and speciation dynamics within capability advancing industrial ecosystems.

We now turn to a third example of best practice in industrial policymaking, this time in the UK.

4 Translational Research and Local Capability Development: Sheffield's AMRC

One of the UK Industrial Strategy's main goals is to increase local capabilities and productivity of underperforming economic regions as a means of addressing aggregate national productivity and innovation challenges. But it is relatively silent on the complex task of explaining how transformation can be brought about other than by enumerating a series of five "foundations" that would be inputs or paths to the transformation. Fortunately, real world experiences of successful regional capability development do exist and offer lessons for industrial policymaking within the wider UK context.

Rivalled only by the US, the UK has a world leading productive resource in the form of a science and engineering research intensive university system that is widely distributed across the nation. But the advanced technology knowledge base is rarely systematically managed into a productive resource that can contribute to local industrial capability development. Despite government efforts, the nation's research system operates to a considerable extent separately from the practices and activities of the nation's business enterprises, resulting in an internationally low level of expenditure on R&D (R&D/GDP in 2017 is only 1.7%).

Sheffield's Advanced Manufacturing Research Centre (AMRC) demonstrates that what can be described as a "triple helix" set of interactions can be created in industrially depressed regions.[5] This triple helix fits the specific context of one of the UK's once thriving industrial regions and its co-located university with world-class science and engineering departments. In the process of establishing the AMRC, a 'translational' model of innovation has been created which has galvanized the business plans of many hundreds of business enterprises and fostered many dozens of shared research projects.

Founded and led by Professor Keith Ridgway at Sheffield University engineering school, the AMRC began as a collaboration with Boeing in purpose-built factory-scale facilities. Rolls-Royce then followed Boeing, and by 2018 had grown to over 600 staff and 215 employers involved (John Yates, head of External Affairs, AMRC). The co-located presence of many companies on the cutting edge of

[5] The triple helix is a concept applied to high tech regions in which government as the major funder of scientific research, universities as the site of both research and education, and innovative enterprises are organizationally interconnected in ways that foster both industrial innovation and preserve the independence of each organizational domain.

technology has been a magnet for SMEs eager to participate in joint research projects to improve their innovation capability and meet the continuous improvement requirements of a supplier to, and learner from, globally competitive enterprises as well as SMEs seeking to establish a proprietorial niche.

Recently, AMRC established *Factory 2050*, a demonstration facility with a focus on next generation technologies for the implementation of Industry 4.0 in the nearby Sheffield Business Park. "Industry 4.0" conveys the idea of a fourth industrial revolution and the integration of digital technologies into production capabilities.[6] It counters the perception that robotics, automation and the introduction of digital manufacturing technologies are just for big businesses with deep pockets.[7]

The AMRC's apprenticeship program now operates on a scale last seen by the giant engineering, steel and coal companies of yesteryear. Thirteen hundred apprentices have been through the centre and are now in full time work in a technical education opportunity pathway that extends to the top level of Sheffield University's engineering program.[8] Along the way, many SMEs have discovered the value of apprentices as agents to transfer advanced manufacturing practices and technical expertise in the Centre into change programs.

Local government has also been a committed participant. In the case of attracting McLaren, Professor Ridgway praises the coordinated activities of the Sheffield Region Local Enterprise Partnership, Sheffield City Council and its inward investment arm, Creative Sheffield and Sheffield University.[9]

What are the lessons to be learned from this example? In the words of Richard Jones:

> "… stories such as those of the Sheffield Advanced Manufacturing Research Centre suggest that manufacturing commons can be rebuilt. The emerging formula brings together several elements. Research facilities need to have an avowedly translational focus, and they should create strong research partnerships between or among academia, large companies already operating at the technological frontier, and smaller companies wishing to improve their innovation practices, possibly to make them more competitive as suppliers to the large companies. Education institutions need to focus on building skills at all levels. They should be linked with these research centres, creating clear pathways for individuals to progress from intermediate-level technical skills to the highest-level qualifications in technology and management. As these research facilities become successful and recognized, this should lead to a virtuous circle in which further inward investment is attracted and the existing business base grows in capability" (2018: 64; see also Jones 2016).[10]

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[6] See http://www.amrc.co.uk/news/mta-and-factory-2050-at-the-amrc-partner-for-exciting-industry-4-0-feature-for-mach-2018 ; and http://www.amrc.co.uk/news/amrc-bring-the-fourth-industrial-revolution-to-the-small-businesses-of-the-uk-at-mach-2018 and http://www.amrc.co.uk/news/northern-powerhouse-must-lead-the-next-industrial-revolution and http://www.amrc.co.uk/news/amrc-reducing-the-barriers-to-r-d-investment

[7] http://www.amrc.co.uk/news/access-to-world-class-facilities-at-amrc-factory-2050-made-easier-for-smes-with-opening-of-new-reconfigurable-factory-resea

[8] Seven hundred apprentices were on the books in 2018 (John Yates email correspondence, November 2, 2018). See also www.amrc.co.uk/news/house-of-commons-visit-for-the-university-of-sheffield-s-amrc-apprentices

[9] https://www.aecom.com/uk/press-releases/aecom-joins-amrc-help-boost-engineering-skills-sheffield/
http://www.amrc.co.uk/news/mclaren-automotive-partnership-with-university-of-sheffield-amrc-will-see-super-car-chassis-built-in

[10] Jones, R. 2016. "Driving productivity growth through innovation in high value manufacturing, A Science and Innovation Audit report sponsored by the Department for Business, Energy & Industrial Strategy", October.

5 Governance and Place: UK Exceptionalism

Why is Sheffield an exceptional experience in the UK? Why are there so few examples?

We learn from the Sheffield experience how a university, enterprise, and city partnership can create and implement a regional economic strategy at the core of which is building a translational research centre. From a Schumpeterian perspective it can also be interpreted as an enterprise strategy to revitalize a metro-region that has suffered from the decline of once major industries. The industrial strategy focused on establishing an enabling environment in which innovating enterprises could thrive and grow. As such, the economic development framework has familiar characteristics as those we have used to explain the US World War II, as well as that of Greater Boston[11].

At the same time, using the concept of space, it is sobering to contrast the destinies of Greater Boston with Greater Manchester from the perspective of the early 1950s. In both metropolitan areas, the textile and footwear industry legacies still loomed large. In the ensuing decades the Commonwealth of Massachusetts underwent massive transformation. Its transformed industrial system can be described as a manufactory of sectors as it spawned new enterprises and new sectors. Its per capita income has long been near or at the top of US states. Its expenditure on R&D is over 5 percent of GDP. Manchester had no such transformation.

From a regional economic development perspective, the Greater Boston, German post-war experience and Sheffield success stories suggests a deep lesson. Transformative growth experiences do not just happen. They need to be made to happen, in the case of cities, regions and nations.

The lesson for the UK from both the Massachusetts post-war transformation and the earlier US World War II transformation was that they were driven by a regional and national economic governance capability that expanded and transformed new fast-growing business enterprises and transformed the performance standards of existing enterprises.

For the US during WW II, the extra-firm infrastructures took the institutional form of mobilization agencies including the War Production Board, the War Manpower Commission, the Defense Plant Corporation amongst others. For Greater Boston, this took the form of the building up of a Triple Helix set of university, industry and government infrastructures and interactions, and in terms of strengthening the components of a regional industrial ecosystem.

Such dramatic economic transformations are organized by governments crafting and implementing development policy frameworks. Stabilization policies, the heartland of economic textbooks and market-centered economics, are important but merely as supports to transformation policies. Debates on stabilization policies dominate public discourse on economics. Unfortunately, there is much less discussion about the policymaking frameworks of economic transformative experiences.

In the case of the UK, a long history of top-down, centralized policy making left metro areas outside of London without economic powers or the array of capability development infrastructures that have evolved in Germany. R&D services are a critical enabler to the new product development and technology management capabilities of a region's enterprises. But access to R&D services are not sufficient to grow a region's economy, particularly if the other enabling infrastructures are not synchronized. The economic governance function for which metro-level government is uniquely equipped is the power to convene for the purpose of crafting an economic policy strategy, identifying

[11] See Best, 2018 (*How Growth Really Happens*), Chapter 3 for a detailed account of the Greater Boston experience.

and coordinating the enabling extra-firm infrastructures, and galvanizing the support of the constituencies required to drive the strategy.

A degree of confusion arises in the UK White Paper on industrial strategy with respect to the optimal kind of spatial governance to assist policy makers charged with implementing the strategy on the ground. The challenges of uneven distribution of activity and standards of performance over the national space are recognised, but there is uncertainty as to whether region-specific policies should be designed at the centre (in a top-down process) or whether policy making should be devolved to some degree to the regions (in a bottom-up process). Although history tells us that major innovations at the level of enterprises have tended to be place specific, often driven by local circumstances and actors, the centre usually feels that it is better organised and informed than the periphery. The centre then tries to connect these two approaches by carrying out extensive regional consultation. But it is usually the centre that shapes the strategy, based on its evaluation of the outcomes of the consultation process. The outcome of this kind of indecision can sometimes result in the worst of both approaches: on the one hand, remote guidance by a centre that lacks local knowledge and on the other hand, insufficient resources and inadequate "power to convene" in the periphery.

The concepts of industrial capabilities, innovation and place need to be at the heart of any national or regional enterprise strategy if it is to have any real prospect of delivering a transformation of economic performance. The key role of any well-designed enterprise strategy is to integrate the separate elements of a complex, modern economy. This does not happen in the absence of an interpretative framework that correctly identifies the different elements and how they interact. By these criteria, we find that the recent UK White Paper falls far short of what is required.

Perhaps the most serious problem that arises in micro-structural policy making of the kind found in strategic approaches is that a taxonomy often comes to be regarded as a strategy. For example, the guiding taxonomy that motivates the UK White Paper is what are termed "five foundations": ideas, people, infrastructure, business environment and places. To some degree, this is a useful list of elements of industrial strategy, but the very extensive bibliography attached to the White Paper does not inspire confidence that this particular selection of "foundations" is soundly based on research into other national strategies or that the complex inter-connection between the five "foundations" has been explored or understood. Similar kinds of thinking by taxonomy appear in *Strategic Prospectus: Building the UKRI Strategy*, in what are termed the four *Values* (collaboration, excellence, innovation and integrity) as well as in the four *Foundations* (leading talent, openness and transparency, a trusted and diverse system, and research culture).

6 The Capability Triad: a better strategic framework

There is an uneasy relationship between the kind of deductive economic processes that motivate much thinking about the performance of the macro or macro-sectoral economy and the largely inductive thinking that motivates micro-level investigations into industrial capabilities, innovation and the role of "place" in designing regional growth strategies. On the macro side there is a huge body of knowledge, much of it incorporated into formal models, that can be used to plan and to explore the consequences of policy actions ranging from short-term fiscal issues to longer term policies involving the likely impacts of investment in physical infrastructure. This kind of top-down, macro analysis has its uses but is not without its problems. Economic theory and official Office for National Statistics economic data have evolved in a way that feeds directly into such macro analysis. There is a wide-spread belief, contested only to a degree by the 2008 global recession and financial collapses, that appeal to data and to using quantitative models can guide policy-makers and permit policy decisions to be planned and their quantitative impacts to be evaluated ex-ante as well as ex-post.

The world of micro policy making of a structural kind is very different. Micro policies of a structural kind are policies directed at individual enterprises or clusters of interacting enterprises that provide insights into their growth and evolution. Such enterprises often have space-specific characteristics that make them different from the wide range of conventional macro-economic policies that tend to be applied and have their effects across space in a homogeneous way. Although there is an evolving literature on spatial issues in economic development and increasing returns can now be handled within conventional general equilibrium models, nevertheless the macro-policy literature has provided little by way of practical guidance to policy-makers tasked with development or re-generation enterprise strategies that have important regional dimensions. Such analysis usually has to fall back on inductive reasoning based on careful examination of what is happening on the ground, drawing on selective case studies, and placing these insights into frameworks that assist in understanding complex economic processes and that lead to useful insights and conclusions.

The challenge for micro-structural or enterprise policy-makers is to find a framework that is closely related to the real drivers of growth and development and which is closely based on a wide range of case studies. Conventional macro frameworks here are of little value. Macroeconomists (indeed, most economists of all persuasions) tend to remain outside the factory gates and often know little or nothing of the complex business structures, technical production processes and the governance systems in which enterprises are embedded.[12] The Capability Triad is a framework that synthesizes these processes.[13]

A development policy strategy and a governance structure need to be designed to organize entrepreneurial activity into a force driving national growth and economic transformation. Here the government needs to accept the role of strategic organizer of what might be termed the governance system within which the enterprise sector is embedded. The enterprise sector is then strategically positioned to drive the transformation of production and industry. The implications for economic theory, education and policymaking take us beyond the standard paradigm to an emergent political economy framework in which production, enterprise, and governance are systemically interconnected. However, this is no mere taxonomy. It is a carefully designed framework for strategic thinking that steps inside the factory gate and takes over where conventional economic analysis leaves off.

The standard paradigm (e.g., conventional neo-classical economics) is theoretically rigorous, but its failure to account for the drivers, processes, and enablers of transformative experiences illustrates the limits of its a priori principles to address complex interactive processes in real world economies. The role of historical experiences as a tool for theory construction and paradigm development signals a methodological divide between the standard equilibrium and the alternative systemic approach to economics and economic inquiry.

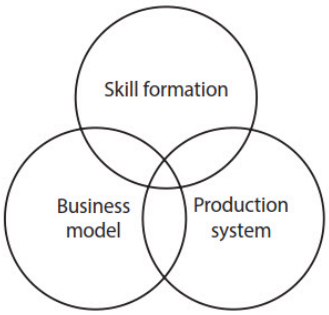
The production-centric economics paradigm is constructed from an examination of real-world transformative experiences applying systemic observation rather than a priori reasoning to economic principles. Historical experiences serve as real world laboratories for investigating patterns of change and characterizing deep structural principles of production and organization. The historical case studies do not start from a blank page. They inform and build on earlier work on successful transitions distilled in terms of a capability triad:

[12] We use the slightly antiquated term "factory gates" to identify the barrier between what goes on inside enterprises of all kinds and what goes on in the wider outside world.
[13] See Best (1990) *The New Competition*; (2001) *The New Competitive Advantage*; and (2018) *How Growth Really Happens* .

> Rapid growth involves coordinated organizational changes in each of three domains: the business model, production capabilities, and skill formation. The three domains are not separable and additive components of growth, but mutually interdependent sub-systems of a single developmental process. No one of the three elements of the Capability Triad can contribute to growth independently of mutual adjustment processes involving all three elements.[14]

Figure 1 visualizes this interconnectedness. The book *How Growth Really Happens* contains other case studies and a chronologically organized supportive account of the major theoretical contributors since Adam Smith and Charles Babbage[15] to an emergent economics in which production and business capability development are the critical dimensions of variation and integral to transformative policy frameworks.

Figure 1 The Capability Triad



The incorporation of business leaders, scientists, and technology experts in the structure of economic governance and their conversion to the desirability of the transformative objectives is also essential. When firms, regions, and nations become stuck in low productivity capability triads (because of out of date production methods, poor business co-ordination, low skills and inadequate R&D), the government is usually the only institution that can coordinate and orchestrate holistic organizational change that cuts across the three domains.

Furthermore, although enterprise development and economic governance are bound together, successful transformative experiences show us that they are indirectly mediated by infrastructural institutions. The policymaking spectrum extends to linking developmental infrastructures in ways that advance change within and across mutually adjusting enterprises. The term "economic governance" is used to emphasize ways in which science and technology, educational, and financial infrastructures can be strategically unified to foster enterprise innovation and cluster dynamic processes at both regional and national levels.[16]

The capability triad provides a useful way to understand how crises can be overcome and robust growth achieved. It is a way to understand how real people react to crises and challenges. It stands in contrast to the standard macro quantitative economic analysis that starts with a fixed model (or

[14] *The Capabilities and Innovation Perspective: The Way Ahead in Northern Ireland* (2000, 56).
[15] *On the Economy of Machinery and Manufactures* was published in 1832.
[16] The term "economic governance" is paradigm specific. From a market centric perspective it is about regulating transactions not covered by detailed contracts or problems in rule enforcement. In the wake of the financial, fiscal, and economic crises that began in 2008, the EU defines economic governance in terms of "coordination and surveillance of both fiscal and macroeconomic policies and the setting-up of a framework for the management of financial crises." On the other hand, in the production centric paradigm economic governance needs to be understood in terms of infrastructural institutions and organizations that galvanize capability triad innovation dynamics.

representation) of the economy as it is today and was in the past, feeds in anticipated changes in the domestic and international policy environments and examines the impacts of such changes where the structure of the economy is often treated as effectively frozen in time. Such an approach is ill-suited to analyse transformative micro-structural experiences. The bottom line is that policymaking not attuned to production and business organisation will be poor and ineffective. Elsewhere these points are illustrated by reflecting on the UK historical industrial experience (see Chapter 6 of *How Growth Really Happens*).

7 UK Industrial Strategy: The Clean Growth Opportunity

Clean Growth is one of four grand challenges contained in the Industrial Strategy White Paper. UK scientists have been at the forefront of efforts to establish multinational agreements to establish national carbon emission targets to limit global warming to 2% above pre-industrial revolution levels. Achievement of this goal will require an economic transformation on the scale of the world's first industrial revolution. Britain's leadership in the transformation to a post-carbon age economy could be critical to its realization.[17]

The pivotal role of UKRI is evident in the policy documents. The White Paper draws upon the Clean Growth Strategy of the Department for Business, Energy & Industrial Strategy for technical details. Elements of an implementation roadmap are articulated consistent with infrastructural role of the UKRI in partnership with research institutions and enterprises to engage in the research and innovation activities to design new products, processes, technologies, non-toxic materials to assist in transforming major industrial sectors.[18]

The challenge for UKRI and the White Paper is in establishing the linkages in the national innovation process chain which are primarily within the domain of private enterprise. For laboratory innovations to be successful they need feedback from activities such as design for manufacturability, new product pilot runs, tooling for manufacturing, etc. While some enterprises in every region will have advanced product development and technology management capabilities it is likely the number will be fewer than desired. For this reason, the industrial strategy needs an enterprise strategy to advance whole sub-populations of SMEs up the production capability spectrum to drive transformation at the macroeconomic level.[19]

It will require the UKRI to take on a role not unlike that of the OSRD during WWII America or the German R&D extra-firm infrastructures that enable the *mittelstand* SMEs to undertake technological innovation. But in both these cases, the infrastructural research agencies and business strategies were and are interconnected. In the US, the science and technology strategy undertaken by the OSRD was combined with a functionally equivalent business development strategy implemented by the WPB. A national or regional transformative experience with a stated goal of "leading the global technological revolution" (as in the White Paper) needs a policy framework that seamlessly blends policies and

[17] While at present the UK Industrial Strategy does not point the way ahead, two other government documents do. The Clean Growth Strategy of the Department for Business, Energy & Industrial Strategy and the Committee on Climate Change's 2017 Report to Parliament titled 'Meeting Carbon Budgets: Closing the Policy Gap' provide evidence and targets for meeting the policy imperative of science-based climate goals. The Report to Parliament not only provides empirical details on the scale of the challenge but decries a widening policy gap: 'The UK urgently needs new policies to cut greenhouse gas emissions. Parliament has made commitments and the Government has a legal duty to propose policies to meet them. Despite this, no significant new policy plans have been published in the 11 months since the fifth carbon budget was set. Climate change will not wait while other priorities are addressed: plans must be published without delay, setting out how the Government intends to deliver the budget, which requires a 57% reduction in greenhouse gas emissions from 1990 to 2030.'

[18] See also the Committee on Climate Change's 2017 Report to Parliament titled 'Meeting Carbon Budgets: Closing the Policy Gap'.

[19] The ten stages in the production capabilities spectrum are summarized on pages 55-6 of Best (2001).

associated and unified relational infrastructures with mutual adjustments that advance production capabilities, business organization and skill formation within and across firms.

The question is how to get buy-in particularly from the nation's SMEs. The quality revolution of the 1980s is a model for a successful enterprise change methodology at the national level. Following the logic of the quality movement, the idea is that it is cheaper in the long run to design products that are environmentally friendly rather than clean up after the pollution has occurred and enterprises that move early will create a competitive advantage. Before the quality revolution it had been widely assumed that there was a severe trade-off between the quality and cost of production. But Edward Deming's work, as embedded in the post-war Japanese economy, showed how quality and competitive advantage can emerge from the application of systems thinking and the management of the inter-relationships within the enterprise that revolutionized management thinking and practice.

The quality movement maxim is to redesign the organization of production to drive waste out of system. Henry Ford identified waste in the form of underutilized worker earning power caused by bad methods that mass production was designed to eliminate. Taiichi Ohno, the chief engineer at Toyota, added seven forms of waste, the measurement of which became a target for improving throughput efficiency. The TQM movement was a work organization system to mobilize the entire work force in pursuing innovations to measure, target, and change systems to eliminate waste (for references see Best 2001: 59).[20]

Today the conventional wisdom is that accounting for the costs of environmentally toxic emissions will lead to increased prices and lower productivity. This need not be so. It could be the trigger to address the organizational roots of the UK's weak productivity performance.

In principle, UKRI could provide the role of the OSRD or the German equivalent infrastructural research institutions to interface with the nation's business enterprises to design environmental waste out of production processes on a national scale. In this case the objective will be to create opportunities for enterprises to participate in translational research designed to create new production development and technology capabilities otherwise outside of their reach.

Here the government's role is to identify bottlenecks in the national innovation process chain and to organize infrastructures to foster capability development in the weak links. The inter-organizational innovation chain extends from basic research, development research, applied research, design for manufacturability, technology management, new product development, and production. The weak links in the UK innovation chain are translational research and production engineering. They must be addressed for UKRI to achieve its potential impact on private R&D, productivity, and addressing regional imbalance. At the level of government policymaking, the weak links are lack of interconnectedness across the policymaking ministries at the national level and low level of metro-government convening powers to undertake the infrastructural coordination activities specific to regional context.

The first requirement of a 'place-based fund for investing in local research and innovation systems in order to develop local industrial capabilities' is an enterprise capability informed SWOT analysis at the regional level. This will be a necessary but important task because of the invisibility of the UK's SME sector particularly in regions without or with historically limited metro-government economic policymaking powers and capabilities.

[20] A fundamental maxim of welfare economic theory is that waste is economic sin. The virtue of a free market system in theory is that competitive prices force firms to produce at the most efficient level. Wasteful companies will not survive.

Public data on business enterprises such as that made available by the ONS is of limited value because of lack of granularity in the Standard Industrial Classificaiton (SIC) codes and the anonymity requirement. But public data can be complemented by proprietorial enterprise-level databases such as FAME. Qualitative research must be joined with quantitative data to build an assessment of a region's productive capabilities and judgements made on the state of entrepreneurial firms, emergent cluster dynamic processes, and potential for translational research initiatives. Until the production dimensions of the economy are brought into view, the attention of policymakers, media, etc will continue to engage in debates over stabilization policy which deflect attention from the forces that drive modern economies.

Maturity curve models were developed in the 1980s to locate a company along a five-stage journey to achieve world class manufacturing performance standards in quality and continuous innovation. They were designed to measure the commitment, extent and pace of a company's transformation to a new business strategy and organizational structure. Applied to climate change management, increasing maturity reflects progress milestones along a journey to drive long-term deep decarbonization of processes, products and operations. The five stages of the maturity curve are as follows:[21]

Stage 0. Pre-engagement. The firm does not recognize the relevance of climate issues to business operations.

Stage 1. Initial engagement. The firm introduces policy procedures and/or broad statements of intent.

Stage 2. Systematic management. The firm measures and reports facts relevant to its operations and its impacts on greenhouse gas emissions, sets goals and assesses performance progress relative to universal standards, and provides a business case for achieving leadership in innovation for lowering environmentally damaging emissions.

Stage 3. Transforming the core. The company demonstrates progress and scalable plans for transforming the key processes and products for consistency with the International Energy Agency's 2-degree emissions guidance.

Stage 4. New business model creation and creating competitive advantage. The firm has built the capability for continuous improvement of low-carbon value propositions over time, including across transitions in management. Corporate culture drives progress.

Maturity curve analysis can be a criterion for UKRI research awards. While the maturity curve framework was designed to assist business leadership in transforming the core processes of a company, it can be applied to characterize a company and translational research agencies journey to transform its practices to achieve climate change targets as well.

8 Concluding Comments

The key objective of the UK Industrial Strategy is to address the challenge of the low R&D intensity of the UK economy. Thirty years ago it was among the highest in the world. Today it is low compared not only with traditional OECD competitor nations, but also with fast growing east Asian economies such as Korea and China. Much of the historical UK experience with industrial strategy to arrest decline has been a muddled story of a combination of formal and informal industrial policies set within a shifting and often erratic policy framework dominated by debates over macroeconomic stabilization perspectives. In the past UK industrial policies have seldom if ever been informed by lessons from

[21] Adapted from The sustainability imperative, David A. Lubin and Daniel C. Esty, *Harvard Business Review*, May, 2010.

economic transformation experiences in leading industrial nations like the USA, Germany, or Japan. And any strategies that have moved in a capabilities-informed direction were often undermined by shifting stabilization priorities. The absence of a clear understanding of these processes at the higher levels of government may have seriously affected the nature of the national debate on BREXIT.

Rather than reinventing the wheel, UK policy makers need to learn from international best practice of the enactment of strategic development policy frameworks. In the case of the USA, we have pointed to the WW2 and the post-war strategies that served to transform the US economy. In the case of Germany, we have pointed to the key role played by "place" in an industrial strategy designed at a national level but implemented across the regions of the Federal Republic.

The AMRC case in the UK calls attention to intermediate objectives with inter-organization action plans drawn from an experience that has galvanized top management policies within and across firms at the regional level to drive the capability development processes by which productivity is advanced. It is a 'translation research' model that mediates between otherwise disconnected science and engineering research and business enterprises that leverages the UK's fundamental research capabilities to advance the innovation performance of its business enterprises.

The important role of initiatives that serve to galvanise transformation at a national level was also emphasised, and the case of environmentally sustainable growth was advanced as an example. As a vision for transformational policymaking, the climate change challenge has the iconic virtue of scale. It cuts across virtually all sectors and activities in every place. In this, it holds out the promise of tapping into a whole range of innovation dynamics from Babbage, Penrose, Young, Richardson, Jacobs which can foster dynamic increasing returns or cumulative and collective capability development of entrepreneurial firms. This takes us far from the conventional economics of optimal resource allocation and free markets into the world of production economics and the capability triad perspective. It takes us into transformation economics and production engineering, with the government as an organizer of infrastructures to foster capability development and of layered governance in which top down and bottom up feedback and feedforward.

The crucial lesson that emerges from using the capability triad as a production-centric basis for strategic thinking is that the individual elements of the triad - production, enterprise, and governance - need to be pursued and integrated jointly and simultaneously and that the feed-forward outcomes of regional renewal need to be integrated with national challenges and feed-back mechanisms. Once one begins to think in this integrated way, the elements of industrial strategy tend to fall into place and become self-evident, are compelling and are more likely to have a higher probability of success.