Building Systems

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Abstract A system is a set of elements which are connected in particular ways. The formal general equilibrium model is an extreme case in which every element is directly connected to every other and in which all potential external connections, including connections from the future, are incorporated in the data. The foundational assumption of this paper is that viable systems must be selectively connected, and that viable large systems are highly-decomposable assemblies of smaller systems. As Simon argued, quasi-decomposability has made evolution possible from the beginning of the universe. Economies are evolutionary systems, in which human intentionality is a novel feature which modifies but does not supersede the processes of novelty generation, selection and diffusion. The microfoundations for this study are found in the characteristics of the human brain as a system of selective connections. Human knowledge consists of domain-limited patterns imposed on events. Organization—selective connections—is thus basic; but the potential for human knowledge is greatly enhanced by specialisation between domains, combined with variation within each. Co-ordination and development, so often separated in economic theory, are interconnected; they are both ordered processes—not states, in which markets (alongside many other institutions) are prime sources of order.

1 Equilibrium and Evolution

A system is a set of elements which are connected in particular ways. The behaviour of a system therefore depends both on the particular elements of which it is composed and also on the particular pattern of connections between them; indeed

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the relationship between structure and performance is a major topic in many fields of study.

A familiar example in economics is the perfectly competitive economy, for which an existence proof of equilibrium was provided by Gerard Debreu. This has two distinctive characteristics. First, the system is completely isolated from any external influences. Second, every element is directly connected to every other: each agent makes a single comprehensive set of choices, formalised in a complete set of contracts to purchase and supply goods and services in specific circumstances and at particular prices. This combination of external isolation and internally complete connections is sufficient to support a proof of equilibrium. Everyone is optimising, subject to the constraints inherent in the data, which are known to be complete and correct, and those imposed by the optimal choices of everyone else. Thus there can be no reason for anyone to depart from the equilibrium once it has been established. What is notable, and essential to the analysis, is the extreme simplicity of its structure: indeed in terms of the opening sentence it has no structure.

There are certain problems with this model system. First, these results rely on the assumption that every agent's actions are insignificant in relation to the supply or demand for any good or service, and no agents act in concert. Next all goods must be defined, not only by their inherent characteristics, but also by their location, date, and the state of the world at each date, where it is necessary to specify all possible states. Providing such definitions may seem straightforward (though time-consuming), but it is not. How much differentiation may be allowed before we must allocate goods to distinct categories? Since all agents are interested in the distance from their own particular locations, how can we draw boundaries which are equally appropriate to all? Since some goods are likely to be used at particular times of day, how finely should we define time? What constitutes a relevantly distinctive state of the world at each date, and may we not also need to specify each anticipated history of the world to this date, which may influence agents' responses? Moreover, there is no obvious time horizon, and should we not be including within our closed system people who are not yet born? They too must have perfect information.

We next encounter a fundamental logical impasse. Although the model does not require us to know what will happen, it does require us to list all possibilities, and therefore to be quite certain what will not happen. There can be no surprises and no discoveries; either would demonstrate that the apparent general equilibrium was false. However if we have a correct description of our situation and of all possible futures, the equilibrium will last for all time and everyone will fulfil all relevant contracts. What is more, that equilibrium should have been achieved long ago; the time for choosing is already past, and our role in each contingency is already prescribed. As Frank Knight (1921) observed 90 years ago, a world without uncertainty requires only automata. It certainly does not require economists—and, since it is efficient, it will not tolerate them.

Finally, no-one has explained how equilibrium can be achieved in a way which is consistent with the model (Richardson 1960). The process of equilibration must require no resources, which are all allocated to their equilibrium uses; no agent is allowed to set any price; and because false trading may frustrate the attainment of the equilibrium inherent in the data, a complete set of contracts must be established in markets which close—forever—before the economy begins to function. How they are to be established is not considered; and the fundamental reason for that I believe is crucial. Markets are superfluous in a full general equilibrium; their role is to order processes which can lead to situations which may be described as equilibria in the sense of rest points—or more precisely as stable processes, and the ways of ordering each market may have significant effects. The key questions in economics are about processes—as is increasingly true in other sciences, notably in physics, and processes are conditioned by structure, which is precisely what is lacking in perfect competition and, on the grand scale, in general equilibrium. Systems that work must be selectively, not universally, connected, and large systems must be complex assemblies of smaller systems. The classic general equilibrium model is not appropriate.

The essential argument was made by Herbert Simon in 1962 in his parable of the watchmakers Tempus and Hora. Both made excellent watches, composed of 1,000 parts each; but whereas Tempus used general equilibrium principles, in which only a complete set of relationships was stable, Hora decomposed his design into ten major assemblies, each of ten subassemblies of ten elements, thus providing independent stability at each level. Both watchmakers attracted many customers, and had to put down their work in order to deal with them; but whereas Tempus then had to restart from the basic elements, Hora lost only the connections within the particular unit on which he was working (Simon [1962] 1969).

Simon's first crucial proposition is that building a system in an environment which is subject to disturbance is likely to be almost impossible without stable intermediate forms—which are necessarily excluded from general equilibrium systems. In Hora's design the connections between levels are independent of the internal arrangements at each level; however near decomposability (very few interactions of elements across boundaries) is often sufficient to ensure a high degree of stability, with the significant qualification of exposure to surprise through the activation of a latent connection. This is a common feature of failures in economic systems (as in other areas of human experience) and deserves more attention from economists—not least when giving advice. Simon argues that the survivors of evolutionary processes which rely on environmental selection may be expected to be predominantly of this kind, and he explicitly—and significantly—includes the evolution of physical as well as biological structures. He then proposes the natural corollary that social and economic systems which function well in a turbulent environment exhibit such properties. Richardson (who has had little connection with Simon's work) reaches the same conclusion, differently expressed, about economic systems. As we shall see, both have illustrious predecessors in economics.

Simon's reasoning invites comparison with the theories developed by Georges Cuvier (1769–1832), a major French contributor to zoology and paleontology. Cuvier believed that every organism was a single fully-integrated system (a foundational principle of general equilibrium) and that the evolution of species was therefore impossible. Consequently no species could respond to shocks, as he claimed was demonstrated by the fossil evidence of extinction. (The exclusion of turbulence is, of course, a condition of general equilibrium.) Thus he could have agreed with Simon's explanation of the fate of Tempus's watchmaking business, but he would have rejected the viability of Hora's alternative design. Raffaelli (2008) uses Cuvier's theory to argue that evolutionary theories necessarily require partial, not general equilibrium.

Discussions and debates about evolution, within economics as well as biology, predominantly focus on variation, selection and retention, at the expense of the fundamental principle of the self-organization of complex systems by selective connections within each level and a high degree of decomposability between levels. (These debates lie outside the focus of this paper.) As Cuvier's argument shows by counterpoint, these features greatly facilitate variation through minor adjustments to the set of elements or the connections between them; and although most modifications are likely to be rejected, decomposability is even more likely to be a feature of those which survive. As Simon argues, it also facilitates retention and reproduction of these survivors.

Present ideas strongly suggest that the history of the universe may be summarised as the building of successive quasi-decomposable systems: first the coalescence of elementary particles into chemical elements, then the emergence of particular combinations of these elements as chemical compounds, next the beginnings of life as some compounds combined to form cells, and then the development of progressively more elaborate life forms, in which direct genetic instructions have become increasingly modified—and sometimes superseded—by interactions between genes which are not deducible simply from a knowledge of the genes themselves.

That is not the end of the sequence, but it will suffice. This is clearly an evolutionary story, in which each stage provides the building blocks for the next and so is a necessary precursor for it. Selecting different collections of elements from a rather small set, and linking the members of each collection in different ways is a far more effective means of generating variety, and thus facilitating evolution, at each level than the independent construction of each system. (The relationship between the number of elements and the number of chemical compounds is a striking illustration.) Moreover this method of building complex systems is particularly appropriate to a process which must proceed by trial and error, and which cannot go into reverse (Prigogine 2005), but which may follow alternative paths to very similar outcomes. Evolution proceeds by self-organization and results in spontaneous order, though with a good deal of disorder from failed innovations along the way.

We may therefore feel justified in treating economic systems as a relatively new class of manifestations of a general evolutionary principle of building systems by making selective connections between elements of existing systems. We may also feel justified in seeking to analyse the structure of each system without investigating its elements in detail. However, when we encounter human-based systems an important modification of the neoDarwinian version of this principle is required: neither random genetic mutation nor selection by differential genetic inheritance is appropriate. We must introduce intentionality. In economic evolution (as in science) trial and error is typically guided by conjectures which are intended to produce particular results, although (like genetic mutations) most conjectures are refuted and unintended consequences are rather common. In addition, the diffusion of ideas and practices in economic systems, which are also social systems, is much more complex than a precisely-defined process of replication. As many studies of innovation have shown, adoption is typically accompanied by adaptation.

2 Microfoundations

To understand how economic systems emerge, we must first have an adequate understanding of human potential, and in particular of the human mind. (The design of watches is the outcome of mental processes, and depends on mental capabilities.) In Raffaelli's (2003, p. 50) phrase, we must consider 'human beings as evolving, organized systems whose behaviour depends on previous clusters of nervous connections which change over time ... [because of] the relationships between their internal structure and the external world'. This is a perspective that in a substantial degree is shared by three great economists, Smith, Marshall, and Hayek.

Let us begin with Hayek.

> Any apparatus of classification must possess a structure of a higher degree of complexity than is possessed by the objects that it classifies; ... therefore, the capacity of any explaining agents must be limited to objects with a structure possessing a degree of complexity lower than its own. (Hayek 1952, p. 185)

The human brain cannot fully understand its own operations, let alone its extraordinarily complex environment. It must make do with representations, each of which is likely to have substantial deficiencies. Sight provides a powerful example, developed by the mathematician Michael Atiyah in a Presidential Lecture to the Royal Society of Edinburgh (Atiyah 2008). Although a substantial part of the brain is allotted to the sense of sight, what we 'see' is not a record of the light falling on the eyes but a neural construction. Hence the phenomenon of illusions, some of which persist even when we know that they are illusions: indeed the acceptance of illusions is essential to classical painting and photography, which require configurations of paint or pixels to be interpreted as places and people. Other kinds of representations are allotted much smaller shares of the brain's resources. That many of them work well within limits may be attributed to the prevalence of decomposability in our universe. Simon clearly recognised the disparity between the capacity of the human brain and the complexity of the environment in which it had to operate, and argued that it was the high degree of decomposability in that environment which enables scientists to produce valuable results by focussing on particular systems while making rather simple assumptions about both the higher and lower systems with which they are connected, though with a high proportion of failures along the way. (The significance of decomposability for the development of scientific knowledge was recognised by Lord Rees, President of the Royal Society, in the BBC Reith Lectures of 2010.) But since decomposability is incomplete the patterns created within the brain will not be reproductions of the phenomena being investigated, and so there will always be limits to the applicability of our representations; these limits may not be easy to recognise. Uncertainty is inherent in our representations.

However, uncertainty is a precondition of intelligence. '[T]o live intelligently in our world . . . we must use the principle that things similar in some respects will behave similarly in certain other respects even when they are very different in still other respects' (Knight 1921, p. 206); and what similarities matter, and what differences do not, depends on 'the purpose or problem in view'. Thus we may choose incompatible models for different purposes. Popper (1972, pp. 420–421) also observes that the criteria for similarity are always the product of a point of view. This conception of intelligence as domain-limited order is strikingly similar to Kelly's (1963) proposition that we cope with complexity by constructing patterns that we try to impose on particular events, and that alternative constructions are, in principle, possible.

In what may now be regarded as a pioneering contribution to neuroscience, Hayek (who had dissected brains during his early studies in psychology) identified 'the transmission of impulses from neuron to neuron within the central nervous system . . . as the apparatus of classification'; thus 'the qualities which we attribute to experienced objects are strictly speaking not properties of that object at all, but a set of relations by which our brain classifies them' (Hayek 1952, pp. 53, 143). These attributed qualities may therefore incorporate distortions which can lead to error (Hayek 1952, pp. 145–146).

The human brain has an extraordinarily wide potential for organizing new systems in many different fields and consolidating them into automatic procedures; this consolidation economises the scarce resource of cognition, allowing it to be allocated to new problems. However each brain can effectively exploit only a small proportion of this potential. This fundamental economic problem, and its solution, is ignored in most economic analysis but was central to Simon's thinking. As Raffaelli above all has insisted, it was also central to Marshall's thinking. It is the basis of his explanation of the progressive construction, retention and application of knowledge in his early mechanical model of a 'brain' which built up connections by trial and error and embedded those which seemed to work in routines, thus creating the scope and some of the material for the creation and trial of new possibilities. Raffaelli (2003) shows how Marshall later applied this dialectical relationship between innovation and automaticity to economic development as a never-ending process of experimentation and consolidation.

Like Hayek and Marshall, Adam Smith took an early interest in the process of knowledge creation and also produced a theory in which knowledge consists of schemes of order which are created within the brain and prove serviceable as means of guiding understanding and action while economising on cognition. Smith ([1795] 1980), however, began by identifying the motives which 'lead and direct' this process. These are the discomfort, or worse, experienced when confronted with phenomena which do not fit within any established pattern, and delight in the realisation that some novel pattern encompasses them. The growth of knowledge is directed towards particular problems, and therefore shaped by the context within which the individual is operating.

Smith's recognition that success in creating and applying patterns is necessarily provisional is exemplified by his account of the development of astronomy, especially in his comments on the status of Newton's theory. New knowledge is produced by an imaginative conjecture which replaces some troubling appearance of disorder by a new pattern of 'harmony and proportion' (to use Copernicus's account of his own motivation). Ziman (2000, p. 120) implicitly endorses Smith's analysis by insisting that 'the human capability for pattern recognition is deeply embedded in scientific practice' (see also Ziman 1978); and the mathematician Atiyah (2008) insists that pattern-making, not logic, is the mathematician's supreme delight. For Smith, Ziman and Atiyah, imagination is the key to knowledge. Imagination builds systems.

This powerful incentive to imagine new schemes of order within particular contexts could hardly be effective if the universe were not a highly decomposable system, as Simon noted. There is an implicit warning here of the desirability of maintaining decomposability in the systems that we create, currently illustrated by our financial systems. All our knowledge consists of conjectured representations; many conjectures may not work at all, and those that do have a limited range of application and may fail unexpectedly in conditions not previously experienced. The rational choice mindset encourages the belief that the fallibility of our models is a technical problem—and even an opportunity to gain a Nobel Prize.

Because we rely on our representations, there is a natural pathology here, which was explored by the clinical psychologist George Kelly (1963). If a particular structure of knowledge has become firmly established as a basis of understanding and behaviour, then it may be extremely difficult to accept an alternative structure, and even more difficult to invent one. This was Kelly's theory of personal breakdown. His own belief, which is consistent with the view of knowledge in this paper, is that there are always alternatives which might be imagined, and that the clinical psychologist's role is to supply an alternative which the patient can accept. Because failure is a normal element in progress, this pathology should not be neglected in our analysis. It is not confined to individuals; indeed it is a familiar problem in formal organizations, because of the requirement for internal coherence. Here too the financial sector provides current examples.

If the principles of similarity on which categories may be most effectively based, or interpretative systems constructed, differ between domains, then (as Smith noted) we should expect people in different circumstances to develop different categories and so to think and act differently. Path-dependence will be common, but is very unlikely to extend to path-determination because the boundaries of interpretative systems are typically not well defined and categories may be modified in various ways. Orderly specialisation within a quasi-decomposable economic system is therefore a very effective way of accelerating the growth of knowledge. It has allowed humans to create new ways of exploiting their environment, which emerge and diffuse far more rapidly than the slow products of random genetic mutation followed by differential inheritance.

3 Organization

Specialisation between domains as the principal means of enlarging the knowledge and capabilities of a society is Adam Smith's fundamental principle of economic development (Smith [1776] 1976b, pp. 13–24). That there may be alternative bases of specialisation, with different effects, is indicated by his observation that ideas for improved machinery may be prompted by experience of particular operations, by the search for applications of particular machine-building skills, or by the application of expertise in making novel connections between apparently 'distant and dissimilar objects'. Marshall's theory of development rested on a combination of specialisation between fields and variation within each (which is implicit in Smith's exposition): thus both monopoly and perfect competition are defective because they restrict the sources of imagination of novel possibilities.

Specialisation necessarily replaces self-sufficiency with interdependence, and therefore presents two organizational problems: the arrangement of contexts within which knowledge will be developed, which as we have noted will affect (though not always in predictable ways) what kinds of knowledge will emerge, and the arrangement of ways in which the products of knowledge will be distributed. Since this is a system which generates change, not just in quantity but in the form and content of goods, technology, production methods, skills and understanding, neither organizational problem can be adequately represented in terms of an overall equilibrium; both require continual adjustment, and perhaps intermittent radical change. From this perspective we may observe that the problems of co-ordination and growth, which have traditionally been separated in much economic reasoning—but not by Smith or Marshall—are remarkably similar; they each have to be approached, both in economic theory and in particular situations, in terms of partial rather than general equilibrium—where 'equilibrium' is to be interpreted as stable locally-appropriate processes.

Smith envisaged a cumulative progression: the division of labour is limited by the extent of the market, but its effects on productivity lead to an expansion of the market, and so to further division of labour. Marshall developed this theme, in ways that can be summarised in two passages. 'Knowledge is our most powerful engine of production... Organization aids knowledge; it has many forms' (Marshall 1920, pp. 138–139). 'The law of increasing return may be worded thus: an increase of labour and capital leads generally to improved organization, which increases the efficiency of the work of labour and capital' (Marshall 1920, p. 318). Organization and knowledge are both endogenous in the economic system—as they are in the individual. The power of the constant interaction between them was emphasised by

Allyn Young (1928): increasing return is a property, not of a single production function, but of a sequence of productive arrangements.

Different forms of organization promote economic development by providing varied contexts in each of which particular people may build and apply their own particular internal systems of knowledge. In surveying some of these systems it will be appropriate to follow Marshall's distinction between internal and external organization, which is a distinction between dense and sparse networks, corresponding to the architecture of complexity. We begin by recognising that the internal organization of the human brain into categories and connections is powerfully supplemented by access to external knowledge. An essential element in Adam Smith's overall system of thought is the human capacity and willingness to adopt principles and practices which have been developed by others; this promotes the diffusion of knowledge and cohesion within groups—although as Smith recognised, it has its own pathology, because what is adopted may not be appropriate in the new context (Smith [1759] 1976a). We could not talk to the butcher, brewer and baker of 'their advantages' without this interest in the activities and perceptions of other people.

The outstanding example of this reliance on external organizations is the multiplicity of what are normally called 'institutions', each of which orders a repeatable process with its particular, though often ill-defined, range of application. This external support enables us to acquire many routines ready-made—a notable cognitive economy, though we do need the appropriate absorptive capacity to incorporate them into our existing structures of knowledge. Though of established interest as an aid to interpersonal co-ordination, their role in private cognition seems under-appreciated.

The first form of organization noted by Marshall as an aid to knowledge is the firm, and the outstanding analysis of the firm as a context for the generation and application of knowledge was produced by Edith Penrose (1959) as a response to the discovery that the standard 'theory of the firm' was irrelevant to the study of the growth of firms in which she was participating. Coase (1937, p. 393) had defined the firm as 'a system of relationships which comes into being when the direction of resources is dependent on an entrepreneur', but had not sought to examine how the entrepreneur would use his power of direction. Penrose (1959, p. 2) argued that '[a] ll the evidence we have indicates that the growth of the firm is connected with attempts of particular groups of people to do something', and what they are trying to do is not to maximise their profits within a well-defined system but to discover and exploit opportunities. The imagination of new combinations is central.

A Penrosian firm is 'a pool of resources the utilisation of which is organized within an administrative framework' (Penrose 1959, p. 142). That sounds very Marshallian (and seems to anticipate Simon), as does the implication that differences in administrative frameworks are likely to lead to differences in outcome, because they provide different contexts for the development and application of knowledge. (Penrose later recognised the 'Marshallian' character of her analysis.) Because 'the very processes of operation and expansion are intimately associated with a process by which knowledge is increased, . . . the productive opportunity of a firm will change even in the absence of any change in external circumstances or in fundamental technical knowledge' (Penrose 1959, p. 56). In Penrose's analytical system, resources are not defined by a complete and closed list of their potential uses, not least because resources—what Richardson (1972) later decided to call 'capabilities'—are modified by use. 'It is of the essence of intelligent practices that one performance is modified by its predecessors. The agent is still learning' (Ryle 1949, p. 42). As Heraclitus observed long ago, we cannot step into the same river twice, moreover the river is continually changed by our own actions. An open economy, like open science, generates knowledge which undermines some established knowledge, but which also supplies the elements for further innovation: creative destruction makes possible new creations.

Organization frames the growth of knowledge. It also frames the imagination of connections between enhanced capabilities and the services which they might provide, and of connections between new services and productive opportunities, which, as Richardson (1960) argued, do not reveal themselves. (The effects of the structure of product divisions in the chemical industry provide many examples.) Turning a perceived opportunity into a successful line of business typically requires the acquisition of additional skills and the building of new relationships, both inside and outside the firm; but if this is successfully achieved, then the firm will find itself not only with additional productive resources, but also with managerial capacity which is progressively released (normally with enhanced capabilities) as new tasks become settled routines. Then the sequence can begin again.

Thus each firm's range is always limited, but these limits may recede as a direct consequence of its own activities (Penrose 1959, pp. 60–63). (That people are changed by what they do was the basis of Marshall's hopes for progress.) Moreover entrepreneurs believe that they can act in ways which will change their environment (Penrose 1959, p. 42): 'it is reasonable to suppose that consumers' tastes are formed by the range of commodities which are available to them or, at least, about which they know' and therefore that an entrepreneur may consider demand 'as something he ought to be able to do something about' (Penrose 1959, p. 80). Marshall (1920, p. 280) includes among the standard tasks of businessmen 'showing people things which they had never thought of having before; but which they want to have as soon as the notion is suggested to them'. Preferences are not 'natural givens', but constructed within contexts which are externally influenced, and subsequently order decision processes.

Opportunity sets within an economy change as a result of the activities, capabilities and ideas of the individuals within that economy, and these capabilities and ideas depend not only on each person's ability to construct and modify systems of knowledge but on the context of their activities and the interactions with other people which are shaped by that context. That is why firms are so important—and why the differences between firms are so important. The consequences of differences between fields are generally recognised, though the dynamics are neglected in much of economics, but the crucial role of heterogeneity within each specialism, to which Marshall attached so much importance, was rejected by his successors as a major threat to economic efficiency. This rejection was carried over into policy in the notion of 'the one best way' and the fashion for a 'national champion' in each industry which would simply deploy the correct knowledge. Fortunately, evolutionary ideas include the importance of variety-preserving systems in developing knowledge.

The effect of the internal structure of a firm on its performance, including its creation and application of knowledge, and the process and effects of its internal institutions, deserves a substantive examination which cannot be attempted here: analyses of enduring quality were produced by Barnard (1938), Chandler (1960) and Burns and Stalker (1961), and an exemplary study of Du Pont provides detailed evidence of both success and failure from a company whose directors thought about such issues and recorded their reasoning (Hounshell and Smith 1988). However something must be said about the firm's external organization, which is inadequately represented by the notion of 'market'.

Coase (1937) famously explained the firm as a means of organizing a particular set of activities more cheaply than by creating a network of market contracts. That creating a system uses resources (not least the scarce resource of cognition) is an important truth; but for his particular purpose Coase did not need to consider who bears the costs of market transactions. In particular, who makes markets, and why? Kirzner (1973) offered an answer: when people do not know what options are available, someone who perceives a particular opportunity can gain by taking it, and in the process provides valuable knowledge to others, prompting further transactions. Kirzner's basic case is a price disparity between locations, not hitherto noticed because no-one has travelled between them: the opportunity already exists, and requires nothing but alertness, which for Kirzner is a natural characteristic, though unevenly distributed and always associated with a particular context. It is this differentiation which provides the Kirznerian entrepreneur with a profit opportunity which others do not perceive.

The Penrosian firm, however, does not simply recognise what already exists; it is a creator of opportunities in product space by imagining new applications for evolving knowledge and capabilities; therefore it has an incentive to incur some costs in order to attract custom. If there are any fixed costs in making a market (as there usually are), then it is the party who expects to engage in most transactions who has the strongest incentive to bear them. Casson (1982) exploited this principle to produce the first substantial analysis of the entrepreneur as market-maker, though Marshall (1919) had already used it to observe that product markets were organized by suppliers and labour markets by customers.

Though these are not the 'perfect markets' of economic theory, they are much closer to them than many of the relationships between firms which depend on goods or services which must match particular requirements. Such production systems are less decomposable. Because transaction costs in such cases tend to be high, one might expect the relationship to be internalised, and indeed this often happens; but when the activities involved are strikingly different, relying on different skills and different ways of thinking that are best managed in different organizational contexts, there is a strong case for maintaining organizational distance to preserve the advantages of specialisation. Consequently we find a remarkable array of firm-specific arrangements, as Richardson (1972) exemplified and explained. Bart Nooteboom has made particularly valuable contributions in this field.

4 Conclusion

The growth of knowledge is an evolutionary process. Knowledge is a structure of classifications and connections: it is the product of imaginative conjectures created by the human mind in response to particular problem situations, each installed in a particular neural network. Such conjectures are often falsified; and there may be deliberate attempts to falsify them in order to avoid the consequences of actions based on error. (This is a major element in both scientific research and the commercial development of new products, which often focusses on exploring the limits of decomposability in order to identify, and if possible remove, obstacles to a particular innovation.) They may also be qualified, extended or amended. All these procedures are influenced by context, and the context is often provided by some form of formal or informal organization. All knowledge is limited in scope; but the limits can never be known for certain. If knowledge and its application are always context-limited, then the creation, modification, and connection of contexts are major determinants of the rate at which knowledge is generated and of the kinds of knowledge which are produced. Marshall indicates the importance of different forms of organization, each with their internal variations, in providing distinctive and complementary kinds of environment for knowledge creation. Of particular current interest is the widespread use of modularisation within ICT, by which interface rules give firms freedom to innovate within their own modules; this reduces their knowledge requirements, but reduces the prospects of new combinations across modules.

For Marshall, and for evolutionary economists, co-ordination and development are necessarily interlinked; and it is decomposability which makes this possible. Schumpeter, by contrast, wished to avoid any direct challenge to Walrasian theory. His prime emphasis was not on entrepreneurial imagination; indeed he may be thought to have underrated the imagination needed to envisage new combinations even of elements already well developed. His distinctive focus was the great effort of will necessary to challenge established patterns, and the corresponding need for a powerful motive, which he identified as personal ambition. He also argued that the prevalence of these patterns, which he noted gave an illusion of rational choice (Schumpeter 1934, p. 80), provided a secure basis for entrepreneurial calculation and planning, and that the entrepreneur's success in disrupting them undermined the basis for subsequent entrepreneurship. Thus Schumpeterian innovation implied a business cycle, for which Keynesian remedies were inappropriate. We may note that Marshall (1920, p. 711) also attributed depression to 'commercial disorganization' resulting from the failure of familiar practices, and more subtly, that both identified routine as a precondition of innovation. However, for Marshall this was implicit in the characteristics of the human mind; and in this respect Simon was a Marshallian.

Human knowledge relies on decomposability; but how well the decomposition of any knowledge structure matches the decomposition of the phenomena to which it is applied is always open to question at many levels, including the boundaries between disciplines and the scope of particular theoretical formulations within each discipline as well as within each of the many kinds of organization that compose an economic system. We should be especially sensitive to the opportunities and dangers of incomplete decomposability in an environment where evolutionary processes are often driven by deliberate attempts not only to introduce novelty but to modify the processes of selection and retention, and where these attempts are often being conducted within administrative systems (whether public or private) that rely on the compatability of knowledge structures which may be undermined by the outcomes of their own policies. We may recall Kelly's warning of the possibility of breakdown, even of structures which have proved serviceable over a long period, and of the potential difficulties of devising and accepting novel systems. If such a change also requires a new foundation for interpersonal and interdepartmental compatabilities, the difficulties may prove insurmountable. Chester Barnard (1938, p. 5) observed that most organizations disappear; and the problems of replacing knowledge and skills in response to unimagined challenges are often the trigger—even for Barnard's own extraordinarily successful business. Evolution is intrinsically about failure; and policy-makers should be reminded that '(w)e want privately owned businesses precisely because we want institutions that... can disappear' (Drucker 1969, p. 293). In building systems we might give more attention to building systems that are less likely to fail, and that can better accommodate failure in the systems which provide the elements in their own structure.

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