Knowledge Products and Network Externalities: Implications for the Business Strategy

Joan Torrent-Sellens

Abstract This article analyses the changes in production and demand for knowledge products arising from network externalities. The demand curve of a product under network effects is concave in shape. This specificity is determined by the intrinsic value (value that it itself contributes), the marginal value (value contributed to other users of the network) and the relative size (size of the network in relation to the size of the market). The analysis reveals two distinct patterns of behaviour in knowledge-based products. Observable knowledge products are governed by the effect of direct and indirect network externalities. Also, their demand curve and business strategy depend on new-user entry (marginal value) and the relative size of the network. However, tacit knowledge products are governed by learning network externalities and their demand curve, and business strategies are dependent on the value generated by the addition of the goods themselves to the network (intrinsic value).

Keywords Decision support · Explicit knowledge · Ttacit knowledge · Knowledge management strategy · Networks

Introduction

Actually, economic activity (production, distribution, exchange and consumption) is undergoing a process of profound transformation, which we can be summarised as having started with the migration from an industrial economy towards a new structure characterised by the decisive importance of information, communication and knowledge streams. Although there are several reasons for this evolution, there is a certain academic consensus which places responsibility for this change on a triple feedback interaction (Kranzberg 1985; David 1990; Mokyr 1990, 2002; Castells 1996, 2004; Vilaseca and Torrent-Sellens 2005): first of all, a process of technological revolution

J. Torrent-Sellens (✉)
Economics and Business Studies, Open University of Catalonia (UOC), Barcelona, Spain
e-mail: jtorrent@uoc.edu
URL: http://i2tic.net/en/people/joan-torrent-sellens/

led by investment and the massive use of information and communication technologies (ICTs); secondly, by virtue of the dynamics of the space–time extension of the market for factors and products, or process of globalisation, which assume the capacity to situate the economic sphere on a planet-wide scale in real time; and thirdly, because of a new pattern in the process of demand from economic agents, which can be characterised through the increased importance of intangibles in both the family and corporate expenditure and investment structures.

From the perspective of the interaction between technology, economy and society, we might say that ICTs—which, broadly speaking, include the converging array of items of equipment and digital applications in the areas of microelectronics, information technologies, telecommunications, optoelectronics and the recent advances made in nanotechnology and biotechnology—have become one of the main foundations of the current process of radical change in economic activity and social structure. We can characterise this process of disruptive change induced by ICTs with three basic affirmations. Firstly, ICTs are fast becoming general-purpose technologies, that is, technologies which can be used on a massive scale and applied systematically by economic and social agents (Bresnahan and Trajtenberg 1995; Jovanovic and Rousseau 2006; Albers 2006). Secondly, ICTs are becoming the building blocks of a new technical and economical paradigm, that is, they are the basis of a new and innovative substrate which radically transforms the structure of basic inputs and relative costs of production (Dosi et al. 1988; Torrent-Sellens 2004). And thirdly, ICTs are the basic infrastructure of a new process of industrial revolution, that is, they are a series of disruptive changes in technique and production, interconnected with social and cultural changes on an enormous scale (DeLong 2001; Atkeson and Kehoe 2001; Baily and Lawrence 2001, 2002; Gordon 2004).

This process of disruptive change is, in fact, characterised by: (a) interconnection over a network, (b) investment, falling prices and the persistent and innovative use of ICTs and (c) the increasing presence of information, communication and knowledge streams in the area of economics, within a context dominated by the globalisation of economic relations. There has been a consensus to identify this process of transition from an industrial economy towards a knowledge-based economy (Pérez 2002; Rodrigues 2002; Foray 2004; Rooney et al. 2005; Dolsfma and Soete 2006). Thus, the knowledge-based economy becomes consolidated through a new technical property: the symbiotic relationship between ICTs and knowledge. ICTs are technologies which, as such, are knowledge and also expand and prolong the human mind in its knowledge-generation process. In other words, what we have here is a social stock of know-how which uses knowledge as an input and which contributes directly to the generation of knowledge as an output.

In short, and using a wide perspective of technological processes, understood as man's dominion over nature and his social environment (McClellan and Dorn 1999), ICTs not only affect the capacity for reproduction and control of the environment but also, more than ever, as a technological apparatus, act directly on man's dominion over himself or, more correctly, over the generation of his own knowledge. Contrary to manufacturing-based technologies, which affected manual labour, the application of ICTs to the apparatus of production extends and replaces mental labour (Autor et al. 2003). So what is the most relevant conclusion we can reach from analysing this intrinsic feature of digital technologies? It seems evident that the productive

application of ICTs is associated, to a great extent, with the stock and dynamics of knowledge within an economy.

In this sense, if we want to conduct research into the main features of the process of transition towards a knowledge-based economy, we cannot obviate the important link between its material basis and the knowledge input and output products, which has the most weight in this explanation of economic change. And, bearing in mind the symbiotic relationship between ICTs and knowledge, this article is designed to analyse the impact of network externalities on the economic structure from a conceptual perspective and within an analytical context. To do so, and after this brief introduction, we shall follow an analytical process to discuss the most general aspects to the most specific ones. First of all, and once we have explained the general context of the knowledge-based economy, we shall cover the microeconomic foundations, i.e. provide our analysis of the particular transformations that using knowledge as an input and product subject to market transactions means. Secondly, after discussing the microeconomics of knowledge, we shall be in a position to study one of its basic components: network externalities. At this point, we shall ask what impact the network effects have on economic functions and market structure. The article will end with the main conclusions of our analysis and the references used in the text.

The Knowledge-Based Microeconomy: Economic Properties of Knowledge

Following on from the above analysis, which allowed us to establish the conceptual bases of the process of transition towards a new technical–economic paradigm, characterised by the importance of streams of knowledge, we shall now conduct a more detailed economic analysis of this resource of such vital importance for a competitive future and material well-being. To do so, we need to ask ourselves the following questions: Is it possible to identify any characteristics which show how knowledge is being incorporated into economic activity? And if so, which are they? And finally, how do they transform the structure of the economy and the markets? Or, what role do they play in building a new economic substrate which is different from the industrial economy? The answers to these questions lead us inevitably towards economic characterisation as a resource and a product of knowledge and the distinction between the structure of the economy and the markets in either an industrial economy or a knowledge-based economy.

We understand the term "knowledge" as given in epistemology, the theory of knowledge: the human and dynamic process which consists of justifying a personal belief to the point of certainty (Neef 1998). This vision of knowledge as a true, adequately justified belief places the central problem of its theory on the issue of how we justify beliefs, i.e. on the explanation of the difference between knowledge and simple, true belief. Leaving these matters aside, the very epistemological definition of knowledge refers to two, very important elements which need to be highlighted from an economic point of view: first, the fact that knowledge is related to human action, and second, the fact that the generation of knowledge is a dynamic process, since it is created on the basis of interactions between individuals, groups, organisations and societies. These two characteristics allow us to place knowledge within our own

domain. That is to say, the dynamic, human action of knowledge creation can be interpreted, among other things, as an economic activity.

More specifically, can we approach a production of knowledge? To respond to this question, we need to refine even further the interpretation we make of knowledge from the perspective of economic analysis. In this context, the first thing we need to make clear is the distinction between knowledge and information, or the stream of messages from which knowledge is generated (Neef et al. 1998; Stehr 2002). Although both concepts are closely related, the economic approach focuses on the fact that information is one, if not the only, input in the process whereby knowledge is generated. The information provides a new perspective for interpreting events or objects and, as such, is a means or material necessary for obtaining and building knowledge. Information affects knowledge and adds something or restructures it. In fact, we might even say that in the act of knowing, an accumulative flow between three elements is established: data, information and knowledge. This stream of generating know-how consolidates knowledge as a resource used daily by economic agents to take decisions within the economic structure. And not only that: the knowledge generated can be represented economically through its production-based function. We could say, then, that knowledge, as a tool for production, distribution, exchange and use, is economically relevant (Lundvall and Johnson 1994; Foray and Lundvall 1996).

Actually, economic activity basically covers four types of knowledge: *know-what*, *know-why*, *know-how* and *know-who*. As regards know-what, it is easy to see how this kind of knowledge is identified with information, since it can easily be segmented and represented through bit streams. Know-what, then, refers to knowledge about facts. Know-why is an extremely important kind of knowledge for technological development in some areas of production. The production and reproduction of this kind of knowledge occurs within the context of specialised organisations, such as universities, for example. In short, know-why refers to scientific knowledge of the laws on how nature, the human mind and society develop. Know-how refers to the development of a person's capabilities and attitudes. It refers, then, to the capacity that individuals interacting in the economic activity have to do things (*skills*). This includes a wide range of characteristics that people have and which can go from abilities and capacities to skill and talent. Finally, know-who refers to a kind of knowledge that is becoming more and more important and which is based on a combination of skills, including the possibility of social action. Currently, this kind of knowledge is very important because in the knowledge-based economy, people are considering the need to access a very varied range of knowledge (who knows what and who knows how to do what), knowledge which is also extremely scattered. In short, know-who refers to the concept of knowledge networks and how to use them. As a result, this is what relates and causes the other three to interact.

We can acquire these four types of knowledge through different channels. Whereas know-what and know-why can be gleaned from books and access to data, the other two are mainly gained through practical experience. Know-how comes mainly from the educational learning relationships and also from professional development. Know-who is acquired through the social exercise of one's profession and sometimes from specialised educational environments.

One additional characteristic of these four kinds of knowledge is that whereas know-what and know-why are easily reproducible, know-how and know-who are more difficult to turn into information. This feature—facility of reproduction—leads us to a grouping of knowledge production which is very interesting for our own purposes (Polanyi 1978; Nonaka and Takeuchi 1995). It refers to the distinction between the production of explicit, observable or codifiable knowledge and that of tacit or implicit knowledge. The production of explicit, observable or codifiable knowledge is that which can be expressed in a formal and systematic language, so that it can easily be processed, transmitted and stored. The production of tacit or implicit knowledge is associated with the work factor and includes technical and cognitive elements, such as practical experience, skill and qualifications which are difficult to list.

Once we have defined the main characteristics of the production of knowledge, that is, the different, relevant forms of knowledge as an economic resource and how it is grouped together on the basis of ease of reproduction, we will be in a position to discuss how to incorporate it into economic activity as a whole. At this point, we need to highlight two elements. First of all, knowledge will be economically relevant providing it manifests itself in economic activity. For example, the knowledge incorporated by people who are economically non-active, scientific knowledge not applied to production or observable knowledge which is not used for economic activity are of no interest to us from the perspective of incorporating knowledge into the economy. However, from the point of view of production of knowledge itself, all aspects of knowledge which are not economically manifest actually do interest us—a lot. Secondly, economic activity has always incorporated knowledge as a resource: the innovative entrepreneur and human capital are two of the most illustrative examples of this. The vision of the innovative entrepreneur, who accumulates knowledge about production and the market for his new product, or the efforts to capitalise work, linked to education and training for people, are two important examples of how knowledge is incorporated into production structures.

However, it is important to point out that, over the last few decades, digital technologies have allowed us to encourage, extend and modify the economic supply of knowledge. This substantial increase in the presence of knowledge in economic activities can be seen basically from two things: the first has been the significant increase in observable knowledge used in economic activity. It is evident that the spectacular improvement in the access to, and management of, streams of information and knowledge has caused the barriers to distribution and the productive use of observable knowledge to come down to a great extent. The second is the transformation of tacit knowledge into observable knowledge, and the change in the training requirements and skills and in experience that the knowledge-based economy demands of the workforce. In short, we can conclude this vision of knowledge as a resource of economic activity by saying that the intensive use of ICTs has resulted in: (1) an increase in the supply of observable knowledge, (2) the transformation of tacit knowledge into observable knowledge and (3) the development of new abilities within the workforce, which has ended up generating a virtuous circle between the production of knowledge and its economic and social uses (Antonelli et al. 2000).

We have just seen how, when knowledge interacts with ICTs, it becomes consolidated as a resource of capital importance for economic activity. However, if we were

to limit our description to this single aspect, we would only be able to reach partial conclusions because these days, knowledge is not only an implicit resource for the production of all goods and services, but has also become a product which can be traded, an item or a service which is exchanged on the markets. In this sense, it is important to point out that knowledge goods and services or products have certain special characteristics that we must be able to analyse. To do so, just as with knowledge as a resource, we must make a distinction between: (a) the economic properties of easily reproducible or observable knowledge products deriving from the economic application of know-what and know-why and (b) the economic properties of knowledge products which are difficult to reproduce or tacit in nature, deriving from the economic application of know-how and know-who.

An initial approach to the characteristics of easily reproducible knowledge products is the one that, on the basis of the process of digitalisation, can list the economic properties of what are known as information goods (Shapiro and Varian 1999; Shy 2001). The terms "information goods" or "observable knowledge products" (i.e. the manifestation of observable knowledge as an output) refer to any good or service which can be digitalised, i.e. coded as a series of bits. For our purposes, these can be football results, books, databases, magazines, films, music, stock market listings and web pages, among many others.

Their first, fundamental characteristic relates to the cost structure and comes from the fact that observable knowledge goods and services are expensive to produce and very cheap to reproduce. In economic terminology, they have high fixed costs and very low marginal costs (with a trend towards zero). This, then, leaves us in the world of increasing returns to scale, that is, with increases in output which are higher than the increases in the productive supply of inputs. This cost structure has important consequences when it comes to setting prices, because it cannot be based solely on cost (which is very low for reproduction) but must inevitably include how much the consumer values the good or service. In fact, the presence of increasing returns leads us inexorably to product differentiation strategies as an opportunity to increase the extent to which the end consumer values observable knowledge products.

A second characteristic of observable knowledge as a product is the fact that it is considered to be an experience good. A good or service is an "experience" good or service if consumers need to try it to see whether or not it is useful. In spite of the fact that any new good or service is an experience good, observable knowledge products are experience commodities because the end user cannot determine whether they are useful until he/she consumes them. Also, this occurs each time the need to consume them is considered. The goods and services of the industry creating, editing and disclosing content are a clear example of this. The person who reads a book, the user of an education service or the viewer of a film cannot determine how useful the merchandise that they have purchased is until they use them. From the firm's perspective, this situation occurs when, as experience in production increases, the cost per unit produced falls. Experience economies exist when the average cost of production falls as the firm acquires more experience. In short, firms which produce observable knowledge products reduce the unit cost of production as their experience in the consumer's final perception of its goods increases. As a result, there is a circular flow of perceptions of observable knowledge products between entrepreneurs and consumers as the two economic agencies' experience grows.

A third characteristic of easily reproducible knowledge products is the decreasing marginal usefulness that access causes. This idea of saturation generates a sensation of accessible and observable knowledge overload. So the problem we are currently facing is not one of access to the information, but of information overload. Therefore, this kind of knowledge product is characterised by a degree of consumer satisfaction which decreases as the sensation of saturation increases due to the overload of outputs to which the consumer has access. This, together with the cost structure, is one of the reasons why many firms producing this kind of commodity apply differentiation strategies designed to increase customer loyalty.

A fourth characteristic, related to the convergent evolution of digital technologies and also to companies' product differentiation strategies, is the tremendous barriers to the release of observable knowledge products. In other words, the technological dependency of users of this kind of knowledge means that the costs of changing (*lock-in*) are very high. They may be very wide ranging, from the expense of changing technology to the cost of learning how to obtain the new knowledge required to use it (*wetware*). A typical example of this situation is the problems arising when IT software is changed. These range from incompatibilities with other programmes to the need for new training.

Finally, easily reproducible knowledge products have a fifth attribution, deriving from the progressive usefulness of a growing number of users for consumers. This characteristic—which, in economic terms, is related to the network externalities deriving from its use—is based on the fact that usefulness for consumers grows exponentially as their numbers increase (Metcalfe's Law).

On the other hand, as we said above, knowledge products also incorporate a less easily reproducible kind of knowledge. In fact, this is basically how to market the know-how and the know-who. Some examples of knowledge commodities which are hard to reproduce are the capabilities, abilities, talent or skill which the workforce brings to the economic activity, the knowledge that economic agents have about production, the market or a specific sector and the capacity for social interaction in order to glean in-depth knowledge of the features of an economic activity. In spite of the fact that there are some markets for this kind of knowledge—*headhunters* would be one of the more paradigmatic—many of these exchanges of knowledge occur within the company (internal job markets). However, what are the economic properties of this kind of product?

First of all, we must point out, as we have above, the difficulty of processing, storing and transmitting tacit knowledge products. This leads us to a relevant economic consideration: the difficulty of reproducing them. For example, it is easier to reproduce a book, a CD or a film digitally than it is to reproduce the skills workers use to carry out their jobs. The marginal costs of this kind of knowledge product are higher than those of observable knowledge merchandise, and therefore, the condition for increasing returns is less intense. However, under no circumstances does this mean that tacit knowledge goods and services break away from the concept of non-rivalry, one of the characteristics of knowledge products, or rather one of the characteristics of public goods. The idea of a non-rival good highlights the fact that once a good is produced, it can be consumed by more than one person at a time. The difference between a banana (rival good) and a mathematical formula (non-rival good) is, precisely, that the former can only be consumed once, while the latter—

once generated—can be applied to economic activity as many times as necessary. At present, the fact is that—with the use of ICTs—not only can we access huge amounts of information and training which affect tacit knowledge, but new markets for tacit knowledge products have developed: for example, internet companies which act as intermediaries between the supply and demand for jobs.

The second characteristic of tacit knowledge goods and services that needs to be analysed is the fact that they are considered experience goods. Here they coincide with observable knowledge products, insofar as their usefulness for the consumer is determined once they are consumed. However, as in the previous case, ICTs affect the usefulness of the producer and the consumer, in the sense that they facilitate and improve the exchange of information or displays of content.

With regard to the decreasing marginal usefulness of access to tacit knowledge products, everything seems to point to consumer saturation being lower than in the case of observable knowledge. There are two basic reasons for this: first, because—as we have already said—the difficulty of reproduction means that these products are not present on digital markets in the same way as products which can easily be turned into information, and second, because tacit knowledge products become a priority for developing economic activity, which boosts the demand for them. In this sense, we might even say that, whereas in the case of some observable knowledge products consumers may feel that there is an excess of supply, with tacit knowledge products, there is more a sensation of an excess of demand.

On the other hand, the difficulty of transferring tacit knowledge to an activity which can be economically traded also minimises the effect of barriers to release or to the change from one tacit knowledge product to another. Finally, there is one more highly relevant characteristic. This is the important network externalities and the use of tacit knowledge goods and services. These externalities come from two areas: firstly, as with observable knowledge, given the increase in usefulness which comes from a larger number of users (use network externalities), and secondly, given the characteristics of knowledge in this type of commodity (intrinsic network externalities), which involve a high level of relational knowledge (know-who).

Taking the four types of knowledge included in economic activity and the ease of reproduction of knowledge commodities into account, Table 1 reproduces the economic characteristics of observable and tacit knowledge commodities.

Network Externalities in the Knowledge-Based Microeconomy

After analysing the microeconomic properties of knowledge, we can now cover in greater detail one of the properties which most often develop in digitally based economic activity: network externalities. The concept of externality is very important in economics because it looks at the impact that individual decision-making has on the other agents. It is a concept of comparison, which refers to how decision-making involves others without there being any kind of consideration or exchange (Katz and Shapiro 1985). Externalities can be positive or negative, depending on the direction of the impact (positive or negative) of individual economic decision-making on the other agents. For example, and to cite different directions—externalities—that the same action can generate: the decision by public governments to implement an

Table 1 The economic properties of observable knowledge and tacit knowledge products

Type of knowledge	Ease of reproduction	Type of good	Economic properties	Examples
Know-what	Observable knowledge	No rival	High increasing returns	Digital content
		Experience good	Decreasing marginal usefulness	Media
		Capacity for exclusion	High barriers to release	Hardware, telecommunications and machinery
			Use network externalities	Software and services
Know-why	Observable knowledge	No rival	High increasing returns	Scientific knowledge
		Experience good	Decreasing marginal usefulness	Research and development
		Average exclusion	High barriers to release	Patents
			Use network externalities	Innovation systems
Know-how	Tacit knowledge	No rival	Average increasing returns	Internal labour markets
		Experience good	Decreasing marginal usefulness	Internet job sites
		Low exclusion	Few barriers to release	Wetware
			Use network externalities	Digital competition
Know-who	Tacit knowledge	No rival	Average increasing returns	Capital and social networks
		Experience good	Increasing marginal usefulness	Relational wetware
		Low exclusion	Few barriers to release	Professional networks
		Intrinsic network externalities	Use network externalities	

Source: own elaboration

infrastructure—a road, for example—can generate a series of positive externalities in the sense that it boosts activity and synergies in economic activity, but at the same time, it can also generate negative externalities in the sense of increasing traffic jams and environmental problems.

The term "network externalities" refers to the increased usefulness that a user of a product (technology, good or service) gets as the number of users of the same product increases (Arroyo 2007). This property, also known as "demand-side economies of scale" or "network economies", introduces a dynamic on the market which assumes that the price that users are ready to pay is partly determined by the size of the network to which the product belongs. And not only that: the decision to use or purchase the product is determined by the expectations for success of the different

competing networks (Brynjolfsson and Kremer 1996). However, the appearance of network economies assumes that there is a certain degree of complementariness and/or interaction between the various individual agents/nodes which configure them. As in the more aggregate case, network externalities may be either positive or negative, depending on the interactions involved.

Broadly speaking, network economies fall into three large groups: (1) direct network externalities, (2) indirect network externalities and (3) learning network externalities (Amit and Zott 2001; Zodrow 2003). Direct network externalities refer to the increased usefulness of the network for the user as the number of nodes grows. This is the typical positive effect of Metcalfe's Law which can be seen on communications networks, software users or internet portals. In the same way, negative effects can also be generated, linked to congestion or the problem of a saturation of information. Indirect network externalities refer to the improvement in market conditions directly linked to standardisation. Increases in the number of nodes in a network can cause prices to fall (scale economies), variety to increase (complementary products) and conditions of access and use to improve. This is the typical positive effect linked to the standardisation of a hardware and complementary software as a result of massive use (Basu et al. 2003). As in the previous case, this can also cause negative effects, linked to the existence of dominating position on the market and competition-restricting practices. Finally, the externalities of the learning network refer to the consolidation of a specific, expert knowledge as the network nodes increase. The cumulative contribution of specific knowledge to other network users and the dilution of learning costs are the main reasons for this kind of network economy. This is the typical external effect on which the consolidation of the use of the current computer keyboard, the spread of the PC and even the success Linux and Open Office-type operating systems and software is based (Goolsbee and Klenow 2002). As above, we can also find negative learning network externalities relating to entrance barriers to expert knowledge, changeover costs or the costs of the opportunity to learn.

Although network externalities are not a new phenomenon in economic activity, since they have been found to exist, for example, in transport and analogue communications networks, the massive application of ICTs and the internet and the digitalisation of economic activity mean that they are of paramount importance for the development of the knowledge-based economy. Doubtless the implementation of business strategies, the analysis of consumer patterns and even the development of public policies need to take the growing presence of network economies into account.

In spite of their increasing importance in explaining economic activity, the large amount of academic and inter-disciplinary research into network externalities has mostly been based more on their theoretical aspects than on the empirical corroboration of their effects and implications. To solve this problem, a large number of studies have appeared over the last 10 years which have begun to corroborate the impact of network effects on firm strategy, market structure, consumer standards and the development of public policies (Economides 1996a, b, 2007; Bobzin 2006; Goyal 2007; Jackson 2008).

The concept of *positive feedback* establishes the starting point for research into network economies. This approach, linked to the process of adoption and use of technology, says that when in the presence of network economies, strong products

become even stronger (virtuous circle) whereas weak products become even weaker (vicious circle). Within this context, the process of adopting a product in the presence of network externalities will follow a *winner takes all* pattern, in the sense that a single product will dominate and the rest will be eliminated (McGee and Sammut 2002). Figure 1 shows how the presence of network economies and the result of the feedback process (virtuous/vicious circle) end up explaining the product adoption process.

At this point, it is important to establish certain considerations. First of all, we would point out that the law/rule that value generation fulfils in digital markets in which network effects are present is Metcalfe's Law. This approach states that if a network is made up of n people, the value for each node in the network (user nth) is proportional to the number of the other members of the network, $n-1$. In this way, the total value of the network is proportional to the number of nodes multiplied by the value of the network for each of them. That is to say, $n \times (n-1)$. Although this rule provides us with a simple interpretation of value creation in network-based economies, whether it is fulfilled or not depends on two basic nuances which will provide us with the specific form of the function for adopting a product: (1) the combination of marginal, positive and decreasing returns and decreasing marginal returns from the point at which negative congestion externalities are achieved and (2) the consideration that the interconnection between networks of different sizes adds more value to the smaller network than to the larger one.

Metcalfe's Law postulates that the marginal value provided to the network by one user to all the other users is constant, k. This being so, user nth contributes a value to the rest of the network users which is the result of his/her contribution minus the contribution of the other users, i.e. $k \times (n-1) - k \times (n-2) = k$. If we now calculate the relative contribution of user mth, where $m>n$, we find that $k \times (m-1) - k \times (m-2) = k$. In fact, the assumption that all connections contribute an equal value to the network is highly debatable for at least two reasons (Zodrow 2003; Odlyzko 2006): firstly,
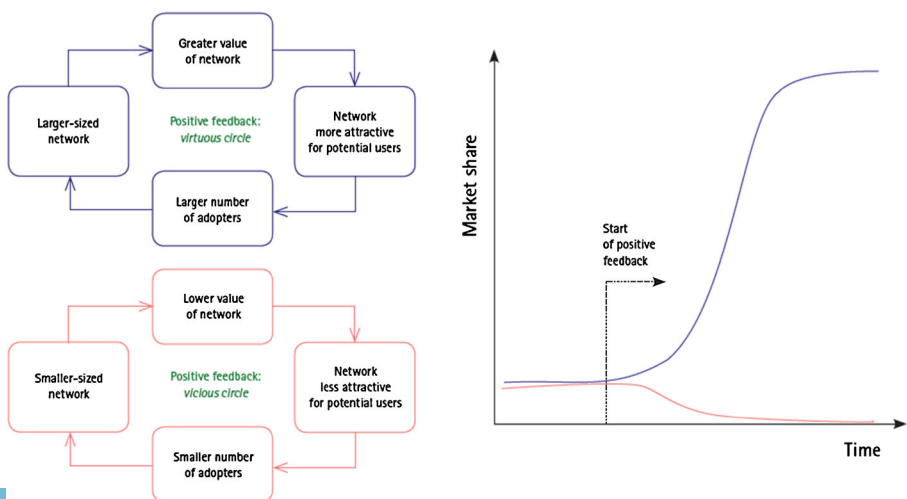

Fig. 1 Network externalities, feedback process and the spread of the product. Source: reproduced from Arroyo (2007)

because the profile of the users who connect up to the network and their value contribution does not necessarily always have to be the same, and secondly, because in large networks, the possibility of additional user interconnection does not have to be total. In mathematical terms, the growth of a network from n to $n+1$ users means an increase in the total number of possible connections of $2n$, the result of deducting the possible connections by $n+1$, i.e. $n\times(n+1)$, from the possible connections at the initial point n, i.e. $n\times(n-1)$. However, for an individual user, the increase in the number of possible connections in the move from a network with a size of n to a network with a size of $n+1$ is 1. Within this context—the increase of one connection to the network—the size of n is tremendously important, because an additional connection to a small network is not the same for a new user as to a large network. As a result, the value added to the network depends on the point of time at which the additional user joins and the size of the network. In this sense, after a certain number of users, congestion externalities may appear because the value that an additional user adds to a large network may be negative since it sets limits to existing connections.

On the other hand, Metcalfe's Law supposes that, when two networks merge, the value of both of them increases by the same amount, regardless of their initial size. Suppose we have two networks, A with n users and B with m users, where $n>m$. With the merging of the two networks, each user of A finds that his value increases proportionally to the number of new connections, m. Therefore, the total increase in value for network A is established in proportion to $n\times m$. Following the same line of reasoning, the total increase in value of network B is established in proportion to $m\times n$. In this way, and regardless of their sizes, A and B would increase their value in the same proportion. This result, which lies at the heart of the second rider to Metcalfe's Law, would not explain why smaller-sized networks are prepared to pay to join a larger network, thanks to the relative increase in value that the merger brings.

Secondly, it should be pointed out that the form of the adoption/purchase of products curve in the presence of network externalities depends on how far a critical mass of users has been achieved. That is to say, the minimum size of the network which encourages potential users to join it (establishes the starting point for positive feedback). The image on the left of Fig. 2 outlines the point at which critical mass is achieved for a product based on its price and the number of people adopting it (size of the network). Given a demand function for a product with network effects, whose functional form (concave) we will analyse in depth later, the figure shows us that there are two possible amounts of balance for a given price, $E1$ and $E2$. $E1$ is an unstable balance and represents the point of achievement of critical mass, whereas $E2$ is a stable balance. In fact, for networks smaller than point $E1$, the demand curve for the product is lower than its price, that is, the price of the networked product is fairly unattractive given the small size of the network. In such a situation, new users are not interested in the network, and even existing ones may feel an incentive to leave it. In the same way, in networks larger than point $E1$, with networked product prices higher than demand, the incentives are for the size of the network to continue to grow until it achieves its size for balance $E2$.

In this sense, it should be noted that the concave shape of demand and reaching the point of critical mass determine the sigmoidal shape (S shape) of a product adoption curve under network effects (the image on the right of Fig. 2). This shape, which is also present in many other product adoption curves without network effects, is
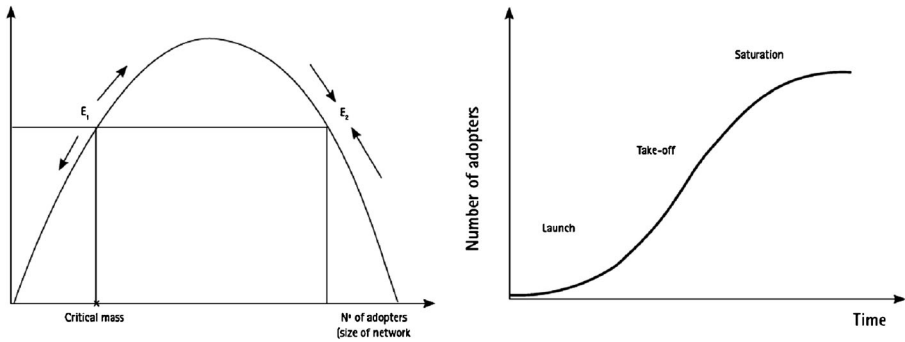
Fig. 2 Critical mass of users and the product adoption curve under network externalities. Source: reproduced from Rohfls (1974)

substantially different from those of other, non-digital products, particularly as regards the duration of their three stages: launch, take-off and saturation. In the first or launch stage, adoption growth is very slow, and the curve is almost flat. This is due to the problems of achieving the necessary critical mass, and this period is often called the *penguin effect*. In the second or take-off stage, there is sharp growth, much greater than where there is no positive feedback, once the network has achieved critical size. In the third or saturation stage, growth slackens off, and the size of the network stabilises. Sometimes, there is also a fourth stage, decline, where the product becomes obsolete, and better replacements consolidate (Rohfls 1974; Goldenberg et al. 2004). Finally, scientific reference material has confirmed that the price, the expectations for success (firm reputation, installed client base, ability to offer a valuable product, property rights, speed of reaction, ability to manage lock-in and strategic alliances) and complementary products become consolidated as the key factors which explain the success of product adoption under network externalities (Arroyo 2007).

Once we have analysed the bases upon which the economy of network effects stands, we are ready to tackle the analysis of its demand function. Contrary to traditional functions, as we can see from the riders to Metcalfe's Law that we discussed above, the demand function for products with network effects is concave in shape, caused by the existence of: (1) an initial, increasing raster which indicates the positive relation between the value of the network and the increase in the number of users and (2) a second, decreasing raster which reflects a marginal contribution to the smaller network from new users from a certain point on (congestion effects).

Within this context, the construction of a demand curve subject to network effects can be considered as follows (Economides and Himmelberg 1995). Firstly, we must point out that the demand for a product subject to network effects depends on the price and the number of network users. If n is the aggregate demand, p the price and n^e the installed client base, we can express the aggregate demand equation as $n=f(n^e, p)$. Secondly, inverting this equation, we can express the price that consumers are prepared to pay through the number of people requesting it and the size of the network, i.e. $p=p(n, n^e)$. Thirdly, and depending on the different sizes of network (n_i^e), we can represent the various price curves as $p=p(n, n_i^e)$, $\forall i=1, 2\ldots n$. Fourthly and finally, the demand curve is obtained from the intersection of each curve $p=p(n,$

n_i^e) with the installed client base (n^e). Figure 3 shows the demand curve for a product under network effects. It should also be pointed out that the vertical axis is also part of the demand curve.

Although the representation of demand under network effects shown in Fig. 3 is one of the most frequent ones, studies have identified different forms in this function, based on the incorporation of three key elements (McGee and Sammut 2002): (1) the intrinsic value of the product, (2) the marginal or synchronisation value and (3) the size of the network in relation to the size of the market. The term "intrinsic value" of a network commodity refers to the value that it provides to the network user. For example, e-mail provides value to the user of a network insofar as he/she can connect with other users, whereas software such as a word processor or a spreadsheet provides an intrinsic value to the user, regardless of whether or not he/she is connected. So, for our purposes, the intrinsic value is the value of a product for a network size of zero. In the case of network products with an intrinsic value of zero, such as e-mail, we refer to *pure networked products*. The term "marginal" or "synchronisation value" means the value that the addition of other users to the network generates for a user. For example, in the case of mobile phones, marginal value will be high, because the value increases for network users with each additional new user. However, in the case of office suite software, the marginal value of the network is lower, since although the increase in value for network users is evident when there is a new user, the increase is lower than with pure network products. The reference material has identified these two characteristics of the demand for network commodities by formulating a value function, U, which is expressed as a function of the intrinsic value and the marginal value (Kauffman et al. 2000). This function, $U=a+b(n^e)$, suggests that the demand for a network product depends on its intrinsic value, a, and its marginal value, $b(n^e)$, established on the basis of the size of the network. We should point out that a represents the ordinate at the source of the function, i.e. for pure network products $a=0$, whereas $b(n^e)$ represents the ordinate which derives from the function, i.e. its marginal increase, with $b(0)=0$. Finally, the value of the network also depends on the relation between its size and the size of the market. For example, statistics software or packages will generate a lower network value than an office suite software or package, because the potential number of users is smaller in the first case.
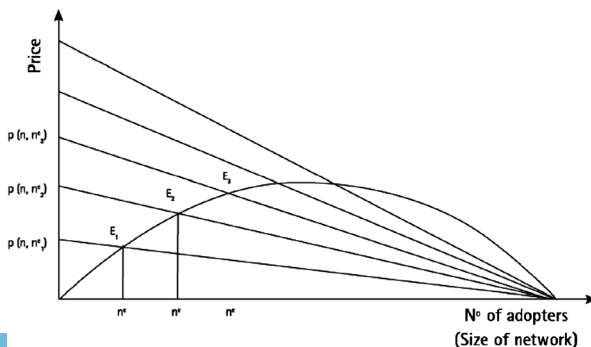

Fig. 3 The demand function of a product under network externalities. Source: reproduced from Economides and Himmelberg (1995)

Figure 4 represents different forms of a demand function under network effects, in accordance with the three properties explained above. In all cases, the demand function is concave, i.e. in the shape of an inverted U, although with various manifestations, depending on its intrinsic value (ordinate at source), its marginal value (slope) and the maximum point of the curve (which tells us the maximum point of balance after which negative externalities appear).

Finally, after characterising the demand function of a product under network effects, in Table 2 we have summarised the link between the analysis conducted on network effects and knowledge products (Torrent-Sellens 2009). We have already discussed above the fact that, broadly speaking, there are two kinds of knowledge product (technology/good/service): observable knowledge products and tacit knowledge products. Basically, the former are maintained under the effect of direct and indirect network externalities, whereas the latter, heavily implicated in people's hard-to-codify knowledge, associate under the effect of learning network externalities. They both have the potential to develop positive and negative effects, depending on the interactions established between the network agents/nodes. However, the true distinction between these two kinds of product can be found in the form of their demand function. Observable knowledge products base their creation of value on the potential that the arrival of new members of the network offers (marginal value) and their large size. However, the creation of value in tacit knowledge product is based in the high intrinsic value that these products have. In this sense, it should be pointed out that this dissociation in demand generates two distinct business strategies. For business based on observable knowledge products, the network effects determine a strategy basically built on a maximum number of agents joining the network. For business based on tacit knowledge products, the network effects determine a strategy basically built on the contribution of value to the network through the commodity itself.
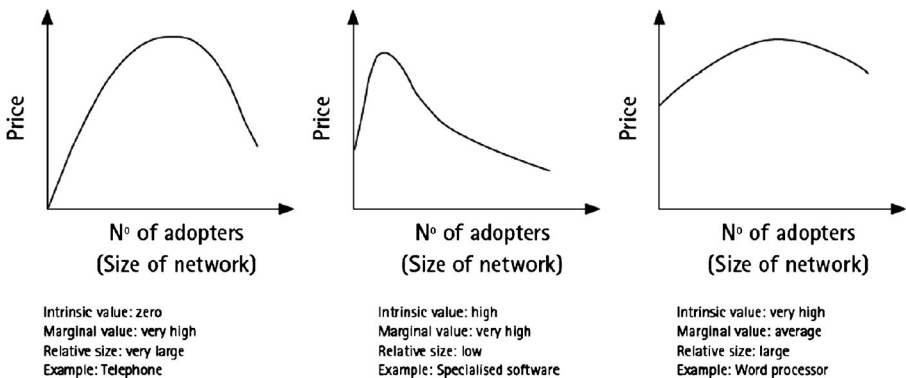

Intrinsic value: zero
Marginal value: very high
Relative size: very large
Example: Telephone

Intrinsic value: high
Marginal value: very high
Relative size: low
Example: Specialised software

Intrinsic value: very high
Marginal value: average
Relative size: large
Example: Word processor

Fig. 4 Demand functions of a product under network externalities in accordance with their intrinsic value, marginal value and size of network, Source: reproduced from McGee and Sammut (2002)

Table 2 A taxonomy of the demand function of knowledge products under network externalities

Type of knowledge	Basic network effects	Types (+/-) of network effects	Properties of demand
Observable knowledge	Direct network externalities Indirect network externalities	+ Increases in value + Falls in pricing + Increases in variety + Improvement of conditions of access and use - Effects of congestion - Saturation of information - Dominant market positions - Restrictions to competition	Low intrinsic value High marginal value Relatively large size Function shape:
Tacit knowledge	Learning network externalities	+ Accumulation and diffusion of knowledge + Dilution of learning costs - Barriers to gaining expert knowledge - Changeover costs - Learning opportunity costs	High intrinsic value Low marginal value Relatively small size Function shape:

Source: own elaboration

Contributions

In the course of this article, we have analysed how the growing productive application of information and communication technologies (ICTs) has opened the gates to change within the technical–economic paradigm, which we call the knowledge-based economy, and contains the resource and the product which explains the progress in productivity and, therefore, in economic growth and material well-being on the threshold of the twenty-first century. We have also seen how important network effects are in explaining the dynamics of production, consumer affairs and markets in the knowledge-based economy. Summing up, and taking into consideration the growing link between knowledge, networks and economic activity, we have reached the following ten conclusions:

1. ICTs and streams of information, communication and knowledge are the material bases for a process of radical economic change, which we call the knowledge-based economy.

2. ICTs increase the allocation of observable knowledge, change tacit knowledge into observable knowledge and allow the economic agents to develop new skills within a context of the virtuous circle between production and the use of knowledge.

3. Observable and tacit knowledge products have the economic properties of a public good and experience, with a high level of externalities. Moreover, as knowledge becomes easier to transmit, the decreasing marginal usefulness of access (the congestion effect) and the barriers to release tend to grow.

4. The term network externalities is considered to mean the increase in value that a user of a product (technology/good/service) obtains as the number of users of the same product increases. There are three large groups of network economies: (a) direct network economies, linked to the increase in the number of network users, (b) indirect network economies, linked to the standardisation of products and markets and (c) learning network economies, linked to the expert knowledge which is generated on the network.

5. Contrary to some excessively optimistic contributions, all network externalities can have positive and negative effects, depending on the dynamics of interaction established between their nodes, and between their nodes and the outside world.

6. The adoption/purchase curve of a product in the presence of network externalities depends on how far a critical mass of users has been achieved. The sigmoidal form (S) of this curve covers three stages: launch, take-off and saturation, with a periodicity and intensity different from the adoption curve of a product without network effects.

7. Contrary to the traditional form, the demand curve of a product under network effects is concave in shape (inverted U). The specificity of this demand curve is determined by the intrinsic value (value that it itself contributes), the marginal value (value contributed to other users of the network) and the relative size (size of the network in relation to the size of the market) of the product being dealt with.

8. Observable knowledge products are governed by the effect of the direct and indirect network externalities. Tacit knowledge products associate under the effect of learning network externalities.

9. The demand curve of observable knowledge products builds their potential through new members joining the network (marginal value) and their large size. However, demand in tacit knowledge products is based on their high intrinsic value.

10. The different form of the demand function in observable and tacit knowledge products also determines differentiated business strategies. For observable knowledge product businesses, the value is generated through the maximum number of users joining the network. For tacit knowledge product businesses, value is generated by the commodity itself being added to the network.

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