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Heuristics and the microeconomics of innovation and development

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ABSTRACT

Researchers have long recognized multiple ways of innovating. However, the expositions fail to connect the microeconomics of production sets to the real-world institutional variety required to build technological capabilities and innovate. This paper argues for explicit attention to institutional variety in the heuristics used in innovation policy and practice, and analyses three such heuristics. While some types of social challenges can be addressed through formal science and industrial R&D, the most common proxies for innovation, most industrializing contexts will require changes in institutions and organizations to frame and solve local development problems. The analysis thus bridges the traditional microeconomics of production sets with innovation and development priorities.

KEYWORDS

Innovation; technological change; economics; development; policy

1. Introduction

Efforts in economics over the past decades have been directed at building cross-paradigmatic theories about institutional change, from both institutional and evolutionary economics traditions (Dequech 2007; Dow 2008; Lee 2012; Saviotti 2001; Srinivas 2020). Furthermore, institutional variety (which institutions, how many, how connected) can clarify intra-paradigmatic confusions in economic theory regarding technological capabilities and innovation and offer some caution for making inferences and judgements about development (Srinivas 2020, 2021a). This article contributes by analyzing three heuristics in innovation of how institutional variety and its evolution are represented, thus bridging ideas in microeconomics about learning and production to core concerns of innovation policy design and development. The article also argues that colonial impact limited what types of institutional variety were permitted, thus affecting the knowledge prerequisites of science and industrial R&D and subsequent development analysis and policy design. The terminology of economic development itself creates obstacles that are not resolved here: Most 'advanced industrialized' countries were colonizers, explicitly involved in actively destroying or selectively sustaining some learning and knowledge institutions over others in their colonies, or

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importing in forms of subjugation such as slavery or destroying universities or language skills. ‘Industrializing’ may be more accurate than ‘developing’ since some societies experience or direct policies at industrial development, while most have experienced many developmental interruptions from medieval invasions or colonial times. . Therefore, innovation policy design within the context of post-colonial, independent nation-states and premised on the microeconomics of innovation based on specific types of industrial histories should be recognized explicitly and differentiated as such. Colonization alone does not complete the analysis since countries take different industrial paths as do products within the same country or across them. Visual representation of institutional change and variety thus offers a useful analysis and policy tool for explicit attention to evolutionary paths and chronology bookending.

The rest of Section 1 below explains the connections between microeconomics and institutional variety as a specific and critical problem of institutional change. Section 2 presents why institutional variety within heuristics matters to policy questions in innovation and development, specifically why heuristics are useful where complex problems and unique cases require other representations of production and learning. Section 2 also analyses the institutional variety in the taxonomy of three heuristics often used in innovation and development: the Linear Model, Pasteur’s Quadrant, and the Scarcity-Induced Innovation (SII) framework. This section also refers explicitly to the economic history of industrial analysis where major ideas have influenced assumptions of learning, the development of technological capabilities, and the importance of innovation ‘for’ development. It argues that the economics even from evolutionary and institutional traditions informing much of innovation scholarship has sidestepped colonization and other invasions, where alternate forms of learning and knowledge systems existed but their evolution was either stunted or actively destroyed. Since much of innovation scholarship and policy interests began with the study of industrialized economies today and their lessons for others, they were mostly colonizer histories but with insufficient attention to the institutions that evolved and their imposition or destructive consequences that permitted their growth. Section 3 briefly discusses some of the implications of such institutional variety in heuristics for innovation and development. Section 4 concludes on social problems facing us today. Such problems underscore the need for new approaches that connect economics to the diverse histories and contemporary institutional variety of learning, knowledge, and innovation.

1.1 The microeconomics of learning and institutional variety

Institutions range from the social norms of society to formal rules and voluntary standards to regulation. Specific industrial institutions include the norms, rules, standards and laws that shape major policy instruments e.g. procurement, intellectual property including trademarks, copyrights, or patents, and sector-specific technical standards and regulations such as food and health safety standards and Good Manufacturing Practice. Standardization itself is now institutionally labelled in ISO markers, and through firm-level, product-level, or industry-wide certification. Industrial systems also continue to use handshakes, digital fingerprinting, or virtual meetings to signal interest, and usually require a range of informal trust-building measures to work within and outside contract systems.

At one level, all economic change is institutional change, and the study of innovations as described by Schumpeter, is explicitly institutional and organizational, not merely technical. Yet, differentiation about why some societies may grow and innovate may focus on some types of ‘formal’ industrial institutions and not others. Combinations of institutions matter (Amable 2000), and yet an evolutionary, institutional approach has paid insufficient attention to the *variety* of institutions and their historical, political, and geographic context in which the epistemology of technological change is inferred (Srinivas 2020, 2021a). Because judgement in economics is rarely taught (Dow 2008, 48), more explicit attention to institutional variety can be aided by taxonomy development and heuristics that make development choices more visible and policy options more explicit (Srinivas 2020).

Nelson and Winter (1982, 59–60) have illustrated the challenge of under-articulation of traditional microeconomics by describing what firms do and how they do it, in the context of production and its formal representation as a vector set of possibilities. ‘The production possibility set is a description of the state of the firm’s knowledge about the possibilities of transforming commodities’ (Arrow and Hahn 1971, 53). But this parsimonious description hides a multitude of unstated heuristics. Importantly, they point out that there are strong assumptions about the sources and conversion of knowledge, but insufficient attention to the ‘fuzzy edges’ of the production set, the producer, or the knowledge and technologies themselves (Nelson and Winter 1982).

The more pluralist evolutionary and institutional traditions have highlighted a variety of institutions in production and innovation. These can address: dynamics of knowledge use with consequences for inequality and innovation in development (e.g. Arocena and Sutz 2000, 2012; Cozzens and Sutz 2014); question differing development emphasis from units of analysis and values in various neo-Schumpeterian schools (e.g. Papaioannou and Srinivas 2019); and explore diverse methods which can bridge gaps to formalization in economics (Safarzyńska and van den Bergh 2010; Elsner 2012). In sum, a recognition of institutional variety in innovation scholarship makes universalist explanations less attractive to explain industrial transformation today, and can differentiate products and processes (the outcomes) from their institutional explanations (their development pathway).

Neo-Schumpeterian microeconomics has sought to systematize this resolution further between theoretical paths in addressing the complexity of development (Robert and Yoguel 2016; Robert, Yoguel, and Lerena 2017). However, this may not explain why institutional variety continues and what its implications are for learning and innovation, gaps evident also in factor-based approaches (see Nelson and Pack 1999). Indeed, market varieties get short shrift in explaining complex organization (e.g. Nelson 2005); and while variety may be high in an economy, it may signal fragmentation rather than creativity (e.g. Saviotti 2001; Srinivas 2020). Within neo-Schumpeterian ‘schools’ themselves, units of innovation analysis and policy may differ based on the economic assumptions (Papaioannou and Srinivas 2019).

The microeconomics of production sets thus tends to leave unexplained the practical consequences for learning of an ‘appropriate’ variety of institutions. This may extend even to well-recognized institutions such as markets: e.g. designing new markets for cardiac stents, where practical questions need answers of which products or services should remain outside of markets partially or entirely. Such routine decisions have to be

made about alternate (non-price) incentives for improvements (e.g. preventable cancers, electric vehicles, or eco-friendly construction materials) and whether markets, technical standards, or procurement may do better than, say, intellectual property rights. This classification process of existing and desirable institutional variety can be seen in ‘menageries’ where economics has focused but which restrict access and scrutiny of institutions, versus those of ‘zoos’ (Srinivas 2012) which further the public goals of research and education.

Thus, to advance innovation analysis- which has developed exceptionally rich case studies of development- and to limit further fragmentation of the field, attention to meta-theoretical development in economics is vital (e.g. Hodgson 2019; Srinivas 2020). The difficulty of resolution of institutional variety - the ‘many ways of doing things’ in an economy is further hamstrung by the histories of industrialized nations. Processes of economic change such as collective action, coordination, and regulation costs, as well as property rights, improvements in technique or the historical rise of the ‘Chandlerian’ business firm, have sharply divided the sub-schools of institutional economics. An institutional economics tradition of development began by the study of Europe and the US, and only later non-Western industrialized economies like Japan. Advances in evolutionary institutional traditions had built on this legacy of national analyses of ‘systems’ of innovation (e.g. Freeman 1987, Stewart 1977; Nelson and Winter 1982; Lundvall and Edquist 1993; Nelson 1993). The challenge is that of representation and formalization to showcase the institutions and organizations visible at any moment within the economy and to generate falsifiable hypotheses. E.g. institutional variety is presumably higher in some democracies, but deep inequalities may narrow them; centralized or other types of communist or authoritarian rule may further narrow the range of available institutions and organizations (e.g. cooperatives only), or confer power disproportionately to some (e.g. town and village enterprises).

The centrality of firms in that ‘innovation system’ and its process of learning is thus a fundamental relational attribute but its representation is often static (Arocena and Sutz 2000). The appropriate technology and Sussex manifesto (Singer et al. 1970) emphasized the gap between such ‘community’ innovation and the deep concentration of investments and a particular form of industrial R&D, requiring more effective measurement and tracking of specific investment and innovation indicators, resulting in the Frascati manual.¹ As such, the line is blurred between innovation indicators and ‘Industrial use’ for precisely the reasons the following sections discuss i.e. for industrialized economies, the R&D process and knowledge production is institutionalized within its own industrial process- but less clearly linked to that of industrializing countries. This has required more explicit conceptual connections of science and technology investments to economic development; acknowledgement of the gaps in the variety of ‘community’ institutions to structural debates; and furthering the evolutionary approach to search and learning; to practical measurement; and the development of extensive case studies of learning and innovation.

Scientific knowledge institutions and the formal R&D system as embedded in industrial systems have thus dominated scholarly focus and representation, narrowing the scope of what types of knowledge sources and learning is included in industrial systems. Public and service domains today have complicated this simpler picture of ‘industrial’ analysis, having to address critical knowledge systems of food, health,

energy, and biodiversity. Even ‘formal science’ may prevent coherence around sustaining existing sub-systems of learning and knowledge. The public benefit may be situated in the translational ability of science institutions but cannot rule out the plurality of knowledge: For example in biodiversity analysis, ‘[...] crucial institutional questions within knowledge generation; it is ‘how we know’ or the evolution of the cognitive order with the social order, that decides what we do with knowledge’ (Raina and Dey 2020). The details create the process by which a negotiable biodiversity science ‘product’ or acceptable system of knowledge emerges into national science and international governance of biodiversity. This, in turn, shapes a region’s biodiversity needs, and equally how specific forms and users are designed into public programs. As science and technology policy and also science, technology, and society scholars have recognized, ‘use’ (beyond commercial importance) in shaping ‘users’, has led development research in different directions. For instance, ‘citizen science’ is now acceptable as a form of knowledge process, but rarely directly influences policy without the mediating power of ‘formal science’ partners; nutrition targets rarely trump agriculture production targets (Ibid); health targets rather than volume of pharmaceuticals rarely define the health industry or its institutional design (Srinivas 2016, 2021c). Moreover, many pre-colonial institutions of knowledge have played important roles in biodiversity or health systems.

Consequently, the reorientation in the debate between the geographic imbalance of R&D investment and the gaps in the nature of ‘appropriate’, ‘inclusive’ products, skills, and knowledge persists, particularly with innovation in non-institutionalized, ‘informal settings’ (Cozzens and Sutz 2014; Chataway, Hanlin, and Kaplinksy 2014; Papaioannou 2014; Joseph 2014; Gupta 2012). Rather than see these as more utopian ‘indigenous’, ‘local’, or ‘community’, the evolutionary approach to institutional variety may offer some perspective about the nature of learning and the combinatorial microeconomics of the firm (Srinivas 2020). The interesting questions are the degree to which problem-framing and logic systems can embed learning in and thrive amidst such variety. To do this, the representation of institutional variety and the consequences for decision-making in policy are discussed next. closely connected. Heuristics can help us understand why representation matters to inferences and judgements, thus to decisions.

2. Heuristics and institutional variety

Institutions evolve and combine. However, this dynamic approach does not consistently translate into representation, formalization, and inference in economics. Furthermore, while dynamic institutional variety is related to how firms learn, the microeconomics and industrial organization of textbooks and journal articles abstract out the variety and evolution.

For such types of representational challenges, heuristics can help balance necessary abstraction with useful inference. Heuristics embody theory and shorthand techniques and serve as dynamic ‘thought experiments’, offering more than the term ‘conceptual framework’. They include a range of analytical methods and interdisciplinary applications from computer science to policy analyses and interactive design fields. While they are sometimes directly used in decision-making, their use may be best in realistic, data-scarce, or complex settings when more data or precision methods may mislead rather than resolve the problem. In professions in planning, policy and engineering, where

agile problem-solving is needed, feedback occurs in circuitous waves from action to the refinement of policy instrument, and no good may come waiting for a ‘theory of everything’ to address generalizability challenges of issue or location (see also Schon 1995).

Heuristics are powerful where real-life mediates such that no ‘clean’ experiment is possible and some bias is tolerable because of urgency. In medicine, for example, a range of rules of thumb is needed to deal with emergency patients, where more complex decision-trees may be unhelpful because a limited number of variables are present. In bibliometrics evaluation, heuristics offer a missing theoretical basis for such analysis to explain why counting and sorting is needed in evaluation (Bornmann and Marewski 2019). Heuristics may also be useful if represented when decision-making reflects social evolution (‘follow the herd’) or cannot wait for some types of learning to occur through individuals (in medicine and ecology, the negative consequences may be undercounting the dangerous outcomes). In our own time, these issues may include everyday action decisions with long-term consequences: slow exposure to computer screen radiation, contaminated foods or water systems, catastrophic biodiversity loss or climate long tails, or death where no individual reports the process of adverse outcomes, and society may miscount (see Bornmann and Marewski 2019; see also Elsner 2012). In the economics of innovation, failures may have extremely valuable lessons for society, but the ‘losing’ innovation may not be selected for by a market despite its advantages; individual or organization may be reduced to poverty, may die or be disabled, or the time lag of evaluation of revolutionary new ideas in technology may cause them to be too slowly accepted into society. In fact, revolution may be neither fast in a technology nor the discipline itself possesses the hallmarks of a scientific revolution, as in economics (Baumberger 1977). Innovations therefore and the institutional variety that generates them have somehow to be differently catalogued.

Inference and judgement in economic cases thus require some dependence on representation, not formal theory or even ‘fully formed’ theory (Srinivas 2020, 2021a). Heuristics can improve insights with cases and can be ‘run’ across time, thus combined with a range of techniques. They are not static representations but with appropriate checks, dynamically generate corrections and policy decisions. Heuristics provide both formalism and experimentation often used in mathematics as a means to classify, frame, and solve specific problems, including those pertaining to design fields. Case-based analysis, which innovation and policy scholars use extensively, requires specific technology context and problem-solving tensions to address improvements and some logic to theorize (see especially Schon 1987; 1995; Srinivas 2016). Group problem-solving often uses implicit heuristics (e.g. class behaviour, or game theoretic ‘winner takes all’ shorthands, or role-playing strategy and foresight exercises) whether derived fully, partially or unconsciously from value propositions and normative bents about individuals and group behaviour or their framing of events and complex scenarios. Unsurprisingly, heuristics have biases in terms of probabilistic outcomes. Precisely because they are intended to encompass complexity, heuristics may collapse some certainties and, in some experimental modes, may lead to consistent biases.

However, when used as production pathways, not probabilistic outcomes of choices, heuristics can be useful to visually represent institutional variety, and verify the inferences and judgements that follow for policy design. Moreover, heuristics may lead to more formalization and computational checks and can be useful especially where

‘rigorous’ (time and data intensive) techniques are assumed necessary but which may compound faulty assumptions of context and generate subsequent errors.

Three heuristics familiar to many innovation scholars are selected below to discuss the representation of institutional variety. For this task they are selected based on the role of science-based knowledge where science is seen as the foundation of commercialized knowledge exploitation through agile firms; the second case where science is only one among many sources of ‘formal’ knowledge and thus as an important but specific historical type of institutional system itself; and third, types of knowledge other than formal science where greater institutional and organization variety exists. This last may be more representative of former colonies or those whose societies have been invaded or whose institutions of learning and knowledge preservation have been repeatedly attacked through wars or other social transformation of major type. The third case thus raises questions for terminology of ‘advanced’ economies and what this implies for institutional change and variety. Several other heuristics common in innovation or development scholarship such as the ‘Sabato triangle’, the ‘Triple Helix’, the ‘Institutional triad’ can also be added to illustrate and analyze complex institutional landscapes in which industrial advance occurs.

2.1 The ‘Linear Model’

In its simplest form, the Linear Model (LM) represents an assumed transition between ‘pure science’ and commercialized economic value. In [Figure 1](#), the simple LM posits a direct path from basic research to the diffusion of products and processes. The ‘R&D’ refers to the conversion of basic scientific research into engineered prototypes that proceed to manufacturing. ‘R&D’ may extend into manufacture correspondingly, since there is considerable technological learning and ‘R&D’ in manufacturing products and processes. In the economic development literature, technological learning corresponds roughly to Applied Research, Development, and Manufacture, even where the scientific establishment of Basic Research may not be strong. This is where technology transfer becomes an important concept, since firms may transfer inward what they do not already possess. In the LM, Basic Science can be seen as an Input, and commercial products and processes as Outputs. The heuristic is the simplest type of an Input–Output (I–O) model (see also [Godin 2006a](#)) and is arguably a way of understanding the sometimes globally determined division of labour within science and engineering.

The LM is an artefact of a hidden institutional variety. Its simplicity positions R&D in a given institutional permutation where the relations between sections of economic activity and actors in the system are deemed self-evident. The activities that are functions of time and place have been represented as universal despite having specific origins: ‘The

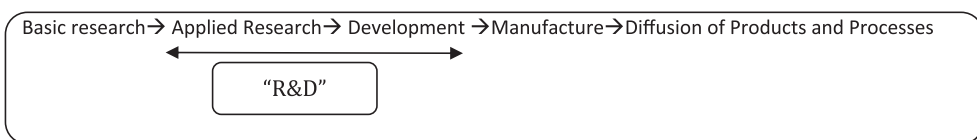


Figure 1. The LM heuristic. Source: Adapted from Stokes (1997).

capacity to advance knowledge in science and technology is itself a result of a product of institutional innovation - 'the great invention of the nineteenth century was the invention of the method of invention' [Whitehead 1925:96]' (Ruttan and Hayami 1984, 203). There are important cautions about its use: the LM sharply reduces variety; the heuristic represents one degree of freedom where knowledge emerges and transitions to how firms commercialize it. It has not been a formal economic model, rather an expedient political one. *'Bush succeeded in putting the ideal of pure science on officials' lips and influencing the emerging science policy [...] But he suggested no more than a casual link between basic research and its applications, and the rhetoric had been developed and discussed at length before him. Nowhere has Bush suggested a model, unless one calls a one-way relationship between two variables a model. Rather, we owe the development of such a model to industrialists, consultants, and business schools'* (Godin 2006a, 647). At the same time, the 'Model' succeeded for years because of strong state intervention, and because scientists and bureaucrats of science (who are often scientists themselves) benefited from the power and lack of scrutiny it offered. Statistics and indicators maintained the heuristic's resilience, despite contradictory findings of its supposed impact, and retrospective association of the 'Model' with different scientific communities (Godin 2006b).

It could be argued that the LM remains attractive in its use because of its simplicity, even if inaccurate. Its attraction is precisely the bold statement of the relationship between 'basic science' and commercial technologies. The LM is thus a heuristic that takes the simplest categorization of science ('basic science') and converts its knowledge to commercialized products and processes and claims a direct (and very simple) link to economic development outcomes. Specific communities e.g. scientists or firms can and do benefit by arguing that more basic research funding leads inevitably to economic growth or that certain types of indicators preserve their place in a social hierarchy of policy relevance. More specifically, R&D funding to laboratories or subsidies such as tax exemptions or reduced land costs for start-up incubators are traditional supply-driven ways that policy design may assume relationships of the LM.

2.2 Pasteur's quadrant

The LM was a highly stylized World War II heuristic. As political rhetoric, it offered a view of basic research and basic scientists as unfettered and creative individuals, while neatly tying together such creative enterprise with practical outputs (Stokes 1997). The wartime effort on science beyond the atomic bomb allowed Vannevar Bush an opportunity to constitute two new assertions: first, that basic research is highly creative and without particular thought of practical ends, thus requiring citizens and policymakers to refrain from constraining the freedom of creative enterprise; second, despite this open-ended creative process, basic research fuels technological improvement desperately needed by a country such as the US (Ibid). He strategically understood that the stakes of war were not military but fundamentally scientific and technological. This category of science is a composite fiction made up of what Stokes argues is in fact four hidden classes of science in the Linear Model (Figure 2).

Stokes' insight is that the nature of research is defined by the initial quest for certain types of understanding, only some of which may translate easily into considerations of

	Considerations of use		
Quest for Fundamental Understanding	NO		YES
	YES	Pure basic research (Bohr)	Use-inspired (Pasteur)
	NO	Fieldwork-driven science ---Peterson?	Applied research (Edison)

Figure 2. Pasteur’s Quadrant. Source: adapted from Stokes (1997) ‘Pasteur’s Quadrant’.

use. In this classification lie different scientists, each embodying different forms of understanding and use (see also Godin 2006b on different types of scientific communities, Vicenti 1990 on use in engineering).

The Upper Left-Hand Quadrant: Niels Bohr represents a unique quest for fundamental understanding, with no consideration of use expressed in his research. Although Bohr’s model of atomic structure transformed a series of technologies from lasers to understanding CT scan machines, he was driven to conceptualize a new atomic model using quantum mechanical ideas. He could not have foreseen the remarkable array of technologies using his insights, nor their applications. Niels Bohr in this sense was the epitome of the pure basic research scientist whose ties to the applied or commercial world were distant in the topics of his inquiry and its techniques.

The Lower Right-Hand Quadrant: In sharp contrast to ‘pure’ basic research in Stokes’ view is Thomas Edison’s ‘applied research’. Edison’s applied science is mainly urban because his revolution in lighting rapidly illuminated cities across the world. There is evidence that despite wider research interests, Edison deliberately focused his Menlo Park enterprise on the applied aspects to benefit a commercial enterprise (Stokes 1997, 74).

The Lower Left-Hand Quadrant: Stokes hastens to say that the lower left-hand quadrant in his typology is not empty. The fact that research neither inspired by a quest for fundamental understanding nor consideration of use can still exist, points to two characteristics of inquiry such as that of Peterson’s Guide to the Birds of North America. Peterson not only systematically documented the incidence of various bird species but also through artistry, captured their brilliance and diversity. Peterson might even be likened to many urban planners who gather, document, and record data in GIS maps or community surveys to advance our understanding of trends, to see patterns, and to share collective knowledge.

‘Pasteur’s Quadrant’ (Upper Right-Hand Quadrant): Finally, we come to the upper right-hand quadrant or what Stokes refers to as Pasteur’s Quadrant. Focused on molecular biology, Pasteur was credited with far-reaching ‘pure’ research insights into bacterial transformation and the related nature of the disease. Along the way, his insights fuelled a revolution in hygiene, in milk processing, and in medicine. Pasteur was far from Bohr, even though Bohr’s insights led to uses, and far from Edison, even though Edison was not averse to fundamental understanding. Pasteur, Stokes argues, saw ‘use-inspired’ science as a means to fundamental breakthrough in understanding. We might consider Pasteur, just as Edison, an ally of science and engineering in the service of development,

but unlike Edison, convinced that user-driven phenomena might advance social utility in literal and abstract scientific ways.

It should hardly surprise us that Stokes' insights on Pasteur's work and his differentiation of science's categories, should lead him to a careful assessment of how Vannevar Bush's LM sought to narrow the scope for science to practically define it as basic scientific research and distinguish it from the wider sciences, including the social sciences and hid the fact that applied science could be highly fundamental itself (Brooks 1967, 1706; Hoddeson 1981; Stokes 1997, 60). Pasteur of course was a product of such colonial systems of scientific teaching and public health, and subsequent and modern forms of global health education continue many types of colonial administrative practices from epidemic legislation to clinical testing. Each type of science had a historical and particular industrial context.

In essence then, Pasteur's Quadrant shows at least four ways in which the knowledge from science can 'move' in terms of institutional pathways, and that these quadrants represent institutional domains in which science is itself institutionalized into economic activity e.g. Edison's electricity efforts and Pasteur's efforts are different in what they consider as useful knowledge from science but their scientific knowledge is not necessarily channelled through the same types of organizations (e.g. central scientific research institutes, business firms, electricity utilities, business districts, etc.) (see also Srinivas 2009; 2014) As Stokes describes, the early Frascati attempt to define categories of research proved difficult to kill.¹ Stokes describes the problem as one of a linear dimension urgently requiring a modification to higher dimensions. He converts the basic-applied unilinear spectrum into a hypothesized attempt that captures Pasteur's position of combining the two ends of the spectrum. In doing so, Pasteur effectively pre-converts a single Cartesian point to a conceptual two dimensionality that Stokes then portrays several different scientific categories within.

As several scholars have asserted, technological knowledge is deemed to have passed if it is shown to be useful (Vicenti 1990). The LM's charm is that it derives from a political economy context (war) that shows it to be evidently useful. Its power rests in a story that talks of science at one end of evolution and engineering ('technology') at another.

As Pasteur represented a specific, French form of colonial science and discovery, and its administrative application, Edison in the U.S. represented different pursuits of use and users. Pasteur's Quadrant thus assumes the institutional context of different sciences and selectively reveals in some quadrants their industrial context. The Industrial Revolution was by no means the direct root of economic growth, rather seen by some as an 'Industrial Enlightenment' driven by intellectual, rather than purely political or economic reformation (see Mokyr 2002, 30). Previously, technological knowledge had a constrained epistemology, where 'propositional knowledge' (what constituted phenomena) did not necessarily or straightforwardly convert to systematic techniques (the how) (Ibid, 4). As we are told, serendipity had played an especially important role, especially in health-where germ theory, anaesthesia, vaccines, and other discoveries all emerged before the nineteenth century (Ibid). Although a slew of life-saving innovations was immediately utilized, process innovations were slower because the principles of discovery were more obscure. But since societies require individuals and groups to preserve that knowledge and systematically grow it, only some emerge into the 'Industrial

Enlightenment'. The new Enlightenment, sharply different from seventeenth century scientific Enlightenment, was a revolution in knowledge about technique and its prerequisites. This new knowledge allowed transfer and diffusion in extraordinary ways within and across sector, and across to Continental Europe. Its effect was to transform social attitudes to viability, attractiveness and access to propositional knowledge about putting technologies into practice (and profits) (Mokyr 2002, 34–35).

The challenge with this view of science(s) and industry is not analytical but empirical since the cases and refinements of arguments build on Euro-centric and colonial ideas of science's own expansion (public health's goals, strategies, and evolution in the colonies are well documented in multiple studies). Science's success was perhaps too easily linked to social superiority or that of industrial technique, without the institutional and organizational context of public control, military might, and colonial bureaucracies which expanded, experimented, and transformed societies. The 'Industrial Enlightenment' offered a stripped-down view of institutional change that often fed into the economic history of technology, for instance why English cotton mills advanced while Indian ones did not or English versus Scottish benefits from colonization in explaining returns to investment. Many 'early' industrialisers were imperial powers with significant extractive strategies and violent response to build industry at home. It may be more helpful rather to analyze arguments of what types of institutional 'revolutions' (industrial, scientific, economic, cultural, etc.) take place in society and under what related conditions a separation of knowledge and its use occurs in local context – which pulls societies in different development and professional directions (Schon 1995; Arocena and Sutz 2000; Srinivas 2020, 2021a; Raina and Dey 2020). It is the contextual and comparative challenge of industrial transformation and its epistemic context that requires explanation for choices in policy design.

For instance, within the U.S. itself, two quadrants of Pasteur's Quadrant may be collapsed through business strategy around 'applied' and 'use'. Edison appears to have been well aware of potential competition and the far-reaching scientific relevance of Nikola Tesla's advances in AC versus DC electricity. From exploitation of animal and alleged human cruelty to test electricity to unfair competition, Edison is documented to have recognized the advantages of controlling and blurring the lines between use-inspired and applied research, since the former weighs significantly in commercial decisions as well. A range of inducements and strategies were used by Edison: animal experiments, investment in and expansion of R&D labs, business associations, municipal utilities, press releases, and prizes-unfair or not. It could be argued that Edison attempted aggressively to generate more institutional variety not less, in order to dominate both types of science quadrants for commercial gain.

2.3 Scarcity-induced innovation

When an evolutionary lens is placed on technological capabilities, however, there is Variation, Selection and Retention (VSR) within the system that produces multiple evolving intermediate sets of knowledge sources, organizations, and actors. For development, evolutionary perspectives emphasize non-equilibria, dynamic but uncertain search and investment, and policies that can act as important selecting devices. As Nelson and Winter (1982) have emphasized, organizational routines through which firms learn,

act as powerful evolutionary mechanisms and the basis of dynamic economic transformation. These routines exemplify how firms search, explore and adapt to their environment, creating 'satisficing' rather than 'maximizing' behaviours. However, there is little inevitable about the direction of such learning or the punctuations in its path. Colonization history resulted in benefits to science and mathematics from cultural exchange and technology transfer of various kinds, but by and large, colonial administrations and mercantilist predecessors were often rapacious and violent, arriving with destructive tendencies, and creating severe blocks to the advance of local knowledge or techniques. As with Edison, brutality as much as 'acceptable' competition has played some role in colonization-led and instituted industrial history- from Portugal to the Netherlands, England to Spain. Thus which forms of institutional combinations are socially acceptable or economically feasible rests on an ex-post explanation of development (Arocena and Sutz 2000).

For innovation scholars, there is arguably now sufficient debate about the challenges of the institutional foundations and generalizability of the National Systems of Innovation (NSI) framework. Freeman's (1987) proposal of the NSI framework arose from Japan's industrial history set in its own Meiji reformation period: '[...] as if many positive feedback loops were operating in a more or less synchronized way. [...] the remarkable fact that so many engineers in Japan had a formal basic science background, the practical training and frequent upgrading in industry of these very same engineers, and the concern with giving every worker some understanding of the relationship between various operations in the firm had as a result that 'the 'system' approach is inculcated at all levels of the work force and not only at top management.' (Freeman 1987, 46; cited in Arocena and Sutz 2000, 57). They conclude that because of this focus and specific relational, bureaucratic structure, on science and engineering in the industrialized economies, the NSI is ex-post, normative, narrowly relational, social consensus-driven and a political-policy subject (Ibid. 58–59). The relational features for science policy and development matter because they may undermine the negative effects of industrial policies themselves (Raina and Dey 2020; Srinivas 2021a).

It could be argued that the LM or Pasteur's Quadrant (PQ) refinements continue to reify the New Enlightenment benefits of scientific knowledge as the crux of improvements to society which when appropriately channelled, benefit commercial economic knowledge. The PQ recognizes that the context of knowledge itself defines the use, and therefore scientific knowledge to use is not independent of the type of scientific endeavour, a point that the LM is unable to clarify and Edison may highlight. Concurrently, it could be argued that the PQ relies on science for economic explanation in a manner that is divorced from the microeconomics or business strategy of technological capabilities.

However, the evolutionary insights of development reveal that countries with technological capabilities may develop sophisticated systems of knowledge that they struggle to generate, protect, and convert into commercially competitive economic positions; alternately, a range of social reorganization can be highly beneficial that recognizes historical, geographic, and cultural sources of knowledge. The Scarcity-Induced Innovation (SII) heuristic (Srinivas and Sutz 2008) is also a 2X2 but which situates innovation in its current industrial context where institutional variety is a key explanatory variable of distinct technological capabilities in industrializing LMICs. The upper left-

hand quadrant frames problems of industrialized economies including their R&D and is therefore similar to the priorities of the LM and Stokes' four quadrants. In the other quadrants, however, the SII showcases existing but idiosyncratic innovations and one quadrant which represents SIIs. For development, knowledge sources are far wider than science, and innovation involves many Schumpeterian features, more focused on contextual technological capabilities, and more likely to connect to the microeconomics of generative competitive domains of knowledge. Engineering, managerial capabilities, logistics and distribution provide the situational advantages of some types of useful knowledge and their scale or scope advantages. The institutional scarcities surrounding a firm in these contexts have to be substituted for by the firm itself, thus making institutional variety and evolutionary pathways explicitly variegated. When societies have multiple systems of knowledge, heuristics that demonstrate institutional variety can highlight the need for deliberative policy design. Ayurveda is a system of knowledge with many elements from its own science and philosophy of transformation, ecological dynamism, source extraction, standardization, diagnosis, treatment, diet. For example, the extensive scientific knowledge of Ayurveda emerges from a different epistemic context of generic and on-patent pharmaceuticals. The former is not fully validated by 'modern' (i.e. Western) science, but the authenticity for users of known 'houses' and regional expertise is not defined by it. Both require production capabilities and manufacturing systems, but their epistemic foundations may require irreconcilable evaluative strategies and approaches to resources (Srinivas 2021b). As such, the nomenclature of 'traditional' and 'alternate' for this system of medicine is misplaced for innovation policy and its economics, since it may be the dominant and contemporary form of medicine and healthcare for many.

The advantage of the Scarcity Induced Innovation approach is that both cognitive problem-solving and structuralist insights can be built in (Srinivas 2014, 2009, Srinivas and Sutz 2008). For example, some countries are clearly more directed at export orientation and others at domestic production and consumption. Some firms are likely to generate innovations that are less amenable to the local context and require different institutional pathways and organizational types. But cognitively, these are different classes of problems based on where (geographically, institutionally) they are framed versus solved. For example, the subsidiary of a multinational firm in an industrializing country may not have the freedom to innovate in local context, rather be seen more as a marketing hub for 'Headquarter-generated innovations'.² Similarly, a religious or other charity, running state of the art hospitals or designing prosthetics, for example, may be highly adapted to complex local settings, but thus global in applicability. Frameworks familiar to innovation and development scholars such as import substitution industrialization vs. export-oriented industrialization, accumulation vs. assimilation, or national vs. sectoral knowledge systems therefore emerge as strategies, not labels, to explain the institutional variety and its context-specific microeconomics (Figure 3).

Similarly, because a structural and cognitive element is built into the framework of SII for development, technology and industry details matter just as historical and context-specific state roles do. In contrast to the Pasteur's Quadrant, the SII framework does not dwell on whether science-generated or 'applied'/science or engineering-generated knowledge is important; here the focus is on problem-framing and problem-solving. Srinivas (2016, 2018b, 2020) emphasizes that the upper left-hand quadrant

	Problems for which solutions have been found in AICs	Problems for which solutions have not been searched or found in AICs
Problems for which solutions suitable for DCs conditions exist	<p>The vast majority of solutions acquired through technology transfer (eventually with minor modifications)</p> <p>e.g., dominant discourse is of intellectual property rights, technical standards etc.</p>	<p>Solutions to problems mainly posed in DCs and developed locally</p> <p>e.g., dirty to potable water, local construction technologies</p>
Problems for which solutions suitable for DCs conditions do not exist	<p>“Canonical” solutions exist, but for different scarcity reasons they are not suitable for DCs conditions</p> <p>e.g., neonatal incubators and burns technologies</p>	<p>No solutions (yet)</p> <p>e.g., health issues like vaccines against Cholera or AIDS</p>

Figure 3. Scarcity-induced innovation (SII) heuristic. Source: Adapted from Srinivas and Sutz (2008, 132) and Srinivas (2009).

of the SII heuristic is tilted toward global value chains or problems existing in the industrialized economies, including the problems framed, the questions asked, and the resources and number of firms available (e.g. as in the health industry or in transport). This makes it less likely that problem-framing is complete or policy-friendly for social change. Innovations from other countries may be easily imported even if they may not necessarily have been generated to solve the local problem. These generate problems of their own.

The SII is thus a heuristic explicitly focused on institutional variety (each quadrant is a distinct institutional domain where several institutional actors, processes, and organizations exist). Firms, other stakeholders and nations can be seen to ‘move’ between quadrants. The heuristic endogenizes knowledge in development since nations may have ‘high science;’ as well as other sources of knowledge and problem-solving but continue to be policy orphans.

The upper left-hand quadrant is closest to the institutional environment of Edison’s quadrant. The paths between quadrants describe a product’s institutional environment and specific national or international journey, i.e. a neonatal incubator or a prosthetic, innovations that have important features serving local users, may have their own multiple innovation and industrial histories and therefore multiple markets, technical standards, intellectual property, materials use, or other considerations. In Uruguay versus the UK, the same product (e.g. neonatal incubators) may be catalogued in the lower left-hand quadrant versus the upper left-hand quadrant. In India, prosthetics may be seen as simultaneously occupying both the upper left-hand and upper right-hand quadrants, and the

latter product- better adapted to the complexities of its context- may be creating new export markets across Asia and Africa.

The institutions of scientific knowledge such as the formal laboratory, modern university or science research centers are then constrained types of learning in this heuristic, not emblematic of its full potential. As such they reflect one type of industrializing endeavour, not all its potential combinatorial production pathways. Therefore, to trace different types of technological capabilities within their industrial and developmental contexts, heuristics that 'see' combinations of institutions can help address the institutional variety of problem-framing and solution-generation.

Just as with neonatal incubators, it is less straightforward to classify (science-led, high or low tech etc.) the peculiarities and origins of essential innovations in industrializing countries. Examples of seemingly simple products but with complex institutional pathways, organizations, materials, markets, include: rapid composting; air or water pollution mitigation through bio filters; new energy storage; Hib vaccine; diagnostics; 3-D prototyping; precision farming techniques, germplasm; oil & gas extraction and supply innovation. What makes the SII quadrants unique is that many products and markets in industrial development that scholars take for granted show alternate national paths as well as stakeholders and institutional combinations when mapped out.

Consequently, there are further changes required to take institutional variety more seriously. Manufactured value addition or patent indicators, relevant to industrial statistics and to some aspects of both Oslo and Frascati manuals, although tempting to study since they allow comparison with industrialized economies, may be looking under the proverbial lamppost. The advantage of the SII heuristic is that it points to contextual debates about design and democracy, considerations that have been narrowly framed within 'late capitalism' as opposed to varied 'late' industrial development. The prosthetics, neonatal incubators, or manufactured products from Ayurveda to vaccines, have come from different institutional contexts for science as well as the routines and learning paths in diverse types of industrial and non-industrial organizations. For cognitive as well as structural reasons, including trade patterns, the variety of institutions now governing these products may range from technical standards of quality and safety to location geo-tagging and geographic indications for sourcing the best inputs. Unless this range of contextual institutional variety is better acknowledged in innovation policy design, the products and service models are likely to remain policy orphans unless explicit attention is given to how learning and value addition occurs. Economists and innovation scholars recognize that problem-framing itself has many elements (cognitive, collective, organizational, institutional). This becomes especially important for policy design and translation when multiple knowledge systems and epistemic systems co-exist which is now the case in several post-colonial and industrializing contexts. If one recognizes that post-colonial industrial paths have been themselves diverse emerging out of different colonial contexts but equally dynamic and responsive paths (Srinivas 2018a), new approaches to and alternate metrics of innovation and technological capabilities are urgently needed (Srinivas 2016, 2021b; Arocena and Sutz 2012, 2015).

While the LM has some institutional variety (e.g. it allows a role for technical standards or patents for example), the framework is limited to science in a formal research

environment, R&D within a traditional business corporation, and a centralized, state-led approach to government in economic development. Pasteur's Quadrant opens up the institutional variety possible on the science 'end' of the LM by showcasing social relevance by use type for different types of science. This is particularly the case of former colonies, where knowledge systems and those individuals or groups supporting them, including languages, oral, cognitive, or physical systems of documentation and education, were deliberately sidelined or actively destroyed. The challenge comes from comparative institutional analysis of colonizer country and colonies (e.g. England vs. India, cotton), or former colonies with countries that were not colonized or whose systems of knowledge or education of context were largely unbroken (Brazil vs. Japan, steel, automotive).

The Pasteur Quadrant framework arguably reproduces some of these challenges of embedding such science in conditions of significant historical inequality or where alternate systems of knowledge may exist but were deliberately dismantled or partly cannibalized. The SII partly addresses this problem by framing each of its quadrants in both structural or cognitive terms by tracing problem-solving. The most dominant ('the history as we know it') is the upper left-hand quadrant where the Linear Model and Pasteur's Quadrant frameworks are implicitly but not exclusively embedded. Similarly, each quadrant is distinctly and dynamically connected to scientific knowledge or epistemologies that are less familiar to the orthodox understanding of science in research institutes. Therefore, even in the Pasteur's Quadrant heuristic where Peterson's quadrant permits the more democratic principles of individual autonomy, description, and scientific analyses of a field-based phenomenon (in his case, observation and taxonomy of birds), there is a little elaboration of the bridge between 'applied science' and true 'citizen science' or strategies of knowledge sharing (commercialized or otherwise). These are arenas where the SII heuristic is arguably more useful because specific products and services can be represented as beginning in one or other quadrant, and depending on their country and context, crossing across quadrants. The institutional combinations and paths can be tracked for these products. Democracy can be interpreted as a call to more institutional variety. A centralized or communist government will have rules that do not permit wider organizational control or ownership experimentation and therefore, cannot encourage institutional variety. However, deep inequalities persist for the institutions of knowledge especially within democracies where debate and cooperation exist. The challenge is acute in former colonies that have lost significant elements of their science, mathematics, scientists, linguists, language, or organizations of social and knowledge creation. This stunting of some types of institutional variety during colonial times and the generation of others has created complexity and fragmentation in independent nation-states, and diverse industrial paths. In these cases, both industrial and innovation histories cannot be simply 'read' across national manufacturing capabilities in specific industries. Explanation of why some types of propositional or innovation approaches exist and combine with each other can become an important area of further analysis.

3. Discussion: taking heuristics seriously

If the microeconomics of innovation is to accommodate institutional variety, then it is essential to explicitly present and represent different combinatorial features of

production sets, their sources of knowledge, and the (evolutionary) patterns of learning of organizations. The persistence of formal economic models to describe R&D and firm-level learning, points to a disconnect between existing theories and the empirics of innovation (e.g. what do with microenterprises and informal learning) and between mainstream views of frictionless learning in contrast to specific E-I advances that have mostly solved the initial analytical challenge of evolution (e.g. ‘appreciative theorizing’ of Nelson and Winter 1982). The explanations for ‘why’ a variety of institutions and organizations persist have tended to be subsumed into the ‘how’ of different types of convergence analysis which can better fit with mainstream models and U.S. or European industrial histories.

For any economy to thrive, it must be able to productively use its systems of knowledge, forms of learning, and its commercial knowledge. This knowledge need not immediately be apparent as innately relevant nor inherently owned or even convertible into a commercial asset. Cultural forms of knowledge fit into many of these categories and may cut across diverse forms of value from the arts to biodiversity to healthcare to architecture. For those arguing for a ‘local knowledge’, the categories of knowledge and their development need clarification. Science, basic or ‘applied’ may be exclusionary because it has specific institutions and organizations through which it accepts knowledge and consequently ‘translation’ to society becomes complex, if not impossible. The health industry offers another pattern and possible heuristic (the ‘institutional triad’) that can be adapted to other industry sectors (Srinivas 2012). Thus, heuristics, even with inherent biases, can accelerate analysis by identifying pattern classes and appropriate methods for inferences and judgements towards refined hypotheses.

The heuristics are best used for hypothesis generation and taxonomy development. Note that no specific recourse to ‘capitalism’ is needed to analyze institutional variety. In the first column ‘Degrees of Institutional Variety’, Table 1 lists common institutional

Table 1. Heuristics for innovation and development.

	Linear model	Pasteur’s Quadrant	Scarcity-induced innovation
Degrees of institutional variety	1	2	Multiple
‘Use’	–	X	X
Science	–	X	–
Industrial firms	X	X	X Especially in upper left-hand quadrant
Problem-solving	Science is the driver	X by science in Pasteur’s case	X by science is an exception
Universities	‘Basic Science’ considered fundamental	X	Not essential to the framework. Knowledge can originate in other sources.
Institutional analysis builds technological innovations, products, and platforms	–	– in Edison’s case	X Dominates
Other knowledge stakeholders e.g. Non-governmental organizations, cooperatives, crowd-sourced/volunteer efforts, oligopolist consortia, hybrid organizations	–	– not discussed but could extrapolate	X Essential to framework
‘Direction’ from organization of knowledge source origin to others	One	Yes; focus from science, formal or experiential	Multiple ‘directions’; no ex-ante preferred stakeholder organizations

varieties discussed in the innovation literature. Each heuristic discussed (deliberately chosen) represents (through an 'X') different degrees of institutional variety. The more Xs, the higher the institutional variety accommodated in the heuristic, but also within quadrants, thus demonstrating many more imagined or actual evolutionary options.

Evolutionary perspectives are essential to the economics of innovation, and innovation could be argued to represent not only unusual types of institutional and organizational combinations but also technological advances that can emerge from and sustain new combinations. The evolution can be represented as a vector set of production possibilities, which includes the messy microeconomics of search and learning of firms. [Table 1](#) provides guidelines for a comparison of heuristics to advance such institutional analysis about the microeconomic assumptions of knowledge creation and use. Other well-known approaches such as the Sabato Triangle or Triple Helix not discussed here, offer 3+ degrees of institutional variety. Other heuristics of industries are more dynamic (e.g. the Institutional Triad Srinivas [2012](#), [2016](#)) which offers an explicit co-evolutionary set of three 'industrial' domains (production, consumption/demand, and delivery), each vertex depicting different institutional start points and different combinations within countries. The Sabato Triangle and the SII are explicitly focused on industrializing contexts and their developmental political economy.

Decisions on institutional variety is a complex province of democracy. The heuristic offers a visual way to 'start the clock' since relative technological capabilities and gains begin differently even as value preferences and ethics shape their institutional variety (Ibid, Papaioannou and Srinivas [2019](#)). Countries move within and across science, within each SII quadrant, and across quadrants. Some countries may build capabilities across two or more such quadrants. If sub-patterns of industrial development are important at the macro- and meso-level, they also significantly undergird the microeconomics of the firm itself. Terminology such as 'developing', the 'Global South' etc. add to the questionable analytical category of economic development because the industrial development patterns are significantly varied (Srinivas [2018a](#), [2021b](#)). The complexity of the pathways rests in the theory of the firm as well as the absence of how economics includes its environment. This leads to patterns of complexity analysis, which may generate different theory-evidence mixes (Robert, Yoguel, and Lerena [2017](#)). Therefore, only some types of knowledge are validated and commercialized. Unlike late industrial scholarship that has emphasized 'catch-up' and even 'lag', there are fundamental questions that remain of how knowledge is sourced and reproduced, how we think of information and how we know what we know. These epistemic and ontological differences persist in co-existing industrial systems within and across Ayurveda (the ancient Indian systems of health and medicine) and pharmaceuticals measurement and delivery systems. Both forms of innovation can (to different degrees) be technologically sophisticated and 'industrialized'. The same is also the case with Chinese 'Traditional' medicine. Because they co-exist with the pharmaceutical industry but draw on different and ancient sciences of health and treatment, they create challenges for contemporary industrial policy design (e.g. Srinivas [2021b](#); [2021c](#)). In this complex case, industrial comparisons using heuristics can quickly demonstrate which institutions (norms, customs, standards, laws, etc.) emerge within a specific combinatorial bundle and when for instance, manufacturing improvements may be common interventions across time or product development. Similarly, the

specific types of organizations and regulations may differ in their forms of appropriation or reward (e.g. cooperatives, guilds, patents). They can be checked, improved, even used early on as research design or for case selection in policy design.

4. Conclusion

Much of the time, microeconomics will be traditionally situated around the orthodox production sets representative of business firms and their learning path, incentives, and relative cost improvements. This abstraction does well represent some types of industrial systems. However, while many types of urgent social challenges can be addressed through such formal science and industrial R&D, most today require varied efforts by multiple stakeholders to frame and solve problems. Climate, health, biodiversity or other problems require a wider institutional lens since many crises have emerged from the old industrial development paradigms. Shifting from viewing institutions primarily through the general institutional ‘rules of the game’ to problem assessment and perceptual frames of reference, requires attention to logical policy steps and to theoretical inference and judgement about institutional change. Whether this lies within countries (e.g. investments in solar power) or in global collaborations (biodiversity and climate) or a combination of both (e.g. Solar Alliance or Covid-19 vaccines), qualitative heuristics can generate insight as well as avenues for formal models, new mixed methods, or quantitative analyses.

While an active debate in innovation scholarship has focused on the normative politics of innovation with more inclusion and wider, open systems of knowledge, this has not translated easily to the intermediate theoretical frameworks available from economics, nor systematization of taxonomies of institutions and organizations to achieve the ends. This systematic enquiry can serve as a vital fork in the theory and policy road for innovation scholarship especially in its claims to ‘development’. Such efforts depend on some representation-which this paper has shown can be heuristics of production sets and possibilities – whether visual, formal, or other. Using these, inferences and judgements about industrial and innovation pathways can be made more specific, in order to advance a more historically accurate and contextual institutional variety becomes both visible and that is worthy of theoretical attention and relevance to policy design.

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Notes

1. The Frascati Manual OECD (p. 4) indicates its use for R&D measurement and the knowledge production process, the manual (2015 comments) indicate its importance for (1)

- Investment i.e. Expenditure on R&D as a capital: formation activity; (2) STI policies. (3) R&D globalisation and funding; (4) Technological balance of payments.
2. Personal communication with a senior team at a leading multinational product development group.

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