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Revisiting Technology and Knowledge:

Their Contributions to Gross Value Added

Contents:

Abstract- **It is shown that the ideas of knowledge, technology and capital largely overlap such that their meanings are far from consensual between engineers, economists, managers and sociologists. This is a language and conceptual problem which introduces further difficulties in understanding, modeling and managing these valuable assets. A methodology is proposed, considering them as independent parameters, which is based on three new reconstructed concepts of knowledge, technology and capital. A deconstruction and reconstruction method is described, based on the concepts' epistemology, on one hand, and, on the other hand, on a criterion that points out to a desirable common understanding from the points of view of engineers, managers and economists. With the new operational concepts, an algorithm is proposed to quantify the values added by the uses of knowledge, of technology and of capital, as well as the value assessment of technology and of capital assets, separately. An application to the whole Portuguese economy, sector by sector, shows this model's potential to individually understanding the production and value adding roles of those three factors, namely by the definition of a technology index that explains a firm's or sector's technological dependence far better that the technological intensity that is currently being used.**

Index Terms **-Technology evaluation, Technology management, Knowledge Management, Industrial Economics, Economic modeling, Economics of technology management, Value assessments for ITT.**

I. INTRODUCTION

Technology, knowledge, and capital could be considered as the most important production factors and so the basic sources of value creation. However, their single contribution to firm's development and economic growth has never been established and the value they separately add is not clear. To enlighten the value creation by each one, it would be necessary to better understand their different natures and how those differences reflect in the production process. This paper proposes criteria and an algorithm to evaluate separately the values added by the uses of knowledge, of technology and of capital. Moreover, that algorithm will allow evaluating, separately, what will be referred to as technology assets and capital assets. The main benefit of this model is to allow managing separately the three factors, to use them in operating models as independent parameters and to acknowledge their different contributions to growth. This issue is especially relevant to engineering management [1], as engineers are the professional group that most use their knowledge for technology innovation. The basic difficulty in this issue is that the three concepts seem to partially overlap: technology is often understood as a kind of knowledge and both technology and knowledge are thought of as forms of capital. It also happens that managers, engineers and economists, three major players in a firm, don't have common semantics when dealing with these concepts: (1) the new discipline of knowledge management extended beyond the older technology management, overtaking personnel management; (2) engineers focus on technology but do not have an easy and clear rational to quantify the contribution of their work and the value of their products to the firm's or sector's value added; (3) micro-economists ignore the values of knowledge and of technology in their accounting; (4) and macro-economists use growth models with very fuzzy parameters, like the one they refer to as capital, wherein they account for all types of assets, and often multiply it by a factor they designate either by technical progress, technology, knowledge or a twiddled blend of these words.

In conclusion, there is a need to understand their essential differences, what they have in common, how they relate, and their specific roles in the economic value adding process. To achieve that, it would be needed to better understand their conception process and their epistemology and rebuild their actual notions such that they could be used as operational independent concepts. An adequate reconstruction of those concepts, as independent parameters, is the first objective of this paper, what is described in section II. It will then be possible to analyze their separate contributions to every organizational and management function. Moreover, that contribution's quantification needs an objective and rigorous metric. For that metric, the criterion that will be used is the value adding process itself, as this process is the current international standard for value accounting. In this way, value adding contributions from each of these factors may be objectively computed for a firm, a sector or an economy. In section III, it will be explained how the value added by the uses of technology, of knowledge and of capital may be assessed separately. A similar algorithm justifies the separate evaluation of both technological and capital assets. In section IV, results of an application to the Portuguese economic sectors will be described, what will show for every division how knowledge, technology and capital separately contribute to the Portuguese gross value added. Finally, in section V, a comparison will be made between the Technological Intensity parameter, which is in current use and is supposed to show how technological dependent a firm or a sector is, and a new parameter – Technological Index, which the author argues that it performs that role much better.

II. Concepts Reconstruction

The current concepts of technology, knowledge and capital will be revisited, through several disciplines and along the centuries. The concepts will be deconstructed and reconstructed, in order to obtain three operational new concepts that could be used as independent parameters in economic and management analysis. The methodology will be explained in section II.A. The sections that follow, II.B to F, will describe the analysis and reconstruction.

A. Methodology

A five steps method will be used. The first step consists of deconstructing each of the three current concepts into their elements. This implies an epistemological investigation of their constituent meanings, tracing them through several disciplines and along history. The second step consists of finding that smallest number of elements that compose each concept's elemental core. The third step is to establish specific criteria for reconstructing the new operational concepts, such that the set goals of this exercise may be met. The forth step is to reconstruct each concept, using its core elements plus the adequate extensions, accordingly to criteria established in the last step. Finally, the fifth step is to identify border lines between the three concepts, such that one may classify every economic asset and its respective use in the production process as being related to either of them.

The rest of this section II will be structured as follows: for each concept, steps 1 to 4 will be applied. At the end, step five will be considered, defining their borders. As step three, reconstructing criteria, is common to the whole exercise, it will be described beforehand, in the next paragraph.

The criteria to be used for reconstructing the three operational concepts are such that it should make possible the following goals: 1) to objectively identify and quantify each one's participation in the economic value adding process; 2) to attain their full understanding by, concurrently, managers, engineers and economists; 3) not to introduce epistemological cuts. The second point is justified by the main requirements expectable from the three mentioned disciplines, as follows: a) managers would like the new concepts to clarify and not to confuse the way they deal with them, namely within the sub-areas of personnel, financing, production, stocks, etc; b) economists and accountants will not easily accept changes in the way they classify assets, liabilities, costs and profits or modify financial analysis; c) engineers need to be able to use those new concepts as independent parameters in order to understand their participation in the value adding process.

B. Technology

Etymologically, the word aggregates the two ideas of *techne* and *logos*. The former is referenced to Aristotle [2] as a method of systematizing knowledge and is understood today as a sequence of actions, using certain tools, or a rational process, in order to achieve a predefined goal. The latter means the words, the study or the understanding. Therefore, an initial frame for its meaning includes both material means and comprehension, in order to be able to create an idea and apply it, building an object or a system. The term technology is modern and it is attributed to the German philosopher Johann Beckmann (1739-1811), who used it in the title of his books [3], adding to the meaning of the word technique, current at the time, the talent to use it. Similarly, the Doctor and Botanist Jaccob Bigelow published his lessons in 1828 with the title *Elements of Technology*. However, the term became part of the public discourse only after the First World War, when the contribution of technology to society and democracy was widely discussed and acknowledged [4].

Sociologically, technology is described [5] as containing three significant levels: the physical objects, the production or transformation processes and the information about them. Historians and sociologists [6] [7], both in America and in Europe, agree that technology is part of society, permeating relations between humans, among them and with nature, acting as a social cement. It is a sort of non-deterministic web that simultaneously makes up and depends on culture. This could also be understood as functionality [8], what underlines the elemental property of technology – its vehicular role or material substrate of a function, social or purely technical.

The sociological and philosophical discussion on technology shows its complex nature, as complex as the discipline itself wherein the discussion takes place. On the other hand, that complexity contrasts with the functional simplicity of a tool, artifact and even sophisticated systems that engineers easily identify as technological forms. This time-line progress, from a simple tool, as a hunter's spear, to a modern information system, as Internet, illustrates some aspects of the epistemological evolution of the concept of technique to the concept of technology, where the complexity arising from the quantity of elements is obvious but the essential elements rest unchanged. To test this hypothesis, one may analyze a simple, primitive economic process where a tool is used, and verify that the concept of technology includes tangible and intangible components and exhibits functionality.

Technology in a Primitive Transformation Process

The simplest process involves only a person and Nature, as follows: the action of collecting a fruit from a tree is a first transformation process where only knowledge and work contribute as production factors. The result of this process is one piece of fruit ready to be consumed. The knowledge base is about the fruit's characteristic and the work corresponds to the man's action.

The hunter and collector can also break a branch from a tree and prepare it to be used as a spear, a hunting tool. This second transformation process is similar to the first but its product, the spear, will not be consumed but kept to be used afterward.

Later, the hunter will use the spear to kill an animal. In this third transformation process, besides knowledge and work, there is a new component, the spear, which is neither consumed during the process (only slightly degraded) nor incorporated in the final product and so remaining ready for further use. This new element is here recognized as a new type of production factor, a technological form. The spear has a material form, the tangible component, needs knowledge to be shaped and used in the hunting process, the intangible component, and has a clear function, to increase the productivity of the hunting process. The material form is shaped in such a way that a second individual, just by visual inspection, will probably infer its function and how should it be used. This is equivalent to say that this technological form contains knowledge that is embedded in the material substrate.

In the modern world, however, the number and complexity of technological forms is so great that the elemental tool concept is no longer obvious. The knowledge to create new technologies is also confined to a small number of the population and the distance between creators and users has been increasing along the time. As the author explained in [9], this creates new qualitative social dependences for knowledge diffusion, adds a new dimension to technology as a crucial knowledge vehicle and emphasizes the importance of education.

Technology as an Economic Factor

Economics has Accounting as its support language, in a similar way that Physics uses Mathematics. It is a fact that accounting rules of firms and economies don't mention technology [10]; hence its value can not be objectively assessed. In deed, we engineers and managers have been discussing technology innovation for decades and, by the end of the day, we don't know either to objectively define it or to quantify its value. Technology management still looks at technology by the eyes of sociologists, playing with all of its possible attributes at the same time, together in one very large spectrum definition [11].

In the macro economy the situation is different. While in micro, technology accounting is simply absent, in macro economy it is omnipresent but very ambiguous. After the Second World War, OECD[1] started an investigation on the differences of economic growth between the USA and other countries. Ever since, it became the main world institution for studies and statistics and the building of what is known as the Science & Technology System. Later joined by the European Union and Eurostat, they characterize this system by a number of parameters like researchers mobility, research & development investment, number of publications and patents, which is all condensed within three manuals [12] [13] [14]. These data have been correlated with economic growth [15] [16] and is the basis for important worldwide periodic publications [17] [18]. Surprisingly, those S&T System manuals do not define technology. Actuality, that system indirectly evaluates change and innovation in what concerns potential products and processes, it doesn't measure technology change and even less it measures technology value or technology contribution for economic growth, at least not explicitly. Along this line of practice, there are indicators aiming at firm technological capabilities and measuring the factors of the S&T System [19].

One other area of macro economy uses extensively the ideas of technical progress: economic growth models, involving what is there referred to as technology, knowledge or a combination of words with comparable meanings. Both the neo-classic and endogenous types of growth models consider technology as a production factor, either in explicit or implicit form. The 1956 Solow-Swan

[1] Organization for Economic Cooperation and Development

[20] [21] neo-classic model used the parameter technical or technological progress, dimensionless, stating that it represented everything else besides capital and the number of workers. Current text books of eminent economists [22] [23] [24] refer that parameter as being proportional to knowledge, technology, technological knowledge, technological progress and similar terms. This ambiguity did not change with endogenous growth models developed by P. Romer [25] and continued by others [26]. In conclusion, macro economists use a concept of technology that seems to overlap with knowledge and innovation. It is unclear and confusing.

An Operational Concept of Technology

After analyzing how different sciences characterize the idea of technology, it follows in Table I a summary of the elemental attributes that were found. The table is divided in two parts: the first, contains the attributes found through the Economy, Engineering and Management points of view; the second, from Sociology and Philosophy. The first five attributes in both parts are equivalent and will be considered as to constitute the essential elements of the technology concept as it has been understood.

TABLE I

Technology – Attributes found

(a) from Economy, Engineering and Management
o (1) It has a form adequate to the function.
o (2) It is the know-how.
o (3) It means material objects and processes as well as rational and organization activities.
o (4) It is a part of progress.
o (5) It is a set of standard means with a specific goal.
o It is a form of capital.
o It is a part of the transformation and production process.
o It is different from a product to be consumed.
o It is a tangible thing, like a tool.

(b) from Sociology and Philosophy
o (1) It has a social functionality.
o (2) It contains individual knowledge incorporated in its structure.
o (3) It is a social-technical system that involves both the knowledge to build it and the knowledge to use it.
o (4) It is a development parameter, an independent agent of change, retains social knowledge for future benefit

and has a crucial role in education between generations.

- (5) It is a systemizing method.
- It is a product of modern metaphysics.
- It is a component of social and cultural life.
- It is an instrument of power over people and over nature.
- It is a result of science and also part of art.
- It is the product of work.

The exercise of applying the method's forth step, reconstruction with a criterion, yields the following basic idea for the technology concept and the corresponding list of attributes, shown in Table II. A final definition for this operational concept, fifth step, will be made later, after establishing clear borders with knowledge and with capital.

TABLE II

Technology – Description of the reconstructed concept

1) It is a material form with embedded knowledge and with a function.
2) Its functionality is often perceptible in its form.
3) Its embedded knowledge is static.
4) It shows forms of artifacts, tools and their respective social-technical systems including methods and algorithms associated to their construction.
5) It has a role in the production process and it is a depository of socially useful knowledge.

C. Knowledge

To understand how the concept of knowledge evolved in our culture it is necessary to analyze the meanings of sentences using the word knowledge. This epistemological exercise will produce a first roll of attributes. In deed, understanding the deepest significance of man and nature is perhaps the oldest quest of man-kind. For that, the word used has been knowledge. It was a matter for philosophers and was expressed by scholars by examining the meaning of being and thinking and their close link to nature and to the metaphysical ideas of truth, the divine and the absolute. The argument of Parmenides'[2] *to be or not to be*, well explained by K. Popper[3] [27], and the Descartes'[4] *cogito ergo sum* [28] illustrate especial philosophical cornerstones of this concept's epistemology. The first argument points out, in our culture, to the man's individuality, from which it follows the

[2] Parménides (born circa 510 BC), Greek Philosopher with an important influence on Plato.
[3] Karl Raimund Popper (1902-1994).
[4] René Descartes (1596-1650).

self-understanding and his working relation with Nature, while in eastern cultures, by about the same time, Confucius[5] developed the seminal idea of a symbiotic relation of Man and Nature, still very apparent today, as in the Japanese *ba* [29]. The Descartes' argument changes the emphasis from the aims of knowing to the process of knowing and marks the divergence between the European continental rationalism and the Anglo-Saxon empiricism. Knowing through experience and observation and knowing exclusively as a result of a rational process were later grouped together, as complementary, by I. Kant[6], although remaining idealist and metaphysical.

The subject who knows and the object to be known, plus the process of knowing were the three main focus of that discussion. A forth focus, about the initiative and action derived from the knowing process, was introduced later by Hegel[7] and, by the end of the XIX century, all religious and metaphysical arguments were put aside by Nietzsche[8]. The structure, context and functional models of knowledge, as well as language, were the main issues of the XX century knowledge philosophers. The four mentioned focus remained largely unchanged and Popper [30] [31] introduced, within the second, the objects of the mind, like theories or questions, and, within the third, the idea that new (objective) knowledge is always built on top of an old one, transforming it through theories, conjectures and refutations. He considered knowledge being subjective or objective. The former is tacit, organic, intuitive and self-centered and the latter built by the joint contributions of information received through the senses and our own products of the mind, previously acquired, like rational logic structures and language.

Today, the mind is known to be a very complex system that is supported, basically, by chemical reactions and physical fields. Through those, the neuron-sciences explain today the very basic mechanism of data input, retrieval and information flows.

From this very brief epistemological description, the main attributes found for the concept of knowledge can be listed as follows: (1) it is part of the mind and is supported by the organism's biology; (2) it is dynamically built with data and information received from nature and rebuilt by rational instruments; and (3) it is convoyed by volitive action and nourished by work. Note that the dependence on data flows from outside and on human's work confirms a social dimension for the concept of knowledge, what attest that this concept has both individual and social components.

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[5] Confucius (551-479 BCE), a thinker, political figure, educator, and founder of the *Ru* School of Chinese thought.
[6] Immanuel Kant (1724-1804).
[7] Georg Wilhelm Friedrich Hegel (1770-1831).
[8] Friedrich Nietzsche (1844-1900).

Data, Information and Knowledge

Most authors consider data and information as being ingredients of knowledge. Those two concepts came from Norbert Wiener's Cybernetics and Claude Shannon's Theory of Information, both on 1948. Data is a quantity of bits and a bit is a discrete variation of something. It is an abstract concept that, however, needs a physical equivalent. It has no attached meaning except in one and only dimension: quantity. One bit is called the unit of information but it does not have informational content. Our brain can store bits in neurons and propagate them through nerves and dendrites, as an electrical pulse. The concept of information, however, needs the existence of data but depends also on the data temporal and spatial structures, as five musical notes in two different sequences originate two different melodies. Furthermore, to generate information, the data receiving structure of the receiver must be adapted to the incoming data structure. In deed, two equal sets of data, received by different structures, originate different information and two different sets of data, received by different structures may originate the same information. In what concerns neurobiological systems, information is only generated when input data has a pattern recognizable by the receiver. With this information, the mind takes conscience of its potential significance, relevance, and usefulness and, accordingly, that information is recorded and may create new knowledge.

It is known that data, information and knowledge decay with time [32], as any other physical phenomenon. On the other hand, the mind is continuously receiving new information and, eventually, making new knowledge with it [33]. So, it should be said that knowledge is not a static occurrence but a very dynamic and continuous process.

Individual and Organization Knowledge

After the idea of technology have risen to a high level of importance, the managers of the eighties realized that people were the crucial constraint for innovation and so extended their interest from technology to individual knowledge. Reference [34] shows a decade of seminal texts on this subject. Tom Peters [35], Toffler [36], and Peter Drucker [37] [38] are authors with important contributions to this movement. They explained the importance of people, the role of knowledge in production, its economic value as a form of capital, defined the knowledge worker and stated clearly that the real business was about knowledge. Peter Senge [39] and Nonaka & Tacheuchi [40] defined the learning organization and the knowledge creating organizations. All in one, knowledge came to be the most essential asset in a firm and the concept extended to the point that, slowly and defiantly, overlapped to most of its neighbor concepts [41] [42]. Among many authors, Boisot [43] defined knowledge assets and Edvinsson & Malone [44] and Stewart [45] defined intellectual capital as a form of knowledge. This new type of capital is mainly intangible, highly subjective, and impossible to list exhaustively but quick and simple to quantify: it is the goodwill, the difference between the firm's commercial value and its book value. An excellent compilation of twenty four contributors to this new idea was edited by Imparato [46]. This type of capital will be analyzed in a latter section.

The idea of knowledge considered as tacit or explicit [Nonaka & Tacheuchi] became common. This difference helped to understand how the concept of knowledge overlapped others, namely the concepts of technology and of capital. Tacit is that knowledge which is not put into words, it is intuitive, subjective, and unconscious, while explicit knowledge is the type that can be described and, as such, written down, shared, taught and discussed. This is the basic idea that explains the transition from individual to social (firm's) knowledge and, therefore, suggests and supports the practice of knowledge management, knowledge transfer [47] and the idea of knowledge assets, also named as technological knowledge assets [Boisot]. It is quite clear that the so called knowledge assets are produced by individual knowledge with its corresponding work. They are extensions of individual knowledge but, as products, have cut the links with their creators. As autonomous products, they may be accessed by the whole firm or by society and, therefore, may be considered as being part of the organization knowledge and valued as intellectual capital [48].

In brief, the concept of knowledge, as seen by management during the last decades, includes what used to be the individual knowledge, plus a number of products directly related and produced by that knowledge, like intellectual property, patents, administrative or process procedures, data-bases, reports, manuals, R&D prototypes, techniques, some technological forms, etc., as far as they need the direct involvement of special individual knowledge [49].

An Operational Concept of Knowledge

After analyzing the contributions of different sciences for knowledge's epistemology, it follows a list, in Table III, of the main elemental attributes found. The table is divided in two parts: the first, contains the attributes found through Philosophy and Sociology; the second, from and Engineering and Management. The numbered six attributes are common (or somehow equivalent) to the two parts of this table and are considered as the essential attributes for the knowledge concept that were found.

TABLE III

Knowledge – Attributes found

from Philosophy and Sociology:

- (1) It has a rational component and develops with logic.
- (2) It is intuitive, subjective, non-conscious and develops uncontrolled.
- (3) It is dynamic.
- (3) It is the product of a dynamic relation between the subject and the object.
- (4) It belongs to the individual.
- (5) It expresses through language, action and work.
- (6) Its content, on a certain time, can be passed to a material substrate.
- It is independent of truth, or the last cause.
- It develops from genetic pre-dispositions.
- It may be considered as objective.

from Engineering and Management:

- (1) It may be taught and managed.
- (2) It is intangible.
- (2) It has a subjective, tacit and immeasurable component.
- (3) It has a dynamic component.
- (4) It belongs to the individual and to society.
- (5) It may be applied.
- (6) It has tangible forms.
- (6) It has an explicit and identifiable component.
- It may be analyzed as data and information.
- It has an economic value.
- It is unlimited.

To reconstruct this concept, the third step, the criteria announced in section A should be used. The result of applying the method's fourth step yields to the description of the reconstructed concept, as shown in Table IV. A

TABLE IV

Knowledge – Description of the reconstructed concept

1)	It is a dynamic process between the subject and the object, which takes place in the biological mind.
2)	It has an intuitive, tacit and subjective component.
3)	It has a rational and objective component which may originate new meanings.

4) It involves both the intuitive and the rational components through language, action and work.

5) Its direct final product is work, which originates products with static knowledge embedded in their material forms.

D. Capital

The classics' view of labor, land and capital, as the three basic production factors, will be taken as a first general reference. Note that labor and land, then, were not considered as capital, what suggests that capital was dissimilar from man's and nature's uniqueness.

Going back to an agrarian primitive economy, where this analysis will begin, there are a few relevant questions that come up naturally and can shed light on the nature of capital. The spear, which was considered above as a form of technology, was it also a form of capital? And dried and salted meat, stored for future consumption or barter? Was a surplus of grain also a form of capital? To the first two questions, the right answer is not clear. The last question, however, is a far-reaching one because there is a very specific fact about crops and sowing that is not so evident in other production processes: people new that they couldn't consume all the produced grain, since they needed to store the best, as seed for next year's sowing. This seed, a new production factor, showed three important characteristics: was not to be consumed, it was already a produced good and had to be stored for later use in the next opportunity. It was different from the spear that could be quickly replaced by a new one. On the other hand, the seed for next year's sowing was irreplaceable, such that it had to be treasured as vital. Its existence was previous to the whole agronomic process. These three attributes: a produced good, a good to be stored for later use, plus this characteristic of having a primal role in a production process, will be retained here as seminal elemental attributes of capital.

Capital in Antiquity and Middle Age

The division of labor, surplus products, local products exchange, markets and commerce are the historical frame stream where other attributes of capital may be found. Long distance commerce asked for intermediary commodities, something that most communities would recognize with value. Shells, salt, cereals and cattle were used as such and, eventually, metal coins became the intermediate commodity most easily to use, with intrinsic and high density value. The Hammurabi's Code of Laws, 1780 BC [50], already mentioned the equivalence of wheat and money, but coined metal (iron) money has only started to be used in Egina by the VII century BC [51]. Three centuries later, Aristotle [52] classified the free men in two groups, plebeians and nobles, and the former in eight categories, being merchants one of them. His time was the time of Alexander, when trade increased enormously with his empire, to be along the centuries substituted and integrated by Phoenicians, by Roman law on the II century BC, and by Islam law after the VII century AD. The generalization of coin use for an increasing number of transactions contributed strongly to institute the idea of credit, as an extension of mortgaging, and, with credit and loans, the idea of interest. Coins and precious metals became easy forms of accumulating wealth, which became a synonymous of capital, especially if it were to be lent, with an interest. So the concept of capital grew to include both the idea of wealth, very especially in its most flexible form - coined precious metal money, and the idea of credit. Note that within the notion of wealth it was also land and slaves. Through the Middle Age, agriculture was economically more important than commerce [53] and its product rose only at the same rate as the population. The world's Gross National Product per capita didn't grow in the first millennium AD and it grew only 50% from the year 1000 to 1820 [54]. This growth was due mainly to capital investment in commerce. In deed, see trade extended from the Mediterranean to the Baltic, and inland trade crossed the new populated Europe from the Baltic to the Bosphor, closing the European trade space and establishing its frontiers up to now. Foreign trade grew exponentially, first by the Venetian Republic, with the East, later by the Portuguese and Spanish discoveries of the new world and the Indian see trade, and, finally, with the Dutch and English empires. The importance of wealth to growth was acknowledged and that meant, at the time, accumulation of precious metal coins and other treasures[9]. By the end of this mercantilist period, however, it became obvious that there was more. The new knowledge on machines and techniques, on agriculture, naval arts, buildings and port facilities, fishing and trade companies, opened new areas for the capital concept's enlargement. William Petty[10] explained to his king that a small country could be as rich as a large one [55]. Slowly, along the centuries, the idea of capital extended from land and slaves to coins and precious metals and to unusually new forms.

Capital in Liberalism, Marxism and Marginalism

Cities were growing quickly, with their guilds and markets, profiting from an increasing commerce activity, domestic and transnational. However, the value created in each country still had the land as its prime origin, where the majority of the population lived and worked. The land owners, conscious of their power, reclaimed their real importance and forced more liberal competition laws, aiming especially at state monopolies. This Physiocracy movement was especially significant in

[9] Between 1500 e 1800, 1700 tons of gold and 70000 tons of silver traveled from America to Europe (Maddison, 2001, Table 2-8).
[10] William Petty (1623-1687) English economist.

France and had the face of Quesnay[11], who explained in great detail the importance of land in the agriculture production process. Land, as a particular form of capital, acquired an especial status: it was the fundamental source of value, by means of a *don gratuite,* a gift that was intrinsic to land and which could be appropriated by landowners [56]. Land and its rent became a distinctive chapter of the history of capital, especially with the classics, namely, David Ricardo[12] [57]. Land was proved in accounting detail to be the major source of wealth, but too important to be considered as just a form of capital.

Adam Smith[13], in England, who met Quesnay and discussed his ideas, explained that land was not the only form of wealth that would produce a surplus, which is, after all, a component of added value in any production process, being agriculture or industry. This author categorized the idea of capital, the forms of which were classified to include the latest machinery and techniques in use, at the time, in a number of trades and industries. He considered capital as having the forms of fixed and circulating [58], and as being, with labor and land, a source of value. A new attribute of capital became apparent and consensually accepted: it was not only a synonym of wealth but also, and above all, a source of value and more wealth. In brief, the classics considered capital as being a source of wealth and having the forms of money and credit, instruments and machinery, raw materials, merchandise, produced and not sold goods and even knowledge and workers' competences. Moreover, as capital is a good that, in his turn, is the result of earlier production processes, labor was, after all, the final and unique source of value. This was also the vision of Karl Marx[14], who additionally considered that labor was being transformed in a new type of merchandise and that both merchandise and money were the two elemental forms of capital [59]. On the nature of capital, he didn't change or added anything relevant but emphasized, more than the classics, the need to invest in capital goods, contributing to consider capital as an endogenous parameter that should be used, as he did, in economic modeling.

By 1871, there was an epistemological cut in the theory of value, when the origin of value was defended to be on the consumer side, the demand, and not on the producer side, the offer. This was the Marginalism school which started the neo-classic movement. On the nature of capital, there was nothing new. Irving Fisher[15] [60] reviewed the notions of capital, stock and surplus concluding that

[11] François Quesnay (1694-1764) French economist.
[12] David Ricardo (1772–1823), English economist.
[13] Adam Smith (1723–1790), Scottish economist.
[14] Karl Marx (1818-1883), German philosopher, sociologist and economist.
[15] Fisher, Irving (1867-1947). American economist and mathematician.

they reflected about the same reality. Also, Alfred Marshall[16] in his *Principles*…[61] wrote that the ideas of fixed and circulating capital were consensual and there was no need to change them. On the XX century the concept of capital, as seen by economists, didn't change much. Schumpeter[17] insisted very much on its function, favoring the idea of means of payment or purchasing power [62] and establishing the differences between capital and capital goods and between capital to found a company and capital to run it. His ideas of creating new technologies and destroying the old ones, what characterized capitalism, induced managers to pay especial attention to workers' knowledge and to technology innovation, in all possible forms. Management and Sociology extended the concept of capital to those areas, respectively at micro and macro levels.

Human, Intellectual and Social Capital

Theodore Schultz[18] introduced the term human capital in 1961 [63], meaning the knowledge of workers. Some macro economic growth models used this idea considering a parameter that is proportional to population competences and school attaining [64]. The argument for knowledge to be considered a form of capital is that it can be accumulated and it may originate new products and benefits. When taking firms into consideration, there are other tangible and intangible assets that are directly related to human knowledge. That is the case of data bases, books, patents, administrative procedures, research methods, etc[19] [65]. Thomas Stewart [1997] defined intellectual capital as everything in a firm that justifies a competitive advantage, including human capital. Finally, when considering society as a whole, it is true that social assets also contribute to generate growth. There are as well cultural and social values, like trust and tolerance, social institutions for specific aims, even social systems like the educational or the judicial structures [66]. These are forms of social capital, which can be divided into structural or cognitive. Note that these three forms of capital: human, intellectual and social, have one common characteristic which is not found in physical capital: it develops and matures with its use. In deed, it is much like human knowledge.

An Operational Concept of Capital

After analyzing the contributions of different sciences for the building of the concept of capital, it follows a list in Table V of the elemental attributes found. The numbered seven attributes are

"Precedents for Defining Capital", *Quarterly Journal of Economics,* volume 18, pp. 386-408. Electronic text on http://socserv2.socsci.mcmaster.ca/%7eecon/ugcm/3ll3/fisher/capital4 [Consult. June 2004].

[16] Alfred Marshall (1842-1924), English economist.

[17] Joseph A. Schumpeter (1883-1950), Austrian economist.

[18] Theodore William Schultz (1902-1998), American economist.

[19] A good example would be the methodology *Balanced Scorecard.*

common (and somehow equivalent) to the two parts of this Table and are concluded to be the essential attributes of the capital concept. The result of applying the method's fourth step yields to the description of the reconstructed concept, as shown in Table VI. A final definition for this operational concept, fifth step, will be made later after establishing clear boundaries between capital and technology.

TABLE V

Capital – Attributes found

from History and Economy:

- (1) It is an economic central parameter.
- (2) It has the potential for reproduction.
- (3) It is a product not to be consumed.
- (4) It is a produced good.
- (5) It has a function within the production process.
- (6) It accumulates value.
- (7) Its versatile in its form.
- It is the product of saving.
- It is tangible.
- It can be used directly or indirectly in the production process.
- It may take the form of money, merchandise or credit.
- It is a form of wealth.

from Sociology and Management:

- (1) It has a crucial role in value adding.
- (2) (3) It is a time bridge between past and future.
- (5) It has a technological component.
- (5) It has a financial component.
- (5) (6) It is an element of culture.
- (6) It is, it accumulates and it reproduces knowledge and work.
- (6) It is a vehicle for education connecting different generations.
- (7) It represents relations and procedures within an organization.
- (7) It can be applied in a number of different ways.
- It aglutinates people's wills and actions.
- It represents human production capabilities.
- It is a vehicle for knowledge diffusion.

TABLE VI

Capital – Description of the reconstructed concept

1)	It is an economic central parameter because it is essential to create value.
2)	It has reproduction potential and bridges the past with the future.
3)	It is durable and is not to be consumed.
4)	It is a produced good.
5)	It has a function within the production process and has technological and financial components.
6)	It is a form of value accumulation and, as such, is, reproduces and convoys knowledge.
7)	It is versatile in its shape and can be quickly transformed and, as such, it has flexible applicability.

E. Boundaries Between Knowledge and Technology and Between Technology and Capital

So far, a cluster of attributes for each of the reconstructed concepts has been completed. However, an inspection of Tables II, IV and VI shows that their boundaries are not perfectly clear. Thus, criteria to distinguish objectively between them are still needed. The three concepts relate between each other and with Nature in a complex and dynamic fashion, as Fig. 1 illustrates. Taking an anthropological point of view, human knowledge and Nature are the essential ones. Along the time, human knowledge, with Nature, creates technological and capital forms, what contributes to create newer knowledge, and so forth. Also, it is important to recognize that the three of them decay with time: people forget and all material forms decompose and rote.

Which borders should be considered? Remembering, from what was described above, that knowledge is the most basic of the three concepts and also that technology precede capital in primitive economies, a simplified scheme of their cause-effect relationship should consider the following: (1) knowledge originates both technology forms and capital forms, but it is epistemologically closer to technology; (2) knowledge is clearly of a different nature; (3) only a small but important single attribute differentiates technology from capital. As such, the two most significant boundaries that will be discussed are between knowledge and technology and between technology and capital.

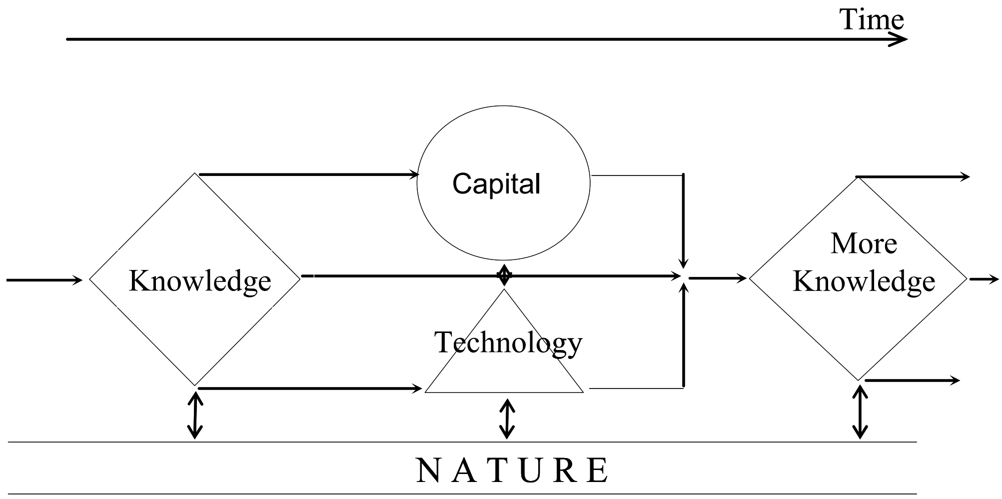

Fig. 1. Dynamics between knowledge, technology, capital and Nature

Boundary Between Knowledge and Technology

When comparing the attributes listed on Tables IV and II, it comes up that technology is, after all, an especial form of knowledge. However, in order to discriminate between them, two important features help to reach that goal: (1) knowledge is dynamic and exists within the human mind and (2) technology is a static form of knowledge that is embedded in a material substrate. They have different natures and exist in different substrates: a living and dynamic, the former, and a static material form, the other. Therefore, an organized thought, a theory, a schematic image, a formulation of a question, a decision algorithm, any image, a melody and so forth are knowledge as far as they exist in the human mind, because they represent data and information constructed and resident there. On the other hand, a message on a paper, a sketch, a hand-written or CD-recorded speech, a built object, a programmed decision algorithm, a methodological written sequence and so on, up to tools, instruments, machines and large systems are technological forms because they are exterior and independent to the human mind, they are objective and static forms in a material state. They are directly available and potentially understood by many people, what allows calling them forms of social knowledge but not any more forms of human knowledge. One other important conclusion may be taken as well. How do humans transform their knowledge into technology? The answer seems to be: through language, intentional action and work[20]. How? Work needs action, which is the product of energy with time, and can also be explained as entropy times time. Thus, human knowledge flows from the mind through the body as a form of energy and entropy, along the time, and, as such, taking the form of

[20] The unit of work is Joule (J), the same as energy. The unit of action is (J.s), which is the Plank constant, the energy of 1 Joule through 1 second.

action. The conclusion is that knowledge originates technology through work and action[21]. One other conclusion materializes: as human mind and, thus, human knowledge are impossible to be directly assessed and quantified, only work and its creations, which are objective forms, can be acknowledged, quantified and valued by society.

Boundary Between Technology and Capital

Carefully comparing Tables VI and II, one realizes that technology and capital attributes coincide mostly. They are products not to be consumed, with a function in the production process, have knowledge content and often a recognizable shape. Only one attribute may discriminate between them: it is the flexible applicability of capital. It is flexible because it is easily transformable and its shape and function are versatile. On the contrary, a technology form has a specific function and can not be used for something else. Therefore, the boundary between technology and capital is traced with this criterion. That form that is versatile in its shape and function and also is easily transformed, is a form of capital. If its shape and function are well defined and can not be easily transformed, it is a technological form. As such, examples of technological forms are patents, bleu prints, reports, tools, instruments, machines, systems, all sorts of equipment etc, while capital forms are, typically, buildings, money and credit. Also, land could be considered as a form of capital. This border is not absolute and sometimes is difficult to draw. This fact will reflect in the way the algorithm to differentiate technology from capital will be built.

F. Reconstructed Operational Concepts Definitions

Individual knowledge is a dynamic system of data and information resident in the human mind, which evolution and constant transformation has two important and mutually dependent components. The first corresponds to the permanent reorganization of data and information that is resident in the human mind, consciously and unconsciously, what may originate new information and new knowledge. The second is the management of bidirectional data flows, between the mind and its exterior, the own body and Nature. Thus, knowledge is an individual quality, unquantifiable, very dynamic and somehow unstable. Knowledge social expressions are language, intentional action and work, which are the aspects that may be socially and economically relevant and can be quantified and assessed.

[21] The word “work” will be used for the meanings of both “work” and “action”. For “action” it is meant “intentional action”.

Technology or technological forms are information and knowledge imbedded in substrate materials. Hence, they are material, objective and identifiable. They are static forms holding the individual knowledge that was crystallized in them, becoming in the process forms of social and available knowledge. In a production process, technology has a specific and well defined function and is a good not to be consumed. Technology is an outstanding form of knowledge that is exterior to the individual and socially relevant.

Capital[22] is a higher form of technology; therefore it is a static form of knowledge, as well. Capital forms are objective and identifiable material goods with the same attributes as technology but, in their functionality, with a much larger flexibility in the way they take part in the production process.

III. Value Added by Knowledge, Technology and Capital

Assuming that the new concepts represent the only three basic resources, it is now possible to quantify the value added by the use of each one and also the value of their respective assets.

First, however, it is important to describe, very briefly, how the concept of value evolved to the primary importance it has today and what the added value in an economic process rigorously represents. An analysis on the epistemology of value [67] showed that, from its philosophical and axiological contents, the process of value creation runs in parallel with the process of knowledge creation and that the latter assures the survival and growth of our species, individuals and society. Outside the human's mind, within society, individual knowledge acquires the very real metaphor of value, circulating and multiplying through society, and circling back to the individual, again in the form of knowledge but now as socially endorsed knowledge. Sociologically, it can be said that societies arranged for conceptual/semantic vehicles for the translation and application of axiological principles, values, to behavioral, social, ethical and moral codes. Economically, it can be concluded that the fluxes of value and the respective stocks are components of a particular social system that objectively regulates all processes of value creation, degradation and transformation. One important conclusion may be taken from these thoughts: if overall and individual knowledge increase naturally along generations, so does individual and socially available value. Therefore, the growth of both knowledge and value are natural and expectable processes.

22 This concept of capital will be written with a different letter type; and the word capital, written with the current letter type, will keep its current meaning. Therefore, Capital = Technology + Capital.

The loop of knowledge/value/knowledge is the following. Individual knowledge is created by the human mind and transferred to society through work, which produces consumer, technology and capital goods. The aim of the whole production process is to increase diversity, quantity and availability of consumption for all society members. Through produced goods and their consumption, value is diffused throughout society. The consumption of goods, services and information facilitate increases in individual knowledge, compensating for its natural decay and promoting new knowledge.

Therefore, the economic system and its theory of value reflect value/knowledge fluxes and stocks and emerge on the social horizon as the top of the iceberg, which constitutes the human evolution process. Value is the social metric of knowledge fluxes, being this metric characterized by a criterion and a scale. From the economic point of view, the criterion is what could be called the production process itself, in general terms, which means that it is within a production process that we objectively assess value creation; and the scale uses, as basic references, both the producer's work and the consumer's sense of utility. How is the economic value accounted today? Value accounting systems are slowly converging globally and, today, within OECD countries, only small differences persist.

A. Value Added

The economic process produces things that society acknowledges with a certain value. Along that production process, there is value that is added: it is called the gross value added (GVA). From the production approach, it is defined in Europe by ESA 1995 [68] and equals, in a simplified closed society without state, the national output value minus the national intermediate consumption value. The GVA in an economy is the sum of all firms' and institutions' GVA. In a firm, taking the European BACH system [69], the GVA is computed by *Total operating income (S)* minus *Cost of materials and consumables (5)* minus *Other operating taxes and charges (8)*. However, instead of calculating GVA by a subtraction, it may be computed by summing up the terms that contribute directly and positively: *Staff costs (6),* plus *Value adjustments on non financial assets (7),* plus *Taxes on profit (Y),* plus *Profit or lost for the financial year (21),* plus *Value adjustments on financial assets (12),* plus *Interests and similar charges (13),* plus *Extraordinary charges (17),* minus *Financial income (9/11),* minus *Extraordinary income (16).* Basically, GVA is the sum of costs of labor, plus depreciation of tangible and intangible assets, plus provisions, plus taxes on profits, plus profits on the financial year, where it is subtracted the part of profits originated in the extraordinary and financial activity. As a sum of accounts, it is as shown in identity (1).

$$GVA=6+7+Y+21-[(16+9/11)-(12+13+17)] \quad (1)$$

The model this paper is describing assumes that the three only resources from which value may be created are knowledge, technology and capital. Therefore, the total GVA should also be the sum of the value added from the use of those three resources: the values added by the use of knowledge, L, by the use of technology, T, and by the use of capital, C. Comparing (1) and (2), it should be possible to identify each term of (2) with the mentioned accounts in (1).

$$GVA=L+T+C \quad (2)$$

Let us see how, starting with the use of knowledge. From the last section, it was proved that individual knowledge was unfeasible to assess. On the other hand, it was established that work is the socially visible and accountable use of individual knowledge. As such, the value added by the use of knowledge is, after all, the value of work, which is accounted as labor costs, L. This is the only direct contribution from knowledge to GVA.

The production process as a value adding process is schematically described in Fig. 2. The values added by the use of technology, T, and by the use of capital, C, correspond to values that are subtracted to the values of technology and capital assets. These values are, mainly, the depreciation values of technological and capital assets, including the borrowed capital costs and yields to firm owners' capital (profits) and to the state (taxes on profit).

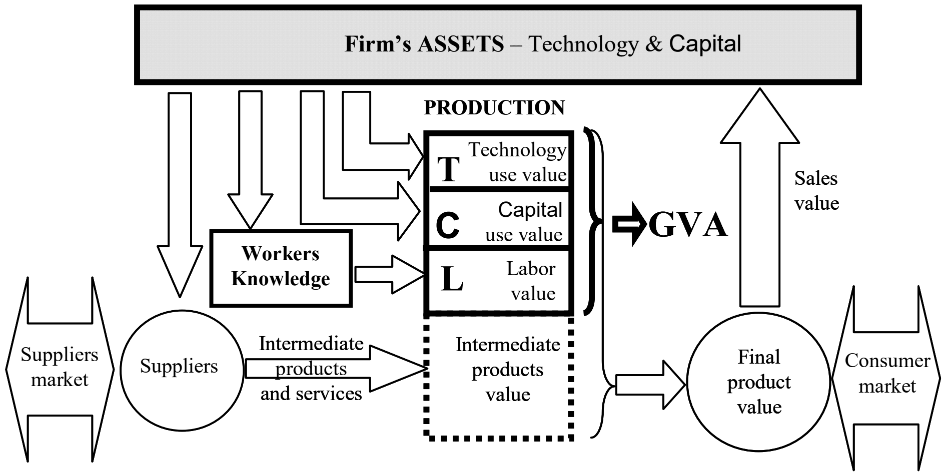

Fig. 2. The production process as a value adding process [66]

Technology, Knowledge and Capital Indexes

The technological index is defined as the percentage of gross value added originated in technology. From (2), dividing both sides by GVA, it may be written

$$1=LI+TI+CI \qquad (3)$$

Hence the definitions of LI – labor index; TI - technology index; and CI – capital index.

To distinguish between technology and capital, a first criterion is proposed, as follows: the firm's assets, which are subject to depreciation, are divided in two lots, technology and capital. The former is the group of equipment, tools and industrial property. The latter is money, land and buildings. These assets depreciate as they are used within the production process. A first criterion will provide the definition of what will be called the technological coefficient. This is the ratio of the two following terms: the depreciation value of equipment, tools, industrial property plus R&D costs; the second is the total depreciation value of tangible and intangible assets.

The used capital value is, basically, the depreciation of land and buildings plus setting up costs. On the other hand, as the analysis of section II showed, there is a continuous and somehow unsteady border between technology and capital. That line depends on the applicability of the specific resource. This idea introduces a second order relation. To reflect that characteristic in the criterion to distinguish the use of technology from the use of capital, the following idea will be applied: that distinction will depend not only on the resource itself but also on the production process where the resource is used. For example, the technological content of a building's depreciation in one firm may be different from the one of another firm with a different production process. That difference is marked by the values of the technology index, TI, the technology coefficient and the GVA coefficient.

Taking the firm's yearly depreciation values map, the technology coefficient is defined as the ratio of technological depreciation value to the total depreciation value. Now, to reflect the difference of costs related to interests from borrowed capital used to pay for intermediate products or for GVA components, another parameter will help to differentiate between uses of technology and of capital: the GVA coefficient. It is defined as the ratio between GVA and firm's total costs. These two coefficients will enable an objective distinction, in every GVA component of (1), between what is originated in technology or in capital, allowing the construction of both the use of technology and the use of capital contributions to GVA, T and C, and, subsequently, their respective indexes, TI and CI. This is a rather laborious task which, in its detail, will depend on each country's accounting items, and so will not be presented here. An application to the Portuguese economic sectors will be described in section IV, unveiling the real importance of technology use for sector's development and national economic growth.

B. Technology and Capital Assets

Fixed and current assets and liabilities are read in the firm's or sector's balance sheet. As it was done for the profit and loss account, where it was evaluated the GVA, the uses of knowledge, of technology and of capital contributions, it is possible now to classify every account of a balance sheet as a form of either technology or capital. Applying the same criteria, the result will be an objective evaluation of technology assets and of capital assets, diminished off the respective liabilities. One important conclusion from this exercise, although well known but never properly quantified, is what could be named as the law of technology's impoverishment. This law could be stated as follows: along a production process, the technology value transforms into capital value such that, at the end of a certain period, the value of the initial technology degrades to zero.

IV. THE CASE OF PORTUGUESE ECONOMIC SECTORS

The algorithm to compute the values added by the uses of knowledge L, technology T and capital C, as explained by identity (1), was applied to the Portuguese economy[23, 24] for every division and sector, from 1996 to 2003, allowing identifying the economy dependence on each of these factors and their relation to economic growth.

Taking the year 2000 as an example, it follows the indexes of knowledge, LI, of technology, TI, and of capital, CI, of a selected number of divisions. Fig. 3 shows indexes related to the whole economy and to Primary (1 to 5), Secondary (11 to 45) and Tertiary (50 to 93) activities.

Fig. 4 shows indexes related to the whole manufacturing industry (15 to 37), to Manufacturing of radio, television and communication equipment (32), Electricity… (40) and Construction (45) activities. Fig. 5 shows indexes of Retail trade (52), Telecommunications (642), Computer and related activities (72) and Education (80).

For the considered universe, Fig. 3 shows that the relative contribution of labor costs, which coincide with what was considered as the knowledge index, is 56%, while the technology index is only 20% and the capital index is 24%. It can also be seen how these numbers change from the Primary to Industry (Secondary) and to Services (Tertiary). In Fig. 4, it is interesting to compare the high technology index TI of division Electricity (40), 34%, with the much lower one of Construction (45), 15%. In Fig. 5, it is surprising to find out that Computer and related activities (72) has a very low technologic index, 8%, almost as low as Education's (80), 6%.

[23] The study considered only the universe of firms with more than twenty employees for all CAE rev. 2 (NACE 4 rev. 1 or ISIC rev. 3) divisions, except: Secondary – 10 Mining of Coal…; Tertiary – 65 Financial Intermediation…; 66 Insurance…; Activities auxiliary to financial…; 75 Public administration…; 91 Activities and membership organizations NEC; 95 private households…; 99 Extra-territorial organizations….

[24] International Standard Industrial Classification ISIC rev. 3 is equivalent to NACE rev. 4 and to Portuguese CAE rev. 2.

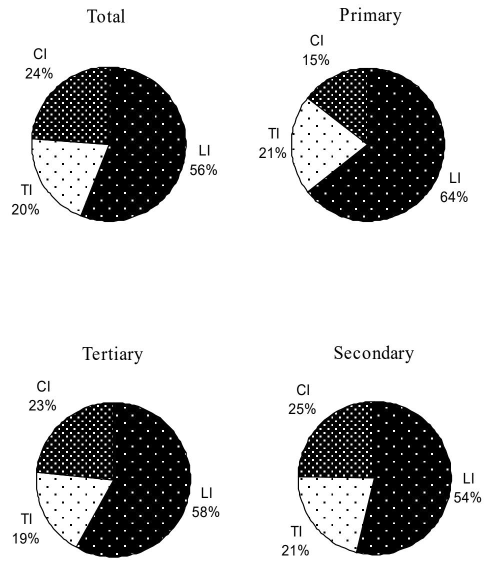

Fig. 3. LI, TI and CI for the whole economy and for Primary, Secondary and Tertiary sectors (year 2000).

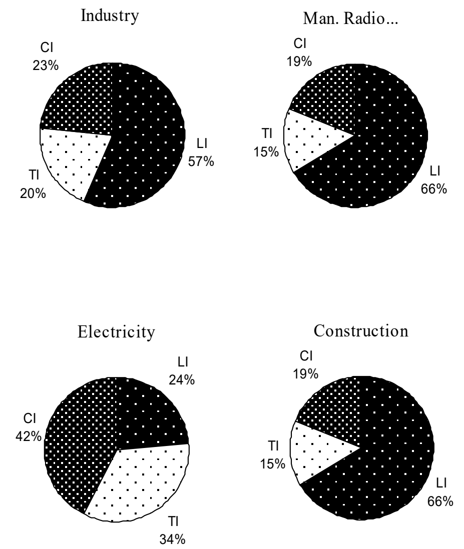

Fig. 4. LI, TI and CI for Manufacturing Industry (15 to 37) and for Manufacturing of radio, television and communication equipment (32), Electricity… (40) and Construction (45) activities (year 2000)

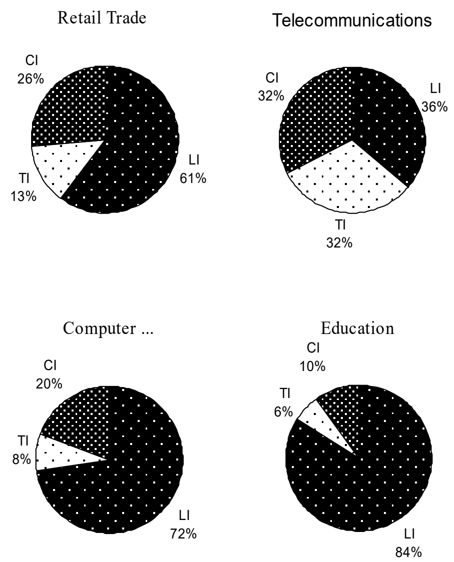

Fig. 5. LI, TI and CI for Retail trade (52), Telecommunications (641), Computer and related activities (72) and Education (80).

V. Technology Index vs. Technology Intensity

The technology index, TI, defined above, relates the value added by the use of technology in relation to the total gross value added, GVA. It was argued by the author [70] that it represents the firm's or sector's dependence on technology better than the parameter technology intensity that currently classifies sectors as of high or low technology. Technology intensity is a factor used by OECD that pretends to indicate how much an industrial sector depends on technology but, actually, it exclusively indicates its dependence on R&D [71]. It is defined as the ratio between R&D costs and the GVA.

The technology intensity parameter shows, at the most, the dependence on technological innovation but it does not show the whole dependence on technology use. Also, it does not hold its significance when comparing the same sectors in different economies. Taking, as an example, the sector (32) Manufacture of Radio, Television and Communication Equipment, it had a Technology Intensity of 18.65%, in USA (1990), while it was almost zero in Portugal (average of 1996 to 2003). Accordingly, one would conclude that this is a high technology sector in the USA and a low-technology sector in Portugal. On the other hand, the Technology Index, as defined in this paper, shows a value of 18% for this same sector in Portugal, what is a real measure of its dependence on the use of technology. Table

VII shows values of Technology Intensity and Technology Index for both countries, for four different sectors.

TABLE VII

TECHNOLOGY INTENSITY AND TECHNOLOGY INDEX IN USA AND PORTUGAL SECTORS

NACE 4 rev.1 designation*	USA (1990)	Portugal (1996 to 2003)	
	Technology Intensity %	Technology Intensity %	Technology Index %
Manuf. of Radio, TV & Commun. Equipment (32)	18.65	0	18
Manuf. of Electrical Machin. n. e. classified (31)	7.63	0	16
Manuf. of other Non-Metallic Mineral Products[#] (26)	2.2	0	29
Manuf. of Food Prod., Bever. and Tobacco Products (15+16)	1.14	0	23

* NACE 4 rev.1 code 32 is ISIC rev. 2 code 3832.

NACE 4 rev.1 code 31 is ISIC rev. 2 code 383.

NACE 4 rev.1 code 26 is ISIC rev. 2 code 36.

NACE 4 rev.1 code (15+16) is ISIC rev. 2 code 31.

[#] Portugal (1997 to 2003)

VI. CONCLUSIONS

The objective of reconstructing the concepts of knowledge, technology and capital, such that they could be used as independent parameters, was carried out, allowing identifying and quantifying each one's participation in the economic value adding process. The reconstruction criteria also asked for attaining the full understanding of each operational concept by, concurrently, managers, engineers and economists. This model's success is still to be proven, as its specific conclusions will have to be accredited as new and relevant by those three professional groups.

To achieve the goal of creating three operational concepts, it was necessary to break up knowledge from technology and find a line border between the two. That border was found to be the human identity. As such, knowledge was defined strictly as human knowledge, i.e. specific dynamic assemblage of data and information located within the human brain. On the other side of the border is technology, a product of work, which is here considered as an expression (action) of human knowledge, and not to be consumed. Therefore, technology remains a form of knowledge but it is a social form of knowledge, static and embedded in a material form. Capital came to be defined as an elevated technological form, which border with the concept of technology is such that capital does not contain a specific and narrow functionality as technology does.

It was proved that it is possible to assess the value added, separately, by the use of knowledge, the use of technology and the use of capital. The same applies to firms' technological assets and capital assets. This model brings a more clear view of the roles of these three production factors. An application to a country's economy showed how different sectors depend differently from them. For sectors and firms, it was shown how the new Technological Index informs on the technological dependence far better than the current Technological Intensity parameter.

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