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University role

On the role of the university in the knowledge economy

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This paper draws on recent conceptual approaches to economic growth, in which the accumulation of knowledge is the fundamental driving force behind growth, to examine the contemporary role of the university. It suggests that the functions that society commonly attributes to the university are beginning to be shared with a wide range of institutions in the context of the knowledge-based economies, so that the university is faced with demands that require a strengthening of its ability to create and disseminate knowledge. While the role of universities is in need of some rethinking, their institutional integrity must be preserved. To cope with the variety of demands and a continuously changing environment, it is argued that the higher-education system needs to be diversified. Specific policy proposals are made in terms of institutional arrangements that assure diversity, while maintaining institutional integrity.

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KNOWLEDGE IS INCREASINGLY the main strategic resource for ensuring economic growth in developed countries, as the World Bank and the OECD (Organisation for Economic Co-operation and Development) have argued in recent publications (World Bank, 1998; OECD, 1996). Abramovitz and David (1996), in a joint work in which this idea is explored, state that:

> "the expansion of the knowledge base … progressed to the stage of fundamentally altering the form and structure of economic growth."

In other words, the importance of creating, distributing and using knowledge challenges more traditional ways of understanding the process of economic development. It also raises new questions about the role of institutions such as firms and universities, as well as the suitability of traditional management methods and public policies given the new reality.

This paper sets out to analyse these questions with reference to the university. As a basis for this analysis, the conceptual framework of the new economic growth theories, which have become of increasing importance in the academic world and in management and the formulation of public policy, has been taken as a reference.

The paper is divided into five sections. Following this introduction is a presentation of certain indicators that underlie the perception that knowledge is increasingly important in developed economies. Our interpretation of the new economic growth theories is described in the third section, which presents the principal concepts associated with these theories that are relevant to our analysis of the present-day role of the

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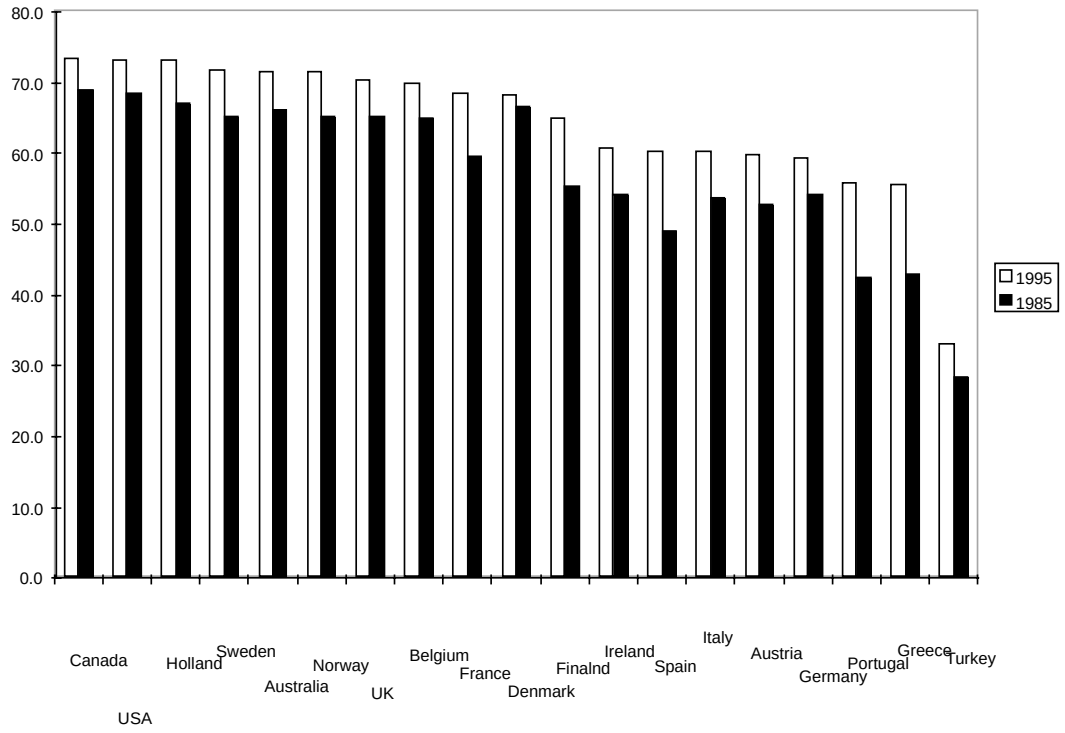

Figure 1. Proportion of workforce employed in the services sector in 1985 and 1995

Source: OECD (1996)

universities. The fourth section discusses the university's functions in terms of our understanding of the interaction between knowledge and learning pro-cesses. Finally, the conclusions of the paper are presented.

Growing economic importance of knowledge

The scarcity of empirical data on intangible economic factors makes it extremely difficult to demonstrate the growing importance of knowledge. The great majority of analyses based on quantitative data enable this importance to be established only indirectly. To a large extent, this comes from the difficulty in using traditional economic indicators to describe current trends in economic growth and job creation. In this section, therefore, certain data are presented that indirectly demonstrate the growing importance of knowledge in developed economies.

Movement of labour to services

The continuing movement of labour into the services sector, as shown in Figure 1, demonstrates the growing importance of activities in which physical goods are not produced. Figure 1 also shows that in more developed countries there is generally a higher proportion of total employment in services than is seen in less developed nations, which indicates a correlation between the proportion of labour employed in services and level of development. But the important point to make is that there is a relative increase in economic activity associated with intangible factors, compared to those associated with the production of physical goods, the exploitation of natural resources, and agriculture.

The conclusion that the growing importance of the service sector is associated with greater emphasis on knowledge-intensive activities should, nevertheless, be analysed in more detail. There are in fact a great number of services which, although by definition are associated with the production of intangibles, are not linked to knowledge in the 'higher' sense of the creation of ideas or the use of intellectual resources. Examples are cleaning services and generally the subcontracting of low added-value services such as security, maintenance and catering, which were previously carried out within an organisation, as well as employment in fast-food restaurant chains.

To shed light on this point, the structure of employment in the United States in recent decades is analysed, based on Wilson (1993). This analysis is also relevant in providing a more rigorous basis for issues raised in the following paragraphs concerning the role of a university education in preparing graduates for the employment market.

Figure 2 shows the proportion of the workforce employed in the services sector, divided into six different categories, classified according to type of demand:

1. Distribution of electricity, gas, water; telecommunications and transport (intermediate services

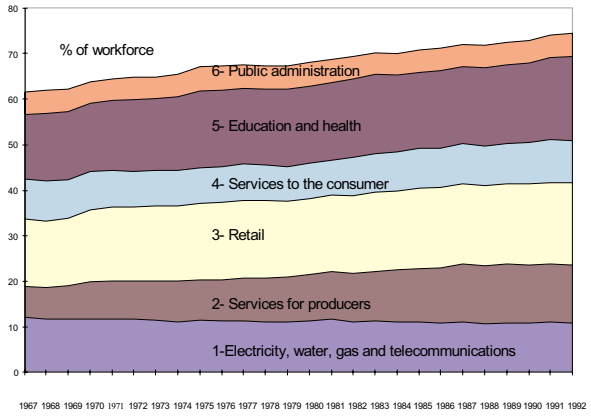

Figure 2. Evolution of the structure of employment in the services sector in the United States between 1967 and 1992

Source: Wilson (1993)

for companies and final services for consumers);
2. Services for producers, provided to companies upstream of consumers, including high added-value activities such as consulting (legal, management, engineering, finance, and accounting), insurance, and asset management;
3. Retail, that is direct sales of finished products to consumers;
4. Services to the end-consumer, similar to category 2 except that the client is the end-consumer;
5. Education and health;
6. Public administration.

The results show that categories 1, 4 and 6 remained at the same proportion during the period under analysis. The relative increase of workforce in services was contributed by categories 2 (from around 7% in 1967 to 13% in 1992), 3 (from 15% to 18% in the same period) and 5 (from 14% to 19%). Services to prod-ucers, and education and health thus increased their share of employment by 11% between the end of the 1960s and the beginning of the 1990s. Both categories are primarily associated with high value-added activities, and typically require qualified personnel. It may thus be concluded that to a large extent the increased proportion of the workforce in services is effectively due to the increasing importance of knowledge in economic activity.

As Figure 2 shows, the increase in relative import-ance of services between 1967 and 1992 is reflected in a rise of some 14% in the proportion of the workforce in this sector, 11% of which arose from increases in employment in categories 2 and 5 and the remaining 3% from an increase in the retail sector. It is important to analyse developments in the retail sector in detail, since this also illustrates the growing importance of knowledge, albeit a kind of knowledge that is formalised and codified, in other words stored on paper or in digital form.

In fact, a considerable proportion of the employment generated in the retail sector is in positions with

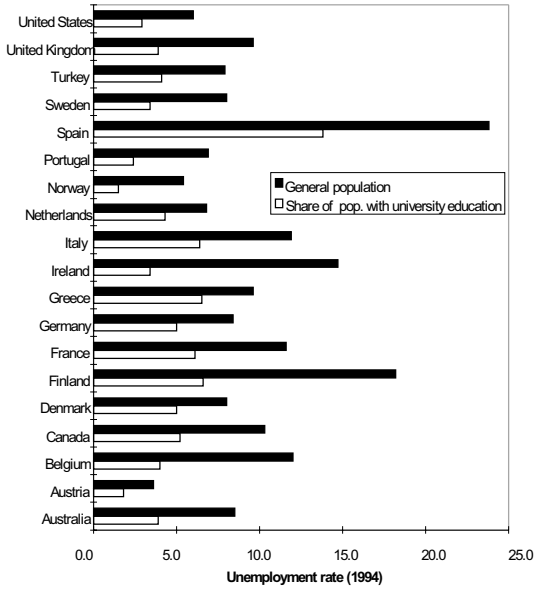

Figure 3. Unemployment rates for workforce and for the proportion of workforce with university education

Source: OECD (1996)

low qualification requirements, from which it could be inferred that in this case the knowledge factor is less significant. However, according to Wilson (1993), growth in the retail sector has taken place in franchises, such as fast-food chains, clothing outlets, book and music shops, and department stores, in which there is a great need for codified knowledge such as sales-point instruction manuals, purchasing regulations, promotions and sales. So here also knowledge is important in the economic activities of the firms that have created employment in the retail sector, even though this knowledge is codified.

Furthermore, the franchising companies require supervisors, who are responsible for the organisation and day-to-day running of each branch, creating a demand for personnel for management positions, which again requires professional and educational qualifications. According to Wilson (1993), the proportion of total employment in the USA classified as involving management tasks rose from 7.6% in 1970 to 12.3% in 1992. As confirmation that these mana-gers were not solely those at high decision-making levels in companies, Wilson (1993) notes that, at the end of the 1960s, salaries for this employment category were double the national average, while in 1992 the ratio was 1.67, against a background of increasing wage inequality in the American economy, especially during the 1980s.

To summarise, the analysis for the case of the United States shows that it may be inferred from changes in the structure of employment in favour of services that economic activity in developed countries is increasingly associated with knowledge. There is also a clear correlation between the ease of getting jobs and the level of educational qualifications.

It is clear that developed economies exhibit a population with high levels of education and, within countries, those with more education are more easily integrated into the economic activity

It can be argued from Figure 3 that this phenomenon is at work in other developed countries beyond the United States. Indeed, the figures show that unemployment rates among those members of the workforce with a university education are generally half those among the total workforce in most OECD countries. This shows that the tendency to favour the employment of qualified personnel is not unique to the American economy.

Nevertheless, the data in Figure 3 do not directly confirm that this results from demand, but could instead reflect different degrees of inflexibility in the employment market for different educational levels, or cultural and institutional factors. Some authors have argued that sociological and psychological factors, rather than economic factors associated with increasing demand for qualified personnel, are dominant.

Thus Dore (1976) differentiates "education" from "schooling", which refers to "mere qualification-earning", leading to an "educational inflation" spiral. Bourdieu and Passeron (1970), Boudon (1973), Jencks (1972), and Bowles and Gintis (1976) are similarly sceptical about a direct relationship between increases in the level of education and economic performance. The differences between the economists of human capital and these other authors, who come primarily from sociology, remain today, and are still a fertile soil for scholarship.

Even with all the reservations outlined and regardless of the reasons or causes for the increased levels of education, it is clear that developed economies exhibit a population with high levels of education and, within countries, those with more education are more easily integrated into the economic activity.

Types of investment

Another indicator that is relevant in establishing the growing importance of knowledge in developed economies relates to types of investment. Investment is essential for economic growth, since it generates the flows that result in the accumulation of the capital production factor. Intangible assets, or intangible capital, result mainly (though not exclusively) from investment in intangible factors. These reflect knowledge that is codified on paper or in digital form or, in many cases, is not codified at all.

Economists have long been aware of the importance of this kind of intangible capital, as human capital theories show. To 'measure' it, approximations or indirect indicators such as level of schooling are used. However, recently other kinds of intangible assets have been considered, such as those related to scientific production or to the level of well-being in the population, measuring expenditure respectively on R&D and on health.

Table 1 shows the increases in the ratio between intangible investment and investment in physical capital. Investment in intangible assets leads to the accumulation of these assets, while physical capital includes natural resources, stock, equipment and physical infrastructure.

In conclusion, the empirical data presented above confirm the perception that the creation and dissemination of knowledge are fundamental factors for the promotion of economic growth. Economic growth has traditionally been explained as being the result of increases in the labour and capital factors and technological change. However, in the light of this analysis, it is necessary to rethink how these three factors influence the process of economic development.

With regard to the contribution of the labour factor, the facts show that a quantitative increase in population is not sufficient, since developed economies produce ever more intangible factors, creating employment mainly in the service sector, in which educational and professional qualifications are required. It is thus essential for growth and job creation to develop human capital, providing access to more and better skills, particularly through education.

With regard to the contribution of capital, it can be seen that the accumulation of intangible assets is gaining in relative importance compared to physical capital. Accordingly, the importance of knowledge is seen not only in its contribution to technological change, a fact that has led to a rethinking of traditional ways of explaining growth. The new economic growth theories, which are analysed below, bring together many of these ideas, putting forward the message that the accumulation of knowledge, which we

Table 1. Ratios of investment in intangible assets to investment in tangible assets

	1929	1948	1973	1990
Ratio of intangible assets to tangible assets	0.535	0.731	0.992	1.15
Ratio of expenditure on education, training and R&D to GDP	3.26	3.88	4.53	5.67
Total capital	0.29	0.36	0.42	0.45

Source: Kendrik (1994)

will identify with learning, is the most important factor in explaining economic development.

New growth theories

The economic importance of knowledge has been analysed in various academic disciplines and from various perspectives (for a review, see Dosi (1996)). The approach presented in this paper, which is related to the new economic growth theories, is thus far from being the only one. However, it has the advantages of being recent, of attempting to include contributions from various disciplines, and of being increasingly accepted in the academic world as well as in the more pragmatic fields of management and public policy (see, for example, the recent book by Barro and Sala-i-Martin (1995), which contains a detailed discussion of modern economic growth theory and empirics).

First, the conceptual differences between the new and traditional ways of analysing economic growth are presented. The main focus here is a definition of the way in which knowledge contributes towards development, which, in the new theories, results from complex interactions between physical objects and two kinds of knowledge — ideas and skills. Then the differences between these two kinds of knowledge are analysed together with an exploration of how ideas and skills differ in their use, diffusion and production. Finally, we discuss the interdependence between skills and ideas in the learning processes that lead to the accumulation of knowledge, the basis for an analysis of the role of the university in a context of sustained economic growth.

Ingredients of economic growth

We must begin by defining knowledge and establishing a taxonomy for different kinds of knowledge. Knowledge is defined by what it is not: thus anything that is not human is not knowledge (Nelson and Romer, 1996), where 'not human' includes all physical goods, natural resources, energy and physical infrastructure. In this literature, that which is not knowledge is termed 'hardware', to give the idea that it covers 'material things', in other words, objects. This paper also uses the term 'objects' to represent 'hardware'.

The next step is to establish a taxonomy of knowledge. It should at this point be stressed that the taxonomy used in the new growth theories is only one of several that have appeared in the literature.[1] Two kinds of knowledge are distinguished:

> software ('ideas'): knowledge codified and stored outside the human brain, for example, in books, CDs (compact disks), records, cassettes);
> wetware ('skills'): knowledge that cannot be dissociated from an individual; stored in the brain of every human, including convictions, abilities, talents, and so on.

The conceptual difference between software and wetware (ideas and skills) lies in the level of codification. While ideas correspond to knowledge that can be articulated in words, symbols or other means of expression, skills cannot be formalised, but always remain in tacit form. Examples of ideas are Pythagoras' theorem, the Coca-Cola recipe, the Windows 95 operating system, the instructions for manufacturing and installing car components, a classical music CD, the crawl technique in swimming, and the Constitution of a nation.

Examples of skills would be Picasso's artistic talent, Einstein's scientific genius, the manual skills of a carpenter, the knowledge of a medical specialist, or the leadership and persuasive powers of a politician. To summarise, in this taxonomy, knowledge is divided into two worlds: the world of codified ideas, and that of non-codified skills.

It may be asked at this point what this discussion has to do with economic growth and the role of the university in the emerging economy. In fact, to evaluate the relevance of the distinction between objects, ideas and skills to an understanding of the development process, the traditional viewpoint mentioned above should be borne in mind. According to that tradition, growth is the result of an accumulation of labour and capital factors, together with technological change. The introduction of technology, as first shown by Solow (1956; 1957), was essential to explain empirically measured levels of growth. A simple accumulation of labour and capital factors alone was never sufficient. However, technology always appeared as external to the economic process, an exogenous component, as it is called in the literature.

In the new theories of economic growth, the viewpoint is completely different. The accumulation of capital, or (in the new terminology) of hardware, remains essential. Nevertheless, the one source of continued growth is knowledge: on one hand new ideas to produce new objects and to organise existing objects in ever more efficient ways, and on the other, new and better skills that enable ideas to be implemented and objects to be used. To illustrate this idea, we need go no further than Romer (1993b), the father of the new growth theories (note the comments within the quotation):

> "To see how the same physical objects can be arranged in more valuable ways, consider first an example involving physical capital. The computer that I used to write this paper is about fifty times faster than the one I used just ten years ago, yet it is constructed from just about the same assortment of aluminium, copper, steel, plastic, silicon, and other raw materials. It is manufactured in about the same way and is sold for about the same price.
>
> Now consider human capital. In my brain there are different physical connections between my neurons. These connections store the commands I need to use the new computer and

In the new growth theories, knowledge first is not restricted to technology, and secondly is not exogenous: instead, it corresponds to new ideas and skills, in technology as well as in social, legal, political, administrative and other areas

> new word-processing software. Just as my new computer is a more productive piece of physical equipment [the result of new ideas on how to rearrange the same objects more efficiently] I have more valuable human capital than I did ten years ago [that is, more skills to take advantage of the productivity gained by the new ideas]."

Romer's story has a simple moral: it is new ideas and new and better skills, that is, increased knowledge, that bring about the gains in productivity and efficiency that lead to economic growth. To expand on this story, since the beginnings of civilisation, humanity has been constrained by the natural resources and energy sources of the planet. There can be no human development except through the creation and accumulation of knowledge, which enables us to rearrange these resources in ever more productive ways.

Thus, in the new growth theories, knowledge first is not restricted to technology, and secondly is not exogenous. Instead, it corresponds to new ideas and skills, in technology as well as in social, legal, political, administrative and other areas. Figure 4 is designed to illustrate how knowledge may be considered endogenous, by showing some of the links between objects, ideas and skills which lead, as in Romer's example, to economic growth.

Given that the accumulation of knowledge contributes most to growth, it is now necessary to analyse how this accumulation takes place. Accumulation of knowledge can also be expressed as learning, not in the narrow sense that is limited to one individual, but in a wider sense that includes learning by organisations, nations and regions. Before moving on to this discussion, it is necessary to begin with a detailed analysis of the reasoning behind the separation of knowledge into the two kinds categorised above.

While the above discussion has given some pointers to the differences that exist, these differences have far-reaching implications for the way in which the learning process is understood in the light of the new economic growth theories. Analysis of these implications is the main focus of the following sub-section.

So we see how the creation, distribution and use of knowledge is crucial to the new understanding of the process of economic growth. Nevertheless, the ways in which ideas and skills are produced, distributed, and used are in some cases profoundly different, even

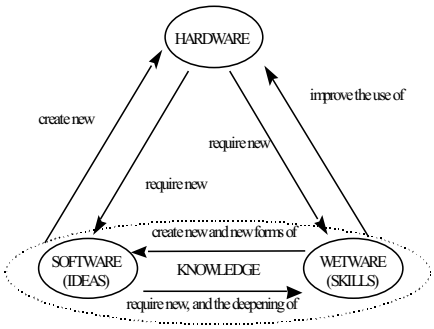

Figure 4. Interactions between knowledge (software and wetware) and hardware (objects) in the new economic growth theories

mutually antagonistic. These differences have important economic implications that also have an effect on public policy-making, notably with regard to the role of the university in the emerging economy.

Use of knowledge

We begin by analysing how the two kinds of knowledge may be used. Ideas have the remarkable quality of being usable by any number of people simultaneously. The fact that someone is reading a novel in no way prevents someone else from having access to it at the same time. The ideas in the novel and the benefit derived from its use may be shared at the same moment in time.

Pythagoras' theorem is another example. It would not be surprising if, at this moment, millions of people were using it to solve school exercises or for practical applications. It may also be in use, incorporated into a variety of algorithms, in thousands of computer programs. In all these cases nobody is hindering, or being hindered by, someone else using the theorem.

Skills, on the other hand, can only be used by those who possess them. It would be good to be able to reproduce Picasso's talent or Einstein's genius, but this is impossible, because skills are inextricably linked to the person who possesses them. It is only this person who can use them, when, how, and where he or she sees fit. In terms of their use, skills are, perhaps deceptively, similar to objects, which also can only be used by one individual at a time.

Formally, codified knowledge is a non-rival good. Literally millions of people share the ideas that make up the Windows 95 operating system or any other software program. Romer (1994) gives more revealing examples of non-rival knowledge:

> "The idea behind the transistor, the principles behind internal combustion, the organisational structure of a modern corporation, the concepts of double entry bookkeeping — all these pieces of information and many more like them have the property that it is technological possible for everybody and every firm to make use of them at the same time."

Table 2. Differences in the use and distribution of ideas and skills

	Software (ideas)	**Wetware** (skills)
Use	non-rival	rival
Distribution	easy and inexpensive	complex and expensive

Distribution of knowledge

Moving on to an analysis of the processes involved in distributing knowledge, the distribution of ideas (that is, software) is, as a rule, easy and inexpensive. To communicate Pythagoras' theorem to the readers of this paper, it is sufficient to state it. Since the knowledge underlying the theorem is codified, it is easily articulated and reproduced by simple, inexpensive means. Pythagoras' theorem represents an extreme case, in which the costs of distribution are practically zero, requiring just one line of text, or ten seconds of oral communication, to transmit the idea. The fact that it takes a lot of prior (tacit) knowledge to use this theorem does not change its non-rival nature.

Still, we are exaggerating and simplifying to illustrate better the core of the argument. Other ideas are more difficult to codify and transmit, but in general the costs of disseminating ideas are extremely low, especially in comparison with the costs of producing them. Indeed, the ease, speed, and low cost of distribution are characteristic of virtually all codified knowledge.

By contrast, the transmission of skills (that is, wetware) is complex, expensive, and slow. Using an extreme example, the case of Picasso's artistic talent, it may even be impossible. Young artists might have learned from Picasso, but this would certainly have required a very long period of interaction, since the knowledge associated with his talent is not codified. Again, we are over-simplifying by using this example, but the aim is to illustrate starkly the difference between tacit and codified knowledge. Skills result from a combination of factors, ranging from their largely innate quality, through individual experience, to formal training.

Table 2 summarises the discussion, showing the differences between ideas and skills. Below, we explore the economic implications of these differences, which are seen mainly in the different modes of production of knowledge.

Production of knowledge

Now we explore the consequences of the differences between ideas and skills set out in Table 2 in terms of their production. As already stated, the rivalry associated with skills implies that, on the level of economic classification, they are similar to objects. As a consequence of this rivalry, it is clear who possesses a given object or ability. On the other hand, objects and skills are scarce. These two properties (ease of assigning property rights and scarcity) mean that, in principle, the market functions as an efficient means of producing skills.

We can think of the specific case of the skills required to pilot a commercial aircraft. To acquire them a considerable personal investment is needed, in both time and money, since the skills can only be gained through a long process of training and accumulation of experience. The would-be pilot makes this investment in the expectation of being able to sell his/her future skills to an airline company. He/she may, if sufficiently skilled, even be able to train other pilots and receive extra benefits. An exceptionally good pilot may become a consultant and sell his/her advice on aviation matters.

This view has been formalised as an increase in human capital. Incentives to make investments that lead to increases in this capital are associated with the expectation of receiving income from accumulated human capital in the future. This is the traditional view of the way in which the market provides the necessary incentives to invest in increasing individual skills. From the standpoint of the new growth theories, and in particular of the increasing importance of knowledge, this view needs to be re-examined. This will be dealt with later, the point for the moment being to contrast the incentives required to produce skills with those needed to produce ideas.

The non-rivalry of ideas, and their low distribution costs, means that, on one hand, it can be very hard to assign property rights to them and to protect those rights, and on the other that there is no lack of ideas. Indeed, ideas tend to be abundant, especially given advances in information technology and telecommunications, which enable codified knowledge to be used and transmitted easily and inexpensively. Terms such as 'the digital economy' and 'the information economy' clearly reflect this. However, it is important to note that these terms are not synonymous with the wider concept of a 'knowledge-based economy', which, as will be seen, has to do with the need for continuous learning processes, involving not only codified knowledge but also the skills needed to use that knowledge.

David (1993) argues explicitly that, as a consequence, the market by itself does not have adequate mechanisms for the production of ideas, and that other institutional mechanisms are required for this purpose. Indeed, as Dosi (1996) notes, the non-rivalry of ideas separates the costs of their creation from the benefits accruing to those who use them. In other words, the effort that somebody has made to arrive at an idea may be inadequately rewarded by the beneficiaries of that idea. To return to Pythagoras' theorem, all the effort (production cost) was borne by Pythagoras over 2000 years ago, while the benefits have been shared without cost by all succeeding generations.

Furthermore, the effort (or cost) of producing a new idea is usually high, especially in comparison to the cost of disseminating it. To make matters more complicated, making that effort does not even

Table 3. Private and social rates of return on private investment in R&D in the United States

Study	Rates of return (%)	
	Private	Social
Nadiri (1993)	20–30	50
Mansfield *et al* (1977)	25	56
Terleckyj (1974)	29	48–78
Sveikauskas (1981)	7–25	50
Goto and Suzuki (1989)	26	80
Bernstein and Nadiri (1988)	10–27	11–111
Scherer (1984)	29–43	64–147
Bernstein and Nadiri (1991)	15–28	20–110

Source: US Presidential Council of Economic Advisors (1996)

guarantee that an idea of any value will result; the production of ideas is highly contingent and its results are uncertain. According to Dasgupta and David (1994), Nelson (1959) was the first author to describe the economic implications of the uncertainties associated with the efforts to produce new ideas, as well as of the difficulty the creator experiences in retaining the benefits of a new idea.

Specifically, Nelson studied the effort put into creating ideas represented by R&D carried out by companies. Even if a company succeeds in its R&D effort, Nelson says, the benefits of a new idea are shared by society in general. The data in Table 3, which compares the rates of individual and social return on investment in R&D, give an empirical demonstration of this argument. Rates of individual return, the benefits that the individual entity responsible for the R&D expenditure receives, are around 20–25%. Rates of social return — benefits to society in general — are around 50%.

The figures in Table 3 confirm Nelson's hypothesis, showing that the social benefits from effort put into creating ideas are indeed considerably higher (approximately double) than the advantages that accrue to the private agents who made that effort. This phenomenon, generally known in the literature as "knowledge spillover", has been interpreted as the result of positive externalities associated with the performance of R&D. Phenomena such as externalities are identified as "shortcomings of the market", and indicate situations in which markets do not function effectively as a means of stimulating production. Using the concepts of the new growth theories, we are now in a position to reinterpret this phenomenon as the result of the non-rivalry and low transmission cost of ideas.

State intervention ensures public access to ideas and subsequent prestige and reputation, while granting intellectual property rights gives the author discretionary rights over such access, with the prospect of monopolistic profits

Table 4. Two alternatives for providing incentives for the production of ideas

	State intervention	Property rights
Ownership of ideas	public	private
Expected return	reputation, prestige	monopolistic profits
Advantages	free access	private incentives
Disadvantages	arbitrary, inefficient	limited diffusion

From this perspective, what type of incentives exist for the production of ideas? David (1993) and Dasgupta and David (1994) suggest that there are basically two alternatives. The first is intervention by the state in the production of ideas, by means of direct production (such as occurs, for instance, in state-controlled research laboratories), or by subsidising production, such as funding university R&D. The second alternative consists of granting property rights for the creation of ideas, that is, by defining regulations for intellectual property — specific instruments that include patents, registered trade marks and copyright.

Table 4 summarises the characteristics of these two alternatives. State intervention ensures public access to ideas, while granting intellectual property rights gives the author discretionary rights over such access. In the latter case, the incentive derives from the prospect of monopolistic profits arising from the granting of a patent or copyright (Schumpeter (1934; 1950) was the first to put forward this idea). In the case of state subsidies, incentives come in the form of the prestige and reputation which, for instance, a scientist acquires through his/her creations, and which, continuing with the example of the scientific community, are reflected in professional advancement and funding (Stephan, 1996).

As Table 4 seeks to illustrate, both alternatives have their strengths and weaknesses, which are in effect complementary. Thus, while direct intervention by the State provides rapid diffusion of, and widespread access to, new ideas, the granting of property rights limits this diffusion to such an extent that monopoly rights can lead to the unwelcome effect of hindering the distribution of ideas.

To illustrate the reality of this problem, Nelson and Romer (1996) ask what would have happened if the concept of the spreadsheet had been protected by law, preventing Microsoft and Borland, with their products Excel and Quattro Pro, from competing with the originator, Lotus. Naturally, the rate of technological progress in the development of spreadsheets would have been considerably slower.

We have presented a detailed analysis of the differences between skills and ideas. It has been seen that the latter show distinctive economic behaviour, a result of the non-rivalry of their use and their low diffusion cost. The production of ideas accordingly requires more complex institutional mechanisms

Table 5. Accumulation of knowledge and learning processes in the new growth theories

		Learning by			
		Formal processes		Informal processes	
		Education	R&D	Experience (by-doing)	Interaction
Accumulation of	Software (ideas)		Romer (1990) Grossman and Helpman (1991)		
	Wetware (skills)	Lucas (1988)		Arrow (1962) Romer (1986)	

than those provided by the market. As for skills, it has been noted that they behave in a similar way to objects and, for this reason, the market provides a large proportion of the incentives needed for their production.

We have deliberately analysed each of the categories of knowledge in isolation, to show more clearly the differences between ideas and skills. However, as was established at the end of the section on distribution of knowledge, it is the accumulation of knowledge as a whole that leads to economic growth: this means that the way ideas and skills are related to each other needs to be analysed. This analysis is found in the next section, with a view to examining the role of the university in the knowledge economy later.

Learning and accumulation of knowledge

According to Solow (1997), the formalisation of the process of economic development in the new growth theories follows the conceptual structure originally proposed by Arrow (1962). It is worth looking briefly at Arrow's analysis, as it contains the kernel of the reasoning behind the idea of economic development as a learning process.

Instead of following the orthodox thinking of his time, which attributed to technological change the component of growth that could not be explained by the accumulation of labour and capital factors, Arrow argued that experience in the use of capital led to an increase in the knowledge used in production. In plainer terms, Arrow drew up a relatively simple model in which workers in a company learn by using the means of production, thereby increasing the company's productivity.

In this way learning, that is the accumulation of knowledge, appears as the driving force behind the increases in efficiency which lead to economic growth. It is interesting to note that Arrow chose an informal way of learning, learning by doing, as the basis for his reasoning. It should also be noted that in this model knowledge is accumulated only in the form of skills. The contribution of the new economic growth theories has been precisely to extend this reasoning to other types of learning, as well as to the accumulation of ideas, starting from when Romer (1986) showed the wider implications of Arrow's arguments.

Thus, Lucas (1988) also analysed the accumulation of knowledge in the form of skills, but this time putting forward education as a formal learning process. In turn, Romer (1990) and Grossman and Helpman (1991) constructed models in which the accumulation of ideas results from effort put into research, another formal learning process.

In this context, Table 5 summarises how these contributions fit into a framework of possibilities which relates the accumulation of knowledge to the different kinds of learning that can lead to this accumulation. The construction of this table was also inspired by Foray and Lundvall's analysis (1996), in which they placed particular emphasis on the formation of networks of personal and professional contacts, which result from processes of social interaction, the fourth process in Table 5.

This table also illustrates three other points. First is the analysis that remains to be made in respect of the empty boxes. Secondly, examination of the dates of the contributions reveals that the emphasis at the beginning of the 1990s was on the study of the accumulation of ideas through R&D, a tendency that has become stronger in recent work (see Romer, 1993a; 1993b; 1994).

There are at least two reasons for this. On one hand, the study of informal learning processes is more complex and less amenable to empirical testing. We are accordingly left with the study of the accumulation of ideas through R&D, because the role of education has already been extensively researched since the theories of human capital appeared in the 1960s. On the other hand, the really striking aspect of the times in which we live is the increasing codification of knowledge, and the potential of the "digital economy" and the "information society" (Romer, 1996; Foray and Lundvall, 1996).

The third point to note is the very recent appearance of attempts to analyse the economic implications of learning processes that result from social interaction, particularly in the 'information society'. Indeed, this aspect puts forward a new vision of the university, notably with reference to the radical change from formal teaching to participatory learning, which is directly associated with continuous (lifelong) training and the need for the university to deal effectively with multiple demands and a multifaceted public. Furthermore, the fact that informal learning processes are shared between a varied range of institutions opens up new possibilities for the

Although to a great extent skills result from the innate characteristics of an individual or from the history of an institution or a country, they also depend on the learning processes in which these entities are involved

universities' ability to create and disseminate knowledge in the emerging economies.

It is important to note that the potential of the "digital economy" is strongly reflected in the existence of increasing returns, which leads to phenomena such as the apparently unstoppable growth of companies that trade in ideas, such as Microsoft. Indeed, the economic value of an idea is associated with its market potential (Romer, 1996). As has been seen, it can be extremely expensive to produce ideas, but they are cheap to distribute. The first disk containing the Windows operating system cost Microsoft several million dollars (the entire cost of development), but all the rest cost less than a dollar each. Since there is a vast market and costs, after initial development, are low, the only limit to Microsoft's growth is the size of the market itself.

Arthur (1994) points out that the fact of increasing returns, besides being linked to the non-rivalry of ideas, is reinforced by the phenomenon, originally explored by David (1986), known as "lock-in". In the case of Microsoft, lock-in took place when the Windows operating system became established as the virtual industry standard. As can be seen, there is much to explore concerning the impact on growth of the accumulation of ideas, but our concern at the moment is to examine the boxes in Table 5 that remain empty, particularly the interaction between ideas and skills.

Interaction between ideas and skills

It is time to begin moving into territory that is still being explored, which requires reference to contributions from other groups of economists concentrating on the study of economic growth. Before pursuing this theme, we should note the difficulties that have beset the new economic growth theories.

The main criticism is linked to their lack of empirical evidence, despite the intellectual validity of their arguments (Pack, 1994). Mankiw (1995), in a relatively recent assessment, even suggested a return to Solow's traditional formulation. However, according to Soete (1996), empirical difficulties should lead not to a reduction in efforts to pursue the new concepts further, but rather to a recognition that new indicators and quantitative methods must be found that are more appropriate for the knowledge-based economy.

One crucial aspect of the accumulation of knowledge is the interaction between ideas and skills, which gives rise to the learning processes in Table 5. Indeed, according to Soete (1996), ideas and skills are no more than two sides of the same coin, two essential aspects of the accumulation of knowledge. Herbert Simon, quoted by Varian (1995), puts the argument as follows:

> "What information [in the sense of ideas, according to our terminology] consumes is rather obvious: it consumes the attention of its recipients. Hence, a wealth of information [that is, of ideas] creates a poverty of attention, and a need to allocate that attention efficiently among the overabundance of information sources that might consume it."

In other words, many good ideas are useless if the skills needed to use them do not exist. Studies by Pavitt (1987), Nelson (1996), and Rosenberg (1990) follow the same line of thinking. Nelson (1997) describes various circumstances, in which individuals, companies, universities and other institutions have made use of their skills to increase their accumulation of knowledge, acquiring further skills as well as ideas.

The main implication of this argument is that the interdependence between ideas and skills casts doubt on the idea that the market supplies the necessary incentives for the production of skills, as was concluded above, where these were analysed in isolation. It seems, therefore, that there is greater scope in the knowledge-based economy for institutional arrangements and public policies that go beyond the logic of the market (World Bank, 1998).

Although to a great extent skills result from the innate characteristics of an individual or from the history of an institution or a country, they also depend on the learning processes (education, research, experience, social interaction) in which these entities are involved (North, 1990). Without skills, ideas may be irrelevant, and without ideas, there is no need for new and better skills, as Figure 4 seeks to show. Analysis of the interaction between ideas and skills understandably brings us to explore learning processes in a more integrated and dynamic way, beyond the mere individual accumulation of ideas and skills set out in Table 5.

To illustrate the close and complex interdependence between ideas and skills, Figure 5 seeks to enlarge the oval in Figure 4 showing the interactions between these two kinds of knowledge.

At this point we should stress that our analysis would be enriched by drawing on the large output of scholarship that originated from the cognitive sciences and from the education sciences on learning. However, this project is outside the aim of this paper, since we do not intend to contribute to a theory of learning. Our purpose is rather to propose a simplified framework to model the dependency between software and hardware, suggesting that it is through this interaction that new knowledge is generated, that is, learning occurs.

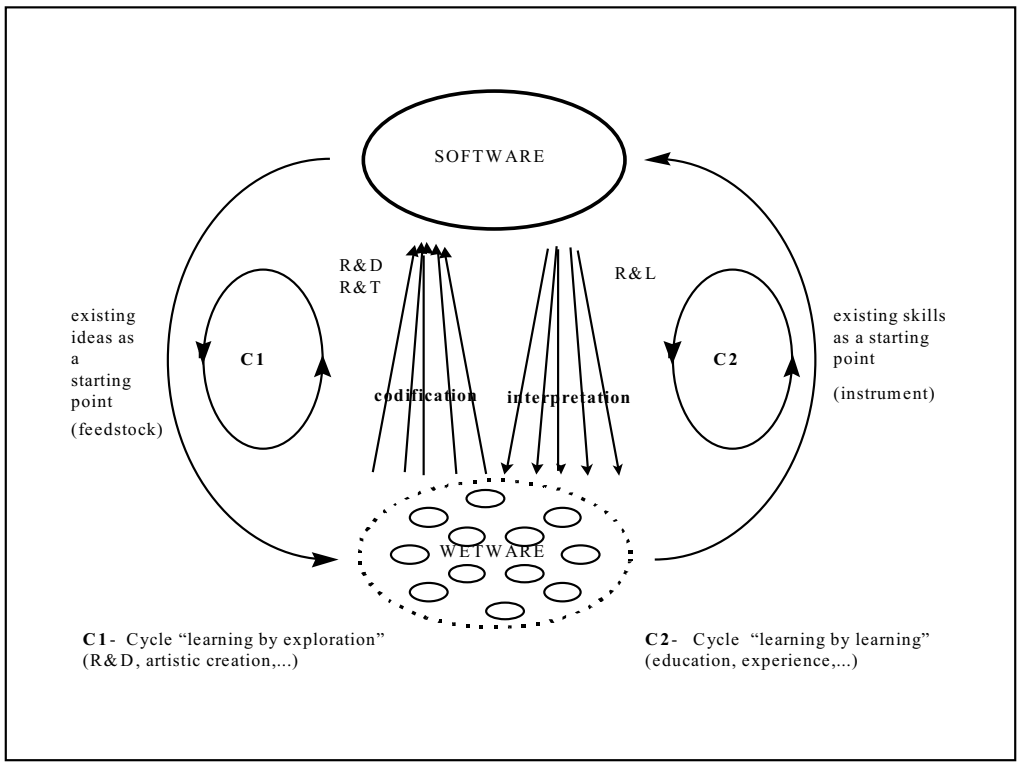

Figure 5. Diagrammatic representation of interaction between learning processes and accumulation of knowledge, identifying various aspects of university research

Note: R&D = research and development
R&T = research and teaching
R&L = research and learning

From Figure 5 it can be seen that, while skills appear as a cluster of small ovals, reflecting the individual nature of the skills of people and of institutions, ideas appear as a single oval. This represents the indivisibility of ideas (David, 1993), meaning that, once created, an idea remains at least potentially accessible everywhere, and there is no need to rediscover it — hence the common expression "There's no need to re-invent the wheel".

Figure 5 shows several learning processes that have been analysed in various places in the literature. Again we should stress that we have been selective in the way we chose the types of learning process depicted in the figure. Our objective is not to be exhaustive, but rather to emphasise the learning mechanisms that are more directly related to the functions of the university, as will become clear in the next section.

Thus, there are two main cycles:

cycle 1: codification of knowledge (Foray and Lundvall, 1996), the result of progress in information technology, telecommunications and the scientific and technological base; that is, the great number of existing ideas that are the starting point or 'feedstock' for new ideas to be constructed using existing skills;
cycle 2: interpretation of codified knowledge (OECD, 1997), using existing skills as a starting point or instrument to decode the ideas which are being studied or used, leading to improved skills.

Cycle 1 covers learning processes that result in the codification of knowledge, that is the generation of new ideas. Specific examples include R&D and artistic creation. In both cases, ideas are generated as a result of a process of exploration, in science or in search of a form of expression. This type of learning is convergent, meaning that on the basis of different and unique skills, ideas are generated that have the potential for common use.

Cycle 2, on the other hand, relates to learning by assimilation of knowledge, which results from activities such as education, experience and social interaction. Through interpretation of these ideas, different skills emerge. Imagine a mathematics class: all the students are using the same book, they attend the same classes, they do the same exercises. However, the ways in which they assimilate and interpret these are different, meaning that the learning process is divergent. Schon (1987) and others expand on the inner workings of this type of learning, but we keep our discussion at a more superficial level.

The main conclusion, as shown in Figure 5, is that the accumulation of knowledge, which is the basis for economic growth, is the result of a series of complex processes, in which there is considerable interdependence between the accumulation of ideas and of skills.

It is necessary to examine the role of the principal institutions of contemporary society and to attempt to determine how they fit into these processes. We now examine the case of the universities and suggest possible implications for the formulation of public policy and university management practices.

Challenges and opportunities for universities

The importance of the universities for economic development is well documented from a historical standpoint in, for instance, Freeman and Soete (1997), Mowery and Rosenberg (1989), and Conceição *et al* (1998a). As expected, in these works the main role of universities is stated as a mission to educate and to carry out research. However, universities have committed themselves recently to a range of additional activities, normally grouped together under the heading of "links with society" (for detailed discussions on the context of the university's mission in Europe, see Caraça *et al* (forthcoming), and in the United States, Lucas (1996)).

At the same time, there is a growing tendency to classify companies as 'learning organisations'. Terms such as 'learning management' are used more and more (Conceição and Heitor, forthcoming). Nonaka and Tekeuchi (1995) are perhaps the classic example of this trend, with the publication of their book *The Knowledge-Creating Company*. Against this background, is the university still the "Knowledge Factory", as described in a recent study in *The Economist* (1997)? Or, given the profusion of activities associated with university extension, should it structure itself along business lines?

At the same time, companies, such as Microsoft, themselves are becoming involved in the production of knowledge, when they were not set up and run from the beginning along similar lines to a university (*The Economist*, 1997). In short, will the trend towards a breakdown of the institutional boundaries between companies and universities become a fact of life in knowledge-based economies?

To a certain extent, the description already given of recent developments in companies and universities indicates that it will. This convergence is the result of two forces that come together to effect an 'identification' between companies and universities. First, the creation of added value and wealth is increasingly associated with the production of knowledge, as seen previously, so it is natural that companies look to the way universities function for inspiration on how to perform creative tasks. Secondly, the universities find themselves facing difficulties in obtaining sufficient funds for their basic tasks of teaching and research (see Caraça *et al*, 1998), so it is also natural that they should look to companies to learn how to derive commercial benefit from their intellectual assets.

As various studies have shown, although this convergence is, to a certain extent, to be welcomed, it can also be dangerous. How are the limits of acceptability to be drawn? Rosenberg and Nelson (1996), Dasgupta and David (1994), David (1993), and Pavitt (1987) argue that whatever does not harm the institutional integrity of the university is acceptable. Companies and universities have evolved in a social context, to the point of attaining what these authors call "institutional speciality".

Thus, whereas companies are concerned to obtain private returns for the knowledge that they generate, universities have traditionally made it public. By means of this specialisation, or 'division of labour', the accumulation of knowledge has taken place at a rapid pace, as is shown by the unprecedented levels of economic growth since the end of the second world war (Rosenberg and Nelson, 1996).

This argument is analysed in detail, in the context of the knowledge-based economies, in Conceição *et al* (1998c). The threats to a university's institutional integrity in fact go beyond the extension of its activities to links with society, which, if excessive, could lead to resources being spread too thinly. This analysis is based on the more serious problems that may arise if universities take the path of privatising the ideas that they produce and the skills that they develop.

Teaching

We begin by analysing the university function of teaching, which contributes to the accumulation of knowledge, specifically of skills, through the formal process of learning through education, or 'learning by learning'. This process, following the analysis earlier, is divergent: a university education combines the transmission of codified knowledge by the teachers with the individual characteristics of the students, in a process in which the interpretation of ideas leads to the accumulation of unique skills. Given this situation, each student can profit from these skills in the future. The university may therefore be tempted to increase the direct price to the students of their education, as a way of increasing its income.

Besides the well-known externalities associated with university education, which justify state support for education in virtually every country in the world, with the possible exception of Japan (Eicher and Chevalier, 1993), analysis of the need to provide the skills necessary for the information society in which we live strengthens the arguments in favour of state support for university education. The threat of increased privatisation of teaching skills could thus cause serious problems, in that it would lead to a reduction in the resource that really is in short supply in the knowledge-based economies: the skills to use and interpret ideas. This conclusion does not cast doubt on the contributions currently made by students, but rather questions a possible trend that could jeopardise the institutional integrity of the university itself, if the tendency to decrease public funding persists.

Research

Moving on to research, it is worth noting that the great majority of the ideas generated in universities are of a public nature, this being the essence of the specific contribution that the university makes to the accumulation of ideas. Incentives for the production of these public ideas come from a complex system of reward and prestige within the academic community. Stephan (1996), following on from the sociological work of Robert K Merton, describes in detail how this system operates and how it rewards creativity, flexibility and autonomy.

In a recent survey of university teachers in the United States, the most satisfying factor, chosen by 86.2% of the sample, was autonomy and independence (UCLA, 1997). Again, the temptation to privatise university research results could threaten fundamental aspects of the way universities work and their essential contribution to the accumulation of ideas.

To summarise, our conclusion is that the institutional integrity of the university should be preserved, and an important point in terms of public policy is that state funding of universities should not be reduced. However, this measure by itself is not enough. From a more pragmatic viewpoint, the university should respond to the needs of society, which include rapid and unforeseeable changes in the structure of the employment market, and the need to furnish its graduates with new skills beyond purely technical ones, in particular, learning skills. Ways of responding to these two issues are dealt with below.

Structure of employment market

The response to the first issue, relating to changes in the structure of the employment market, involves public policies designed to strengthen and preserve the institutional integrity of the university. The universities cannot actually be expected to foresee the demands of the employment market five or six years in advance. If they were to try, this would certainly entail jeopardising their integrity.

This problem could be partially addressed by developing a diversified higher-education system, including various institutions with different vocations, in such a way as to promote a functional stratification of the system. This could be a way to ensure sustained flexibility capable of providing society with the instruments it needs to deal with instability in em-ployment and, more generally, the inevitable changes in technology, tastes, markets and needs.

A diversified higher-education system would ensure sustained flexibility capable of providing society with the instruments it needs to deal with instability in employment and the inevitable changes in technology, tastes, markets and needs

This seems, moreover, to be the way to meet the challenge of maintaining excellence. The expansion of university education is obviously irreversible in the emerging society, but this cannot be allowed to stand in the way of creating centres of excellence. On the contrary, it should encourage their development, notably by means of the stratified system.

The American education system can give some pointers towards a possible path to follow. According to the Carnegie Foundation for the Advancement of Teaching, which produces a semi-official classification of American higher-education institutions, there are around 90 "research universities", being those which have generally been called simply "universities". These 90 institutions operate within a system of 3706 institutions (not counting the 6256 others that only provide vocational training), with a total of over 14 million students enrolled. In this way, the diversity and functional stratification of the system as a whole helps it to respond to rapid changes in the employment market, particularly through those institutions oriented more towards teaching and with shorter graduation times, without putting undue pressure on the universities.

Creating and promoting learning skills

A diversified and stratified system also presents advantages with relation to the second issue, the need to create and promote learning skills. This conclusion is reached by analysing the function of university research. It actually includes various sub-functions, not always clearly defined, but which should be the subject of separate public policies and forms of management, as follows:

R&D, research and development, which aims to accumulate ideas through convergent learning processes, which are associated with the processes of codification represented in Figure 5. This is the commonest form of research, particularly in the context of economic development and from the standpoint of the relationship between universities and companies.

R&T, research and teaching, in which research functions as a way of developing teaching materials, as well as of improving the teaching skills of the teaching staff: it is also associated with the convergent processes of knowledge codification represented in Figure 5.

R&L, research and learning, in which the value of the research is not necessarily in the creation of ideas, but in the development of skills that enhance opportunities for learning. Research thus appears as a divergent function, associated with the process of interpretation represented in Figure 5.

According to these definitions, R&D and R&T are convergent learning processes, the purpose of which is the creation of ideas. In this context, selectivity is required in the choice of individuals with suitable skills for these types of activity. In turn, R&L is associated with a divergent learning process, which seeks to develop learning skills through the experience of doing research. It is important to disseminate these opportunities, presenting research as a cultural factor.

In these circumstances a diversified system could respond effectively to the different demands made of it in the emerging economy, by being selective in R&D and R&T, and comprehensive in R&L. Indeed, in the context of the knowledge economy, the comprehensive nature of research and technology should be extended beyond the university to cover the whole education system, as a way of promoting learning skills.

In this situation, it seems essential to place renewed emphasis on education and, to a certain extent, to reinvent its social and economic role. Educational institutions must rethink their relationships with the individuals, families and communities among which they find themselves, presenting themselves as vital providers of opportunities to develop formal learning processes, while at the same time encouraging a way of life that promotes learning through social interaction.

Among the challenges facing the university and the education system in general, we should also mention the need for lifelong learning. As an essential part of the knowledge economy and facilitated by the new information and telecommunications technologies, lifelong learning should be seen by the universities as an opportunity to implement strategies that will help maintain their sustained flexibility: this confirms the need to diversify the system.

To sum up, rather than presenting a detailed plan of public policy options and forms of management for the universities, we have shown how the concepts developed earlier can be used to analyse the challenges facing the university in the knowledge-based economy, and what kind of opportunities can be discerned. Among the substantive conclusions are the importance of preserving the institutional integrity of the university, not only by avoiding excessive dissipation of its resources in activities related to its links with society, but most importantly by maintaining the academic character of its basic functions of teaching and research.

In a situation in which education should promote learning skills, we put forward the need to identify and understand the different components of university research, so as to enhance the selectivity of the R&D and R&T sub-functions, while ensuring the widespread availability of R&L. It is argued that a diversified higher education system can free the universities of many of the pressures they are experien-cing today, by helping to ensure the preservation of their institutional integrity.

Conclusions

This paper has shown empirically the increasing importance that knowledge is assuming in economic activity in developed countries, and has described recent conceptual advances in efforts to understand the new dynamic of economic growth. These theories accord particular importance to the accumulation of knowledge by means of formal and informal learning processes. This accumulation takes place in the form of ideas and skills, which have different economic properties but whose interdependence in a complex process of interaction requires a rethinking of the traditional role of the university, as well as of contemporary institutions in general.

The analysis shows, in the particular case of the university, that preservation of its institutional integrity is essential in a situation of sustained flexibility, in which education, besides offering a specific qualification, should ensure the assimilation of learning skills. The signs of the knowledge economy, notably the expansion in university education and the need to manage multiple demands and to ensure participative learning, point towards a diversification of the system, with reference to which it is particularly important to identify and understand the different components of the university's research function.

Notes

1. Foray and Lundvall (1996) present a review of these taxonomies and propose one of their own that may, however, be reduced to that presented here, as shown by Conceição *et al* (1998b).

References

M Abramovitz and P David (1996), "Technological change and the rise of intangible investments: the US economy's growth-path in the twentieth century", *Employment and Growth in the Knowledge-based Economy* (OECD, Paris).

K Arrow (1962), "The economic implications of learning by doing", *Review of Economic Studies*, 28, pages 155–173.

W B Arthur (1994), *Increasing Returns and Path Dependency in the Economy* (University of Michigan Press, Ann Arbor).

R J Barro and X Sala-i-Martin (1995), *Economic Growth* (McGraw-Hill, New York).

J Bernstein and I Nadiri (1988), "Interindustry spillovers, rates of return, and production in high-tech industries", *American Economic Review*, 78, pages 429–434.

J Bernstein and I Nadiri (1991), "Product demand, cost of production, spillovers, and the social rate of return to R&D", NBER Working Paper no 3625.

R Boudon (1973), *L'Inegalité des Chances* (Libraire Armand Collin, Paris).

P Bourdieu and J-C Passeron (1970), *La Réproduction. Éléments pour une Théorie du Système d'Ensignement* (Éditions du Minuit, Paris).

B Bowles and H Gintis (1976), *Schooling in Capitalist America* (Routledge, London).

J Caraça, P Conceição and M V Heitor (1998), "A contribution towards a methodology for university public funding", *Higher Education Policy*, 11(1), pages 37–58.

J Caraça, P Conceição and M V Heitor (forthcoming), "On the definition of a public policy towards a research university", *Higher Education Policy*, accepted for publication.

P Conceição, D F G Durão, M V Heitor and F Santos (1998a), *Novas Ideias para a Universidade* [*New Ideas for the University*, in Portuguese] (IST Press, Lisbon).
P Conceição, D V Gibson, M V Heitor and S Shariq (1998b), "The emerging importance of knowledge for development: management and policy implications", *Technological Forecasting and Social Change*, 58(3), pages 181–202.
P Conceição, M V Heitor and P M Oliveira (1998c), "Expectations for the university in the knowledge based economy", *Technological Forecasting and Social Change*, 58(3), pages 203–214.
P Conceição and M V Heitor (forthcoming), "University-based entrepreneurship and economic development: a learning-centred model", *Entrepreneurship and Regional Development*.
P Dasgupta and P David (1994), "Toward a new economics of science", *Research Policy*, 23, pages 487–521.
P David (1986), "Clio and the economics of QWERTY", *American Economic Review*, 75(2), pages 332–337.
P David (1993), "Knowledge, property, and the system dynamics of technological change", in L H Summers and S Shah (editors), *Proceedings of the World Bank Annual Conference on Development Economics 1992* , *Supplement to The World Bank Economic Review*.
R Dore (1976), *The Diploma Disease — Education, Qualification, and Development* (University of California Press, Berkeley, CA).
G Dosi (1996), "The contribution of economic theory to the understanding of a knowledge-based economy", *Employment and Growth in the Knowledge-based Economy* (OECD, Paris).
The Economist (1997), "A survey of universities — the knowledge factory", 4 October.
J-C Eicher and T Chevalier (1993), "Rethinking the finance of post-compulsory education", *International Journal of Educational Research*, 19, pages 445–519.
D Foray and B-A Lundvall (1996), "The knowledge-based economy: from the economics of knowledge to the learning economy", *Employment and Growth in the Knowledge-based Economy* (OECD, Paris).
C Freeman and L Soete (1997), *The Economics of Industrial Innovation* (MIT Press, Cambridge, MA, third edition).
A Goto and K Suzuki (1989), "R&D capital, rate of return on R&D investment and spillover of R&D in Japanese manufacturing industries", *Review of Economics and Statistics*, 71, pages 555–564.
G M Grossman and E Helpman (1991), *Innovation and Growth in the Global Economy* (MIT Press, Cambridge MA).
C Jencks (1972), *Inequality* (Basic Books, New York).
J W Kendrick (1994), "Total capital and economic growth", *Atlantic Economic Journal*, 22(1), pages 1–18.
R E Lucas (1988), "On the mechanics of economic development", *Journal of Monetary Economics*, 22, pages 3–42.
C Lucas (1996), *Crisis in the Academy — Rethinking Higher Education in America* (St Martin's Press, New York).
N G Mankiw (1995), "The growth of nations", in W C Brainard and G L Perry (editors), *Brookings Papers on Economic Activity*, 1 (Brookings Institution, Washington, DC).
E Mansfield, J Rapoport, S Wagner and G Bearsdley (1977), "Social and private rates of return from industrial innovations", *Quarterly Journal of Economics*, 77, pages 221–240.
D C Mowery and N Rosenberg (1989), *Technology and the Pursuit of Economic Growth* (Cambridge University Press, Cambridge).
I Nadiri (1993), "Innovations and technological spillovers", NBER Working Paper no 4423.
R R Nelson (1959), "The simple economics of basic scientific research", *Journal of Political Economy*, 67, pages 297–306.
R R Nelson (1996), "What is 'commercial' and what is 'public' about technology, and what should be?", in N Rosenberg, R Landau and D C Mowery (editors), *Technology and the Wealth of Nations* (Stanford University Press, Stanford, CA).
R R Nelson (1997), "How new is growth theory?", *Challenge*, 40(5), pages 29–58.
R R Nelson and P Romer (1996), "Science, economic growth, and public policy", in B L R Smith and C E Barfield, *Technology, R&D, and the Economy* (Brookings Institute, Washington, DC).
I Nonaka and H Takeuchi (1995), *The Knowledge-Creating Company* (Oxford University Press, Oxford).
D North (1990), *Institutions, Institutional Change and Economic Performance* (Cambridge University Press, Cambridge).
OECD (1996), *Employment and Growth in the Knowledge-based Economy* (OECD, Paris).
OECD (1997), *Technology and Industrial Performance* (OECD, Paris).
H Pack (1994), "Endogenous growth theory: intellectual appeal and empirical shortcomings", *Journal of Economic Perspectives*, 8(1), pages 55–72.
K Pavitt (1987), "The objectives of technology policy", *Science and Public Policy*, 14, pages 182–188.
P M Romer (1986), "Increasing returns and long-run growth", *Journal of Political Economy*, 98(5), pages 1002–1037.
P Romer (1990), "Endogenous technological growth", *Journal of Political Economy*, 98(5), pages s71–s102.
P Romer (1993a), "Idea gaps and object gaps in economic development", *Journal of Monetary Economics*; 32, pages 543–573.
P Romer (1993b), "Two strategies for economic development: using ideas and producing ideas", in L H Summers and S Shah (editors), *Proceedings of the World Bank Annual Conference on Development Economics 1992, Supplement to the World Bank Economic Review*.
P Romer (1994), "The origins of endogenous growth", *Journal of Economic Perspectives*; 8(1), pages 3–22.
P Romer (1996), "Why, indeed, in America? Theory, history, and the origins of modern economic growth", *American Economic Review*; 86(2), pages 202–206.
N Rosenberg (1990), "Why do companies do basic research with their own money?", *Research Policy*, 19, pages 165–174.
N Rosenberg and R R Nelson (1996), "The roles of universities in the advance of industrial technology", in R S Rosenbloom, and W J Spencer, *Engines of Innovation* (Harvard Business School Press, Cambridge, MA).
F Scherer (1984), "Using linked patent and R&D data to measure interindustry technology flows", in Z Griliches (editor), *R&D, Patents, and Productivity* (University of Chicago Press, Chicago).
D Schon (1987), *Educating the Reflective Practitioner* (Jossey-Bass Publishers, San Francisco).
J Schumpeter (1934), *The Theory of Economic Development* (Harvard University Press, Cambridge MA).
J Schumpeter (1950), *Capitalism, Socialism and Democracy* (Harper Row, New York, 1st edition 1942).
L Soete (1996), "The challenges of innovation", *IPTS Report*, 7, pages 7–13.
R M Solow (1956), "A contribution to the theory of economic growth", *Quarterly Journal of Economics*, 70(1), pages 65–94.
R M Solow (1957), "Technical change and the aggregate production function", *Review of Economics and Statistics*, 39, August, pages 312–320.
R M Solow (1997), *Learning from Learning by Doing* (Stanford University Press, Stanford CA).
P E Stephan (1996), "The economics of science", *Journal of Economic Literature*, 34, September, pages 1199–1235.
L Sveikauskas (1981), "Technology inputs and multifactor productivity growth", *Review of Economics and Statistics*, 63, pages 275–282.
N Terleckyj (1974), "Effects of R&D on the productivity growth of industries: an exploration study", National Planning Association, Washington, DC.
UCLA (1997), *The American College Teacher: National Norms for the 1995–95 H.E.R.I. Faculty Survey* (Higher Education Research Institute of the University of California at Los Angeles).
US Presidential Council of Advisors (1996), "Supporting R&D to promote economic growth" (US Government Printing Office, Washington DC).
H R Varian (1995), "The information economy", *Scientific American*, 273(3), pages 200–202.
R H Wilson (1993), *States and the Economy — Poilicymaking and Decentralization* (Praeger, Westport, CT).
World Bank (1998), *World Development Report 1998: Knowledge for Development* (Oxford University Press, Oxford).