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A COMBINATORIAL MODEL OF ORGANIZATIONAL INNOVATION: THE CASE OF PILKINGTON PLC

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Abstract
Based on an in-depth case study of Pilkington Plc, this study illustrates that received perspectives in organization theory and theory of the firm fall short of explaining organizational evolution. The framework of organizational evolution developed in this paper is combinatorial in two ways. First, it shows how factors drawn from different perspectives can be combined in understanding organizational evolution. Second, it shows the explanatory and prescriptive potential of a combinatorial approach to resources and organizational configurations. This approach helps distinguish those features of organizational history that are ineffective and those that are instead effective for the firm survival. In Pilkington, the successful changes of firm boundaries have been predominantly linked to the combination of complementary resources rather than the resolving of transactional problems or realizing economies of scope through related diversification. The changes of internal structure have been successful due to a combination of waves of decentralization and centralization with a stable, robust coordination by communities at the level of research activities.

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1. Introduction

The name Pilkington is linked with one of the greatest process innovations of the 20th century, the float glass process. Introduced in 1959, this revolutionary innovation transformed the glass industry. Previous technologies (i.e. plate and sheet glass) involved a lengthy and costly process of grinding and polishing of the glass ribbon resulting in a large stock of glass wastage. The float process instead involved discharging the ribbon of molten glass from the furnace, floating it onto a bath of molten tin and cutting it directly without polishing. Such an innovative technique enabled production output to increase manifold and production costs to fall dramatically. Float technology replaced the existing glass manufacturing process technologies at an astonishing rate (Barker, 1994; Teece, 2000).

At the time of the invention of the float process, Pilkington was a relatively small British company that lacked in-house financial and managerial capabilities for commercializing float technology worldwide through direct investments. Pilkington licensed float technology to existing glass manufacturers, granting them geographic rights for the use of the new technology in their home markets. Licensees generally received the rights to sell glass anywhere in the world and were also entitled to exchange improvements to the new process that any other users would have come up with. In the second stage, Pilkington expanded its own production via affiliates in those markets that did not have a glass manufacturer. During these two stages Pilkington was characterized by a highly centralized structure (one business UK-based) with authority-based co-ordination mechanisms to deal with intra-divisional issues.

In the third phase, funds for direct international expansion were made available by a combination of royalties from the licensing activities, earnings from float production, and the stock market. Funding from the latter source was made available after the 1970s when the family-owned business Pilkington became a public company (Teece, 2000). Pilkington used this funding to expand via two major acquisitions, namely FlachGlas in Germany and LOF in North America. Because of the lack of managerial capabilities, Pilkington decided to leave these businesses as independent subsidiaries. From an organizational viewpoint, Pilkington adopted a highly decentralized structure and attempted to coordinate the different national units through international committees. The process of expansion and ensuing internationalization brought about a number of organizational and managerial challenges that make the organizational evolution of Pilkington a particularly interesting case to analyze.

This paper attempts to address the following research question: what forces drive the evolution of firm boundaries and their internal organization? The case study conducted on the Pilkington group organizational history and recent turnaround reveals how existing approaches of organizational structure fall far short of capturing some very interesting features of organizational evolution. Specifically, based on data collected during a one-year research project, this case study plays two roles. First, it constitutes a partially falsifying case study with respect to some received perspectives on organizational evolution. Organizational structure theories considered change predominantly as a substitution from one organizational form to another – e.g. from a decentralized to a centralized arrangement (Nickerson and Zenger, 2003), from a divisional to a unitary form, from a market-like or a hybrid to a hierarchical form (Williamson, 1975). The observation that actual changes fall short of exhibiting such neat features is accommodated by the concepts of inertia – i.e. resistance to change due to a variety of attrition factors (Hannan and Freeman, 1984) – and that of path-dependency – i.e. the limited variety of future change trajectories due to the past history of the organization. These concepts, however, are not able to distinguish what part of inertia or path-dependency is effective and which is pathological. Evolutionary theory and strategy literature did actually produce prescriptive implications for change, such as that of following core capabilities

and technological relatedness (Prahalad and Hamler, 1990). The case study presented here partially falsifies these approaches. Based on the Pilkington case study, we attempt to discriminate between ineffective and effective ('shadows of the past') states delivered by path-dependency.

Second, the study presented in this paper is a corroborative one with respect to a wider perspective where factors such as the diversity and complementarity of organizational mechanisms (rather than their coherence as part of a pre-packaged organizational form) are considered (Grandori, 1997). Accordingly, organizational arrangements are not shaped around discrete structural alternatives, but they are formed by innovative combinations of elementary mechanisms that give rise to continuous structural alternatives (Grandori, 2001). The complementary concept to change is not inertia but the *shadow of the past* – conceived as the partition of past arrangements effective to navigate change. Based on the results of the case study, this paper introduces the concept of organizational structures as combinations of pre-existing and emergent elements as opposed to the traditional alternative organizational archetypes.[1] Coordination can be achieved through a portfolio of mechanisms, such as prices and incentives, authority, rules, teaming and negotiating, and communities. The innovative combination of such mechanisms provides the distinctiveness of business organizations.

The theoretical perspectives discussed and the empirical evidence on Pilkington's organizational evolution are presented following the narrative solution crafted by Allison (1970) in his famous case study *Essence of Decision*. Our aim was to assess what could be explained of organizational evolution in a large firm using the theoretical lenses provided by some main relevant traditional perspectives. This exercise gave rise to two stories on boundary change (generated by transaction cost and resource-based approaches), and two 'stories' on internal organizational change (generated by the structural contingency and the organizational alternance approaches). To capture the unexplained on firm boundaries and on internal organization, we propose a third combinatorial story.

The paper is structured as follows. Section 2 presents two 'stories' on the evolution of firm boundaries informed by transaction costs and core capability approaches. Empirical evidence is presented to support the two traditional perspectives. The two stories are then followed by a third combinatorial story. Section 3 discusses empirical evidence on internal organizational change generated by the structural contingency and the organizational alternance approaches. This is followed by a third combinatorial story. Section 4 presents the conclusions to the paper.

2. The evolution of firm boundaries

2.1. Story 1: Transaction costs

The transaction cost approach predicts that firm boundaries expand to internalize the regulation of transactions that involve specific *investments* (in assets which have less value in alternative uses, hence creating 'hold-ups'), are subject to *uncertainty* (thereby making the writing of complete and reliable contracts difficult), and are *frequent* (thereby making investment in specialized administrative structures efficient). This model maintains that asset specificity has a predominant influence in explaining where the efficient boundary of a firm should lie – i.e. it is a 'necessary cause', albeit not sufficient (Williamson, 1981).

Drawing on that work, Stuckey and White (1993) maintained that the most important reason for vertical integration is vertical market failure. According to them, a vertical market 'fails' when there are a small number of buyers and sellers; high asset specificity, durability and intensity; and

[1] The concept of combinatorial organization is complementary to that of combinatorial capabilities as proposed by Kogut and Zander (1992). In this respect, we think that this paper extends that of Kogut and Zander.

frequent transactions. With regards to the second aspect, they put forward the case of automobile assemblers and component suppliers who can become locked together when a component is specific to a particular car model. This often results in high switching costs and, therefore, leads to decisions to vertically integrate. The theory of bilateral monopoly produces the same result – it is not market failure (markets continue to operate) but instead that the double monopoly provides a strong incentive to merge because the combined enterprise can better exploit the market. Teece's theory of co-specialized assets also provides a rationale – inducing supplier investment in assets that can only be used by a single purchaser requires a premium above the costs of production. It may be more efficient to simply purchase the supplier to acquire the input at the cost of manufacture.[2] Similarly, Monteverde and Teece (1982) in their study on the US automotive sector concluded that the vertical integration structure of General Motors and Ford is based on efficiency considerations. First, they argued, it reduces the exposure of the automotive manufacturers to the opportunism of suppliers, since the production process generates specialized know-how leading to high switching costs. Second, the vertical integration structure allows for better coordination of the production process.

The changes in Pilkington's organizational boundaries seem to have been far more sensitive to the control of uncertainty than to asset specificity issues. Pilkington was a relatively small UK-based glass manufacturer whose core business was in glass manufacturing. Through external acquisitions (made possible by the availability of funds from internal funding, licensing activities and successively from the stock market) Pilkington entered into downstream operations of the glass industry, namely glass applications for automotive and building products.

> "So we woke up in the downstream businesses, which were significant in the UK, Scandinavia, Poland, and Switzerland. These businesses were big for those markets, since they had significant market shares."[3]

The international expansion of the mid-1980s entailed the acquisitions of two large companies, namely Flachglas in Germany and LOF in North America that had a very strong automotive soul. In particular, the North America operation had 70% of its business in automotives, whereas 60% of FlachGlass was in automotives. Apparently, Pilkington remained in the downstream businesses to have an outlet for the float glass they produced.

> "Because we were scared that we could not sell our glass and therefore we bought the distribution channels. […] We were in the automotive business at that time to consume glass."[4]

Pilkington expanded its operations in order to control the distribution channels (in both automotive and building products businesses) for its main product, i.e. raw glass. By entering the glass application businesses (i.e. building products and automotives) Pilkington attempted to reduce uncertainty related to the distribution channels. Asset specificity was not an issue, since the production stages were not linked by investments in equipment or know-how with unique and special value only in that specific transaction. In principle, these resources could be used in transactions with other partners and without possessing deep knowledge of the nature of the activities in the cheek-by-jowl stage.

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[2] We would like to thank Edward Steinmueller for drawing our attention to these two approaches.
[3] Interview with the Managing Director of Primary Products and President Building Products Europe – 2nd October 2001.
[4] Interview with the Managing Director of Primary Products and President Building Products Europe – 2nd October 2001.

The transaction cost approach does play a role in explaining the expansion of firm boundaries. Its explanatory power is, however, limited. The part of the approach which finds some correspondence with observed successful changes is the one closer to the resource dependence argument: transaction costs due to uncertain availability of resources are the leading force. Pilkington moved downstream in an attempt to reduce uncertainty in downstream markets – from a capacity planning viewpoint, in fact, securing an assured downstream customer is useful. This was consistent with Pilkington's view at the time of the investments. Transaction cost considerations can give no account of those expansions that did not follow pre-existing transactional links, however. These moves are supposed to be better explained by a capability-based view of the firm. Hence, it is to that approach that we now turn our attention.

2.2. Story 2: Core capabilities and technological relatedness

Scholars belonging to this research tradition understand firms in terms of their resources and capabilities. Accordingly, a firm's evolution in terms of growth, either internal (organic development) or external (through acquisitions), is influenced, if not determined by the trajectory (or trajectories) defined and circumscribed by such resources and capabilities. Firms expand their activities in business areas that are closely *related* to their existing ones. Empirical studies have supported this point (e.g. Patel and Pavitt, 1997). Generally speaking, *relatedness* can be associated with (a) the bodies of scientific and technological knowledge that underlie products and processes, in terms of existence of synergies and their actual and potential exploitation; (b) manufacturing linkages in terms of tools and procedures; and (c) marketing channels (Owen and Harrison, 1995).

The resource-based perspective also distinguishes resources from the services generated by them (Penrose, 1959) and highlights that these two components of firm capabilities need not co-evolve – indeed there are typically imbalances between the two. This leads us to inquire into the relationships between what firms know and what they are able to do (Brusoni, Prencipe and Pavitt, 2001). Sometimes they do more, sometimes they do less than they know how to do, leading to over- or under-diversification (Prahalad and Hamel, 1990).

Pilkington's story should be particularly telling in this respect, because it expanded its operations through international acquisitions in apparently related areas to glass-making as well as in areas apparently unrelated to its core business. The original capabilities of Pilkington were primarily in upstream glass manufacturing. Pilkington entered downstream businesses (building products and automotive applications) in different national regions via acquisitions. The nature of the businesses in terms of critical success factors, market features, technologies, and underlying organizational capabilities were however different.

Upstream glass manufacturing is a large-scale, multinational (e.g. Europe-wide), capital-intensive, and make-to-stock business. This means that the manufacturing side is very much detached from the marketing side. Its most critical success factor is efficiency and the biggest business drivers are low overheads and manufacturing productivity. The product is a commodity and it is the same everywhere. Correspondingly, the market is global, in the sense that customers buy across borders and manufacturing does not necessarily take place where the market is. On the other hand, the downstream building products business (or processing and merchanting) is small-scale, bespoke, and make-to-order.

> "The business makes the product to fill the hole in the building. They cannot make the product until they receive the order, because they do not know what size is the hole. They sit there, the order comes, they have to react decently quickly, they have to get the finished product ready, and deliver it, and if it is broken, they have to

make another one exactly the same. It is a local, service business, more about a service than the product and a lot of the critical success factors are service-related."[5]

The downstream building product business is local, because markets are different, products are different, and the reach of the manufacturing site is only 150 km. It makes sense to run the business with common procedures but with profit and loss responsibilities to really make the best for each local site. Automotive is in between make-to-stock and make-to-order business. It has long series, no stocks, but not make-to-order. Given the relatively high concentration of end customers (ten world-wide car manufacturers), customer relationship management constitutes the critical success factor of this business. Moreover, two important trends render the management of the customer interface even more important. First, there is the increasing sophistication of the glass product requested by car manufacturers. For instance, car manufacturers demand more curved windscreens that in turn call for sophisticated glass-shaping technology. Second, car manufacturers increasingly use subcontracting strategies and increasingly widen the scope of such strategies in that they delegate larger parts or, more precisely, larger modules of the car to first-tier suppliers. The glass components of the car increasingly incorporate a number of sophisticated add-ons, such as sensors, that call for innovative solutions of the manufacturing process (in particular, glazing processes such as encapsulation, extrusion, and assembly). Against this background, Pilkington tried to run the newly acquired companies with a glass-making mentality and "a very much hands-off glass making mentality".[6] Pilkington, in fact, left the newly acquired companies (i.e. LOF and FlachGlas) to operate as independent national companies with their own strategies, technologies, and management.

The capability-based story of Pilkington captured an interesting dimension of the firm structural evolution. The story highlighted that the nature of the businesses entered by Pilkington was different from the original area of operation. Pilkington could not deploy its distinctive capabilities (that rested in fact on glass manufacturing) because of the diverse, and increasingly so, nature that characterized the businesses in terms of both market and technological competitive issues. The relative success and failure of diversification moves cannot be well understood as responding to technological relatedness or to the prescription of staying with the firm's core capability boundaries. Indeed, moves into different capability domains (as in the case of the SIV acquisition, see next section) were very successful. Instead, when Pilkington did try to follow the general movement towards related diversification, in the era of maximum popularity of that strategy, the consequences were definitely not positive.

In fact, in the 1980s following the failed take over by BTR, financial analysts suggested diversification. Pilkington was considered to be too focused and standing on a two-legged stool (building products and automotive businesses). Pilkington entered the ophthalmic business to diversify and therefore create a third leg for its business. Diversification into the ophthalmic business provides a very interesting case of inefficient relatedness-based boundary design. Time proved that in spite of drawing on the same core capability in glass manufacturing, the ophthalmic business was sufficiently different in other respects to offset those advantages. Even worse, the case showed that the logic of relatedness might lead to considerations of market attractiveness being overlooked – in this case, the market for glasses was threatened and then adversely affected by the advent of contact lenses. Finally, a simple logic of following relatedness exposes the risk of being trapped in an escalation of commitment (if a business does not pay off, take other steps rather than divest). In fact, after entering the prescriptive glass business and realizing that it was not profitable because of the advent of contact lenses, Pilkington entered the supposedly related business of

[5] Interview with the Managing Director of Primary Products and President Building Products Europe – 2nd October 2001.
[6] Interview with the President AGR Europe – 8th October 2001.

contact lenses. Subsequently, they entered the business of contact lens liquids. Later on, the entire ophthalmic business turned out to be a clear loss and was then abandoned.

2.3. Story III: Combinatorial capabilities

The foregoing discussion suggests that both transaction cost explanations and the resource-based logic of relatedness and core capabilities share a sort of anchoring bias. Organizational boundaries are expected to expand either in the direction of existing transactions (when they are problematic) or in the directions in which existing capabilities and resources can be transferred generating economies of scope. They both neglect further possibilities, envisaged by questions such as the following: can learning and its costs be avoided altogether by buying and using the output of other firms' learning (Demsetz, 1991)? Or are there directions of action in which a firm can learn faster and absorb new knowledge better than others (Cohen and Levinthal, 1989)? Or in which a firm can create more value than others by combining new complementary resources with those already possessed (Grandori, 2001)?

This perspective opens up more varied trajectories to the efficient expansion of firm boundaries. In fact, high learning potential and high combinatorial potential need not be necessarily located in activities which are technologically related with existing ones or that make use of the same resource base. Research shows that acquisitions or alliances oriented to build new knowledge and capabilities tend to occur more often between firms with some similarity in basic knowledge but different experiences and products, thereby maximizing absorptive capacity and learning potential (which is low if capabilities are too similar) (Cantwell and Colombo, 2000). Analogously, complementary capabilities may be technically unrelated ex-ante and it may be difficult to say which are core and which are not (Prencipe, 1997).

It has been mainly through international acquisitions that Pilkington acquired technological capabilities also in glass applications. Although, for a long time, such a widening set of capabilities was not integrated, it enlarged and strengthened the technological base of the firm. In other words, it constituted a potential pool of capabilities that could be exploited if rationalized and integrated appropriately. [7]

> "[With the] acquisition of SIV, another pool of talent, another center of knowledge, primarily in automotive engineering entered the scene. The issue then becomes an organizational one of determining what technologies would be worked on and where. Because at this point you start to eliminate overlaps and start to shed technologies which might be thought to be acceptable in a single market (…) what are the core technologies that you want to retain and how you are going to organize the engineers." [8]

> "So you could see the major differences in the four major technical groups that coalesced: largely glass melting and coating in the UK, coatings in the US, advanced products in Germany, automotive innovations in Italy. SIV was established to supply any market, and export; this was different from the other national plants that were supposed to serve only national markets. SIV was a latecomer to the market, the Italian market was a reasonable base, but they worked on the fundamentals that could sell to anybody in Europe. Therefore, it has never been a tenet in core Pilkington that we would do as much product as process innovation. In automotives the view was taken that we would buy technology and not invest in our own. It is only when you get the coalescence of four teams that

[7] See Section 3 below.
[8] Interview with the Retired Head of Technology – 9th October 2001.

you get a more balanced portfolio of skills and demands overall. We have now a much better balanced portfolio of skills than any one of the component companies started out with. And we could exploit that with some longer-term view." [9]

These creative combinations of resources are those which generate, in the first place, that uniqueness of each firm that is supposed to find its sustainable competitive advantage and its contribution to collective knowledge and welfare (Schumpeter, 1950). According to this perspective, firms can and should exploit the possibility of not following similar diversification paths, even if they start out with similar capabilities, but of opening up new and distinctive ones. To what extent these opportunities have been exploited in the glass industry is an interesting question emerging from the above analysis, but it would need another study to obtain an answer. It would be interesting to discriminate between bandwagon effects on firm boundaries (e.g. industry-specific recurrent patterns due to the diffusion of business recipes, and to an over-use of imitation and benchmarking) and the discovery of distinctive designs. It is worth noting here that there are signals that a variety of diversification trajectories were possible even in a rather mature industry like glass-making. For example, it is true that the current competitors of Pilkington – such as Guardian Industries Corp. and Saint Gobain – have followed similar (although not identical and usually broader) diversification patterns (actually this is the very reason why they are close competitors). But other firms starting out as glass making companies became successful in quite different sectors – the most striking case perhaps being the BSN French food group who took off on the basis of a diversification from the container (glass) to the content (food).[10]

3. The evolution of internal organization

3.*1.* *Story 1: Structural contingencies*

The evolution of firm organization does not take place independently from what happens in the firm relevant environment. Firms contrive responses (in terms of strategy and policy) to address environmental opportunities and threats. A contingency view of organizational evolution revolves around the concepts of strategy, structure and environment, their relationships and more importantly the degree of fitness that characterizes such relationships. The environment-strategy-structure relation is not deterministic, however. There are several possible responses that firms can contrive depending on specific situations. The firm's macro environment consists of all the external forces that can influence its decisions and actions. External influences can derive from changes in national government and supranational policies, demographic trends, technological change, scientific discovery, social structures (Grant, 1998). The macro environment can be distinguished from the firm's competitive environment. The latter is understood in terms of micro contexts that more directly influence a firm's course of actions. According to Porter's analysis of firm competitive strategy (1980), the main contextual factors lie at an industry level and can be vertical (supplier and customer bargaining power) and horizontal (existing competitors, new entrants, and threat of substitute products). At a more micro level, firm strategies are conceived as a selective collection of relevant tasks to which the structure of organizational units must adapt (Lawrence and Lorsch 1967).

General predictions of the contingency views are that in industries characterized by environmental uncertainty, effective firm organization will be more decentralized, differentiated or divisionalized, firm strategies will be more generalist and more adaptive, and higher levels of organizational slack will be maintained. As the intensity of organizational interdependence increases, the range of coordination mechanisms employed to coordinate specialized firm units is expected to widen and to

[9] Interview with the Retired Head of Technology – 9th October 2001.
[10] Interview with the HR Director – Bocconi University 1992 and Barker (1994).

include richer and more powerful mechanisms (Thompson 1967). For instance, in unitary forms, teams and a variety of integration mechanisms are expected to enrich hierarchical and program-based coordination (Lawrence and Lorsch 1967), whereas in divisional forms, committees, central staff, and community-based coordination prevails over transfer-price and planning based coordination (Lorsch and Allen 1973; Amin and Cohendet 2000).

As far as the international dimension is concerned, contingency perspectives distinguish between global industries and local ones. In the former, products are relatively undifferentiated commodities, and higher degrees of centralization and standardization of form structures are adopted. In the latter industries, products and services must be tailored to site, use, and user specificities and organizational structures need to be more flexible and organic (Bartlett and Ghoshal, 1990; Grant, 1998).

A contingency-based reading of Pilkington organizational evolution revolves around the strategic changes that the UK-based firm underwent over the last two decades to address changes in its relevant competitive environment. Contingency theory would call for (predict and also prescribe) a relationship of fitness between a firm's strategy and its competitive environment, if firms wish to be relatively superior performers in their strategic group.

The Pilkington case lends itself well to a contingency analysis, given the changes that the organizational structure underwent following the international expansion and the related and subsequent changes in the firm's corporate strategy. Pilkington was a relatively small British glass-making company. The relatively small size was also maintained after the invention of the revolutionary float glass process. Its market reach was limited to the British national market along with a couple of international markets (connected with the old British empire) which were served via affiliates.

The over-decentralization and ensuing lack of co-ordination that characterized and pervaded the Pilkington Group resulted in two problems. First, after the invention of the float glass process, Pilkington adopted a technology selling strategy and licensed the new technology to existing glass manufactures that operated in markets that where not served by Pilkington. The license granted glass manufacturers exclusive territorial rights. Such a strategy proved to be successful for a long time and constituted an important source of funding for the acquisitions of other glass manufacturers. The newly acquired Pilkington branches found themselves competing with glass manufacturers that offered glass products based on float technology that Pilkington licensed earlier on, since the different international branches, by operating as independent companies, could enter the markets served by other Pilkington branches, also with aggressive price cuts or more service-based solutions, and cannibalize the offer of their in-house competitors. Second, the portfolio management style that Pilkington adopted created huge opportunity costs. Pilkington did not and could not lever commonalities across the different international branches that operated in the same businesses. In other words, the lack of control of competition from licensees prevented Pilkington from achieving an effective position as a multinational producer. In addition, the national dimension of Pilkington operating branches did not allow the exploitation of a full capacity of float line plants.

> "There was a basic problem. Theoretically there was coordination, there was an agreement, but practically what counted were profits and there were many cases where one division would steal the customers of another."[11]

[11] Interview - Director Operation Planning, Primary Products Europe –2nd October 2001.

After 1996, Pilkington turned to a more protective stance toward its proprietary technology and introduced a series of organizational innovations to reflect and accommodate changes in the external (in particular, consolidation of the major glass manufactures and trend towards globalization) and internal environments (specifically, lack of coordination across the group). The aims of such organizational innovations were to develop products that incorporate Pilkington's proprietary technology, and to make the company a global player. Such changes have reversed the previous organizational solution: centralized governance of subsidiaries under the two main business lines, building products and automotive, with R&D also assigned to them separately.

In the restructuring, it was recognized that Pilkington operated in four distinct and very different businesses. These were (1) flat and large-scale glass production (also upstream operation or primary products); (2) manufacturing and selling glass for building products; (3) supplying the car manufacturers (also automotive original equipment); (4) supplying replacement glass for the automotive market (also automotive glass replacement). Pilkington realized that they had the strengths to be world-class leaders in float glass manufacturing. This entailed the creation of an interface between glass manufacturing and its commercialization. This interface was regulated by transfer prices (market-based) and the two businesses were run as separate businesses. More than half of the downstream businesses (30 out of 53) in building products were closed or sold. The CEO also decided to change the method of control through several workshops and committees. The group became characterized by a number of committees focused on a number of business functions, e.g. marketing, manufacturing, R&D.

Before the split in business lines, technology was organized according to disciplines. There were a number of key disciplines, e.g. melting, coatings, building product groups, and automotive forming group. Melting was in the UK, coating and automotive forming in the US, building products in the UK, and fire products in Germany. Within each of these technical disciplines, there were programs, led by the appropriate specialists, for composition, refining, theory of melting and the appropriate specialist from any center was the leader of that particular research program and could potentially have a multinational team in his program. A cross-discipline type of team would arise if there was a major project that required it. The extent to which these were coordinated was largely loose at the top through the directors and a very small secretariat. Most of the leaders knew each other and coordination was informal.

The cost cutting exercise also affected R&D and Engineering and entailed a severe rationalization. R&D and Engineering were halved. A major cut took place in 1996, and another smaller one in 1998. As part of the rationalization, the R&D teams in Germany, UK and US focused on different technologies. Several functions (e.g. IT, engineering, purchasing) were moved from the national to central organization in order to create and exploit synergies. The creation of two business lines, namely automotive and building products, entailed the creation of two sub-headquarters responsible for each business world-wide whose aim was to coordinate the businesses from a strategic and operational viewpoint with financial control over manufacturing, marketing, and human resources. Coordination by hierarchy and centrally devised procedures gained much more weight.

The contingency-based approach captured an interesting dimension of Pilkington's evolution. When Pilkington started operating in the global market, it was forced to change its strategic posture in relation to its technological base. In fact, the technology-selling strategy and loosely coupled organization was substituted for a more proprietary stance and tight coordination based on procedures and hierarchical decision-making. Competition based on distinctive proprietary know-how required strong integration and could not be achieved in a fragmented, highly decentralized firm. On the other hand, reading Pilkington's organizational evolution with a contingency-based lens did not explain the traditional anomaly represented by delay in adaptation (Scott 1971) and

more interestingly, why over-adaptation occurred. In other words, why was there over-decentralization during the first period of international expansion, and overcentralization in the current form? Where do these features come from? Are they pathologies or signals of some other forces at work?

3.2. Story 2: Organizational alternance

The story of Pilkington's organizational evolution from a decentralized to a centralized arrangement can be read using quite a different analytical approach. Organizational solutions do change also because any solution entails costs as well as benefits, and their alternance over time may optimize the responses to all relevant demands and interests and might be changed just because it has been implemented for some time (Grandori, 2001). The succession of CEOs is likely to give impulse to this kind of change, not only because new managers are less linked to vested interests and past habits, but also their personal motivation and success are typically connected to being able to change the system, and a new leadership needs identity and distinctiveness (Nickerson and Zenger 2003). Therefore, a change of leaders typically sustains and accentuates change in strategy and organization, as research on turnaround processes showed (Barker and Duhaime 1997). In addition, firm size and the degree of diversification have also been shown to be positively correlated to the amount of change occurring in turnaround processes, because of the wider set of possible moves (especially through divestments) and of possible recombination of activities (Barker and Duhaime 1997). Firm size can be expected to amplify the alternance between programs governing them, also because it becomes difficult to satisfy the demands of all relevant stakeholders simultaneously.

Organizational programs may differ on various dimensions, but one especially salient alternative is between decentralization and centralization. Hence, we should expect oscillations between centralization and decentralization to take place. In this respect, the shadow of the past pushes the system towards assuming a sequence of opposite arrangements, rather than towards continuity, as usually pointed out. On the other side, there are forces limiting the wideness of effective variations. For example, initial organizational imprinting has been argued to mark firms forever (Stinchcombe, 1985; Hannan and Freeman, 1984; Baron and Kreps, 1999). The path to growth is also important, as growth by acquisitions and aggregation of pre-existing firms can be expected to lead to more decentralized and fragmented multidivisional structures than internally generated growth (Chandler, 1962). In this respect, the shadow of the past prolongs and maintains some features of the previous arrangement in the new. Therefore, in this perspective, oscillations between opposite solutions can be expected, which in turn depend on the starting point and on the irreversible choices among possible trajectories made in the past.

In the original Pilkington firm, technology was centralized, organized by technical disciplines, e.g. melting, forming, coating. Technology reported to the General Board through one of the main Board Directors, responsible for technology, who looked after budget and personnel. During the 1980s, the major changes that affected Pilkington were the acquisitions of the German company (FlachGlas) and LOF in North America. Both had business interests that matched Pilkington (building products and the automotive business). The automotive business of LOF was much stronger than in Pilkington. The German firm was a mixed business and the automotive business concentrated on higher technology products than was demanded at the original Pilkington firm. Those two acquisitions brought two major technical organizations in their own right, both R&D and Engineering.

Company policy at the time was to leave these businesses as independent subsidiaries, which ran their own business but shared cash and profit with the UK. At that time, a Group Technology Function existed and it combined those of all three firms. The US and German technology functions continued to report to the local CEO in US or Germany. There was a desire on the part of

those businesses to remain independent, but gradually a coordination system was implemented whereby the technical directors of these businesses met with the UK-based technical director. Discussions on how to work together occurred, "but there was no management at all, there was a consensus sort of thing. This arrangement led to some cooperation, but not a lot."[12] Cooperation was in terms of exchange of information on what was happening in the projects that each national unit carried out and there was an attempt to start trying to eliminate duplications.

> "There was, however, always a desire not to give up, rationalization was OK, provided the other guy continued his work, and we continued ours. In those days we were fighting: why should people cooperate and why should we rationalize." [13]

Roger Leverton started restructuring in the direction of increasing coordination at the beginning of the 1990s. Leverton's focus was on an organization that would contemplate three worldwide units, namely North America, Europe, and rest of the world, coordinated from the top of the group. In fact, in Europe work towards this direction went on in the Brussels office with the establishment of Pilkington Europe with Heads of automotive and building products, and automotive glass replacement. The automotive part was led by a German, automotive glass replacement by a Finn, and the building products from the UK. The move towards a European organization entailed more control of the German group.

Roger Leverton's efforts were directed especially to establishing *workshops and committees* as coordinating mechanisms. The new CEO also started a *company identity* exercise. A booklet was produced, rules were established on how to use the Pilkington brand and how to cope with the former companies' names. "This was basic, since we wanted to start using the Pilkington name."[14] The outcome was, however, very weak. In fact, it changed paperwork, since the regional businesses kept doing what they wanted to do. Towards the end of the 1990s, the Italian-born CEO Paolo Scaroni continued the centralizing efforts by means of creating *centralized functions, establishing common rules, and reviving the use of hierarchy.* The ensuing changes were especially dramatic in technology function. A decisive infusion of hierarchy, in fact, occurred when Dr. Wilkinson was appointed head of global functions and had direct line authority over the technical functions in Germany, Italy, US and UK so that technical people reported to him and not to the local managers. That persisted until 1999, when it was decided to maintain a global authority but to split global function into two, one for building products, and the other for automotive.

As the description of the decentralization and re-centralization process at Pilkington shows, the alternance hypothesis does contribute in interpreting the changes, especially the over-reaction – rather than the continuity – to the previous state of the system. These political structural shifts, however, took place through progressive and partial investments and divestments in different mechanisms. The system never returned to a previous configuration. In other terms, rather than oscillations between stable extremes, we observe alternance of arrangements around a moving average, or between moving extremes. The configuration of these moving alternatives can be understood, and even predicted, considering the possibility of combination among different mechanisms.

3.3. Story 3: The combinatorial organization

Both the contingency and the alternance perspectives shared the limitation of viewing organizational change as a substitution between alternative and mutually exclusive organizational packages, thereby underrating the practical and conceptual possibility of *combining* coordination

[12] Interview – Head of Group Technology – 3rd October 2001.
[13] Interview – Head of Group Technology – 3rd October 2001.
[14] Interview – Managing Director of Primary Products and President Building Products Europe – 2nd October 2001.

mechanisms of different types. The possibility and the superiority of combinatorial organization over the traditional alternative organizational archetypes constitute our third story. Coordination can be achieved through a portfolio of mechanisms. They include: prices and incentives, authority, rules; teaming and negotiating, and communities. Their conditions of applicability can be specified at the level of each single mechanism. These conditions cluster around two main factors: the level of uncertainty and information complexity and the potential for conflict among different interests (Grandori, 2001). The particular collection of activities and transactions defining a firm (i.e. its combinatorial capability profile – see Section 2) can be effectively managed by a particular collection or mix of coordination mechanisms. The uniqueness of the mix of resources and activities, as well as the mix of coordination mechanisms, contributes to the distinctiveness of the firm.

In the Pilkington case, the two stories discussed above produced only partial explanations of organizational evolution. A few questions remained unanswered. How did Pilkington manage to produce research? How did engineers discuss? How did knowledge circulate? There has been an increasing recognition of the role of *communities* as a crucially important coordination mechanism in innovation-oriented and technologically complex multinational corporations (Amin and Cohendet 2000). Therefore, we expect that even in periods of re-centralization, decentralized (participative, horizontal) knowledge communities survive. Our tentative answer was that knowledge was not governed either through transfer prices, or through hierarchy, procedures, or even committees. The organization produced different solutions, i.e. the knowledge community of engineers that acted as an invisible hand capable of governing knowledge that survived throughout and despite the heavy organizational restructuring. The persistence of a community of engineers was an important and effective shadow of the past. In addition, this coordination mechanism was compatible, even complementary, with both the decentralized and centralized formal structure regimes.

An important aspect of the Pilkington story is the step-by-step process that characterized the evolution of the firm's structure. Such slow and painstaking evolution puts great emphasis on the instrumental role of each of the solutions for the successive ones. Nevertheless, they suggest the hypothesis that some *shadow of the past* may be a positive and precious property of change processes rather than a resistance to be simply fought, as suggested by the following two quotes:

> "These changes were progressive, instrumental to each one, and necessary steps towards the integration of the technical function. Hypothetically, you could argue that you could go from one to another without going through the intermediary steps, but it would be extremely difficult. What happened was that people started working more closely together in the European structure, which then amalgamated with the American structure." [15]

> "The work of taking total control of the technology is an evolutionary step from the coordination. A coordinating body ought to run out of things to coordinate and understand. By the time there was an understanding of what the technical program was in Germany, the body with NSG continued because that was an arms-length relationship. In Roger Leverton's time, we started to see more effort applied from Pilkington technology centrally to examine in more detail and to control the programs that were still operated in the three centers. There were other smaller centers where work was being done; particularly some engineering development

[15] Interview– Retired Head of Technology – 9th October 2001.

> work was done in Finland. Throughout Leverton's era, Pilkington moved from co-ordination to more control." [16]

The committees that were introduced to understand, coordinate, and eventually rationalize the work of the different R&D units located worldwide constituted the basis for the shift from a decentralized to a centralized structure. In addition, the centralization of technology function created networks of practitioners focused on technological disciplines or particular subject areas. These networks, though located in different countries, constituted an informal organization that smoothed communication and exchange of technological know-how across countries as well as disciplines. It is worth noting that such a community-based mechanism maintained or, as some interviewees have argued, increased its relevance after the split of technology function that characterized the new organizational arrangement. In fact, the flow of technological information between the two business lines was maintained due to the existence of such a network and, even more important, the functioning of some important technical processes (e.g. concept design of float plants). A survey was conducted among engineers to analyze the functioning of this community.

The aim of the survey was to analyze and identify the type of approach to information and knowledge sharing that Pilkington adopted. The survey focused on the relevance of both informal and formal community-like knowledge sharing mechanisms. In particular, we attempted to understand the relevance of informal network relationships which developed over time among engineers and researchers which were important for knowledge sharing (i.e. going from mere information exchange to the transfer of solutions to complex engineering problems) in the face of the heavy organizational structure changes that the company experienced.

Table 1 reports on the average responses to the set of 13 questions reported in Appendix 1 (scores can vary from 1 to 5). A first glance at the data reported in Table 1 confirmed the hypothesis of the relevance of the *shadow of the past,* notwithstanding continuous changes in the organizational structure. Long-standing common experience for knowledge sharing was highly ranked by respondents (statement 11, score 4), and technical people, informally recognized as subject experts, constituted important nodes for information and knowledge on specific matters (statement 1, score 3). Respondents' comments on mechanisms for sharing knowledge between and within departments corroborated such results.

> "The Pilkington way of sharing knowledge is through key knowledge holders giving the information/solutions to those people who are willing to approach and talk to them. Resident experts are in each department, some more approachable than others and share their knowledge in verbal form only..."

Respondents also highlighted the importance of the informal character of such a network of relationships and the relevance of face-to-face communications in conjunction with the formal tools for exchanging knowledge.

> "The main method of sharing is the individual contact between members of the various laboratories. On critical occasions the interchange will be in formal meetings and, in some areas, during formal training sessions."

> "Web-based searchable databases for all main areas of knowledge.... structured electronic files...face-to-face information sharing is essential to support these electronic systems – particularly where location of individuals prevents informal contacts."

[16] Interview – Retired Head of Technology – 9th October 2001.

> "There is no report system through which we see lists of reports and can request copies...Most contact comes from a personal knowledge of who does what and the making of direct contact when assistance is needed."

> "Most sharing of knowledge, apart from Intranet databases, is through teams of people who know and respect each other's opinions."

Subject-matter experts identified by the top management are regarded as particularly important for researchers and engineers (statement 2, score 4). The relevance of people-to-people knowledge and information sharing is further confirmed by the survey responses. Statements 6, 7, and 8 on people acting as nodes through which information, know-how and experience is diffused at various levels of the organizational hierarchy, i.e. head of department, project manager, or project member, scored relatively high (4 throughout).

> "People working within related technology groups will discuss issues and developments with colleagues. Known experts or experienced personnel will be used to sound out ideas...."

The relevance of the *shadow of the past* for innovation was analyzed in relation to (a) respondents' experience measured as the number of years spent in the company and (b) respondents' age. With respect to the time spent in the company, results were comparable across the three periods identified. This result indicated that respondents' approach to knowledge sharing is irrespective of the time spent in the company. In addition, this might indicate that the presence of informal links of communication and information exchange, or more precisely *communities of practice*, worked (and probably also well) to the extent that people are 'easily' accepted and involved in such invisible organizations. Hence, we can argue that time spent in the organization did not heavily influence respondents' approaches to knowledge sharing.

[Table 1 about here]

A similar pattern of responses emerged when the age of respondents was taken into account. Scores provided by the three analyzed age classes were comparable. The alignment among the age classes further confirmed the relevance of informal yet long-standing network relationships among engineers and researchers. Younger engineers and researchers may be highly motivated to share information, knowledge, and experience mainly because they were supposedly the recipients of such experience. On the other hand, older engineers and researchers, which could be considered as 'owners' of information, knowledge, and experience, were probably in the position of coachers of such youngsters and therefore open to informally sharing knowledge. As mentioned above, the relevance of coaching young researchers and engineers and the importance of subject-matter experts as crucial trouble shooters and problem solvers in R&D activities and therefore as principal nodes through which information and know-how is exchanged, were confirmed by interviewees' comments.

According to these results, Pilkington has a coherent corporate culture, which has been successfully reproduced across generations. This culture explains to participants 'how things are done at Pilkington'.

4. Conclusion

The case study presented in this paper has illustrated the analytic advantages of viewing firm organization as a combinatorial artifact, a collection of resources and activities and of mechanisms governing them. The laws governing the change of these configurations are far less deterministic than usually assumed. In the light of the empirical evidence presented in this paper, some of the most popular variables seem to be even misleading guides to change, in particular, strategic and environmental contingencies, transaction cost reduction and technological relatedness. Nevertheless, these less deterministic 'laws' of organizational evolution should and can be specified. This can be achieved, we have proposed, by means of a shift from the prevalent contingency logic (the most frequently adopted solutions) to a logic of combinatorial possibilities (the chemistry specifying compatible and complementary combinations among elements).

It has been further discussed that organizational alternance captured important dimensions of organizational evolution in the firm studied, but, again, such an approach does not square with the observation that change was not a succession of mutually exclusive, discrete structural alternatives, but a selective retention of past arrangements (shadows of the past) in which new mechanisms are infused. The empirical evidence discussed in this paper supported the hypothesis that a relevant shadow of the past in Pilkington was the engineers' research community. Despite the profound changes that affected the company, engineers and researchers always relied on a community of peers to solve problems, test new ideas, and gather information for new product development. The case study then revealed the successful co-existence of decentralized, participative, horizontal types of coordination with both a decentralized, loosely coupled, even market-like structure and a hierarchical, rule-based structure.

The company took a variety of measures to sustain the internal knowledge community, albeit the latter was not seen as part of their structural arrangement - as the company's leaders rationalized the firm going from decentralization to centralization and from one stage of development to another. We contend that the combinatorial approach developed in this paper can contribute to expanding organizational structure and evolution and to maintaining those organizational traits which, otherwise, even if precious, might become extinct.

Table 1. Knowledge sharing scores (authors' elaboration on survey data, 1 = strongly disagree; 5 = strongly agree; see Appendix 2 for the full questionnaire)

Statement	Tot	Age			Experience		
		35	45	55	1980	1990	2000
1. Individuals and groups, informally recognized as 'experts' are extensively consulted by others on specific matters	4	4	4	4	4	4	4
2. Individuals and groups, formally recognized as 'expert' are consulted by others on specific matters	4	4	4	4	4	4	4
3. There are organizational roles dedicated to support the exchange and dissemination of knowledge (e.g. knowledge brokers, forum feeders, etc.)	3	2	2	3	3	2	2
4. There is a computerized system where people can contribute significant experience useful for the work of others	2	3	2	2	2	2	1
5. Individuals are rewarded (i.e. this is reflected in employees' appraisal) for sharing knowledge within and between departments and business lines	2	2	2	2	3	2	2
6. Heads of departments are important nodes through which information, experience, and know-how is exchanged	4	4	3	3	4	2	4
7. Project managers are important nodes through which information, experience, and know-how is exchanged	4	2	3	4	4	3	4
8. Project members are important nodes through which information, experience, and know-how is exchanged	4	4	3	4	4	3	4
9. There is an internal patenting system or other means for transferring codified know-how through 'selling' one's inventions	1	1	1	1	3	1	1
10. There are possibilities to form internal 'joint ventures' among people with different knowledge to generate innovations and become responsible (and rewarded) for the results	3	2	2	3	3	1	2
11. Individuals share common practices thanks to long-standing common experience rather than through explicit communication	3	3	4	3	3	3	4
12. In your work there is no need for extensive knowledge exchange or sharing with others (either through communication or other means, like common practice, routines, documents)	1	1	1	1	1	1	1
13. In your work there is no need for extensive communication (face-to-face or by other means) with others	1	1	1	1	1	1	1

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Appendix 1: Research Method

This single case study (Yin, 1994) draws on qualitative and quantitative data collected during a field study of organizational changes in Pilkington. Qualitative data were collected through research involving both primary and secondary sources. Primary sources included on-site interviews with company representatives and a survey questionnaire. Secondary sources of data included reviews of technical reports and publications, company annual reports and internal documentation (e.g. organizational charts), and company Internet web sites.

Interviews were semi-structured and lasted between sixty minutes and two-and-a-half hours (see Appendix 2 for a sample of questions used in the interviews). The aim of the interviews was to collect information on the organizational changes in Pilkington. Interviewees were all senior staff, such as Chief Executive Officer, Vice Presidents of Technology, President of the Business Line, and such like. Thirteen interviews were carried out in total. Hand-written notes were taken during the interviews in order to collect as much evidence as possible. These notes were written up soon after conducting the interviews. This technique enabled a preliminary scan of the interview data. Interviews were also taped and then transcribed. Interview transcriptions were used in conjunction with the hand-written notes to develop the case study. To validate our analysis, a draft of the paper was sent to a company representative, and the accuracy of the account was discussed in a supplementary face-to-face interview. The use of key informants helps strengthen the *construct validity* of the research (Yin, 1994).

The survey was developed by the authors and commented upon by the Director of Group Human Resources and Head of Technology. The survey was circulated among researchers and engineers in the Group Engineering and R&D units based at the Pilkington plant in Lathom, UK. These two units were chosen because they are the sources and main actors in the innovation process in Pilkington. While Group Engineering develops and installs new glass manufacturing plants, R&D is focused on the development of new glass products and its underlying process of production. The questionnaires were sent by the Director of Group Human Resources via email. 190 questionnaires were sent. 32 completed questionnaires were received. A first reminder was circulated by the Director of Group Human Resources and a further 20 completed questionnaires were received. A second reminder was circulated by one of the authors and a further 18 completed questionnaires were received. All 70 completed questionnaires but one were received via email.

The survey questionnaire contained structured open-ended questions (See Appendix 3 for the survey questionnaire circulated). Responses to the survey questionnaire were read and then grouped by questions to be used in conjunction with other data. The survey also contained structured closed-questions. Responses to these questions were entered manually in an Excel Spreadsheet. The data were then analyzed using the SPSS software package.

Respondents were asked to express their level of agreement on a 1-5 Likert scale in relation to the statements reported in question 1. Given the ordinal nature of the scale used, the mode was chosen among descriptive statistics to illustrate and synthesize results. The questionnaire included a section on respondents' biographical data, such as age, year of joining the company, business line, type of degree, and degree subject. This information was double checked with information provided by the Pilkington Group Human Resources Department to assess for any discrepancy. The year that individuals joined the company was used to measure experience. Three age classes were created, namely under 35, between 35 and 45, and over 55. Three classes of experience were created, people joining Pilkington before 1980, between 1980 and 1990, and from 1990 onwards. The influence of age and experience on information and knowledge exchange was also analyzed.

Appendix 2: Sample of questions used in the interviews

General information on the interviewee

Present position, previous positions
Role
Years with Pilkington
Background

Business unit analysis

What are the critical success factors of the business units (e.g. product branding, low cost, economies of scale, positioning to exploit locality, understanding customer needs)?
What are the challenges of the business units?
What are the opportunities of the business units?
Which are the influences of the parent company on the business units?

Management systems, structures, processes, and coordination mechanisms

What are the services provided centrally? Which resources are 'held' centrally (e.g. patents)?
Are the two business units independent profit centers? How are they controlled (budgeting and planning system)? How are they motivated? What is done centrally? What is delegated to the business unit's managers?
Is there a centrally-led program aimed at changing the actual role of the parent company in the management of the business units? If so, is there a team in place? Who is part of such a team? Who is responsible? Does it have a budget?
List of barriers/frictions and enablers for process change (e.g. culture, language barriers, 'old boys network').

Layers in the hierarchy, transfer-pricing system, capital approval system, other coordination, and linking mechanisms.
Do business units have common procedures/processes? If so, are they defined centrally? If not, is there a team (independent and centrally-appointed, or per function) whose aim is to create common procedures? Who is part of such a team? Who is responsible? Does it have a budget?
Are corporate/business procedures mainly routine-based (i.e. tacitly understood) or rule-based (i.e. is there a manual for each procedure, which is regularly updated)? Is there a trend towards more rule-based procedures?
Benefits of codification, risks.
List of barriers/frictions and enablers for process change (e.g. culture, language barriers, 'old boys network').

Technological issues (only for R&D and Group Engineering)

List of suppliers
List of collaborators (e.g. universities, research centers, competitors)
List of R&D programs carried out with collaborators
Maps of the process/product technologies.

Appendix 3: Knowledge-sharing questionnaire

1. Please assign 1 to 5 to indicate your level of *agreement/disagreement* with the following mechanisms as significantly applied in Pilkington as far as your job is concerned

Statements	Score (1=strongly disagree, 5=strongly agree)
1. Individuals and groups, informally recognized as 'experts', are extensively consulted by others on specific matters	① ② ③ ④ ⑤
2. Individuals and groups, formally recognized as 'expert', are consulted by others on specific matters	① ② ③ ④ ⑤
3. There are organizational roles dedicated to support the exchange and dissemination of knowledge (e.g. knowledge brokers, forum feeders, etc.)	① ② ③ ④ ⑤
4. There is a computerized system where people can contribute significant experiences useful for the work of others	① ② ③ ④ ⑤
5. Individuals are rewarded (i.e. this is reflected in employees' appraisal) for sharing knowledge within and between departments and business lines	① ② ③ ④ ⑤
6. Heads of departments are important nodes through which information, experience, and know-how is exchanged	① ② ③ ④ ⑤
7. Project managers are important nodes through which information, experience, and know-how is exchanged	① ② ③ ④ ⑤
8. Project members are important nodes through which information, experience, and know-how is exchanged	① ② ③ ④ ⑤
9. There is an internal patenting system or other means for transferring codified know-how through 'selling' one's inventions	① ② ③ ④ ⑤
10. There are possibilities for forming internal 'joint ventures' among people with different knowledge to generate innovations and become responsible (and rewarded) for the results	① ② ③ ④ ⑤
11. Individuals share common practices thanks to long-standing common experience rather than through explicit communication	① ② ③ ④ ⑤
12. In your work there is no need for extensive knowledge exchange or sharing with others (either through communication or other means, such as common practice, routines, documents)	① ② ③ ④ ⑤
13. In your work there is no need for extensive communication (face-to-face or by other means) with others	① ② ③ ④ ⑤