Via Po, 53 – 10124 Torino (Italy)
Tel. (+39) 011 6702704 - Fax (+39) 011 6702762
URL: http//www.de.unito.it

WORKING PAPER SERIES

TO USE OR TO SELL TECHNOLOGICAL KNOWLEDGE

Cristiano Antonelli

Dipartimento di Economia “S. Cognetti de Martiis”

Laboratorio di Economia dell’Innovazione “Franco Momigliano”

Working paper No. 05/2004

Università di Torino

TO USE OR TO SELL TECHNOLOGICAL KNOWLEDGE

CRISTIANO ANTONELLI
DIPRTIMENTO DI ECONOMIA
LABORATORIO DI ECONOMIA DELL'INNOVAZIONE FRANCO MOMIGLIANO
UNIVERSITA' DI TORINO

ABSTRACT

The analysis of the trade-off between to make and to buy is an essential tool of the theory of the firm. Much less attention has been paid to the analysis of the effects and determinants of the trade--off between to sell and to make. Transaction costs matter both on the demand and the supply side. Knowledge transaction costs on the supply side play a major role to make operational the notion of imperfect approprability. This approach applies to the economics of knowledge. Technological knowledge, in fact, can be conceived as an intermediary product which can be either sold in the markets for disembodied knowledge or used as an internal input for other products.

KEY-WORDS: GOVERNANCE- MODULARITY- TECHNOLOGICAL KNOWLEDGE

JEL CLASSICIFICATION CODE: D23 - O31 - O34

1. INTRODUCTION

The grafting of the recent advances of the theory of the firm into the economics of knowledge seems a promising field of investigation and cross-fertilization. The result can be relevant both for the economics of knowledge and for the theory of the firm itself.

Economics of governance has benefited from the resource based theory of the firm so as to include the analysis of: a) the accumulation of competence and knowledge, b) of introduction ad selection of technological and organizational innovations and c) their effects on the design of the portfolio of activities which are sorted to be respectively included within the firm and assigned to transactions in the market place. The dynamics of the firm is shaped by the dynamic interdependence among the accumulation of localized knowledge and competence respectively in coordination, transaction and production. The characteristics of the process of accumulation of competence, of the generation of technological knowledge and of the introduction of technological and organizational innovations, are key factors to understanding the firm. Parallel to knowledge, competence is a central ingredient. Competence is defined in terms of problem-solving capabilities and makes it possible for the firm not only to know-how, but also to know-where, to know-when, and to know what to produce, to sell, and to buy. Competence and knowledge apply to the full set of activities: production activities, transaction activities and coordination activities.

The fabric of the economics of governance however can be extended farther so as to include in its knitting the broader array of issues related to the alternative means of exploitation of technological knowledge.

The attention of governance economics has been traditionally concentrated upon the "make or buy" alternative. More and more attention is now being paid to the symmetric and yet complementary issue of the "use or sell" alternative. The "use or sell" alternative requires the assessment of the relative costs of using the markets to sell a product with respect to the costs of using that product in a further stage and eventually sell it, embodied in a more elaborated product. The inclusion/exclusion choice concerns whether to sell the output at a given stage of the production process or to use it to make another product. The firm is seen here as an intermediary between production stages coordinated by the market place (Spulber, 1999).

The "use or sell" trade-off applies to a wide range of industries where the general production process is broken down into production units characterized by high levels of specialization and technical indivisibility. The selective internalization of modules highlights the choice between the direct sale of the goods of a given module into the intermediary markets or the use of its products to feeding further sequential manufacturing modules. On a similar ground the extensive growth of the service economy and the decline of the manufacturing industry at large, seems characterized by the intensive externalization of knowledge intensive business services. Again firms decide whether to sell their knowledge as a service or embody it into goods, through internalized manufacturing activities.

The "use or sell" choice seems most relevant from the viewpoint of the integration of the transaction costs economics and the resource based theory of the firm into the broader context of the economics of governance in general. This approach becomes extremely fertile, for its analytical and normative implications, when attention is paid to technological knowledge, as a good which can be either sold as such in the markets for technology or used as an intermediary internal input.

The rest of the paper is organized as follows. Section 2 explores the context of this trade-off in the analysis of modularity in manufacturing. Section 3 provides an assessment of the 'use or sell' trade-off to the governance of technological knowledge. On this basis a model is developed in section 4. The implications for knowledge exploitation strategies are considered in section 5.The conclusions summarize the results of the analysis and put it in perspective.

2. SUPPLY SIDE TRANSACTION COSTS

Modularity is swarming into economics and the economy. The architecture of the production process is more and more articulated in an array of modules of quasi-

indivisible production units. Modularity is the result of the intensive and systematic break down of complex production processes into self-contained production units where technical indivisibility is stretched to minimum levels (Baldwin and Clark, 2000).

The governance of the transactions between modules is more and more complex. Modules can be included within corporations or excluded, according to the economics of governance as dictated by the assessment of the costs of using both the inputs and products markets with respect to the costs of internal coordination. The coordination of the supply and the demand for the products of the modules can be either left to the market place or provided by means of bureaucratic organization within the firm.

This process is well documented in many industries. In the automobile industry as well as in most engineering industries, the traditional vertical integration has been supplanted by a variety of interdependent players which contribute the general production process with their specialized services and products. The general production process leading to automobiles, as well as appliances and machinery, has been broken down into a variety of complementary modules of specialized units, which sell and buy in the market place their components and their products. The inclusion and exclusion of these units may take place at different stages of the general production process and it is frequently re-assessed (Bonazzi and Antonelli, 2003).

Traditional industries, such as textiles, garment and generally the fashion industries have a long-standing tradition of modularized production processes. The stages of the production process have been multiplied and assigned to modules of specialized production already for many years now. Their relations take place either in the market place or by means of the bureaucratic coordination operated by the management of corporations. The evidence shows that the inclusion and exclusion of the modules in these industries is no longer organized along the sequential lines of the general production process but rather according to systematic evaluation of the incentives to buy or make and to make or sell. The design of the structure of each company gets closer and closer to a flexible jigsaw where each element enters and exits the company. The correspondence between the structure of the corporation and the lay out of the general production process leading to the final products purchased by households is more and more fuzzy.

The communication industry provides excellent evidence on these processes. Following Fransman (2002), in the communication industry, six layers of specialized activity can be identified: equipment and software; networks; connectivity; navigation and middleware; applications, contents packaging. The actual specialization of firms into each layer depends upon a variety of factors. The levels of transaction costs in each market differ widely as well as barriers to entry and levels of mark-ups. Sunk costs characterize in different way each firm. The dynamics of the

institutional factors affecting the definition of the property rights such as the forms and levels of mandatory interconnection and the evolution of de-facto and de-jure standards plays a major role. The borders of the firms with respect to the layers vary according to their own specific and idiosyncratic characteristics. In the communication industries a great variety of firms can be found with respect to the mix of layers into which they are active. Fully vertically integrated firms coexist next to others, fully specialized in just one layer. Many firms select specific combinations of layers and they systematically operate in the intermediary markets either as sellers and/or buyers (Krafft, 2003).

In this context the characteristics of intermediary markets play a key role. The product of each module is sold and bought in markets that are far away from the final consumers. In intermediary markets customers are firms. The same firms are also sellers. Often the same firm is at the same time a customer and a supplier. Because of modularity and inclusion/exclusion practices, intermediary markets are more and more thick with an increasing number of players on both the demand and the supply side. The relative efficiency of intermediary markets both from an informational viewpoint and a competitive one plays now a key role in the design of the portfolio of activities that are retained within the companies. The firm considers whether to make or buy a specific component or stage of the production process, and also whether to sell the products of each module in the intermediary markets or to use the output of the same module as an intermediary input for the following production process and eventually deliver the product to the final markets where households are the customers (Teubal, Yinnon, and Zuscovitch, 1991).

The appreciation of the effects of inclusion and exclusion is based on the efficiency of the production process and the relative efficiency of the coordination and transaction activities. Such transaction activities must be considered not only on the demand side, as in the “make or buy” tradition, but also but also on the supply side.

Transaction costs on the supply side include an array of resource-consuming activities. The actual sale of a product requires appropriate levels of marketing, advertising, credit assessment, post-sale assistance. Customization and versioning costs can be assigned to transaction costs on the supply side when monopolistic competition prevails and the entry in a market requires that dedicated investments be made in order to identify and implement a niche of loyal customers.

Markets differ widely in terms of the quality of information available on the products and the dispersion of prices, the characteristics of users and customers. The distribution of information among vendors as well as among customers has varying levels of asymmetry. Markets differ widely also in terms of their conditions of competition. Market power can be found with varying levels of intensity, either on the supply or on the demand side. These differences matter when a firm is

considering whether to sell a product or use it as an intermediary input for the production of another downstream good.

When transaction costs, on the demand side, are high, coordination costs are lower, and the market price for the product is higher than the internal production costs, the firm decides to make a component instead of buying it. Upward integration in the general production process takes place. A new module is added to the portfolio of activities retained within the borders of the firm and the coordination between the production of the upstream module and the production process of the downstream module is provided internally by bureaucratic structures. The firm is not a customer in the market for that intermediary input. The firm instead enters the market for that input, on the demand side, when it chooses to buy. Here the supply of the product is provided by third parties and the coordination takes place externally in the market.

Symmetrically, in the "use or sell" approach the firm needs to assess whether to enter the market for each component or intermediary product or to use each product as a component of a downstream product. The role of transaction costs on the supply side becomes evident. When the costs of using upstream markets is high and in any case much higher than the cost of using the markets for downstream products, the firm has a clear incentive to integrate downstream and enter the market in next stage of the production process.

More specifically it is clear that the firm confronts the costs of using the market upstream, with the costs of using downstream markets, after discounting the costs of the internal coordination between the two stages of the production process, and the direct manufacturing costs of the second stage of the production process. In other words it is clear that the firm has an incentive to integrate downstream when the net revenue of the sale in the upstream markets is lower than that stemming from the entry in the downstream markets. The case is interesting when such difference is determined primarily by lower transaction costs.

It is now clear that the firm can decide whether to integrate and diversify downward, as well as upward selectively. The firm can also make the choice to sell and eventually to buy again at a later stage of the production process. Here the firm selects the stages of complex and interdependent production processes, which can be internalized, and the stages to externalize, but retains the control of the overall production process articulated in sequential steps. The market and the organization become interdependent. The firm can be at the same time a vendor of a product and a buyer at a later stage of the same chain of complementary and interdependent modules. The firm can buy back the full amount of the goods produced with her own original inputs or only a part. The borders between the firm and the markets become more and more flexible and subject to continual redefinition.

The choice between make or sell and make or buy, moreover, is most frequently partial, rather than exclusive. Firms decide whether to sell in the intermediary markets varying shares of the production of upstream production modules. They rarely swing from the sale of the full output to its full inclusion. For the same token firms rely upon intermediary markets for the provision of varying shares of the intermediary inputs that are necessary for subsequent production stages: some production is retained within the borders of the firm.

In this broader economics of governance context, transaction costs are defined as the costs of using the markets on both the supply and the demand side. The firm uses the markets also to sell its products not only to buy the intermediary inputs to manufacture its products.

In the governance economics context of analysis a new area of analysis emerges, one where the governance choice concerns also the markets for outputs, rather than the sole markets for inputs. The firm in fact considers not only the possibility to make or buy a specific component or stage of the production process, but also whether to sell its products in the intermediary markets or to the final ones. Needless to say the stages of the intermediary markets where to sell are also a matter of choice and assessment. The firm can decide whether to integrate and diversify downward, as well as upward. In this context the firm can also make the choice to sell and eventually to buy again at a later stage of the production process. Here the firm selects the stages of complex and interdependent production processes, which can be internalized, and the stages to externalize, but retains the control of the overall production process articulated in sequential steps. The market and the organization become interdependent. The firm can be at the same time the vendor of a product and the buyer at a later stage. The firm can buy back the full amount of the goods produced with her own original inputs or only a part. The borders between the firm and the markets become more and more flexible and subject to continual redefinition.

3. A NEW KNOWLEDGE TRADE-OFF: TO USE OR TO SELL

3.1. THE RATIONALE

The analysis developed so far has important applications to understanding the conduct of the innovative firm and more broadly the economics of knowledge governance. The stock of proprietary technological knowledge accumulated within each firm and the competence built by means of learning processes and formal research and development activities can be considered an output per se, rather than exclusively and necessarily an input for the subsequent production of goods and services in the markets for technological knowledge.

In this context the analysis of the factors affecting the choice between to sell or to make use of the knowledge as input, makes sense. Specifically firms implement not

only knowledge exploration strategies, but also knowledge exploitation strategies. This means that firms need to assess not only whether to produce internally all the knowledge that is necessary for the introduction of new technology or purchase it in the markets for external knowledge, but also whether to sell the knowledge in the markets for knowledge or to use it to make other products.

The use of the market place to exchange technological knowledge is more and more common. Technological knowledge can be fully generated internally or partly purchased in the markets for knowledge: external knowledge can be an intermediary input for the production of other knowledge[1].

Markets for technological knowledge are spreading in the economic systems. The use of the market place to exchange technological knowledge is more and more common. Technological knowledge can be sold with varying levels of embodiment into other goods and services. Technological knowledge can be sold as an intangible good, more or less associated with other services such as the assistance of the vendors to the customers. Technological knowledge can be sold as a service, knowledge-intensive-business-service. Technological knowledge can be sold incorporated in weightless products such as software. Technological knowledge can be sold embodied at an early stage of a broader production process, or embodied in products that are manufactured at other stages farther down in the general production process within the same filiere or across different filieres leading to the products actually purchased by the final consumer: the household (Arora, Fosfuri, and Gambardella, 2001; Guilhon, 2001).

The case of numerical control provides the full range of cases. The technology of numerical control can be sold as a patent or a license. It can be sold embodied in software, in the numerical control itself or finally it can be embodied in a machine tool with numerical control. The machine tool in turn can be sold as such or it can be used as a capital good in the production of car and trucks. The engineering industries and specifically the packaging and textile machinery industry provide similar evidence. Each of these industries differ widely in terms of transaction costs on the supply side.

The chemical industry is characterized by similar trend with the identification of companies specialized in the supply of the design for chemical plants, as well as by companies that coordinate internally the competence in the design and the deliver of the plants. Finally important companies in the chemical industries operate the full 'filiere' of activities from the design of the plants, to their construction to the use for the deliver of chemical products to the markets.

[1] See Antonelli, Marchionatti and Usai (2003) for an analysis of the international markets for technology and an empirical estimate of the role of external knowledge.

In the resource-based theory of the firm, the generation of technological knowledge is regarded as the distinctive feature of the firm. The firm does not coincide with the production function and cannot be reduced to a production function because its essential role is the accumulation of competence, technological and organizational knowledge and the eventual introduction of technological and organizational innovations. From this viewpoint the firm precedes the production function: the technology is in fact the result of the accumulation of knowledge and its application to a specific economic activity. Technological knowledge can be considered the primary output of the firm or in turn an intermediary input. The choice whether to sell it or to use and make with it a new product, is especially relevant. This approach contributes the economics of knowledge governance (Penrose, 1959; Foss, 1997).

The analysis of the "make use or sell" trade-off makes clear that the knowledge exploitation strategies of the firm will be influenced, for given levels of relative revenues in either markets, by the relative levels of transaction costs on the supply side in the upstream markets for knowledge as a product per se, compared with the costs of coordinating internally the application of the knowledge to the production of a new good, the costs of the sheer production and the costs of using the downstream markets to sell the products.

3.2. KNOWLEDGE TRANSACTION COSTS

The governance approach elaborated by Oliver Williamson can be successfully applied to the analysis of knowledge generation and dissemination. The characteristics of knowledge and the details of its generation and dissemination process can be appreciated from the view point of the economics of governance especially when the basic ingredients of the resource based theory of the firm are taken into account and properly integrated into a single interpretative frame (Coase, 1937; Williamson, 1975, 1985, 1996; Penrose, 1959; Foss, 1997).

This range of choices in terms of governance and the borders of the corporation, as a learning agent, can be analyzed and understood with respect to the characteristics of the processes of knowledge generation and usage. Different viable governance mechanisms and governance choices emerge according to the characteristics of technological knowledge and to the related levels of knowledge transaction costs. The integration of the transaction costs approach with the resource based theory of the firm shows that firms select inclusion and exclusion not only with respect to the static assessment of coordination, transaction and production costs for a given product and a given item of technological knowledge, but also and mainly with respect to the technological opportunities that are associated with the future learning processes (Antonelli, 2001; Antonelli and Quèrè, 2002; Antonelli, 2003 and 2003a).

In this context the distinctive notions of knowledge transactions and interactions costs can be identified and defined in terms of the costs of all the activities that are necessary to exchange bits of knowledge among independent parties. Two important distinctions must be introduced here. The first concern the distinction between knowledge transaction costs on the demand side and knowledge transaction costs on the supply side.

Knowledge transaction costs on the supply side define all the costs that agents bear to use the markets for knowledge as a product per se[2]. Knowledge transaction costs on the supply side consist primarily of all the exploitation activities that are necessary to make sure that proprietary knowledge does not leak out depriving the legitimate holder of part of, if not the whole revenue. Knowledge transaction costs on the supply side can also be quantified by the sum of the costs of the activities that are carried on to prevent disclosure and to secure the possession of proprietary knowledge plus the missing portions of revenue stemming from unintentional disclosure and the following leakage. Next to the problems determined by imperfect appropriability, the costs of using the markets for knowledge include more traditional activities such as marketing, advertising, technical assistance and in general al the activities that are necessary to identify perspective customers and to strike appropriate contract with them.

The provision of technical assistance to the users of the technological knowledge is at the same time a cause of considerable costs and an effective mechanism to prevent uncontrolled leakage, opportunistic behavior of users. Technical assistance is the base on which to implement pricing strategies that take into account the effective amount of economic benefits stemming from the downstream use of the knowledge.

The second distinction is between static knowledge transaction costs and dynamic knowledge transaction costs. Static transaction costs are defined by the costs of using the markets to trade knowledge at each point in time and with no understanding of the stream of long term consequences engendered by the use of the markets. Dynamic transaction and coordination costs are defined in terms of opportunity costs of the governance of the stock of knowledge with respect to the stream of generation of new knowledge. Inclusion now yield the opportunity to appropriate the eventual benefits stemming from the accumulation of knowledge in terms of higher opportunities for the introduction of additional units of knowledge. Exclusion and transaction instead

[2] In this context is seems appropriate to note that knowledge transaction costs on the demand side define all the costs associated with the exploration activities in the markets for disembodied knowledge such as search, screening, processing, contracting. Knowledge exploration strategies take into account knowledge transaction costs on the demand side in the context of the choice between ‘make’ internal knowledge or ‘buy’ external one. As it is well known the assessment of the actual quality of the knowledge can be difficult when the vendor bears the risks of opportunistic behavior and dangerous disclosure. A close interaction takes place between knowledge transaction costs on the demand side and knowledge transaction costs on the supply side.

yields new costs in terms of the missing opportunities to benefit from the cumulative learning processes associated with the production process itself.

Dynamic knowledge transaction costs are relevant both on the demand and the supply side. On the demand side, search and screening costs include the resources to evaluate the scope for incremental advance on the supply side; dynamic knowledge transaction costs arise mainly because of the high risks of opportunistic behavior of the customers with respect to derivative knowledge. When derivative knowledge matters, the vendor of the knowledge bears the risks of non-appropriation of the results of the scope of implementation of the knowledge, which has been sold. Uncontrolled appropriation of the stream of rents associated to use of the stock of proprietary knowledge, by means of small incremental research costs, can take place with evident damages for the vendor (Scotchmer, 1996).

The working of the markets for knowledge is greatly favored by the extent to which patents and copyrights can be enforced in the market place and licensing is an effective tool to trade specific items of knowledge and competence. The enforcement of the markets for patents is a primary condition for the reduction of knowledge transaction costs and hence the creation of markets for knowledge. The role of the judiciary system in this context is extremely important.

When the markets for knowledge are available, the selection of knowledge activities that firms retain within their borders is much wider. The exploration for external sources of knowledge and knowledge outsourcing becomes common practice. Firms can rely on external providers for specific bits of complementary knowledge. Knowledge outsourcing on the demand side matches the supply of specialized knowledge intensive business service firms. Universities and other public research centers can complement their top-down research activities finalized to the production of scientific knowledge with the provision of elements of technological knowledge to business firms. The exploitation of the knowledge generated as well can take a variety of forms: firms can use it to produce a new product or sell it as a product per se.

Following the resource-based theory of the firm, the corporation is a resource pool designed and managed so as to implement the opportunities for the accumulation of both new technological and organizational knowledge. The rates of technological and organizational learning influence each other in shaping the dynamics of the firm and the evolving composition of the collection of activities that are retained within its borders and ultimately its growth (Chandler, Hagstrom, and Solvell, 1999; Teece, 2000; Antonelli, 2004a).

The borders of the firm and the choices of inclusion and exclusion of different activities are based upon the balance of production, coordination[3] and transaction costs. Such costs concern each specific activity. The governance of technological knowledge is deeply affected by the comparative assessment of the costs of making, buying and selling each component of the knowledge that is required. With low coordination costs and high transaction costs in upstream market the firm has a clear incentive to make internally all the knowledge that is necessary. Conversely, with low coordination costs and high transaction costs in downstream markets, the firm has a strong incentive to use the knowledge and apply it to manufacturing products and eventually sell them. Coordination costs apply both the specific activities that are required to generate new knowledge and to the production processes that are necessary in order to use the knowledge generated. When transaction costs are low and coordination costs high, on the opposite, the firm has a strong incentive to act as a knowledge intensive business service provider. It will acquire the bits of knowledge in the markets for knowledge, add its specific competence, and sell it as a disembodied piece of knowledge, a product per se[4] (Holmstrom,1989).

In the context of analysis of the governance of knowledge a new area of analysis emerges, one where the governance choice concerns also the markets for outputs, rather than the sole markets for inputs. The firm, in fact, considers not only the possibility to make or buy a specific component or stage of the production process, but also whether to sell its products in the intermediary markets or to the final ones. Needless to say the stages of the intermediary markets where to sell are also a matter of choice and assessment. The firm can decide whether to integrate and diversify downward, as well as upward. In this context the firm can also make the choice to sell and eventually to buy again at a later stage of the production process. Here the firm selects the stages of complex and interdependent production processes, which can be internalized, and the stages to externalize, but retains the control of the overall production process articulated in sequential steps. The market and the organization become interdependent. The firm can be at the same time the vendor of a product and the buyer at a later stage. The firm can buy back the full amount of the goods produced with her own original inputs or only a part. The borders between the firm and the markets become more and more flexible and subject to continual redefinition. The firm is more and more a system integrator, able to combine the subsystems that are included and those that are delivered by third parties (Antonelli, 2004a; Bonazzi and Antonelli, 2003).

As a matter of fact, the failure of markets as the appropriate governance mechanisms for the organization of the generation and circulation of knowledge does not necessarily lead to undersupply but rather pushes the knowledge-creating firm to use it as an intermediary input for the sequential production of economic goods.

[3] Coordination costs include here agency costs.

[4] In this context all assessment is a comparative one. Upstream transaction costs are assessed in relative terms with respect to the sum of internal coordination costs, production costs and transaction costs in downstream markets.

Downstream vertical integration is the remedy to the problems raised by the non-appropriability and low tradability of knowledge as an economic good.

Poor appropriabilty of proprietary technological knowledge can be considered a specific cause of knowledge transaction costs on the supply side. When knowledge appropriability is reduced to nihil, firms will integrate downstream. On the opposite, when knowledge appropriability is high, firms will specialize in the production of knowledge and will rely on the market place as an appropriate mechanism for its economic exploitation. With imperfect knowledge appropriability firms will select the markets where proprietary knowledge can be sold. In other contexts firms will exploit their proprietary knowledge by means of vertical integration.

This result is important as it contrasts the traditional argument about the failure of markets, as a coordination system, in the allocation of resources to the production of knowledge because of the lack of incentives stemming from low appropriability and the related 'knowledge as a public good' tradition of analysis (Antonelli, 2004). The generation of appropriate quantities of knowledge can be stimulated by the opportunities in the markets for the products that are manufactured and delivered by means of the technological knowledge they embody.

The analysis developed so far has important applications to understanding the conduct of the innovative firm when the stock of technological knowledge accumulated within each firm and the competence built by means of learning processes and formal research and development activities is considered an output per se, rather than an input for the subsequent production of goods and services in the markets for technological knowledge. Now the choice between to make or to buy is integrated by the choice between to sell or to make. Specifically firms assess both whether to produce internally all the knowledge that is necessary for the introduction of new technology or purchase it in the markets for external knowledge, and whether to sell the knowledge in the markets for knowledge or to use it to make other products.

3.3. A SIMPLE MODEL

At any point in time, the firm needs to assess whether to sell the stock of proprietary knowledge or to use it as an intermediary input for sequential stages. . The levels of profitability attained with inclusion are compared with the profitability stemming from exclusion. The inclusion of a sequential step into the complex production process that takes place within the borders of the firm and hence the choice to make instead of selling, depends upon a number of factors. Three classes of factors can be identified: the quality of the markets from an informational and competitive viewpoint, the relative efficiency of the internal stage with respect to that performed

by third parties, the implications for the process of accumulation of technological knowledge.

The sale of a knowledge product is a resource consuming activity. In intermediary markets the number of potential customers is small and market power on the demand side is often found. The markets for intermediary knowledge products are often global with a scattered geographical distribution. Customers need to be identified and convinced about the quality of the knowledge product sold: dedicated marketing activities need to be carried on. Full disclosure cannot take place and yet perspective customers need to be convinced about the actual technological advance made possible in their specific context of application. The risks of opportunistic behavior of customers and perspective customers are high and the vendors need to secure, as much as possible, the actual possession of their proprietary knowledge. Knowledge transaction costs on the supply side consist mainly in long term technical assistance. Technical assistance, as a matter of fact, makes it possible to implement appropriate strategies to hold the risks of derivative knowledge: both parties in fact have access to the stream of incremental knowledge made possible by the enrichment of the proprietary knowledge that has been the object of the transaction. This is the case especially when high levels of cumulability characterize knowledge

Price and revenue elasticity differ widely across markets as well as the sensitivity of users to advertising expenditures. The distribution of customers in geographical space and in the spaces of product characteristics is not necessarily homogenous even within the same 'filiere'. Customization plays a relevant role and the packaging of the details of the products is not a trivial activity. Major resources are necessary to apply the knowledge to the specific characteristics of the production process of perspective users. The efforts that are necessary to write the contracts are major for the complexity of timing, quality, and quantity contingencies (Hart, 1995).

Intangible sunken assets play a major role in this context. The firm may enjoy advantages of a reputation in downstream markets, which is not easy to extend upstream, and viceversa. For the same token, distribution channels and competence accumulated in dealing with some classes of buyers cannot be easily transferred to other upstream or downstream markets. The dedicated competence of the firm in dealing with the markets plays a major role and its spectrum of application is limited. The competence of an organization in dealing with the markets in selling a product cannot be easily transferred and applied to selling other products.

When upstream markets are less transparent and opportunistic behavior is more rooted in the business practice than in downstream markets, transaction costs are higher and hence firms will be induced to use the products of the upstream module rather than to sell them. When upstream markets are less competitive than downstream ones and hence price-costs margins are higher instead firms have a clear incentive to sell rather than to make.

The firm has a strong incentive to compare both the relative amounts of resources that are necessary to produce and to sell the product in a market with respect to another sequential one and the relative revenue of the sale downstream and upstream.

Upon this basis a simple model can be set forth.

The revenue function is defined as the revenue obtained by the firm by the sale of its products. Two revenue functions (R) can be identified respectively for the proprietary knowledge K and the product Z, which embodies the proprietary knowledge. The revenue functions for the proprietary knowledge PK (RK) and Z respectively (RZ) are equal to the standard product of prices and quantities (PK QK) and (PZ* QZ):

(1) RK = PK QK
(2) RZ = PZ QZ

Equation (1) and (2) provide the basic ingredients to build a map of isorevenues. Their slope is measured by the ratio of the unit revenue of the proprietary knowledge PK sold as a product with respect to the unit revenue of the good Z (PZ/PK). The map of isorevenues in turn provides the constraint to the to make or to sell decision-making.

The firm will decide whether to sell directly the proprietary knowledge K or to use it as an intermediary input for the sequential production of the good Z, also according to their comprehensive production costs.

The firm is represented as the set of activities that are necessary to produce and deliver the proprietary knowledge K and the product Z. It includes the strict manufacturing process as well as the organization activities necessary to coordinate the internal exchanges between the research and the production functions and to use the downstream markets. In the case of the specialized production of proprietary knowledge, no coordination activity is necessary: here all the production is contained within with the single module specialized in research activities. The activities that are necessary to use the market to sell the proprietary knowledge K must be considered.

The organizational inputs, that are necessary to use the markets on the supply and the demand side and to coordinate the exchanges between modules within the firm, are they the product of well identified activities with inputs, outputs and specific levels of efficiency. This confirms that the firm is a set of activities, which goes beyond the production functions of the modules. Formally we have then the activities that are necessary to use the markets for knowledge on the supply side (TRSK); the activities that are necessary to use the markets for the products Z on the supply side (TRSZ) and the activities that are necessary to coordinate internally the applications of the proprietary knowledge K to the production of the good Z. Hence:

(3) TRSK = a (I) H(QK)

here the supply transaction dedicated activities necessary for the sale of the proprietary knowledge (K) are the result of appropriate inputs (I) and specific efficiency levels (a) with a fixed coefficient H.

(4) TRSZ = b (I) W(QZ)

where the transaction dedicated inputs necessary for the sale of the quantities of the product Z (QZ) are the result of appropriate inputs (I) and specific efficiency levels (b) with a fixed coefficient W.

(5) CO = c (I) T(QK)

where the dedicated inputs necessary for the coordination of the production of proprietary knowledge K and the product Z are the result of appropriate inputs (I) and specific efficiency levels (b) with a fixed coefficient T.

The production and sale of the proprietary knowledge K requires the combination of research and development activities and transaction cost activities on the supply side to operate in the markets for knowledge. Formally we have:

(6)K = (R&D +TRSK)

where R&D measures the unit of inputs specialized in research and development activities, and TRSK measures the units of inputs that are necessary to use the market to sell the proprietary knowledge K as a good per se.

In the case of the product Z the resources that are necessary to perform the coordination between the modules K and Z are taken into account together with the inputs into the production function of the module Z and the resources that are necessary to use the markets on the supply side. Formally

(7) Z = (R&D + PRO +TRSZ + CO)

where PRO measures the units if inputs that are necessary to manufacture the good Z, TRSZ, the units of inputs that are necessary to use downstream markets for the product Z, (CO) measures the activities that are necessary to coordinate internally the exchanges between the module R&D and the module Z.

The total cost equation is determined by the unit costs of all the inputs:

(8) TC = r(R&D) + e(PRO) + f (I)

where, as usually, r stands for the unit costs of R&D activities (R&D), e for the unit manufacturing costs of the product Z and f measures the unit costs of the organizational resources (I).

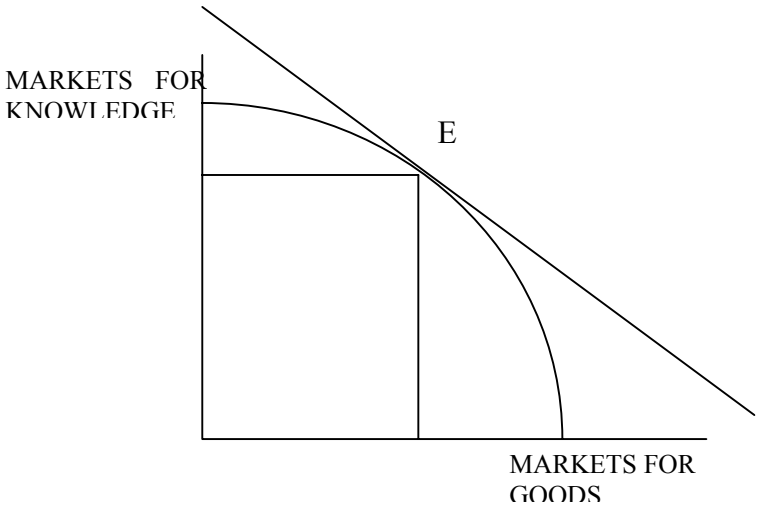
The combination of the two sets of activities yields the transformation curve:

(9) $K = f(Z)$

According to standard optimization procedures, the equilibrium conditions are easily found where the slope of the isorevenue equals the slope of the transformation curve:

(10) $f'(Z) = PZ / PK$

INSERT DIAGRAM 1 ABOUT HERE: THE FRONTIER OF POSSIBLE MARKETS



The shape of the transformation curve reflects the relative convenience of the supply conditions in the two alternative markets. The slope of the isorevenue reflects the relative prices of the two products in their respective markets. The equilibrium point found in the tangency of the relevant isorevenue and transformation curve identifies the best mix of make-use and sells for the profit-maximizing firm.

The decision whether to sell or to make use of the proprietary knowledge is now framed into an analytical context where many variables matter: the relative prices of the goods delivered to the market place, the relative efficiency of production in the modules, the relative efficiency of the two transaction activities on the output markets, the efficiency of the internal coordination activities. Let us consider them in turn.

The effects of transaction costs on the supply side are now fully accounted for. It is clear that, when transaction costs on the supply side, in the upstream markets are too high, firms prefer to make-and-use rather than to sell. On the opposite, efficient and transparent upstream markets favor specialization. When the markets for intermediary products do not exist, transaction costs are very high both on the supply and the demand side. The prices of the proprietary knowledge PK can incorporate a relevant portion of transaction costs on the supply side. Prices are too low, well below marginal costs, when for instance appropriability is low and uncontrolled leakage takes place beyond all possible efforts of vendors to retain some control on the knowledge. The case for loss of profits (lucrum cessans) due to imperfect inappropriability can be registered on this side of the equation as well, when it occurs even after that all possible measures have been taken by the holders of proprietary knowledge, and relative transaction costs on the supply side have been registered on the cost side.

The degree of relative competitiveness of upstream and downstream markets respectively matters. If in upstream markets barriers to entry are high and large mark-ups prevail, while the downstream product market is closer to perfect competition, the firm operating the module R&D has a strong incentive to sell rather than make. Conversely if higher price-cost margins are founds in downstream markets will not sell, but rather make.

When the upstream activity is shaped by technologies, which cannot be easily imitated, the sale of both products, upstream and downstream, can affect the competitive conditions of the markets. Here the firm will choose whether to be a monopolist upstream or downstream according to the differences in the revenue and price elasticity of the demand. The rates of imitative entry downstream can play a role in non-myopic decision-making. The equilibrium conditions can easily identify the convenience for the firm to either sell or use to manufacture and sell downstream products. This result is consistent with much empirical evidence and confirms the heuristic strength of the analytical framework elaborated.

The efficiency of the internal coordination of the production of the modules K and Z has a direct bearing on the make-use or sell trade-off. Firms may be forced to sell their proprietary knowledge simply because internal coordination is too expensive. This in turn may depend on the size of the firm. The slope of the curve of coordination costs may become steeper and stepper with the general size of the firm. Large firms may be obliged by coordination costs to be very selective with respect to the make-use option and sell their proprietary knowledge or simply let it 'spilling in the air'. While smaller firm may prefer, coeteris paribus, to make-use of their proprietary knowledge and integrate downstream.

Production costs exert similar effects, coeteris paribus the conditions of the markets from the view point of their informational efficiency, firms are induced to make-use or sell by the slope of production costs, and specifically by the levels of their production costs with respect to those of downstream competitors. Entry in downstream markets may be foreclosed by sharp differences in production costs that favor downstream incumbents. The sale of proprietary knowledge remains the single possibility to exploit it.

4.IMPLICATIONS FOR KNOWLEDGE EXPLOITATION STRATEGIES

The implications of the analysis on knowledge transaction costs on the supply side and vertical integration, as a remedy to imperfect knowledge appropriability, are most important for understanding knowledge exploitation strategies.

When an individual generates new technological knowledge, downstream vertical integration takes the form of entrepreneurship. Individual inventors face the clear alternative of either selling their proprietary knowledge as a product per se or using it as an intermediary input. To do so, however, the inventor needs to create a new firm. Firm natality, hence, can be seen as the direct consequence of a flow of new technological knowledge modules, which cannot be sold as products per se. Actually the creation of a corporation can be the indirect form of the trade of the technological knowledge. An incumbent corporation in fact can eventually acquire the new company. The inventor in this case sells the property rights on the company, rather than the intellectual property rights. Here there is a direct relationship between patents and shares, and the markets for knowledge and the financial markets.

When the inventor is an incumbent corporation, already existing and active at least in a given product market, knowledge exploitation strategies lead to the growth of the firm. The application of the technological knowledge to the current activities of the firms is expected to have positive effects in terms of performance and ultimately profitability. In turn the growth can be internal or external. Takeovers, mergers and acquisitions can be seen as the direct consequence of the internal use of new

technological knowledge by the firm. The acquisition of new firms makes it possible to extend the scope of application of the new knowledge and hence the range of its exploitation. Such growth can take place within the same product market or in adjacent ones. When technological knowledge applies to products that differ from the current ones, diversification, vertical integration and multinational growth can be seen as remedies to the imperfect appropriability of proprietary technological knowledge. The coherence in the growth strategies can be found with respect to the characteristics of the new technological knowledge rather than with respect to the portfolio of current activities.

Strategies of internal exploitation, by means of downstream vertical integration, and strategies of external exploitation by means of the sale of the technological knowledge as a product in the markets for knowledge can coexist, especially when some barriers to mobility across markets can be found. The sale of the technological knowledge can coexist with the direct exploitation when geographic distance matter, when the new knowledge applies to different products, when barriers to international trade are found. Coexistence can be diachronic in that firms sell their technological knowledge but retain the right to implement it and to use the derivative knowledge. In this case the firm sells the proprietary knowledge that already exists but does not sell the rights to take advantage of the stream of new knowledge.

Mixed strategies of direct and indirect exploitation take place within the borders provided by property rights. Low knowledge transaction costs on the supply side can be found within global corporations where the internal markets are made reliable by proprietary ties among affiliates that are at least partially owned by a central holding. In this case the central laboratories can sell the knowledge to divisions and affiliates when appropriability is lower and use external markets for knowledge with higher levels of natural appropriability.

The trade in markets for technological knowledge is also frequent within technological districts where trusts is enforced by high risks of retaliation and localization exposes firms to reciprocity. In these circumstances firms may specialize in the production of knowledge and in its trade as a product per se with strong benefits in terms of specialization and access to technological knowledge.

In sum, the application of this analysis to the economics of knowledge is fruitful. The market place provides the opportunity for firms to sell their technological knowledge in the form of patents, licenses and services, or embodied in products. The sale of technological knowledge can substitute its use as input into the downstream production of new goods or new processes. The sale of disembodied knowledge, however, can complement the sale of embodied knowledge. Substitution takes place when the profits stemming from its disembodied sale are larger than those provided by its embodied sale. This can take place when the costs of internal coordination are larger than transaction costs in the markets for knowledge, or when competition is

stronger in downstream markets rather than in upstream ones. Complementarity between the sale in the markets for knowledge and its internal exploitation takes place when the customers of knowledge operate in different markets from the customers of the products (Baumol, 2002).

Ex-ante standardization in this context emerges as a powerful knowledge exploitation mechanism. Firms that command proprietary knowledge can impose the standards of the manufacturing process and the design of the modules that are likely to contribute the final product. Standards matter in this context as the codes of technological platforms that define the interfaces between modules and the role of each specific player. Standards are defined before the actual implementation of the manufacturing process. Ex-ante standards precede and complement patents as appropriation mechanisms. Standards make it possible to select the downstream applications that are retained within the borders of the corporations and the markets into which proprietary knowledge can be sold as a product per se.

5. CONCLUSION

Transaction costs economics has paved the way to understanding the firm as a bundle of activities, which coexist when the costs of internal coordination are lower than the costs of using the markets. The analysis, so far, has mainly focused the costs of using the markets on the demand side. Upward integration has been regarded as the consequence of high costs of transaction in the markets for complementary products and intermediary inputs at large.

The spreading of modularization has brought to the attention the key role of the costs of using the markets on the supply side. The relative levels of transaction costs in the usage of the markets on the supply side become a relevant factor in assessing the choice of the firm between the sale of the products of upstream modules or their integration into the operation of downward modules as intermediary inputs. When the firm decides to use the products of a module as an intermediary product for the following module, the exchange takes place in the internal market, coordinated by means of bureaucratic procedures. The firm is no longer a vendor. The firm instead is a vendor of the product of a module when the relative transaction costs on the supply side are lower upstream.

The economics of knowledge has long been shaped by the seminal contributions of Kenneth Arrow and Richard Nelson about the public good character of technological knowledge. In this approach technological knowledge is regarded as a public good for the high levels of non-appropriability and hence non-tradability. The public good nature of technological knowledge as a matter of fact, however, does not necessarily lead to under supply but rather pushes the knowledge-creating firm to use it as an intermediary input for the sequential production of economic goods. Vertical

integration into downstream activities is an important alternative that the possessor of technological knowledge can assess, in order to exploit its economic rents. The incentives to the generation of appropriate quantities of knowledge can be found in the markets for the products that are manufactured and delivered by means of the technological knowledge they embody. This analysis contrasts the traditional argument according to which the market supply of technological knowledge is deemed to under supply because of its public good nature.

The application of this analytical framework is especially fertile in the economics of knowledge. When knowledge cannot be sold as a good, there are still opportunities for its exploitation in the markets for the products that can make use of it as an intermediary input. The strategies for knowledge exploitation include downstream vertical integration into the production of goods that incorporate the new knowledge and yet deliver it to the market place. It is clear that all factors increasing the absolute and relative tradability of technological knowledge have positive effects for two classes of reasons. First better knowledge tradability leads to more effective incentive alignment and hence a better allocation of resources to generate new knowledge. Second, better knowledge tradability favors better division of labor and specialization hence higher efficiency. When and if the exploitation of technological knowledge as an intermediary input and its embodiment in downstream products is not the cause of limitations to its dissemination, the plurality of markets, rather than the single market place, can provide viable mechanisms of an efficient generation of technological knowledge. Even with low levels of natural appropriability in fact, appropriate levels of incentives and division of labor in fact are provided by the opportunity to exploit the proprietary knowledge embodied in downstream products.

REFERENCES

Aghion, P., Tirole, J. (1994), The management of innovation, *Quarterly Journal of Economics* CIX, 1185-1209.

Alchian, A. A. and Demsetz, H. (1972), Production information costs and economic organization, *American Economic Review* 62, 777-795.

Antonelli, C. (1999), *The microdynamics of technological change*, London, Routledge.

Antonelli, C. (2001), *The microeconomics of technological systems*, Oxford, Oxford University Press.

Antonelli, C. (2003a), *The economics of innovation, new technologies and structural change*, London, Routledge

Antonelli C. (2003b), Knowledge complementarity and fungeability: Implications for regional strategy, *Regional Studies* 39: 595-606.

Antonelli, C. (2004a), The economics of governance: The role of localized technological change in the interdependence among transaction, coordination and production, in Green, K., Miozzo, M. and Dewick, P. (eds.), *Knowledge and technology: Implications for firm strategy and industrial change*, Cheltenham, Edward Elgar.

Antonelli, C. (2004b), The governance of localized technological knowledge and the evolution of intellectual property rights, in Colombatto, E. (eds.), *The Elgar companion to property rights*, Cheltenham, Edward Elgar.

Argyres, N.S. (1995), Technology strategy governance structure and interdivisional coordination, *Journal of Economic Behavior and Organization* 28, 337-358

Arora, A., Fosfuri, A. and Gambardella, A. (2001), *Markets for technology*, Cambridge, MIT Press.

Arrow, K. J. (1962), Economic welfare and the allocation of resources for invention, in Nelson, R. R. (ed.) *The rate and direction of inventive activity: Economic and social factors,* Princeton, Princeton University Press for N.B.E.R.

Baldwin, C. Y. and Clark, K. (2000), *Design rules: The power of modularity*, Cambridge, Mass., MIT Press.

Bonazzi, G. and Antonelli, C, To make or to sell?: The case of in-house outsourcing at FIAT-Auto, *Organization Studies* 24, 575-594, 2003.

Brusoni, S. and Prencipe, A. (2001), Unpacking the black box of modularity: Technologies products and organizations, *Industrial and Corporate Change* 10, 179-205.

Chandler, A. D. (1990), *Scale and scope: The dynamics of industrial capitalism*, Cambridge, The Belknap Press.

Chandler, A.D., Hagstrom, P. and Solvell, O. (eds.) (1998), *The dynamic firm: The role of technology strategy organization and regions*, Oxford, Oxford University Press.

Coase, R. H. (1937), The nature of the firm, *Economica* 4, 386-405.

Cowan, R. and Foray D. (1997), The economics of codification and the diffusion of knowledge, *Industrial and Corporate Change* 6, 595-622.

Cowan, R., David, P. and Foray, D. (2000), The explicit economics of knowledge codification and tacitness, *Industrial and Corporate Change* 9, 211-253.

Dasgupta, P. and David, P. (1987), Information disclosure and the economics of science and technology, in Feiwel G. (ed.), *Arrow and the ascent of modern economic theory*, London, Macmillan.

Foss, N. (1997), *Resources firms and strategies. A reader in the resource-based perspective*, Oxford, Oxford University Press.

Foss, N., Mahnke, V. (eds.) (2000), *Competence governance and entrepreneurship. Advances in economic strategy research*, Oxford, Oxford University Press.

Fransman, M. (2002), *Telecoms in the internet age*, Forthcoming.

Guilhon, B. (ed.) (2001), *Technology and markets for knowledge. Knowledge creation, diffusion and exchange within a growing economy*, Boston, Kluwer Academics.

Hart, O.D. (1995), *Firms contracts and financial structure*, Clarendon Lectures in Economics, Oxford, Oxford University Press.

Geroski, P. (1995), Markets for technology, in Stoneman, P. (ed*.), Handbook of the economics of innovation and new technology*, Oxford, Basil Blackwell.

Krafft, J. (2003), Vertical structure of the industry and competition: An analysis of the evolution of the infocommunicaton industry, *Telecommunications Policy* 27, 625-649.

Kingston, W. (2001), Innovation needs patents reform, *Research Policy* 30, 403-423.

Langlois, R.N. and Robertson, P. L. (1995), *Firms markets and economic change. A dynamic theory of business institutions*, London, Routledge.

Langlois, R.N. and Foss, N.J. (1999), Capabilities and governance: The rebirth of production in the theory of economic organization, *Kyklos* 52, 201-218.

Loasby, B.J. (1999), *Knowledge institutions and evolution in economics*, London, Routledge.

Oxley, J.E. (1999), Institutional environment and the mechanisms of governance: The impact of intellectual property protection on the structure of inter-firm alliances, *Journal of Economic Behavior and Organization* 38, 283-309.

Penrose, E.T. (1959), *The theory of the growth of the firm*, Oxford, Basil Blackwell.

Spulber, D. (1999*), Market microstructures: Intermediaries and the theory of the firm*, Cambridge, Cambridge University Press.

Teece, D.J. (1986), Profiting from technological innovation: Implications for integration collaboration licensing and public policy, *Research Policy* 15, 285-305.

Teece, D.J. (1998), Capturing value from knowledge assets: The new economy, markets for know-how and intangible assets, *California Management Review* 40, 55-79.

Teece, D.J. (2000), *Managing intellectual capital*, Oxford, Oxford University Press.

Teubal, M., Yinnon, T., and Zuscovitch, E. (1991), Networks and market creation, *Research Policy* 20, 381-392.

Williamson, O.E. (1975), *Markets and hierarchies: Analysis and antitrust implications*, New York, Free Press.

Williamson, O. E. (1985), *The economic institutions of capitalism: Firms, markets, relational contracting.* New York, Free Press.

Williamson, O. E. (1990), The firm as a nexus of treaties: An introduction, in Aoki, M., Gustaffson, B. and Williamson, O.E. (eds.), *The firm as a nexus of treaties*., London, Sage Publications, 1-25.

Williamson, O. E.(1996), *The mechanisms of governance*, Oxford University Press, New York.

Williamson, O. E. and Winter, S.G. (eds.) (1993), *The nature of the firm*, Oxford, Oxford University Press.

ACKNOWLEDGMENTS. I acknowledge the financial support of the Research Funds of the University of Torino (Department of Economics: research grants for the years 2000, 2001 and 2002) and of the European Union Directorate for Research, within the context of the Key Action ‘Improving the socio-economic knowledge

base' as a part of the project 'Technological Knowledge and Localised Learning: What Perspectives for a European Policy?' carried on under the research contract No. HPSE-CT2001- 00051.