ON MARKETS IN KNOWLEDGE

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Abstract

This paper consider the conditions which must be met in order for specialised markets in knowledge to emerge.
The first is the alienation of knowledge from its context which allows knowledge to become a commoditisable product that can be bought and sold and transferred thereafter to different uses. Property rights are sufficient to such alienation and commoditisation.
The second is the establishment of a reasonable volume of exchange transactions in that commodified knowledge, which in turn requires cross sectoral application and horizontal integration. Institutional structures facilitate the continuance of exchanges and are sufficient to the second condition. The second condition is more stringent than the first. Empirical evidence suggests that technological convergence may be the specific and important historical occurrence when markets in technological knowledge emerge. Technological convergence meant that there were areas where knowledge could be transferred across industries, and in that process of transference knowledge also became more generic and abstract.

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1. Introduction

Many recent contributions on the dynamics of technological change have revolved around a recognition of the centrality of knowledge in the technology and growth process. However, a crucial and important debate in this area has hinged around the possibility and existence of markets in technological knowledge.

One view of technological change sees technology as endogenous primarily because it is what drives competition in imperfect markets. Technological change is embedded in the routines and organisations of firms. Technological knowledge is a resource specific to the firm and acquired through the firm's unique experience of learning. Competition selects the better firms, who may also be the carriers of new technologies (Nelson and Winter 1982, Dosi 1988). The emphasis on the firm specificity of technological resources, also referred to as tacitness of technical knowledge, however implies the impossibility of trading this knowledge, because of the high costs of transferring this information to another firm (Teece 1980).

In this tradition, a distinction is drawn between 'information' and 'knowledge' and while the former may be marketed and traded the latter may not (Fransman 1994). This view sees many of the models of technology markets in the neo-classical tradition (Arrow 1962, Dasgupta and David 1992) which have concentrated on the public good nature of knowledge markets as information processing and information co-ordination models. Knowledge is seen as the more intrinsic capacity to recognise the usefulness of information and blurring this distinction is neither rigorous nor desirable (Nightingale 1997:10).

To this old controversy about the impossibility of trading knowledge, has been added in recent years, a new twist. Some writers on

technological change (Arora and Gambardella 1994) have observed that new developments in scientific disciplines along with the progress in computational capabilities and instrumentation have enabled the relevant knowledge required for innovation to be cast in more general and universal frameworks.[1] This opens up the possibility for division of labour in inventive activity, and the consequent emergence of specialised firms that produce knowledge based products to other firms. They argue that specialised markets in knowledge have emerged.

Such markets in knowledge are seen as emerging as a result of the possibility of specialised markets in a process of vertical disintegration. This in turn is facilitated by the widespread use of abstract knowledge, which is generic in contrast to tacit knowledge that is more specific. The widespread use of codified and universal knowledge reduces the transactions costs of transferring information and also increases the precision with which such knowledge could be obtained for the buying firm, allowing a specialised market for knowledge to develop if the size of such a market and intellectual property protection are favourable.

Thus the Arora and Gambardella (1994) story is a plausible and persuasive one about why markets in knowledge may emerge and its consequences for the organisation of innovative activity. It is controversial because it asserts a generality for markets in knowledge. The technology of technological change is changing in that such knowledge markets are here to stay. Is the critique of the impossibility of marketing knowledge, due to the firm specificity of such knowledge still valid?

There are at least two ways in which one may go about ascertaining the validity of the above position. One may ask if there is indeed a greater use of "universal and abstract" knowledge in the innovation process.[2] Empirical studies that have tried to do so have generally come up with mixed results depending upon the sector that was

considered. Thus, in general studies on the biotechnology and pharmaceutical sector appear to support the existence of specialised knowledge markets while studies on more complex products like aircraft and automobiles point to the importance of developed in-house capabilities in explaining innovations.

One interpretation that could be given to this mixed evidence is that the development of markets specialising in the exchange of knowledge-type commodities is not a general phenomenon. What then are the constraints to the generality of this phenomenon? Another way of looking at this question is to ask, as this paper does, under what conditions will such specialised knowledge markets emerge and are these conditions generally prevalent across all sectors of industrial activity?

The paper is organised in the following way. The next section discusses the problematique within which the above question is considered, viz. of vertical disintegration due to increasing division of labour, and a delineation of the possible dimensions and characteristics of a knowledge market. In Section 3 the paper considers the historical literature on market emergence to identify the conditions under which we can expect any commodity market to emerge. These conditions are then related to the knowledge market in Section 4. The importance of cross sectoral applications in specialised markets is highlighted and the role and meaning of technological convergence in facilitating knowledge markets is also discussed. Section 5 draws on some examples of knowledge markets, from empirical studies on specialised engineering firms (SEFs) in the chemicals sector, the package software industry, and the biotech sector, and highlights the role of technological convergence in the emergence and development of these industrial sectors. The final section summarises the argument made in the paper and draws out its implications for our conceptualisation of the process of technological change and the structural changes associated with it, and for policy

that hopes to stimulate such externalities associated with the development of specialised markets.

2. The problematique

The problematique within which this paper would like to analyse the issue of when specialised markets in technological knowledge emerge, is that of increasing specialisation made possible due to vertical disintegration. This allows some functions that were previously undertaken within a firm to be "externalised" in a specialised market. In a previous generation of mechanised technologies the increasing division of labour, in some economies, led to the emergence of a capital goods sector that was specialised in the manufacture of a whole range of machinery. The importance of the existence of such specialised sectors, as Rosenberg (1963) had pointed out, was in the immense external economy they conferred on other producing industries within that economy, in production and also in innovating activities. The emergence of such markets meant that producers had the opportunity to search for the kind of machinery they wanted without having to incur all the costs of learning to make the machinery themselves. Further, improvements in one area of mechanical engineering technology were transmitted through the industrial sector through improvements to manufactured capital goods. This had an important impact on technological innovation and the direction of this innovation, in that labour saving technology became the dominant technological trajectory in such economies.

By analogy we may ask if the further development of industry and markets has increased the potential for the division of labour and is creating a specialised industrial sector in the economy that produces the knowledge-embodied goods that facilitate the manufacture of machines and production. Both the division of labour paradigm and the analogy with the capital goods sector allow us to delineate some of the functional characteristics of such a market.

The first characteristic that is useful to underline is that the product in such a knowledge market is a producer good which is an input into further production in the economy. It is also likely that the market for knowledge is a subset of the market for technology in general. We expect producing firms to search in this market for technological know-how and to be the consumers of the product of this market. This predominance of firms as consumers of the products of this market makes the knowledge market different from the market for certain kinds of professional services such as those of hairdressers or musicians.

There is however a range of information services that are sold on a regular basis to households and firms, such as bibliographic packages and specialised journals on-line, which may be utilised by firms as sources of technological knowledge. Should these be included as constituting the knowledge market? Here again the capital goods analogy is useful. The capital goods sector developed as the machine producing sector for various industries in the economy. The range of machinery that the capital goods sector in an economy was capable of producing was an important index of its sophistication and its importance for the rest of the economy.[3] Functionally it allowed producers who might formerly have fabricated their own machinery to shop for machinery that best suited their requirements for production and also for innovation. Thus, the capital goods sector was able to accommodate one-off transactions in machinery (on account of adaptation to the needs of particular firms) or deal in bulk machinery markets when the derived demand was large enough, such as the sale of replacement machinery.

In a similar way the knowledge producing sector of the economy should enable producers to search for the technological knowledge necessary for production and innovation. A well developed knowledge market should allow firms to shop for those outputs, information, and tasks that would formerly have been undertaken within their R&D laboratories. As firms can search in such markets

for highly specific products it is difficult to treat the products of these markets as purely information goods.

Thus several classes of information services that are general to the use of all categories of users but cannot be tailored to the needs of one particular user are automatically ruled out. Technical information supplied by an on-line bibliographic service does not change for the needs of a particular firm. However, consultancy firms can and do accommodate such one-off transactions in providing solutions to the production and organisational problems of firms. They may also sell the same solution more than once and even commercialise the solution to a problem that occurs quite frequently in the form of a commodity e.g. a diagnostic kit. Nevertheless it is their ability to customise if necessary that distinguishes them as producers in a knowledge market.

The above two functional characteristics, viz. that knowledge markets sell producer goods and that they must be capable of including one-off transactions help us to differentiate these markets from several other markets that might share certain product characteristics in common with knowledge markets. These are the markets for professional services which share the characteristic of intangibility of product with knowledge markets, and the market for general information services which like the knowledge market sells goods that are information-embodied.

Beyond these characteristics it is difficult to define the precise product types that would be encompassed by a knowledge market. This difficulty is for two reasons. Firstly, the vertical disintegration due to increasing division of labour paradigm, within which this question is set, is one where markets are seen as emerging due to functional specialisation. Often this functional specialisation can be associated with a product(s), but it may be harder to enumerate all the products to which this specialisation can correspond. Secondly, as will be argued in the next section, particular product markets emerge as the consolidation of exchange overtime produces a stable market.

The concern of this paper is in understanding the conditions under which knowledge markets, possessing the functional characteristics outlined above, might emerge. Particular definitions and distinctions between knowledge and information are less relevant to the understanding of this question. This is because the products sold in such a market are clearly goods (and not an abstract capacity) but at the same time they are not pure information as well. Something is exchanged between firms which substitutes for the firm's own production of the knowledge type input. Secondly, the focus is on the conditions of market emergence which implies, in turn, that the object of analysis is the exchange of knowledge type commodities rather than their creation. The paper also abstracts from the related questions of how markets in knowledge might emerge, or why they might emerge as an alternative to the firm [4].

The central question of when markets in knowledge will emerge is in turn split into two related questions: When do markets emerge? When will markets in knowledge emerge? In particular the paper will argue that the following two conditions must be met in order for markets in knowledge to emerge:

(i) The alienation of knowledge from its context, which allows knowledge to assume dimensions of a commoditisable product that can be bought and sold and transferred thereafter to different uses.

(ii) The establishment of a reasonable frequency of transactions in that commoditisable knowledge to establish a specialised market in it. The existence of specialised market does not depend only upon the existence of product or even the possibility of exchange. Regular markets[5] emerge when producers can expect the existence of a minimum volume of exchange transactions. Only this allows knowledge to become a commodity in that producers of knowledge may be induced to make capital outlays and employ capital in order to produce knowledge-embodied goods for exchange.

Further, it argues that the second condition is more difficult to satisfy than the first. Thus examples from the experience of recent industrial history suggest that the few successful cases of genuine knowledge markets have come in areas where knowledge could be transferred across industries, i.e. the cases of SEFs in the chemical industry in the post war period, the emergence of package software markets and the emergence of new biotechnology firms in the more recent past.

The process of transference of technological knowledge across sectors of original use created the conditions when knowledge became both commoditisable and reasonably frequently exchanged, because of the cross-industry nature of its applications. Far from being a general trend this suggests that technological convergence may be the specific and important historical occurrence when knowledge could be successfully commoditised, and markets in knowledge could be expected to emerge.

3. When will markets emerge ?

For a subject preoccupied with markets and their functioning, economic writing on the issue of when markets emerge has been surprisingly sparse. We know much about imperfect markets, perfect markets, market failures, incomplete markets, but all of these assume the existence of exchange markets. Indeed one has to travel very far back in the history of economic thought to understand when markets may emerge.

Among economists in the classical tradition, Marx is the best remembered for analysing the market form of organisation under capitalism. Stressing that the most important aspect of capitalism is commodity production, and that one implied the other, Marx additionally outlined the minimum characteristics of a commodity. Commodity production takes place when production is not for the direct use of the producer but for sale on the market, i.e. for exchange.

Thus when a baker bakes bread for his own consumption it is a product but when he bakes bread to sell in the market it assumes the form of a commodity (Bhaduri 1986 : 4-6).

A product thus becomes a commodity when it can possess a exchange value which is independent of its use-value. This defining feature of a commodity is important in the context of a market. This is because in a market products are traded at their exchange values in order to satisfy the use-values that the final consumer of product derives from the product. However, the fact that the use value of the product has nothing to do with the exchange value (prices) that it commands in the market, is an important feature of both markets and commodities. Possessing this essential duality of exchange value in a market and use value for a consumer, requires the alienation of the commodity as a prerequisite. Property rights are an important institutional necessity for such an occurrence.[6] It is only in the transfer of ownership involved in an act of market exchange, that both the exchange and use values are realised for the seller and the buyer respectively. Thus, we may regard the existence of property rights as sufficient to the condition of alienation.

Commodities exist with generalised exchange and generalised exchange already presumes markets have emerged. However, the continuous or frequent nature of such exchanges is also a pre-requisite for commodity production in the Marxist sense. If a producer is to be induced to produce for a market and in the expectation of a profit, then some frequency of transaction in the commodity must already be established. Put in another way, the "expectation" of the producer may be about how many units of a good he may sell, but usually it is not about whether he will find any customers at all.[7]

The other important explanation for when markets emerge was given by Adam Smith in the context of the emergence of specialised markets. Writing in 1776, Smith saw the specialisation process as being contained in the division of labour due to the expansion of the

market for exchange. He also observed that this process operated within the factory and also at the inter-firm level in society. The division of labour in society (or vertical disintegration) was the emergence of specialised commodity markets. The stimulus for both specialisation within a firm and in society was however the same, viz. an increase in the extent of the exchange market. The extent of the exchange market in turn was positively related to population size and density, amount of natural resources and accumulated capital available (Book 1, chapter 3), the ease of transportation (Book 2, pp.259-61), extent of trade, and lastly the stability of the market.

A somewhat different interpretation of the above factors mentioned by Smith is obtained when one reads Torrens (1821). Torrens explicitly refers to the frequency of transactions as leading to permanent divisions of labour in society.[8] Smithian division of labour has usually been discussed in the context of scale of market demand. Among later economists both Young (1929) and Stigler (1951) had recognised the scale of the market as the one factor which ultimately determines the emergence of new industries through specialised markets and vertical disintegration. However, it is easy to see that an increased frequency of exchange transaction would in fact be the result of all the factors considered by Smith as the factors increasing the extent of the market positively, so that what lies behind the extent of the market is in fact the increased frequency of exchange.

It is necessary to distinguish between the size of the market, which defines static scale, and the continuing or growing size of the market which defines dynamic scale effects. The continuation of some "reasonable frequency of exchange" must thus lie behind the sort of dynamic scale effects that Smith expected caused the division of labour and specialisation. In this context it is also interesting to note that Smith had recognised that the instability of demand might negatively affect this process of specialisation.[9] More importantly, when there is not a continuous and minimum frequency of exchange transactions some types of market may also disappear. A good

example of this is the appearance and disappearance of ice-cream sellers during the week of the May Bumps on the Towpath in Cambridge. Once the boat races are over one seldom sees these sellers on the same path.

It is also worth noting that the size of the exchange market is actually subject to two separate sorts of influences. At any point of time, the size of the exchange market is defined by the number of participants in the market multiplied by the frequency of exchange to any one participant.[10] In arguing that it is the frequency of exchange transactions that determines the emergence of a market I am holding the number of participants constant and small as one may expect at the start of a market emergence process. Once a exchange market has been established in one period, however, its continuance could come about by an increasing frequency of exchange or by an increase in the number of participants.[11] Thus, if the Towpath became an important tourist attraction in Cambridge, for some reason, then the ice-cream sellers may stay even beyond the boat races, as the number of participants in the markets will have dramatically increased.

Once a market has emerged in a commodity, institutions may emerge to support the continuance of this market. These are likely to differ according to the volume of exchanges and also according to the differing social norms in different environments. They may also give rise to increasing returns in the process of exchange (North 1990). The emergence of standards in several industries is a good example of the role of institutions. Quality standards cut down the buyer risks associated with exchange and facilitate the continuation of the exchange process. Simultaneously by making for compatibility across different users and manufacturers they also facilitate the increase in the size of the market making seller risks low.[12] Thus, the emergence and existence of institutions is sufficient to the second condition viz. the maintenance of reasonably frequent and continuing exchanges.

The above discussion suggests that the defining features of a market are both the existence of an exchangeable product and the existence of reasonably frequent and continuing exchange transactions in that product. On reflection it is also clear that theoretical conceptions of what a market is also implicitly assume these two characteristics. A "commoditisable product" alone is sufficient to define sporadic exchange. Routine exchange however establishes a regular market which can establish stable behavioural regularities and the possibility of stable prices that reflect differences in quality or costs of production.[13]

Textbook representations of perfect and imperfect markets distinguish between the spread of transactions on both sides of the market (in the case of competitive markets) or concentration of transactions on one side of the market (as in the cases of monopoly oligopoly, or monopsony), but there is always the implicit assumption of continuous exchange transactions which lie behind this symmetry or asymmetry on the two sides of the market.

In the discussion so far the term market has not been defined except as an organisational mode that facilitates production through exchange and the incentive for which is the profit from such exchange. From this the paper has tried to deduce the preconditions that are necessary for this form of organisation to emerge in any one period. In particular I have tried to avoid a product based definition of the market because if we think of the emergence of regular markets in more dynamic terms or over several time periods, it should be clear that the consolidation of the process of exchange and the considerations of profitability of the producers will also define the product which is being sold. What is exchanged between buyers and sellers in a market gets determined simultaneously with what can or cannot be alienated as a commodity and with what combination of products a reasonable frequency of exchange transactions might emerge to make it profitable for the producer to sell his product.[14]

Two examples may clarify this last point. In several economies consumer durables are sold along with a guarantee of after sales service. This is a composite product with a product element and a service element. There is no reason why the two should not exist as separate markets by a product definition of a market. In several developing countries markets for repair often act as guarantors for consumer durables, or sometimes no guarantees are sold. Another example is that several developing country firms diversify into several lines of production because often markets do not exist in complementary products such as machinery. Here again is the case of a market that gets established in a composite rather than a single product.[15] Excessive preoccupation with product based definitions of the market could obscure the process and function of exchange which lies at the heart of the regular market abstraction and the organisational mode of the market.

4. Markets in technological knowledge

Markets in technological knowledge can be identified by the selling of specialised knowledge-embodied goods which are bought by other firms as inputs into their production.[16] While knowledge markets deal in specialised knowledge-embodied goods they are also general to the use of several firms. Further this market should be capable of incorporating routine production (commodities) and non-routine project based production, which is similar to customised work. The minimum conditions for regular markets are the existence of commodities (in the sense in which commodities are discussed in section 3), and of continuing and frequent exchange transactions, as we argued in the previous section, then it follows that for markets in technological knowledge to emerge, technological knowledge must appear as a commoditisable and exchangeable knowledge and further this exchangeable product must be frequently and continuously (period after period) exchanged.

If technological knowledge must exist as a exchangeable product then following Marx, that technological knowledge must be produced by a firm not for use by itself but to sell to another firm for use in its production process. This in turn implies the production of technological knowledge in an alienated form, i.e. divorced from its specific context of origin. Arora and Gambardella (1994) point to precisely this kind of alienation when they stress the greater use of abstract and generalised knowledge in innovation processes or indeed processes of production. Whether such an alienation is possible and the extent to which it is possible in different sectors appears from the empirical evidence to be highly variable across sectors of activity. Much of the debate about knowledge versus information, and codified versus tacit knowledge, is actually about the possibility of, and difficulties with, such alienation in the case of technological knowledge.

An important implication of the difficulty of alienating knowledge is that the particular product forms that such knowledge markets could take can vary widely. On one end of the spectrum is completely disembodied intellectual capital. On the other end of the knowledge market lies the firm with its specific production and organisational knowledge history that is so technologically and organisationally specific that it cannot be alienated and traded. When the knowledge embededdness is very great the technological knowledge market may take the form of trade in whole firms (i.e. a market in firms).[17]

The case for intellectual property rights too must be seen in the context of attempts to commoditise and alienate the benefits of some abstract discovery in an attempt to define exchangeable products in a system of private production. An exchangeable product must belong to someone who will then undertake to invest in its production. This connection between alienation and the institution of property rights was discussed in the previous section. To the difficulties of alienation, must be added the difficulties in enforcing a system of property rights on knowledge-embodied goods because of their public good

characteristics i.e. it is non-excludable and it is non-rival, making appropriation of benefits from producing information very difficult, and imitation quite easy.[18] Transfer of the product too cannot always be mediated through the transfer of ownership as is the case with most exchanged goods.

However, it is the second characteristic associated with a market in knowledge that this paper would like to emphasise. This is that a market for knowledge must be associated with reasonably frequent and continuing exchange transactions in such knowledge. The existence of knowledge as an exchangeable product alone does not actually ensure this.[19] Having defined the knowledge market as one which is often engaged in custom or non-routine, project based work, the meaning of frequent exchanges in a commodity as it applies to this case needs to be explained. Custom work implies that successive units of what is sold are rarely identical. Identical additional units (as in the case of markets for shoes, for example) allow the producer to have predictable costs that can be recovered in prices when the unit is sold. In the case of knowledge markets that do something like custom work, the costs of additional units of the product should have reasonably low and predictable costs of adaptation that are recoverable in prices. When this happens even if each unit of the product sold is dissimilar it approximates in its properties the essential features of a commodity market. What this implies is that frequent exchanges in the knowledge market will often happen if the costs of adaptability are low and predictable, or the opportunities of adaptability of the exchangeable knowledge are high.

Of course if the initial derived demand for the knowledge good is large enough (including the global market as the potential market may achieve this for the firm), then it is not necessary for the market to expand in this way. Cross sectoral applications become important as a way of increasing exchange market scale only when derived demands are small for the original application. In practice it is difficult to find

many empirical examples of the emergence of specialised markets on the basis of one sector alone.

Rosenberg's (1976) study of the machine tool sector in the US economy highlighted the importance of technological convergence and the sharing of similar technological (mechanical engineering) principles across different industrial sectors in expanding the scale of market demand for machine tool producers and allowing a specialised machine tool sector to emerge. Ville (1993) studied the growth of specialisation in English ship-owning in the period 1750-1850. The study concluded that specialisation in ship-owning occurred with horizontal integration replacing the earlier fractional ship-owning system where trading companies owned a part of the ship and could use it when they needed to and exclusively for their individual trading purposes. As the demand for shipping grew owner-entrepreneurs who provided shipping services across several industrial sectors emerged replacing the earlier fractional system. In particular the author concludes that vertical specialisation with horizontal integration provided a legitimate alternative path of development to vertical integration for the expanding and successful shipping industry.

The importance of cross sectoral demand and the more generic nature of the specialised product is also confirmed by a recent study by Lyons (1991) that has sought to examine the make-or-buy decision of firms within a transactions cost perspective. Lyons (1991) has argued that the buying in of specialised inputs by engineering firms is higher, when the production technology is non-specific, or if there are economies of scale and scope. He also adds that the economies of scale effect is much reduced in the presence of specific assets. However, economies of scale and scope exist together only when the sharability of variable costs is very high.[20] This suggests differentiated (non-routine) production of a non-specific technology-embodied good on the part of the specialised input suppliers.

Looking at particular examples of the emergence of knowledge markets (detailed in the following section) we find that both the conditions of market emergence are met in the case of knowledge embodied goods when there is a process of technological convergence at work. Technological convergence is the process by which industries which were once different in terms of their technological and therefore knowledge bases, come to share similar technological and knowledge bases.[21] Within the rubric of technological should also be included organisational similarities. Rosenberg (1976) coined this phrase to describe the process by which similar technological principles guided such diverse industrial activities as sewing machine manufacture, bicycle manufacture and firearms manufacture. In recent years examples of technological convergence, such as that between computers and telecommunications, have actually come about by an underlying fusion of technologies, so that what appears as industries sharing similar technological principles is actually because of technological fusion in the production of commodities.[22]

The historical occurrence of technological convergence, however, creates unique conditions under which specialised markets selling knowledge-embodied products can emerge. Technological convergence goes hand in hand with the emergence of new generic technologies. The emergence of machine tools was accompanied by the dominance of mechanical engineering principles, just as the more recent convergence in telecommunications and computing has been accompanied by the dominance of micro-processor technology. The rise of such generic technologies facilitates the process of the alienation of technologies and also appears to facilitate the institution of property rights in them.

When industries come to share similar technological bases, technological knowledge can be freed of its particular context and be sold in more generalised ways. This is what we have termed as the process of alienation. A system of property rights is in some cases, where one is dealing with completely disembodied products,

sufficient to such alienation. This alienation is not so much a matter for codification as the incentive to be specialised within a narrow range of expertise that can be assimilated in services and goods capable of being sold to several firms. For example, consultant firms are often used by smaller electric steel firms wishing to redesign their furnaces. However, such consultancy firms are usually specialised in knowledge on refractory principles and indeed advise a wide range of metal-producing firms. Their specialisation is general (in refractories) but their product could be specific and designed to suit a particular firm and often this customisation happens with substantial 'specific' inputs from the buying firm.

Technological convergence also makes possible the second necessary condition for the emergence of specialised markets selling knowledge-embodied goods, i.e. the existence of recurring and reasonably frequent exchanges in such knowledge exchange transactions. This happens for different reasons on both sides of the market. For a firm wishing to sell knowledge-embodied goods technological convergence effectively enlarges the potential number of exchange transactions to encompass not one but two or more industries. It also reduces the costs of adaptation compared to the case when convergence was absent. From the point of view of the buying firm technological convergence can often make for technological complexity and the need for diversified competencies (Von Tunzelmann 1996, Patel and Pavitt 1995). This may also impose severe learning, investment and supervision costs on such a firm and thus make outsourcing of some technological tasks an attractive alternative. Exchange of generic knowledge in the form of bought inputs from another firm may cut down on some (though not all) of the costs of acquiring this knowledge. The situation thus becomes ripe for the emergence of a market exchange in technological knowledge-embodied goods.

5. Technological convergence and specialised knowledge markets

The importance of technological convergence in the emergence of specialised markets is evident when we consider examples from our recent industrial history, where something like specialised markets in knowledge have emerged. This section will briefly detail three such histories, viz. the emergence of SEF plants in the US economy that specialised in the selling of plant designs to a wide range of chemical industries, the development of software applications to other industrial sectors, and lastly the growth of new bio-technology firms in the US. In all these cases markets have traded in goods that were knowledge-embodied, and sold production as an intermediate good into the production of other firms in the economy. Further in all three cases technological convergence was important as the one exogenous factor that faclitated the emergence of these markets.

Specialised engineering firms (SEFs) came to play an important role in the chemicals sector in the years following the Second World War. In the 1960s it was estimated that nearly 3/4 of the major new chemical plants had been engineered, procured and contracted by SEFs.[23] This was in sharp contrast to what obtained before the War when chemical firms carried out their own process design and used external contractors to handle construction, piping, electricity and other components of the project. Arora and Gambardella (1997) point out that post war SEFs provided three kinds of services to their clients. All SEFs provided design and engineering services, which included designing plant layout, specifying equipment and doing detailed engineering. Many SEFs also sold their own proprietary licenses for improving existing processes and plant designs. These improvements have involved a modification of the catalyst system or in recent years more environmentally-friendly processes, and these incremental improvements are often proprietary to the SEFs. Lastly, many SEFs also acted as general contractors managing the actual construction of refineries and chemical plants.

The emergence and activities of these firms represented a market in knowledge because they were selling technological designs and process improvements often to firms in related sectors such as refining, natural gas, coal, and petrochemicals. Their selling activities were also highly global and in the immediate post-war climate of reconstruction in Europe and of a major boost to development programs in the newly emerging countries, the global market was a large one to tap. Nevertheless, both the variable nature of their products and the cross sectoral nature of their selling activities are worth noting.

The variable nature of their products reflects the fact that the same technological service needs to be provided with greater or lesser complementary inputs in different contexts. Thus, the developing country firm might have wished to have a turnkey plant from a SEF firm because of the problems of co-ordination and of missing intermediate markets in large scale engineering construction work. However, in a more developed economy, such as to a European firm, the SEF might have used only the design services of the SEF. It also underlines the point that was made earlier in the paper, viz. excessive preoccupation with product based definitions obscure the process of exchange which lies at the heart of the market formation process. The global nature of the potential market meant that SEFs had to be prepared to sell some of the complementary services associated with the particular knowledge-embodied good they wished to sell.

An explanation for the cross sectoral nature of demand is contained in Landau and Rosenberg (1994). Explaining the asymmetrical development where American SEFs dominated the world market, the authors point to the peculiar nature of American industrial development in that America used a petroleum-based technology system far ahead of their European counterparts. This gave US firms engaged in petroleum an understanding and capability in large scale plant design which they then exploited when other chemical firms tried to scale up their production technology.

The process of scaling up a chemical process encompasses common sets of problems, even if the actual chemical processes underlying the two sets of industries are quite different. Thus the design of the process may have to be changed to optimise such characteristics as heat loss, energy transfer, energy consumption and yield from the process. This is why additionally knowledge of catalysts and ways to control the waste from the process is useful. If they are incorporated in the design of the plant there are enormous productivity gains to be made. Some of these design and product improvements can be incorporated across a range of product categories. When this happens we can conclude that there is a process of technological convergence when scaling up takes place.

The growth and development of chemical engineering technologies was an important factor facilitating the emergence and development of the SEF firms. It has been argued (Arora 1997) that advances in chemical engineering developed more abstract and general ways of conceptualising chemical process so that the chemical engineer could see the commonality in the problem of scaling up across different chemical processes. Knowledge about the process could thus be alienated from the specifics of the chemical process itself in a way that would not have been possible for a chemist of the earlier generation. Secondly, chemical engineering also provided the language in which product and process patents could be separately obtained and then the technology contained in them be sold as licenses. Since licensing was an important instrument through which fees were realised, patent protection was also important in the growth of the sector.

The second example is the recent growth of the package software market. In the early 1950s and 1960s when the seeds of the software industry were being sown, the software firms that existed in the market acted as consultancies to the military and space agencies and later to the hardware manufacturers who were struggling to develop

operating systems for third generation computers. It was estimated that by 1965, forty to fifty major independent suppliers of software and programming services and several hundred smaller organisations had been established (Steinmuller 1996:24). In this initial stage of the industry the frequency of contracts obtained by the software firms given the small number of participants was vital to sustaining the growth of this sector.

The growth of the package software industry really took off in the late sixties and three events are acknowledged as being important in this development, viz. the introduction of the System/360 operating software which for the first time standardised the operating system software on a wide range of computers; the unbundling decision of the IBM; and the development of the minicomputer industry. The spread of the minicomputer allowed the greater use of computers in general and also created a demand for software tools and applications, and the unification/standardisation of the operating system under the IBM family of computers also opened up the prospect of writing software applications for different uses. The technological convergence at work was the widespread computerisation of various activities made possible by the decreasing price of computational power.

It is often argued that it took the "unbundling" decision of IBM and following it other hardware manufacturers to really create the conditions for a separate package software industry to emerge. However, as Steinmuller (1996) has pointed out, it has been argued that IBM took its "unbundling" decision following a rapid increase in its costs of software support. The costs of developing System/360 had been high. Further, the existence of independent software vendors made it possible for the company to separately price its software and to back away from its earlier commitment to provide the full range of software tools that IBM users might need. In other words, an integrated computer manufacturing firm decided to shed some of its extended activities as a software industry was already emerging. The

standardisation around the Systems/360 software should also be seen in this light, viz. decreasing the cost of future production of computers.

The package software industry emerged and grew around various applications that were usually cross-sectoral in application. Thus, Brady et al. (1992) suggest that many of the smaller emerging software firms began to offer packages which reflected primarily *"the converging needs of large numbers of computer users across many sectors. With respect to application software specialisation developed along two lines. Some software firms developed products for general purpose applications such as payroll or accounts where there was a commonality in the requirements of users across many sectors. Other firms evolved to sell to particular large vertical markets such as banking or insurance or the military".*[24] However, where such cross-sectoral convergence of application needs did not take place, such as in the case of firm specific applications designed to achieve competitive advantage computerised systems were more likely to be produced internally, or be developed as bespoke software by software houses.

It is important to recognise that the package software market now acts as a generalised opportunity for various kinds of producers to search for software that most closely fit their IT needs, for administration or production, in a way that it did not do in the early 1950s. The studies quoted above (Brady et al. 1992, Steinmuller 1996) show that the emergence of the package software industry and its subsequent differentiation along application lines, depended upon the spread of computerisation due to the falling cost of computation, which in turn also required a standardised operating system. If growing computerisation created a growing need for software across a range of industries (and thus increasing the participation in the software market) the developments in software languages allowed rapid progress to be made in writing applications packages that were capable of doing a larger and larger range of tasks in newer ways. But

the use of software languages required that software be made independent of the hardware wiring which was the practice in the early computers. The development and use of software languages represents the successful alienation of application instructions from the "hardware" of the computer. The role of intellectual property protection is less clear (Merges 1996). Copyright law still is weaker than patent law and no successful ways of copyrighting pure algorithms have been found. However, there is evidence that a broad interpretation of copyright laws has helped US package software firms. In countries where customised production has been more dominant copyright law is also weak and little recourse is taken to it. It is less clear if the latter may be regarded as causative.

To summarise, the story of the emergence of the package software sector demonstrates the important role that technological convergence due to computerisation has played in the growth of the industry. As more and more industrial sectors began to use computers in various production and administrative activities, the need for software applications in all these sectors grew. Some of the needs of software across sectors were convergent and some were divergent. The subsequent differentiation of the software sector along bulk packaged applications and a customised sector reveals the strategies firms employed to deal with this emergent market. As important as the market demand were the advances and developments in software programming which influenced what software suppliers could offer and develop in their applications.

New biotechnology firms in the US represent yet another example of what might be identified as a knowledge market emerging due to a convergence of technologies. New biotechnology fundamentally represents the use of biological methods to identify molecular structures for the production of a wide range of chemical products such as therapeutic proteins and enzymes, and biological organisms themselves such as seeds, biological pesticides, engineered yeast and modified human cells for treating genetic diseases.[25] New

biotechnology thus represents the convergence between biological methods (based upon r-DNA and hybridomas methods) and chemical processes. Its successful commercialisation has, however, only exploited the use of biological methods as a research tool in identifying the contours of a solution.

Early firms that entered the biotech market were established with a belief in the generality of the basic techniques. This is confirmed if we read the case studies of particular companies such as Gentech and Cetus (Daly 1985), or if we look at more qualitative survey results about the founder's motivations in setting up the biotech firm as reported by Oakey et al (1990). The stronger patent regime in chemicals generally and the possibility of patenting genes in particular, because of developments in genetic coding, appear to have been important facilitating trends. The development of molecular biology and genetic engineering have meant that the two techniques of r-DNA and hybridomas can be applied across a range of similar cells.

The differentiation of this industry after its emergence has followed particular user sectors more closely than the other examples we considered.[26] Firms that started with a wide range of activity have been forced to concentrate on a smaller range of applications. Thus while the end markets for software are spread across the financial and manufacturing industrial sectors, the biotechnology firms have tended to specialise according to applications to a particular industry. In the early days of the biotechnology industry however, the cross sectoral nature of industry demand was more important (Swann and Pervezer 1996: 1141).

New bio-technology has revolutionised production in the pharmaceutical industry, often drawing upon the large demand base and marketing skills available to the big multi-product pharmaceutical companies. The large and continuing nature of these markets permitted the kind of specialised markets in biotech applications

which did emerge. These firms relied upon the marketing and product launching skills of larger pharmaceutical companies in order to carry them through the "commercialisation" stages of the innovation process in an industry that is still highly integrated. Thus a division of labour has emerged in these sectors where biotech firms act like R&D labs of large pharmaceutical firms, and several writers have commented on this feature (Orsenigo 1989, Pisano 1990, Gambardella 1995).

A number of factors have been advanced to explain the differential success of new biotechnology, despite its early potential for cross-sectoral application. First it is argued that the ethical problems surrounding the injection into the environment of genetically engineered seeds and pesticides have not been fully resolved so that the production of biotechnology has had to be small-scale and in specialist areas where their potential and use will not present a threat to society at large. Secondly it has been argued that patent protection is more effective in the areas of human treatments than in the areas of plant biotechnology and this severely affects the presence of specialised biotech firms. Lastly, it is argued that costs of introducing product innovations in the more bulk agricultural markets are prohibitively high both in terms of the underlying technological problems and the time required to bring the product to the market (Oakey et al 1990: 10-25). While biotechnology helps cut down on the period between discovery and production by reducing the need for costly trial and error processes, other costs are involved in the complete innovation process. In many potential markets such as therapeutic drugs and agricultural products for environmental release detailed testing is required in order to meet safety requirements and this process is time consuming, costly and often uncertain. The differences in the growth of biotech as a specialist sector are probably also linked to the fact that biotech drugs tend to replace traditional drugs and so the competition with incumbent firms and practices is an important element that determines successful commercialisation. In this respect the case of biotech firms is different from that of software

firms or SEFs. It is beyond the scope of this paper to pursue this difference further.

To summarise, in studying the emergence of the biotechnology industry too we find the importance of a large initial market. The largeness of volume was facilitated by the use of biological methods and information technology to the revolutionising of production in a range of products particularly therapeutic proteins and enzymes. This range of products is less than what was first envisaged for this sector. However if we remember that the methods of new biotechnology are essentially just a few, the range of applications is still wide. After its emergence and early period of growth the differentiation of the biotechnology industry has centred around its function as an external source of R&D for multiproduct pharmaceutical companies. Developments in the more generic technologies of molecular biology and genetic engineering have accompanied the growth of this sector representing a successful alienation of the knowledge surrounding cell structures and replication. The stronger patent regime in the pharmaceutical structure and the prevalence of broad patenting have also worked to the advantage of the growth of this sector.

6. Conclusions

In conclusion this paper would like to recall the question that it started with. This was to ask if the existence of specialised markets selling knowledge-embodied goods and which it is argued have changed the technology of technological change (Arora and Gambardella 1994) is in fact a general trend. Our interpretation of the mixed sectoral evidence on this question was that the emergence of knowledge markets was a more specific (less universal) experience.

In this paper we have argued that this is because both the alienation of generic (exchangeable) knowledge and the existence of a minimum volume of exchange transactions are necessary conditions for such exchange markets trading in knowledge embodied goods and services

to emerge. The different roles of frequent exchange by existing participants and the growth of participants in the market, in the growth of markets were highlighted. From a study of the empirical literature on specialised markets (Section 4) and a study of three historical examples of knowledge markets (Section 5) we have induced (i) the central role played by cross-sectoral demand in the specialisation process and (ii) the role of technological convergence in the creation of knowledge markets.

From this we can argue that the emergence of exchange markets in technological knowledge is actually an historically specific occurrence and confined to periods and areas of technological convergence. All examples we considered point to the centrality of the process of technological convergence in establishing the cross-industry nature of a knowledge application which in turn appears to create a large enough market size to permit specialised production. Further all our examples confirmed the role of generic technologies and their development, which in turn highlights the necessary roles that the alienation of technological knowledge and the development of abstract principles played.

Where such specialised markets in knowledge type goods have emerged they have conferred the same efficiencies of specialisation and dynamic efficiency which were once observed to be characteristic of well developed capital goods sectors. Innovations that come from this sector are an important externality that raise the technological efficiency of the related sectors. One implication of this for our conceptualisation of technological change could be to think about such specialised markets as giving rise to a distributed (and more sectorally diffused) adoption of innovations economy-wide, and consequently also distributing perhaps the gains from innovation in a more uniform way.

In sectors where such specialisation does not take place and there is vertical integration of activity within the firm rather than vertical

disintegration, firms will still create knowledge and hone science and technology for successful innovation, but such firms will retain a large part of the advantages of innovation internally within the firm. In this situation the innovative firm will be capable of a range of competencies and activities and considerable valuable knowledge will be embedded in the routines and organisations of firms in a manner that has been described by several writers in a new evolutionary tradition (Nelson and Winter 1982, Dosi 1988). The gains from innovation however will be relatively less distributed (or more concentrated in particular firms and sectors). Competition between such firms will weed out the poorer firms from the better firms but the distributed externality of the previous situation may not obtain. Such a scenario would give a qualitatitively different kind of economy-wide technological change and growth from the case of specialised markets. Both the organisation of technological change and the structure of growth would be different.

There are two additional policy implications that are worth pointing out. In sectors where such knowledge markets have emerged, such as biotechnology and software, small initial demands may force such firms to seek their continued growth by depending upon globalised markets in an important way, as globalisation would expand the exchange markets for this sector. In other words, the emergence of such markets are likely to be very quickly accompanied by global markets because the derived demands from domestic demand and production can be quite small. However, in these global markets the first comer firms will always have an advantage which will not go away too easily. This may be an uncomfortable situation for countries that hope to somehow "catch-up".

Secondly, it is unlikely that subcontracting out of R&D to small technology-based firms and other organisational consequences of such specialised markets in knowledge-embodied goods will emerge in the absence of technological convergence. Policy measures which hope to stimulate the symptom, that is encourage across the board

development of small firms through subsidies, may nevertheless not be able to replicate the cause, and may correspondingly meet with a high rate of failure of such policy.

Notes

1. This has often been wrongly read as an argument suggesting the decrease in importance of tacit knowledge within the firm. Greater universal knowledge also requires the use of greater tacit knowledge in order to seek and apply the available knowledge to a specific context. " to be sure, we are not saying that experience - based learning, and tacit skills and capabilities embedded in organisational routines is no longer important. Not only does the generation of general and abstract knowledge itself depend upon tacit skills and capabilities, but...firms cannot be content just with understanding problems in abstract terms. In order to come up with specific new products or processes, they have to deal with the complexity and idiosyncratic aspects of applying knowledge to concrete problems, a process which relies heavily upon tacit abilities and trial-and-error" Arora and Gambardella (1994: 528). This makes the position of the authors different from others who have argued for the substitution of erstwhile tacit knowledge with codified knowledge (Ergas 1994).

2. This is indeed the object of study of Nightingale (1997).

3. See Rosenberg (1963) : 218-219.

4. Loasby (1993) has an excellent discussion of why markets are necessary and why firms may invest in such institutions.

5. The term regular markets refers here to the existence of buyers and sellers period after period. Regular markets may or may not be perfect.

6. This is explained in the following passage about commodities, exchange and circulation, from Grundrisse: "To have circulation, what is essential is that exchange appears as a

process, a fluid whole of purchases and sales. Its first presupposition is the circulation of commodities themselves, as a natural many-sided circulation of commodities. The precondition of commodity circulation is that they be produced as exchange values not as immediate use values, but as mediated through exchange value. Appropriation through and means of divestiture (Entäusserung) and alienation (Veräusserung) is the fundamental condition. Circulation as the realisation of exchange values implies : (1) that my product is a product only insofar it is for others; hence suspended singularity, generality; (2) that it is a product for me only insofar as it has been alienated, become for others; (3) that it is for the other only in so far as he himself alienates his product; which already implies (4) that production is not an end in itself for me but a means." Marx, K. (1857:1973) page 196. Alienation is usually discussed in a specific context popularised by existentialist philosophers, viz. the lack of control over the end use of its product by labour. However, Marx's discussion of the historical development of labour power as a commodity makes clear that the alienation of labour from the means of production was an important historical necessity in the transforming of labour power into a commodity.

7. Bala and Goyal (1994) demonstrate that such expectations may cause the birth of markets.

8. Explaining the determination of exchange values, Torrens contrasts the situation under barter with that under a society subject to division of labour in the following way: "In this rude and early state, therefore there would be no criterion to regulate or determine exchangeable value; and the terms of barter which occasionally took place, would, in each successive instance, be regulated by the immediate wants and desires of the contracting parties.

The case would be different as soon as **the frequency of exchanges began to lead to permanent divisions of employment.**" (Torrens 1821:1965 page 19). Emphasis is mine.

9. Piore and Berger (1980) used this feature of the Smithian division of labour theory to explain dualistic market structures and the co-existence of specialised large firms and transient and small firms.

10. I am grateful to Ashish Arora for clarifying this point in a discussion. The use of loyalty cards to induce buyers to shop again, in most UK superstores, reveals the importance of the frequency factor in expanding the exchange market.

11. The division of labour process is cumulative. The efficiency gains due to the division of labour ultimately lower prices which should induce more consumption. Because this decrease in price does not happen at the expense of profitability but by cutting down costs, it also allows induces more production by existing firms or by new entrants.

12. Yamin, M. (1997).

13. Roncaglia (1985) discusses this in the context of evaluating Petty's conceptualisation of the market as evidenced in The Dialogue of Diamonds: "There is nevertheless, a crucial relationship between the way an economic system functions and the possibility of extracting significant abstract categories capable of providing a theoretical representation of reality. In the absence of a market where routine exchange occurs, the characteristics and circumstances of differentiation...operate in such a way as to make each act of exchange a unique episode. The price is subject to erratic fluctuation, and the relative bargaining abilities of the buyer and seller play a significant role in its determination.

On the other hand, the existence of a regular market, large enough to even out extreme fluctuations, allows the transformation of those elements that differentiate individual elements of exchange from one another into homogenous differences in price. Mr. A, the expert, is in fact aware of the existence of precise quantitative relationships between the prices of the different types of diamond determined by weight, dimension, colour and defects".

14. Complementarities, transaction costs etc. do not contradict this argument.

15. Arora et al. (1996) make a similar point.

16. This rules out markets in professional services which may also be termed knowledge-embodied, but are for final consumption such as music, hairdressing etc. This focuses the argument towards the question that the paper tries to investigate. Section 2 tries to deal with the issue of how knowledge markets may be identified.

17. This is one interpretation that could be given to the work on technology based acquisitions as sourcing strategies for firms. See Lindholm (1994, 1996).

18. Arrow (1962) discusses the case of 'market failure' in knowledge production in a market economy.

19. However, if one takes the opposite position that knowledge cannot be context-independent then of course, the only transactions in it will always be within the firm.

20. Nadiri (1989).

21. Rosenberg (1976).

22. Sahal (1985) first pointed to the importance of technological fusion as an alternative guidepost for innovations. Kodama (1992) has discussed the impact of technological fusion in eroding industry boundaries. This erosion is not universal however. Gambardella and Torrisi (1997) show that for the electronics sector technological convergence has not actually led to a convergence in markets as product specific costs such as marketing are still important as determinants of firm performance.

23. Freeman (1968) as quoted in Landau and Rosenberg (1994) page 200.

24. Brady et. al. (1992) page 495.

25. Bud (1993) pages 190-191.

26. Despite the potential for a wide range of biotech activity, the R&D developed by this sector is highly concentrated on a narrow range of product areas notably high value human health care products. It is estimated that in early 1988, in the US two-thirds of the R&D effort by the biotechnology industry was in health care and almost 85% of this effort was in therapeutics (Yarrow 1988 as quoted in Galhardi 1994: 57).

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