Product architecture and the organisation of industry. The role of firm competitive behaviour

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The idea that the design of a product crucially affects the innovation capabilities and competitiveness of the firm that manufactures it, is by now an established result [Henderson and Clark (1990), Ulrich (1995), Baldwin and Clark (2000)]. A number of research papers, starting from the seminal work by Sanchez and Mahoney (1996), have shown that this effect works mainly through the relationship between product architectures and organisational ones, as their matching — or “mirroring” — is responsible for the firm capacity to compete with its rivals in developing new products and facing industry dynamics (e.g. Brusoni and Prencipe (2001)).

Although such a link has received both theoretical and empirical support, its inner mechanisms are still far from fully understood. Indeed, although quite useful, the “mirroring hypothesis” appears to us too simplistic an interpretation. In particular, because it does not account for both the complexity of the relationships between technological and organisational change, and the role of product architecture in at least two respects. First of all, it should be recognised that the presence of strong interdependencies between the components

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of a complex product – i.e. an integral architecture – makes the choice of an innovative optimal design extremely difficult and sometimes even works as an “obstacle of technological change” (such as, for example, in the case of manufacturing automation and fuel-cell technology (Buenstorf 2005, p. 223)). On the other hand, modular architectures, while allowing for modifications of individual components, prevent innovations related to the “global performance characteristics” of the product (Ulrich 1995, p. 432).

Very often, the design and the manufacturing of a product architecture amounts to that of a complex system, as “one made up of a large number of parts that interact in a non simple way” (Simon 1962, p. 468). In front of it, bounded rational economic agents thus need to resort to behavioural patterns of problem solving and search routines which have been proved to be suitably described by the so called NK methodology (Kauffman 1993). Following Frenken (2006), the NK model will be generalised to disentangle the difference between decomposability and modularity in complex systems. Indeed, as several authors in the field have argued (e.g. Baldwin and Clark 2000; Langlois and Robertson 1992), complex products can be modular without being necessarily decomposable, at least in the sense Simon alludes by referring to the presence of independent sub-systems.

The main aim of this paper is to analyse the evolution of those strategies across a population of firms in a specific industry, their effect on the organisation of the industry and on products life cycle, and the feedback from industry life cycle to the selection of successful strategies.

The paper’s methodology draws on previous works of ours (e.g. Ciarli et al. 2008), in order to study the intertwining of problem decomposability, product and organisational modularity and technological search, by means of a computational model that represents one industrial sector, in which a final good for the consumers’ market is produced. Heterogeneous firms compete for a final demand for which consumers have preferences on a number of characteristics of the good. In order to produce the good, each assembling firm uses a certain number of input components. Each input component contributes to each assembled good characteristic in a way which depends on the technological architecture of the good (the degree of modularity among components).

Improvements in the technological performance is achieved by exploiting a ‘corrugated’ technological landscape. The landscape exploration is modelled through a continuous version of the NK model. The characteristics contribution of a single module is increased by looking for a maximum (either global or local) value of its fitness. However, the global fitness of the integrated good is determined by the correlation structure between the whole set of components, as defined by the NK model.

This opens the possibility to strategically opt for a change in the correlation structure, i.e. the product architecture. The architecture can be changed in two directions: on the one hand a firm may increase the decomposability of the technological search on the single components, by standardising the interfaces. Standardisation also has the effect of increasing the diffusion of the component as an intermediate good. On the other hand, firms may chose the
technological standard of a diffused component, reducing the modularity with other components.

Finally, the decision on which components are outsourced and which are produced in–house depends both on cost and on technological reasons. The advantages of specialisation reduce the costs of producing a single component on a large scale, but increase technological transaction costs, and reduce the capability to search the technological landscape, when the product architecture is complex.

In order to better understand the organisation and innovation impact of product architecture, we claim that the idea of “interface” has to be defined by distinguishing between the product components and the bundles of components that can be grouped into modules according to well specified relationships. Indeed, the role of interfaces is to allow the firm to improve one module without evaluating each state of the others: that is, to deal with a pre–determined list of possible states of input and output relations between modules. The set of interfaces may thus appear as an instrument for reducing the complexity of the research space. This is actually not the case, if we consider the usual method of assessing the level of complexity by the difficulty to reach the global peak of a problem space (Frenken et al. 1999). However, if the goal is not to reach the global theoretical peak, but to facilitate the improvement of the performance with respect to the current configuration of a product, then the use of interfaces hugely simplifies the process. In the paper, we show why this is the case, and derive some predictions of such a perspective regarding firms engaged in technological competition.

By exploiting the flexibility of the, previously developed, pseudo NK model (e.g. Ciarli et al. 2008), it is possible to generate a technological space made of interfaces and modules. The simplest structure of this type can be represented by one module being connected to all other modules (the interface), while the remaining modules are connected only to the interface. From the technical point of view, this space shows the highest level of complexity, but, keeping constant the first dimension, the resulting sub–space is fully modular.

Adopting this technological space, we ran a competition model with respect to an industry composed of 50 firms, each producing a six–component product, only one of which (the interface) is related to all the other ones. In this way, we obtain highly interesting results allowing us to provide a preliminary illustration of the conjectures derived from the literature on the role of interfaces on firms’ innovation and organisation.

Figure 1 reports the average fitness increments per innovations for 5 independent runs (Figure 1a) and the number of successful innovations at the end of the 10,000 time simulation steps (Figure 1b). The different grey series indicate the values for each module, while the darker series refers to the interface module.

The figures show that the “interfacing” module is modified more rarely than the modules having no connections (Figure 1b). However, the average products’ fitness increment resulting from these fewer innovations is higher than the innovations generated by the other modules (Figure 1a). This result confirms
that modules with a high degree of connections are much harder to modify, although if such an innovation succeeds, it is highly rewarding. Moreover, this result is perfectly in line with the perspective on interfaces that we described at the beginning of the section, confirming the robustness of its logic by means of simulation results.

We also found confirmation of our perspective on firms’ organisation. Figure 2 reports the number of firms actively producing each module (instead of buying it), out of the 50 firms in the industry (Figure 2a), and the total amount of traded modules (Figure 2b). Again, the results confirm the implications described above. The interface dimension results to be actively produced only by a small number of firms. However, the interface is traded in larger quantity, than other dimensions, showing that the emergence of a sort of “standard” is generally imposed by a bunch of producers able to supply other firms with a given (working) format for the interface module.

Figure 1: Innovation pattern per module: performance increase (a) and number of innovations (b). The darker series is the interface. The x axis refers to 5 independent runs.

Figure 2: Number of firms producing and trading the interface (dark series) and the remaining modules (grey series). The x axis refers to 5 independent runs.
References


