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Something new under the sun.

The role of new technologies in a growing economy

by

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Something new under the sun – The role of new technologies in a growing economy

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Abstract: This paper inquires into radical innovations and into their role to promote economic growth. Can an economic system grow only in quantitative terms, or the process of structural change, that underlines the emergence of new technologies, is an essential ingredient? To put it philosophically: is there something new under the sun of a growing economy or not? The paper attempts to deal with this quest both in terms of analysis and in terms of evidence. In terms of analysis, it conceptualizes the taxonomy of innovation, proposed by Chris Freeman (1994), in an input-output framework. It shows how the rate of growth will eventually peter out without the essential contribution of new sectors in the economy. In terms of evidence, it brings the case of electronics to study the impact of a new technology in changing the economic structure and the knowledge structure of the UK and US economy between the 1970s and 1990s. The changes are profound, and they may help to start explaining a sort of reverse of Solow's paradox. Namely, computer are everywhere, now also in the statistics of the tertiary sector.

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1. Introduction

Economics nowadays is increasingly treated as a physical science, which little or no connections to philosophical questions. A recent biography on Keynes reports an opposite view. Keynes thought economics not as a physical science, and neither simply as a social science. He thought it as a moral science (Newbury 2007). The question that I am addressing in this paper may offer some support to this latter interpretation: Is there something new under the sun of an economic system or not?

The quest is not itself new. It resembles the old biblical statement: "What has been is what will be [...] and there is nothing new under the sun" of the Ecclesiastes (Bible, Old Testament, 1998). Although this part of the bible (known as the Qohelet in Hebrew) seems to be written around the 250 B.C., the essence

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of what it states is even older than that. Classic Greek philosophers of pre-Socratic time were in fact the first to put under scrutiny the role of novelties in nature and in society. In fact, they discussed and offered to us two very opposite answers. In the Dialogues, Plato (2005) reports the famous dispute between Parmenides and Heraclitus.

The former, Parmenides (c500bC), argued that Nature never changes. It is fixed and repeats itself. If to us something appears as new, this is just an illusion due to the fact that substance and appearance may not be one and the same thing. The consequences of this interpretation for different branches of knowledge (not only philosophy) are indeed dramatic (Curd 1998). Parmenides is, in many respects, considered the grandfather of modern philosophy, and it should not come as a surprise the fact that his interpretation of the world has pervaded most branches of moral sciences – economics included.

The latter, Heraclitus (c500bC), argued that Nature is change. And without change there would be no nature, as we know it. Everything evolves, and human beings are not an exception. Contrary to Parmenides, he concluded that change is real and stability just an illusion. The Panta Rei aphorism well summarizes the point (Plato, Cratylus, ([402bC], 1926)): "Everything flows and nothing stands still", or as Aristotle later reported Heraclitus said: “No man ever steps in the same river twice, for it’s not the same river and he’s not the same man. Everything flows and nothing abides. [...] If we do not expect the unexpected, we will never find it.” Change is universal, which it does not mean that the world is chaotic. There is an underlying order or reason behind change too – the Logos in the Greek philosophy. Also Heraclitus had an impact on modern thought. An evolutionary approach to reality resembles, explicitly or implicitly, a world sympathetic to Heraclitus, since “the explanation to why something exists intimately rests on how it became what it is” (Dosi 1997: 1531). Karl Popper (2002) criticized the Heraclitus interpretation for offering support to historicism, which is seen suspiciously nowadays among natural sciences, including – for those who acknowledge the linkage – economics.

Despite the Popperian suspicion, in the following pages I will take up a Heraclitus stand. The paper will argue that the modern economic growth (in the sense of Kuznets 1966) is made up by economic systems that do not change simply in scale, that is in their overall quantitative dimension. They change in substance, that is in their intrinsic structure. In a sentence, to understand the dramatic quantitative changes of the industrial world, one cannot dismiss its qualitative transformations, provoked by new goods, and by new knowledge necessary to produce new goods.

To stress this point the paper is organized in three main parts. First, it offers a workable taxonomic grid to interpret and measure the qualitative productive changes of an economic system. The term “workable” is referred to the attempt to bring the taxonomy within an input output representation of the economic system, where structural changes, and an expansion of sectors are explicitly considered. Second, by dissecting the immediate forces that affect the movements of per capita income, it inquiries logically whether or not a long run process of economic growth is possible, without phenomena of structural change, and without the emergence of new sectors in the economy. Third, the paper inquires finally the empirical relevance of the taxonomy proposed and the logical interpretation of an expansion of the economic system for the case of the electronic sector.

Some broader, and more philosophically inclined, considerations will be put forward at the end of the paper.

2. Structural change and economic growth

The phenomenon of economic growth is an ideal terrain, in economics, to confront and contrast the two philosophical interpretations just presented. Does a growing economy change only exteriorly, in quantitative terms, or does it change also in its substance, i.e. qualitatively? The Parmenides interpretation would accept a kind of growth that repeats itself, without changing the underlying relations of the economy. The different parts of an economy may grow in scale, but without affecting the structure that keeps them together. This is what for a long time has been the essence of the multisectoral theories of economic growth. Such theories deal with proportional dynamics. The term "proportional" means that each single part of the economic system moves precisely at the same rate of change of the other parts, so that the economy expands or shrinks at once, while leaving the relationship between its parts untouched. The dimensions of the economy are allowed to change, not its underline structure.

A typical theoretical example of this kind is represented by the von Neumann model (1945) of economic growth. The model shows a perfect mapping between sectoral positions and aggregate outcomes. Once the equilibrium exists at the initial state, it will persist in each further state. If the relative outputs are turned into a vector, the von Neumann model describes a multisectoral economy as it would be "one commodity world". Accepting a representation of reality of this kind, in which there is no point to look in the internal structural movements, appears a powerful excuse for sticking with the aggregate models of economic growth, which in fact still dominate economics.

A Heraclitus interpretation of modern economic growth would not accept a world (and a theory) like this. It would assert that an economy grows because economic reality re-invents itself, so as to make the vector of commodities in continuous (and sometime spasmodic) transformation. Economic variables (income, employment, inputs and outputs) do not simply alter their size, they alter also their composition, i.e. their relative weights and structure. New economic sectors may emerge and old sectors may disappear, be displaced or transformed. This implies the presence of qualitative changes within the economic system. Such qualitative changes are not accidental or marginal. They are "like the beat of the heart", to paraphrase Schumpeter (1939: v) of a modern economic system. As one cannot step twice in the same river, in a growing economy too one cannot step twice into the same economic structure.

One could argue that a Heraclitus interpretation of this kind seems akin more to the field of economic development, than to the field of economic growth. In fact, economic development has been defined as economic growth (i.e. quantitative changes) *cum* structural changes (*i.e.* qualitative changes). Despite its relevance, it is a discipline usually confined to the study of the less developed economies.[1] The underlined argument is that the less developed economies, in order to growth, require a much deeper degree of change – not just the growth of production, but also a profound transformation of technology, institutions, preferences, and even values. In the attempt to keep up with all these elements, the theories of economic development adopt a less technical language than the theories of economic growth. This is not a pitfall in itself, but in practice economic development is not usually seen at the heart of high theory.[2] Yet, in our context, are the theories of economic development which seem better equipped in explaining a Heraclitus world.

This does not mean that all great economists have dismissed or overlooked the subject. For instance, Karl Marx among the Classical economists of the XIX century and Joseph Schumpeter[3] among the economists of the XX century considered structural changes absolutely essential in explaining the process of economic growth. For them, the dynamism of capitalism cannot occur without a profound process of transformation. Not surprisingly, they are considered among the founders of the theory of economic development.

Schumpeter, Mark I (the young Schumpeter), is more explicit in this sense. In one of his first works (Schumpeter [1912], 1983), he made a clear distinction between an economy that repeats itself, despite the fact it may grow, and an economy that qualitatively changes overtime. He calls the first phenomenon circular flow (Ch. I), and deserves only to the second "fundamental phenomenon" (Ch. II), the label of economic development. The crucial difference between the two phenomena is played by innovation: i.e. the implementation of some new knowledge in production or distribution of goods. When an innovation is introduced in an economic system it will change its structure, and by changing its structure it will break the existent circular flow. The economy enters in a process of "creative destruction" as later Schumpeter (1950) called it. At the end of such a process, the economy is in a new state almost unrecognizable from its previous one.

Nowadays there is a growing amount of models that call themselves "Schumpeterian", acknowledging that innovation is one of the most important engines of growth. In many of these new models, though, it persists the idea that innovations just bring "more" rather than they bring "different". The impression is that formal Schumpeterian models still stress aggregate outcomes and causes of wealth, more than dynamic structure and nature of wealth. Aghion and Howitt (1998) in their advanced textbook on

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[1] See, among others, Thirlwall (2002).

[2] In Shackle's (1967), "high theory" referred to a period (1926-39) in which new conceptual theories were formulated. Nowadays the term took a much narrower interpretation of mathematized model building.

[3] See particularly Marx (Marx 1990) and the essays collected in Schumpeter (Schumpeter [1912], 1983) with the original (1928) article on "The instability of Capitalism".

endogenous growth theories, for instance, deserve just few pages to the phenomenon of structural change caused by new goods.

In what follows I shall try to reverse these weights, by paying a greater attention to the economic consequences of new goods, new sectors and new economic structures. Conversely, I shall pay less attention to the quantitative growth, that innovations may produce, though I shall not dismiss the argument completely (see Section 6 and 8). The point I shall try to make is that a quantitative economic growth cannot exist without a qualitative underlined phenomenon of structural change.

The argument will be developed with a bias towards empirics rather than pure theory. Formal models on structural change and economic dynamics or industrial dynamics though still marginal in mainstream economics, are well discussed in alternative paradigms. I refer, just to cite the classical references, the works of Pasinetti (1981) and (1993) and of the evolutionary economists Nelson and Winter (1982), and Dosi *et al.* (1988).

3. An insight into technology: Freeman's taxonomy of innovation

According to *The Merriam-Webster Dictionary* (1994), an innovation is "the act of introducing something new". Schumpeter ([1912], 1983) called this "something" an invention, i.e. an object, process, or technique which is novel.

By accepting these standard definitions, and by observing the number of innovations around us, no one could probably dispute that in a modern economic system there is "something new under the sun". What may be discussed, however, is the extent of consequences it may or may not procure to the essence of an economic system. The world (in our case, the economic world) may well run, after each innovation, exactly in the same way as it run before it. A conception of this kind should be sufficient to overlook the Heraclitus interpretation, and stick with the Parmenides one, by simply focusing on the epiphenomenon that each innovation hopefully procures: an aggregate growth of income.

To put it differently, a Parmenides interpretation of the world is not incompatible with the presence of innovations, as long as the latter leaves substantially untouched the structure of the economy, i.e. as long as they do not introduce fundamental qualitative changes.

The idea that not all innovations had the power of changing the foundations of an economic system is nothing less than common sense in fact. So, to test whether a Heraclitus interpretation is acceptable or not one needs to ask a further question. Namely, are (at least some) innovations able to induce these qualitative changes? Or to put it sharply, do technological revolutions exist? This is still nowadays a much debated question.[4] It was again Schumpeter (1939) who forcefully highlighted that not all innovations were the same: just few of them were able to generate a new economic era – a new

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[4] See, among others, the critical review of the literature in Rosenberg and Frischtak (1984).

Kondratieff wave. He made a distinction between small innovations and radical innovations. The first were improvements of the *existing* economic world, while the second were *novel additions* to the economic world, that could not be obtain by a simple re-organization of the existent. “"Add successively as many mail coaches as you please, you will never get a railway thereby" (Schumpeter [1912], 1983, p. 64).[5] He considered these radical innovations as the first mover of the long run process of development.

Chris Freeman, a great estimator of Schumpeter, moved forward this initial distinction and proposed a more elaborate taxonomy of innovations. The attempt was to conceptualize the different types of technological change, according to the impact they were able to exert on the economic system.

Based on empirical work (Freeman 1984, 1987, 1988, 1994), he distinguished between 1) Incremental innovations, 2) Radical innovations; 3) New technology systems; 4) Technological revolutions or ‘New techno-economic paradigms’. Table 1 refers to the set of definitions that he proposed.

Table 1 TAXONOMY OF INNOVATIONS

1 Incremental Innovations	Gradual improvement of existing array of products, processes, organisations and systems of production, distribution and communication.
2 Radical Innovations	A discontinuity in products, processes, organisations and systems of production, distribution and communication, i.e. a departure from incremental improvement, involving a new factory, new market or new organisation
3 New Technology Systems	Economically and technically inter-related clusters of innovations (radical and incremental)
4 Technological Revolution	A pervasive combination of system innovations affecting the entire economy and the typical ‘common-sense’ for designers and managers in most or all industries.

Source: Freeman C. (1994), “Technological Revolutions and Catching-Up: ICT and the NICs” in Fagerberg et al. (ed.), *The Dynamics of Technology, Trade and Growth*, Aldershot: Edward Elgar.

To make this taxonomy somewhat more workable, we could attempt to implement its significance in a multisectoral economy, as represented by an input-output matrix, in which economic sectors are organized in rows and columns. In a typical Leontievian interpretation (Leontief [1951] 1986), each column is a process of production that represents an economic sector. Each sector is supposed to

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[5] Let us be careful here. Locomotive apart, the first trains were made by wagons of adjusted mail couches.

produce a homogenous economic good.[6] Each economic good can be either capital good, or consumption good, or both. The rows of the input-output table indicate how economic goods are utilized by the system. Each good will be an input for one or more sectors of the economy (corn is used, for instance, as input in the food industry), including its own sector (corn is used as seed). When an economic good is used completely as an "input" in the final sector, it is called consumption good. When it is used completely in the inter-industrial sectors is called capital good. There are goods that belong to both categories.

Usually the input-output matrix is expressed in unitary terms, i.e. in technical coefficients: the quantity of inputs necessary to produce one unit of output.

The traditional Leontief input output matrix has two key characteristics about technology:

a) the number of sectors are given;

b) the technical coefficients are fixed.

Both characteristics have been assumed to make the input-output matrix mathematically tractable. The first characteristic assures that the dimension of the matrix does not change, allowing therefore to make two or more matrixes commensurable, i.e. one comparable to the other. The second characteristic allows to say something about the properties of the matrix (of the economic system, in fact), without worrying that the coefficients that have produced, in first instance, such properties have not meanwhile changed.

A matrix of this kind seems suitable to describe at best a static world. But it is not so. It has been used to describe also a growing economy. While coefficients and the size of matrix may be constant, there is no requirement that total quantities are so. The matrix in other words is compatible with a Parmenides kind of growth.

Henceforth, I shall call a Parmenides input-output matrix of the economic system, a matrix that holds characteristics:

a) and b) as defined above, but possibly also characteristic c), namely:

c) the technical coefficients of the matrix are allow to change, if they *all* change by the same degree.[7]

Can anyone of Freeman's innovations be present in a Parmenides matrix? The answer is negative. The technology is fixed, or is changing in a complete proportional (and unrealistic) fashion, with no new goods (point *a*), and no uneven technological improvements (point *b* and point *c*). Hence, there is no room for any kind of localized sectoral innovation, small or large as it may be. An interesting point is to ask therefore, *how* Freeman taxonomy may change the Parmenides input-output matrix.

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[6] I shall use the term economic good extensively to represent also "immaterial" services.

[7] This is like assuming a technical progress *à la* Solow (1957): exogenous and "manna from heaven" that indistinctly affects all sectors.

With the help of Figure 1, I shall try to answer precisely this question.

[around here Figure 1]

1. Incremental innovations mainly have the effect of reducing the existent technical coefficients, which means an increase in productivity levels. The size of the table (i.e. the number of sectors and technologies in the economy) is left unchanged. Its effects are not flashy in the short term and do not cause profound structural changes, but as time goes by, they are essential to increase economic efficiency and hence to promote economic growth. Learning by doing, learning by using, and interactions between users and producers, are the main forces behind these improvements. The typical characteristic of cumulativeness of such improvements generates increasing returns. A consistent number of studies have shown how they constitute an important, if not essential, source of competitiveness at sectoral as well as at country level (Hollander 1965, Townsend 1976, Rosenberg 1988).

2. Radical innovations are represented (figure 1, point b) by a new column and a new row, which means a new sector or productive branch of the economy. It is a situation that occurs when a new good is produced, which was not produced before. Its key feature is discontinuity. At the beginning the new good that embodies the radical innovation is still completely dependent on the old technologies, which are in use in the economic system, both in terms of productive inputs and organisation. Not surprisingly at this stage, the rest of the matrix seems unaffected by the new presence. For this reason the new column is full of inputs received from the rest of the matrix, while the new row of the infant sector is practically empty. Examples of radical innovations are not so numerous as in the case of incremental innovations, but in the modern world they can be singled out in the case, for instance, of drugs, lamps, televisions, mp3 players, etc..

3. A new cluster, or new technology system (figure 1, point c) is represented at aggregate level by a table of the same size as stage 2, but with the new sector (risen from the previous point) which begins to spread its influence, both directly and indirectly in other selected parts of the matrix. The influence occurs by giving to some other sectors, those involved in the "new cluster", some own inputs. The majority of the table is still unchanged, but focusing our attention on particular industries, differences clearly emerge. A new constellation of sectors is established and further levels of specialisation with new lines of business appear. Examples are synthetic materials, petrol-chemical innovations, nuclear energy, machinery innovations in injection moulding and extrusion, and innumerable applications introduced between the 1920s, and the 1950s (Freeman, Clark and Soete 1982).

4. A technological revolution (figure 1, point d) is a complete change of the matrix, both because one or more sectors have emerged (from the initial radical innovation) and because the rest of the "traditional" sectors have started to be affected (mostly) *directly* by the new sector(s). A new cluster is a natural candidate to become a technological revolution, though not all new clusters had the sufficient "energy"

to achieve that stage.[8] Only those technological clusters that become as pervasive as to be able to give inputs to the majority of other productive branches, or industries, will achieve the status of technological revolutions. The new technical coefficients, which have emerged in the new row (of the new sector, or of the new cluster of sectors), appear highly pervasive. They affect the composition of other inputs too in the various productive sectors. This is why the majority of technical coefficients are changing throughout the matrix, provoking transformation of technological, and organisational type. Both the real system as well as the price system – Sraffa's system (1960) – are affected. Inputs, that previously were considered uncompetitive, could become competitive and vice versa, outputs that could have been expensive could become cheap. The changes of the quantity system and the price system tend to reinforce each other: relative prices may change because the underlined technologies have changed, and changes of relative prices may push further changes of techniques. The label 'revolution' is crucially connected, then, with the economic consequences on the structure of the economy, more than with the essence of the technology itself.[9]

Admittedly, this taxonomy (and our representation of it) does not serve the primary purpose of detecting the degree of novelty of a new good or a new process of production. It serves instead the purpose of offering a way to detect the disruption (and hence the relevance) provoked by an innovation on the fabric of an economic system. Obviously, there is no a perfect coincidence between technological novelty and economic novelty. History counts many cases of truly revolutionary innovations, that did not survived in the market place, or that did not make, from an economic point of view, any significant impact. This means that we are to a certain extent conservative too, and economically bias, in highlighting the novelties "under the sun".

With this limitation in mind, we shall call a Heraclitus input-output matrix that kind of matrix which allow for:

a) radical innovations and the emergence of new sectors,

b) uneven changes of technological coefficients of the matrix.

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[8] Irony of the destiny, it has been said (see Freeman 1994, again) that the nuclear energy did not have such enough "energy" to become a Technological revolution. This is a fascinating story where the stumbling blocks were more social than technological. But the end of the story is still to be written: the future could be open to something new under the sun, in this branch too.

[9] This may sound selective, but it is not surprising. A political revolution is only a *coupe de etat* that succeeds in changing government: being conceptually "revolutionary" is just not enough. To stress the linkage technology-economy, Freeman prefers the adoption of the concept of 'techno-economic paradigm' from Perez (1983, 1985, 1988), as a more precise definition, in substitution of the more appealing concept of "technological revolution".

4. The dynamics towards a technological revolution

Technological revolutions are very rare, while innovations are abundant, at least in the Western world. Simple logic tells us that not all innovations become technological revolutions. What are the typical features -if any- that transform an innovation into a revolution? Analysing the previous taxonomy within an input-output framework, one perceives that there are two key attributes:

- the presence of a radical innovation at some point, and

- the interconnections that the radical innovation is able to make over time, both with the other sectors of the economy and with the new ones that the radical innovation is able to generate itself.

Following the representation of figure 2, one can envisage some stylized steps.

[around here Figure 2]

1. When a radical innovation emerges from an invention, it potentially creates a fertile ground for incremental innovations. The radical innovation, in order to foster some incremental innovations, does not need to be economically very important right away. But it requires to be a 'hopeful monster' as Mayr (1988: 465) has put it – i.e. a new conceptual departure that is technologically feasible. Like every infant, the new production line usually receives more than what it is able to offer. Its column is full of inputs, its row is almost empty. For this reason we shall find that a radical innovation incubates for a long time in one of the existing sectors – the parental sector. If what it does is competitive, or becomes so, a process of diffusion initiates. The persistently higher rate of growth of its output prepares for independence. Statistically, at first, it continues to be recorded jointly with other sectors (see later the electronics case study), but eventually it would be recorded as a completely independent sector. This means that every time we use statistics to highlight (and measure) novelties there is a time lag penalty between the evolution (and disruption) of reality and the data available to represent it.

2. When a new sector emerge, the question to ask is what kind of sector? The answer is dependent, most of the time, on the kind of radical innovation we are facing. Some new technologies embody the characteristic of satisfying directly the needs of consumers. In this case the new sector will satisfy the final demand and the size of the new sector will mirror the size of the final demand for the new good. As long as it meets consumer preferences, this new consumer good can expand and become even an important share of the economy. It will never become, though, a technological revolution, since the rest of the input-output matrix will remain (technologically) unaffected: the row of the new sector will be almost empty –and largely it will remain so. The rest of the technological coefficients remain unchanged. Examples abound. The innovation of the oral contraceptive device had a major impact on sexual behaviour in the 1960s and 1970s in most countries, giving rise to some fundamental debates about medical and social ethics. Its economic impact on the rest of the economy it was however almost nil.

3. All these can change if the new sector is a capital good, which is used as intermediate input in other sectors. For this kind of radical innovations, the first steps of interindustry diffusion consists in influencing some few sectors connected with the parental sector. It starts, in other words, a quite common process in technology: the cross fertilisation of 'old' industries with the direct introduction of new means of production.[10] The row of the new sector starts to be filled with some inputs given to other sectors. The latter will change inevitably their technical coefficients. As long as these sectors are also connected with the rest of the economy, a rolling ball starts to take off.

4. To understand where (and when) the rolling ball stops, the best proxy is the analysis of the direct inputs that the new sector gives to the rest of the economy. We know, from input output analysis, that a basic sector is a sector which produces a good that is directly or indirectly necessary for the production of all other goods. In practice to be classified as a basic sector (or a basic good), it will be sufficient for a new sector (call it A) to affect a technical coefficient of just another sector (call it B). If B is sufficiently connected to the rest of the economy, it will turn A (and for the matter, any sector that gives an input to B) into a basic sector. Yet, being a basic sector is a necessary, but not a sufficient condition for building a new technological system and far less a new technological revolution. Though the basic sectors regulate the equilibrium properties of the rest of the economy, the impact of some of them could be limited, both in terms of the size of the sector, and of the degree of structural changes induced in the rest of the economy.

5. A different story is when the new sector starts to affect *directly* the other sectors. It is the extension of these new inputs, and hence the density of the row of the new sector, that will determine if the new radical innovation will become either a technological system (affecting a cluster of sectors) or a new technological revolution (a general purpose technology, as it also been called that affects *directly* almost the whole economic system). This direct impact on the rest of the sectors is just a start for a wave of other incremental innovations that pervades the matrix. In some cases the wave of innovations are of such dimension and importance to generate new sectors, so that the Heraclitus matrix unfolds in its full extent.

6. Obviously qualitative changes as the ones involved in a technological revolution bring with them a complete reshaping of the economic environment: sectoral production changes, employment moves across sectors, sectoral productivities levels are altered, relative prices transformed. The emergence of new markets, new opportunities of investment and new (and better) goods induces profound changes also of the demand side, and not just of the supply side.

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[10] An immediate implication of this process is that a "mature" sector could become, with the new inputs, very innovative.

5. Two additions: the final (consumption) demand and the role of labour

The previous analysis in defining a Heraclitus matrix – as we call it – seems to have undermined two crucial dimensions. On the one hand, the role of final demand, and hence of consumer goods, which constitute usually more than two thirds of final demand. On the other hand, the role of the labour employed. In fact we could formally take account of both these two dimensions by adding an additional column (final demand) and an additional row (labour inputs).

An analysis of final demand, allow us to re-consider in particular the role of consumer goods that so far we have left at stage 2 of the previous Section, assigning them a secondary position. Such a statement could be disputed. At the end of the day, "the final aim of all production is consumption" (Adam Smith 1776). Though the consumption sector collects the benefits of any technological innovation, it does not hold the characteristics of generating a technological revolution. It, so to speak, stays at the surface, without entering at the heart, of an economic system. And this is why it misses to produce the devastating effects described in steps 3-6 of Section 4.

However, some consumer sectors are able to constitute the centre of a new technological system, when a new sector constantly increases its production to satisfy an even higher potential demand. The increased production, in fact, is able to compact suppliers around the productive needs of the consumer sector. And a high demand is also an incentive for further incremental innovations, as Schmookler (1966) showed with its "demand-pull" theory of technological change. This was the case for textiles at the beginning of the First Industrial Revolution, the mass-consumption of automobile and household appliances during the middle of this century, and the leisure industry (cinema, television) after the second World War.

Another vector (a row vector) is also essential to complete the picture of our framework: the vector of labour. Human labour embodies knowledge. Above all, it embodies new knowledge through the human process of learning. This acquisition of new knowledge is preliminary in providing the basis of any innovation at the shop floor.

A new sector in a Heraclitus matrix therefore should display its labour coefficient, that are (initially at least) quite high, since a new technology, precisely because it is new, lacks specialized capital goods. In particular the new sector utterly needs the kind of labour which embodies the emergent technological knowledge. This kind of labour, with its own skills and competencies, will be necessary also to any sector that is going to adopt (not just produce) the new technology.

To put it sharply, only the diffusion of human learning across sectors, and hence only through the presence of a qualified labour force that is able to manage the new technology, a radical innovation could aspire to generate a Heraclitus matrix in its full extent. Without the spread of new skills and competences, throughout the economy, even the most promising radical innovation would abort its take off. The evolving structure of competences and skills will be therefore another (complementary) way to capture the pervasiveness of a new technology across the economy.

6. Is Heraclitus matrix essential for economic growth?

The question of how much growth should be attributed to technical change is an old quest in economics (Solow 1957, Denison, 1967, 1983). In this paragraph, I shall not follow the same approach that is traditionally adopted, and which is known in the literature as "growth accounting". This kind of exercise has not been exempt from criticisms both at theoretical level (it assumes a well "behaved" production function) and at empirical level (some required estimates are little more than "guess work").[11] I shall however ask the same type of question, though geared to better fit the title of this paper. Namely, are radical innovations necessary for long term economic growth? And consequently, is the emergence of a Heraclitus matrix a *precondition* to the raise of per capita income?

The following table sets the symbols adopted in organizing an answer.

TABLE 2. List of symbols

Symbol		Macroeconomic and institutional variables
$Y\,;Y_{PC}$	=	GDP; and per capita GDP
P	=	Population
P_A	=	Active Population
LF	=	Labour force
$\mu = \frac{LF}{P}$	=	rate of gross labour participation
E	=	Employment (in units)
L^h	=	Employment as yearly hours
$\nu = \frac{L^h}{E}$	=	Number of hours per employee
$\theta = \frac{E}{LF}$	=	Rate of employment
$u = 1 - \theta$	=	Rate of unemployment

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[11] C. Freeman (1988, 9) writes on this point: "The various 'growth accounting' exercises, even after allowing for an entire Kamasutra of variables, generally remain with a big unexplained 'residual' (e.g. 1982) and fail to deal with the complementarities and interactions of these variables (Nelson 1981)".

$\frac{Y}{L^h}=\pi$	=	Total labour productivity, i.e. ∑Yi / ∑L^{h}i
		Sectoral variables
Y_i	=	Value added in the sector, i
L_i^h	=	Yearly man-hours employed in sector, i
$\frac{L_i^h}{L^h}=\lambda_i$	=	Share of labour force in sector, i
π_i	=	Labour productivity of sector i
		Sub- & super-scripts
t	=	time
i	=	productive sector
m	=	number of sectors at time t
n	=	number of sectors at time t+1
$j=n-m$	=	new sector

Thus the subscript, i, affixed below the symbol refers to an individual sector of activity. The same variable (or other variables) without the subscript, *i,* refers to the economy as a whole.

Synthetically, per capita income of an economic system, with many sectors, each of which characterized by a different technology and a presumably different productivity, can be decomposed to a set of immediate factors and to another set of mediate factors, as follows:

$$Y_{PC} \equiv \frac{Y}{P} \equiv \mu \cdot \nu \cdot \theta \frac{Y}{L^h} \equiv \eta \frac{Y}{L^h} \qquad (1)$$

$$\eta \equiv \mu \cdot \theta \cdot \nu \equiv \frac{P_A}{P}\frac{LF}{P_A}\frac{E}{LF}\frac{L^h}{E} \equiv \mu \cdot \nu \cdot (1-u) \qquad (2)$$

a) The first coefficient of equation (1), μ, concerns the share of labour force in the country, which we can be called “gross” rate of participation. It is made up by two ratios: the first is the active to total population ratio, which is the result of demographic forces and of other institutional decisions on retirement and schooling age. The second rate is the “proper” labour participation ratio, which is dependent mainly (but not exclusively, see Okun’s law implication (Wachter et al. 1977)) on individual decisions and on social conventions.

b) The other two ratios (θ, ν) are connected to the labour actually employed. The coefficient, θ, expresses the rate of employment, defined (traditionally, since the definition has in recent decades changed) as the share employees in the total labour force. The coefficient, ν, is the yearly number of working hours per employee, which is affected by the legislation on working time (holidays, maximum working hours per week) and by other social and natural factors (strikes, environment conditions, etc.). The index is also crucially affected by the structure of the employees, for instance in their composition between full time versus part time workers.

Historically, these indexes have moved (and are moving) in different directions. Among the developed world, the ratio of active population is lower nowadays than it was in the past. The rate of participation has decreased until sometime ago, but now in many advanced countries, it is turning up again. The rate of employment follows, more or less synchronously, the business cycle of each economy. The number of yearly hours per employee has been slowly, but systematically, lowered overtime, with few exceptions.

It is sufficient this fragmentary information to envisage that the raise of per capita income experienced by the advanced countries, since the First industrial revolution, cannot be explained by a systematic raise of the above ratios.

But the quest of whether the above coefficients are or are not responsible for the long run economic growth could be settled even without empirical evidence. All three coefficients, we have examined, are upper bounded –they cannot increase indefinitely. The first two (μ ,θ) are ratios constrained to be lower than or equal to 1. The third coefficient (ν) is bounded (at the upper extreme) to the amount of hours that are available in a year. Hence, no one of them can move exponentially upwards.

There are further motives even to deny that these ratios could progress synchronously towards their upper limit. As we see from equation (2), each ratio has at the denominator the variable that it is usually at the nominator in the previous ratio. So when there is the tendency of one ratio to, let us say, move up there is the simultaneous tendency for the other to move down, if no counter measures intervene. Sometimes these interdependences are exploited by policy makers. The more macroscopic case is the relation between the working hours per employee ν and the rate of employment (the rate of unemployment, u, in fact). Higher rates of unemployment have induced policy makers to lower the working hours per employee, in the attempt to bring the rate of employment up again. A constant decrease of active population, aged 15-64, has called for policies in the attempt to increase the participation rate, so as a higher share of active population (mainly females) that were working free of charge outside the market, or tax-free in the black market, were induced (through incentives of different nature or tighter laws) of being part of the “official” labour market, and hence of the “official” labour force.

In any case, whatever the actual trends, these institutional considerations weaken further the hypotheses that the above ratios may count as the cause of the modern economic growth. Historically, if nothing else, they have contributed to lessen it.

The factors behind the output per working hours are therefore essential to explain the long growth of per-capital income. The last ratio of formula (1) in fact refers precisely to the immediate factor of labour productivity.

c) Labour productivity, π, is a variable that is dependent of the level of technology that, in a multisectoral economic system, is diversified from sector to sector. More specifically, it will be a weighted average of the sectoral labour productivities that makes up the economy. Formally:

$$\frac{Y}{L^{(h)}} = \pi = \frac{\sum_{i=1}^{m} Y_i}{\sum_{i=1}^{m} L_i^{(h)}} = \sum_{i=1}^{n}\left(\frac{L_i^{(h)}}{L^{(h)}}\frac{Y_i}{L_i^{(h)}}\right) = \sum_{i=1}^{m}(\lambda_i \pi_i) \tag{3}$$

Being interested in its rate of change, and keeping in mind that a new sector, j, could appear in the new period, we could write the rate of change of labour productivity, by adding also the new sector that from one period to the next emerges from the economy :

$$\frac{\dot{\pi}}{\pi} = \sum_{i=1}^{m}\dot{\lambda}_i\frac{\pi_i}{\pi} + \sum_{i=1}^{m}\frac{\lambda_i}{\pi}\dot{\pi}_i + \left[\dot{\lambda}_j\frac{\pi_j}{\pi} + \frac{\lambda_j}{\pi}\dot{\pi}_j\right] \tag{4}$$

Being the terms in the square bracket the addition from the new sector.

Equation (4) can be further elaborated if we multiply the first and third addendum for $\frac{\lambda i}{\lambda i}$, and if we add the nil term $\sum \lambda_i + \lambda_j$.

$$\frac{\dot{\pi}}{\pi} = \sum_{i=1}^{m}\frac{\dot{\lambda}_i}{\lambda_i}(\alpha_i - \lambda_i) + \sum_{i=1}^{m}\frac{\dot{\pi}_i}{\pi}\lambda_i + \left[\frac{\dot{\lambda}_j}{\lambda_j}(\alpha_j - \lambda_j) + \frac{\dot{\pi}_j}{\pi}\lambda_j\right] \tag{5}$$

This decomposes the rate of change of labour productivity in two meaningful components:

a) One related to the labour force movements, weighted by the difference between the shares of Value added and the shares of labour force.

b) The other related to the dynamics of labour productivity within each sector, weighted for the importance of the sector in terms of labour employed.

Moreover, if we accept that an industrial economy is constrained mainly by demand side, the first (and third addendum) can be further decomposed and equation (5) consequentially re-organized, by recalling that $\lambda_i = y_i^D/(\eta \cdot \pi_i)$. By applying logs and derivatives and substituting the rate of change of labour shares, we will obtain, after some simplifications, the following meaningful formulae.

$$\frac{\dot{\pi}}{\pi}=\sum_{i=1}^{m}\frac{\dot{y}_i^D}{y_i^D}(\alpha_i-\lambda_i)+\sum_{i=1}^{m}\frac{\dot{\pi}_i}{\pi}\alpha_i+\left[\frac{\dot{y}_j^D}{y_j^D}(\alpha_j-\lambda_j)+\frac{\dot{\pi}_j}{\pi}\alpha_j\right] \tag{6}$$

To explain, therefore, to what extent we may experience a long run growth of labour productivity, we shall inquiry on the movements of three sets of factors.

The first factor is the dynamic of per-capita demand on each sector. It may produce positive or negative effects on average productivity according to the sectors in which it occurs. If a positive change of demand occurs in a sector with a share of value added higher than its share of labour (which is a way to say that such a sector in the economy has an-above-average level of productivity) the contribution will be positive. Otherwise it will be negative, or nil in the special case in which a sector shows precisely the same productivity of the economy.

The movements of demand therefore will induce (through the movements of the labour force across sectors) mixed effects on productivity. To be positive a raise of demand concentrated on the high value added sectors is necessary. We may call this component of labour productivity, the *Keynesian component* of labour productivity, since it is demand driven.

The second factor is the internal movement of labour productivities within each sector. This is mainly due to technological improvements, which can be fostered unevenly across sectors by many factors, following the different opportunities and level of maturity of the technology in use. A given positive change of sectoral productivity will produce always a positive impact on the overall productivity. But this impact of the rate of change of labour productivity could be higher or lower than the impact of other sectors, once weighted by their share of income (measured in terms of value added) in the economy.

Therefore, as long as we have technical progress within one or more sectors, we will have a raise of labour productivity in the whole economy. Certainly, the raise could be of big or small dimensions, but the contribution is however positive. We may call this component the *Schumpeterian component* of labour productivity, for being strictly linked on the rate of innovativeness experienced by each productive sector.

The third factor is the expansion of the number of sectors, from *m* to *n*, due to the emergence of new capital goods or new final goods. This expansion affects both the Keynesian component (the new demand induces the labour force to move on the new sector, *j*, where the level of productivity may be different) and the Schumpeterian component (the new sector, *j*, may change its productivity at a different rate, as compared to the rest of the economy). We may call this latter component the *Heraclitus component* of economic growth.

To experience a persistent growth of per capita income we must detect therefore if one or more than one of these three components can move indefinitely upwards.

The Keynesian component can certainly contribute to the growth of labour productivity as long as the movement of the sectoral labour force is made towards those sectors with higher value added. To make it possible, one needs favourable circumstances with a particular evolution of demand. Namely a change of demand concentrated *only*, or *mainly*, in those sectors with a level of per capita valued added above-average. In all other cases the Keynesian component will lower the overall labour productivity.

To push forward the argument, let us suppose that the above favourable condition takes place. Can a positive contribution continue indefinitely? The answer is obviously negative. Even in a very hypothetical case of this kind, the Keynesian component cannot be a long run source of productivity improvements in the economy. A stop will happen when all demand (and hence all labour force) would be (by hypothesis) concentrated in one single sector – the sector with the highest value added in the economy. In this case the average value added of the economy, will coincide with the value added of the sector itself, bringing the Keynesian component to zero.

The Schumpeterian component, internal to each sector, is a simple weighted average of the rates of change of sectoral productivities. As long as the productivity within each sector grows, the Schumpeterian component will contribute positively to the growth of the overall labour productivity and hence of the per capita income. Any growth of sectoral productivity will affect the growth of the total labour productivity, in proportion to the weight assumed in the economy by each sector, as measured by the relative shares of value added.

Is it possible, we may ask, that changes of labour productivity within each sector (or within just a number of them, or at least one of them) can be indefinitely positive? Assuming this, it would be like to assume that in each sector incremental innovations can always be introduced, without experiencing a process of petering out, i.e. without ever approaching a level of technological maturity. Only a continuous technological change within each sector will be conducive with a persistent positive contribution of the Schumpeterian component to labour productivity.

This possibility, however, seems somewhat questionable. As many other human phenomena also technological change is subject to a sort of logistic pattern. It grows relatively fast in the first phases of a newborn technology, it keeps a steady growth in the middle age of development, but at some point the impact on the economic system inevitably start losing momentum, by envisaging a phase of rest.[12]

A Parmenides matrix, with even incremental innovations, i.e. with an even change of its technical coefficients, will eventually lose this feature, if no radical innovations are allowed. It is the emergence of the latter that may promote "gales of innovations" (in Schumpeter words) through time so as to keep

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[12] The analogy that has been made (see Dosi, 1982) between technological paradigms and scientific paradigms that at some point do not produce new knowledge is not casual, and has been widely acknowledged.

positive the Schumpeterian component in the long run. Otherwise also this component will approach at some point a position of rest.

The third component refers to the role of the new sectors, and hence refers properly to the Heraclitus matrix. The existence of new sectors plays a crucial role in sustaining the long run of per-capita income for at least three reasons.

First, as long as the new sector shows a level of productivity higher than the average economy, this new sector will contribute with a positive sign to the Keynesian component of productivity growth. If the new sector is "scientific based", in the taxonomy of Pavitt (1984), the occurrence is very likely, since "high tech" sectors hold usually a higher value added per worker, as compared the rest of the economy. However, if by any chance this does not occur, the Keynesian component in the new sector will affect negatively the total labour productivity.

Second, the new sector will certainly produce a positive effect on the Schumpeterian component, since it is an innovative sector by definition (otherwise it would not have appeared in our matrix, in the first place). Moreover, we have already argued that according to overwhelming evidence, a new sector, with a radical innovation at its heart, should experience substantial improvements, hence raising the rate of change of its own labour productivity through time.

Moreover, if the new sector produces capital goods so to affect the rest of the economy, also the Schumpeterian component of the other "old" sectors, from *1* to *m*, will start to be affected positively. New capital goods have, at least in the medium long run, beneficial effects on productivity improvements in the sectors in which they are used. They are also a source of further waves of incremental innovations throughout the economy. These spillover effects will burst the Schumpeterian component of the rest of the economy too, with an evident impact on the overall labour productivity.

Third, even supposing that the new sector does not contribute positively to the overall productivity with the lack of both the Keynesian component (a case possible), and the Schumpeterian component (a case very improbable), there exist a further important channel through which the Heraclitus matrix can promote the long run economic growth. This is through the channel of the growth of demand, when the demand side constitutes a constrained for the economy. Let us see the logical argument. Equation 1, can be re-written as follows, $Y_{PC} = \mu v \pi \frac{Y^D}{\pi \cdot LF}$, which shows that an increment of the average productivity will not bring any positive effect on per capita income *if* it is not kept up with a contemporary raise of demand. The reason is simple. Without increases of demand, any productivity improvement will result in higher unemployment (technological unemployment). Therefore, productivity will increase, but the employment rate, θ, will drop: the movement of one variable will cancel the movement of the other out, with an overall nil effect

A radical innovation allows the emergence of new markets and new goods, which in turn relax the demand side constrain. In this context, consumer goods play a crucial role indeed. Once accepted that the demand of the traditional ("old") goods may at some point reach a threshold level, - the so called, saturation level – only the emergence of new goods will be able to remove the feebleness of demand. In presence of unemployment, a raise of demand is a direct raise (see equation 1) of per capita income.

Hence, only this third component (the Heraclitus component) can promote the growth of per capita income in the long run. It can bring productivity up, it can generate new demand, and it can cure unemployment, each of which factor is beneficial to the long run economic growth.

7. Evidence from data: the electronic revolution

7.1. VI The raise of a Heraclitus matrix

In modern science, evidence is the Supreme Court of theory. The rest of the paper is devoted to gather some pieces of it around the concepts proposed so far. More specifically, our attention will be addressed to testing whether the technological changes, initially, in microelectronics, and then in information and communication technology (ICT) could or could not be considered "something new under the sun" as defined in the previous sections.

I shall use data from the two Anglo-Saxon countries: the UK and the US – two economies that more than others have been exposed to the this new technology. I am considering the decades from the late 1960s to 1990s, in which electronic technologies started to make their timid appearance and then to spread throughout in the economic system. Its consequences in terms of pure economic performance will use (in Section 8) more recent figures.

Data have been collected from difference sources made available from SPRU and Cambridge University, during a postgraduate stay. If not differently indicated, elaborations are our own. The attempt, as it will be clear, is not that of crunching data in econometric models to estimate particular coefficients. To engage in such exercises it would require a quality of data that unfortunately is not there.[13] Instead of asking econometric questions, that the data may not able to answer, I shall try to organize at best the statistical information that can be retrieved from what it is available, without much numerical "tortures".

[around here Figure 3]

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[13] Input-output tables, made up by statistical offices, have not a high reputation of reliability. To built these tables, in an advanced society with thousand of productive branches, requires a high quantity of resources, and highly detailed recordings. Both the former (resources) and the latter (detailed recordings) are admittedly less than optimal, so that for many branches input-output data are just a rough evaluation of reality instead of being a trusted representation of it.

Figure 3 refers to input-output data of the UK, for the year 1968. It represents the new born technology, electronics, in terms of inputs given to the other productive sectors of the UK economy. At that time, the input-output tables recorded 90 productive branches. They are represented numerically in the x-axes, with a short explanation of their subdivision by broad categories. Indicatively, the first part of the scale includes the primary sector, the central part of the scale includes the secondary sector and the final part of the scale the tertiary (or service) sector. Electronics production line, at that time, was not recorded as an independent sector. It was incorporated with telecommunication in the "productive branch 43". So our empirical analysis in terms of direct inputs given to the rest of the economy of the row "electronics" will appear over-estimated for being recorded with another sector.

In any case this is what Figure 3 has to say. The analysis of the distribution of the direct inputs shows that the vast majority of the economy remains unaffected by the presence of electronics & telecommunication equipment. The only noticeable input is that given to their own sector, and to other three sectors: namely "instrumental engineering", "aerospace equipment", and to lower degree to a bunch of other sectors in the secondary sector (electrical machinery, other electrical goods) and in the tertiary sector, in particular "all other services".

We may conclude that the influence of electronics in the late 1960, was negligible in re-shaping the structure of the UK economy. It was a radical innovation (the transistor was discovered in the late 1940s) that just made its appearance in the official statistics. The inspection of its column, shows that it is heavily dependent from the inputs of particular branches, like "other mechanical engineering" and "electrical engineering" (the two parental sectors from where it born). The inspection of its row in the input output tables is, instead, almost empty, as we have seen.

[around here Figure 4]

Figure 4 illustrates how the situation is evolved 16 years later, in 1984, when the next input-output tables were made available. The new tables doe not contain the same sectors. Some of them have been re-classified, others emerged anew, and only few of them disappeared from the statistical information. The "entries" outnumber the "exits", so the total number of sectors are now extended to 101. The expansion of the new recorded productive branches involved particularly the tertiary sector. The re-classification involved also the branch "electronics & telecommunication", which is by now split up in two. Figure 4 records the inputs given to the economy of the branch "electronic components".

From the number and size of bars it is evident that the electronic inputs start to pervade the manufacturing industry. In the attempt to clarify the main sectors involved, the Figure picks, with an explicit label, those branches which show in their production process a relevant presence of inputs from "electronics components". It is worth noticing two patterns.

First, electronics seems to increasingly integrate, in terms of inputs, to some key sectors of manufacturing – most notably, office equipment (computers), and telecommunication equipment.

Second, electronics exerts some influence, as an intermediate good, also in the service sector, particularly affecting the branch of Telecommunication and finance. This latter influence is easily detectable if we count the inputs that the integrated cluster of computers and telecommunication equipment gives to the tertiary sector (panel b of Figure 4). In this case there is an evident increase of influence both in terms of the higher number of branches affected, and in terms of the magnitude of its inputs.

[around here Figure 5]

Figure 5 presents the same situation for year 1990. As compared to the previous statistical scenario, we notice at least three distinctive features.

First, the sectors did continue to increase, and still these increases involve the tertiary sector. We have now 30 branches to record "Distribution and services" – twenty-two years earlier the branches were just two.

Second, taken alone the branch of "electronic components" affects even more consistently the manufacturing sector, in particular the kind of manufactures labelled as "light" manufactures. The pervasiveness of the technology affects directly, though not with the same intensity, many more sectors. If we observe the service section of the input-output tables (on the right of the Figure), we may notice a minor quantitative impact, but a substantial widespread effect.

Third, if we aggregate in a single cluster "electronics", "telecommunication equipment" and "computers" and inquiry how their integrated row affects the rest of the input-output table, the influence towards services is even more noticeable (see Figure 5b). Almost the entire tertiary sector receives a heavy quantity of inputs from this cluster of electronic branches. There is almost no sector that on the right side of the input-output table has been left untouched.

This pervasiveness of the technology in affecting not only manufacturing, or industry, but also directly the service sector, it is a feature in line with what we call a technological revolution. Electronics transformed the old tertiary sectors and contributed in creating new sectors across the economy. This seems a feasible representation of a dramatic technological change, in the sense that electronics and related sectors, have modified the matrix of inputs and hence the technical coefficients throughout the economy. It has promoted the creation of new sectors, and has contributed to the re-generation of others, expanding the matrix, in particular towards tertiarization. If by chance the semi-conductor sector will stop working, there would be very few sectors– if any - that could keep their process of production activated.

This is what we mean for a revolution: the structure of the economy is changed, and the nature of wealth is changed too. To be a great economic power nowadays a country needs to crunch chips, digital devices, and software, as it was necessary to crunch carbon, iron, steel in the first two industrial revolutions.

7.2. Electronics knowledge and the labour vector

Following our framework, it would be interesting to detect also the movements across the economy of that labour force with electronic competences.

Information on the composition of the labour force, according to the skills and competences it possesses, is available in a much higher detail for the US economy than for the UK economy. I shall therefore present data from the former country. The proxy adopted to capture the cognitive abilities is the number of engineers according to their university field of specialization.

The underlying argument is that the raise and the subsequent impact of electronics on the rest of the economy should be detectable by a different composition of knowledge in the labour force. The following Figures shall highlight this composition, first across the economy, and then within specific branches. The period examined mirrors only partially what has been done in Section 7.1 by examining the crucial period between 1980 to the beginning of 1990s.

[around here Figure 6]

Figure 6 presents the absolute numbers of engineers in the economy and their composition by field of specialization. They have been grouped in two broad categories for simplicity, so to allow a comparison between the two main technological paradigms of the past century. A first group of mechanical and industrial engineers, and a second group of Electronic and Computer engineers. The total number of engineers in the economy has constantly increased over the whole period. In this growing overall trend, we may detect however the changing structure of knowledge-base towards the new technology.

The message conveyed by the Figure is self-explanatory. In the 1980 the mechanical and industrial paradigm was already no longer dominant, but the proportion, between the two fields of knowledge, was comparable (24% vs. 33%). However in the following decade emerges an evident divide between the two shares. At the end of the period (1992) electronics and computer engineers counted by almost half of the whole engineers in the labour force, leaving mechanical and industrial engineers behind of more than 25 percentage points (42% vs. 16%).

[around here Figure 7]

Figure 7 allows detecting these relative movements within the two main sectors of the economy: manufacturing and services. By making equal to 1 the initial levels, we note clearly how the economy absorbed an increasing number of electronic and computer engineers and how the relative level of mechanical and industrial engineers remained relatively constant through time. Therefore, the increasing number of engineers in industry – we have seen in the previous Figure – was due almost exclusively by the field of technical knowledge we are examining. This pattern involves both the manufacturing sector as well as the service sector with a striking similitude of behaviour, in line with the findings already made in the input-output analysis.

[around here Figure 8]

Figure 8 inquiries more in detail whether the overall pattern that has emerged at aggregate level and with a basic disaggregation (industry vs. service) holds also at more detailed level. Six different productive branches are presented separately: the first three belong to manufacturing, the last three to services. The main reason we have grouped them together is that they convey the idea of a uniform trend. Namely, in all sectors, during the 1980s and beginning of the 1990s, the number of engineers in electronics and computer science went up well above the number of the mechanical and industrial engineers (and from what can tell the data, the rest of engineers). There is no exception to this pattern. Even in the machinery sector the trend is confirmed, let alone the other productive branches.

[around here Figure 9]

Figure 9 inquires more specifically what actually happens within the machinery sector, in terms of the relative presence of engineers with different specialization. In this productive branch it is plausible that the dominant paradigm in terms of competences of the labour force employed would be mechanics. This was clearly the case in 1980, when the majority of engineers, employed in the sector, were precisely mechanical and industrial engineers. Yet, in 1992 the picture is reversed –almost 50 per cent of engineers held a degree in electronics or computer science, while the first group of engineers dropped almost 20 points behind.

To sum up, according to these figures, the composition of competences of the labour force across the sectors show a widespread infiltration of engineers with electronic and computer degrees, with no relevant exceptions. This even occurs within the machinery sector, which should have been the kingdom of mechanics. Yet, it is no longer so. The electronic competences dominate also at mechanics' homeland.

8. The economic consequences on the nature of the service sector

A last point worth enquiring refers on the economic consequences of a changing nature of a sector.

A point, which clearly emerges from the previous two Sections, is the crucial role of electronics in shaping the service sector. What are the implications of all this? The service sector has been considered always a sort of rag-bag where those goods that are not commodities are collected all together.[14] Throwing light on its composition, would reveal the presence of a vary different mix: high value added sectors, but with low productivity growth (the professionals services), low value added sectors with low productivity growth (cleaning services, and alike), as well as the opposite (advanced tertiary sector).

For long time, the prevalent synthesis that emerged from statistical offices, and from the common perception too, is that services was a sector with the lowest change of labour productivity in the economy. Hence, tertiarization was seen as a threat in the promotion of economic growth. The argument was developed with the support of several theoretical models. Baumol's disease model (Baumol and

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[14] The branch "services" are called by many statistical offices simply as "other sectors".

Bowen 1965) predicts, for instance, the raising of relative prices of the tertiary sector due to this lack of productivity growth. As Baumol once recalled, it is striking that with all the progress around us, it still takes four musicians to play a string quartet. Verdoorn's law (1949 and 1980) argued that productivity growth was a by-product of manufacturing output. Bringing the share of the latter down, and the service up, would inevitably slow down economic growth of any advanced economy (Kaldor 1966).

The tertiarization process, according to these views, would at some point imply a stage of 'climacteric' in a hypothetical life cycle of the economic system. This pessimistic foresight joints the crowded room of those who predicts a gloomy future.[15] Yet, from the evidence of the previous sections, we should be concerned not with a sort of the 'end of history', but with the constant necessity to wash our eyes from the dust of time in order to notice the emergence of novelties and offer them some intellectual hospitality.

The empirical case of electronics seems to suggest that there is indeed "something new under the sun" also in the service sector. What are then the consequences? In the literature in the past decades there has been different quantitative analysis in the attempt to capture the economic effects of these secular transformation.[16] The prevalent outcomes of this research have been well summarized by the so called "Solow paradox": "You can see the computer age everywhere but in the productivity statistics" (Solow 1987, 36). In other words, what we called a technological revolution, seems it have not produced any significant effect on the growth of labour productivity and – according to the connection we made in Section 6 – on the growth of per capita income, at least as it is recorded by the statistical offices.

The argument is somewhat hackneyed. Economic historians already put in doubt the significance (and sometimes also the existence) of the First industrial revolution on the ground that Britain, between the end of the XVIII century and the beginning XIX century, did not show any significant economic growth.[17]

In fact the industrial revolution did more. It changed, as a technological revolution is supposed to do, the nature of wealth. But also the quantity of wealth seems a point not to dismiss entirely. After all, Britain dominated the tables of per capita income in XIX century, from 1820 to 1900, according to some estimates (Maddison 1995, 2001)[18].

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[15] One of the most famous reports of this kind, which became very influential, was promoted by the Club of Rome (Meadows et al. 1974). In the occasion it was Chris Freeman and his colleagues at SPRU, who reminded that technical change will not go to disappear.

[16] See, among others, Griliches (1994).

[17] On this line of thought, see Clark (1986), Cameron (1985), Fores (1981), Coleman (1983).

[18] Great Britain comes first in the per capita income table in the benchmark years, 1820, 1850, 1900. In 1870, Australia takes the first place. It is not difficult to see that this latter leadership was due mainly to the great quantity

Will the electronic revolution (or ICT revolution as it is better known) produce at some point, *mutatis mutandis,* the same quantitative effects?

In what follows, I shall attempt to analyze the role played by Keynesian and the Schumpeterian component of equation 6 for the US economy.

[around here Figure 10]

Figure 10 is the focus of the following considerations. It is divided in three panels. The first depicts the process of structural change of the US economy from 1965 to 2005, measured in terms of shares of value added in the three main sectors: agriculture, industry, services.

The second panel compares in the same period the shares of value added and the shares of labour force of the service sector in the economy, by showing the evolution of these two variables in the same forty-year period. It allows us to detect whether the Keynesian component of productivity growth in the service sector contributes positively or negatively to the overall performance.

The lower panel shows the rate of change of labour productivity within the service sector, and compares it with the same variable for the whole economy. It gives indications of the contribution to the overall productivity rate of change, played by the Schumpeterian component of productivity growth in the service sector.

From the three panels this is the information that can be gained from the data.

i) 1965-75. The process of de-industrialisation combined with the strong process of tertiarization is one of the various factors that help to explain why US growth has slowed down its process of growth.

The second panel shows that the contribution to growth of the Keynesian component has been since (almost) the beginning of the period always negative, and consistently so thereafter. Therefore, the higher shares of labour concentrated in the service sectors accentuated the negative impact of this component in accounting to the overall economic performance.

The third panel shows moreover that the rate of change of labour productivity in the service sector has remained systematically below the average value of the economy too. The undergoing process of tertiarization, by giving weight to a less dynamic sector (as compared to those that were growing above the average), weakened further the process of economic growth of the economy. The Schumpeterian component of the service sector is therefore another factor that helps to explain the slow down of the US performance in the past decades.

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of natural resources (i.e. the old type of wealth) that Australia experienced at the time, as compared with the very small proportion of its population. Yet, the revisionists have still to explain the leadership of the UK, in the other three benchmark years, across the century.

ii) 1995-2005. The tertiarization process seems to persist (upper panel), but its contribution to growth has somewhat changed (centre and lower panel). The central panel still shows a value added component which is lower than its counterpart shares of labour force in the service sector. Therefore this component is still negative, though with a lesser degree.

However, the lower panel indicates that the rate of change of labour productivity in the tertiary sector has started to increase consistently, bringing up with it (given its weight in the economy), the rate of change of the overall labour productivity. Though the data for the service sector are highly controversial, it seems that tertiarization in the last decade is no longer a synonym of low productivity growth. Without the growth of productivity in the service sector, it would be hard to explain the exceptional performance of the US in the last decade or so.

When about one hundred years ago, a member of the Royal Institute asked Faraday what was the practical impact of his innovation, he seemed to have answered: “What is the use of a newborn child?” As a child, also the electronic innovations – the novelty under the sun we have examined – took time to serve its free lunch to the economic system. The childhood may have been long and the benefits still uncertain. But there is hope. After all, the tertiarization process does not necessary seem the beginning of the end of (economic) history. Solow’s paradox may be explained and solved. And the Baumol’s disease may be eventually cured.

9. Concluding remarks

In this paper we have tried to argue that, from an economic point of view, an industrial world could not live without novelties. The old quest of whether there is something new under the sun or not has received both a logical answer (Section 6) and an empirical inquiry (Section 7 and 8). From our point of view, at least, Heraclitus has something more to say than Parmenides in explaining the modern process of economic growth.

In a world that it is not ergodic, in which the future may not be qualitatively equal to the present, it is very difficult to say something that concludes an argument about novelties. However, an attempt will be made to see the implications of our results:

- Technology is the main cause of structural change in the economy, this structural change relates not only to movements in production or occupation of given sectors, but also in the creation of new industries, the profound transformation of others, and the destruction, or obsolescence of other productive branches too.

- Without this injection of new sectors, the modern economic growth will come to a halt. Schumpeter was right to deserve only to the process that started with an innovation the term of “economic development”. In fact we have shown that not all the innovations have the power to change profoundly the economic world. But some innovations do have this power. Are these innovations that keep, after more than two centuries since the First industrial revolution, the process of economic development alive. They promote – through what we called the Schumpeterian component – an increase of labour productivity, a burst of demand, while reshuffling the technology of the other sectors too.

• Technological revolutions therefore exist. They are quite different from "political revolutions", from which the term is borrowed. Political revolutions are usually instantaneous, the coupe d'état being the emblem that best represents it. A technological revolution takes tremendously more time to make its mark. At the beginning it may appear insignificant and even costly for the society. In fact, any profound structural change pays in a short (and sometimes no-so-short) run a cost in terms of economic performance. The technological revolution affects the rest of the economy – as we have seen – with new inputs. But new inputs initially bring technical coefficients up, not down as the typical conceptualization of technical progress, that economists had in mind, presumes.

• If technological revolutions exist, several concepts in economics are at risk. To begin with, the proportional models, which still nowadays dominate economic growth. Second, the industrial theories and policies need to be constantly revised. The 'life cycle theory' may misguide both analysis and industrial policies, since what is an old sector today, could become a dynamic sector tomorrow – and vice versa. We have seen an example of this kind with the service sector. Third, the emphasis that economists deserve respectively to competition (neoclassics) and selection (evolutionists) should not overshadow the great importance of the industrial interdependences – and hence to the collaboration and the inter-linkages issue between economic sectors. Forth, the long standing debate on the existence or not existence of long waves in economic history must not be dismissed from the modern economic agenda, as sometimes one has the impression it has been nowadays.

So, will the long waves continue to sustain the economies and offer to us a sustainable long term economic development? This is a (the) big question, which it has intrigued the great economists. To put it in our language, shall we have also tomorrow something new under the sun? Schumpeter's (1950: 118) answer does not leave doubts on the matter. "Technological possibilities are an uncharted sea, [and] there is no reason to expect slackening of the rate of output through exhaustion of technological possibilities". But probably the most encouraging answer to this big question, among all, came again from Keynes (1930: 326-28). In the middle of the Great depression, he wrote: "the economic problem may be solved, or at least within sight solution, within a hundred years. [...] Thus for the first time since his creation man will be faced with his real, his permanent problem — how to use his freedom from pressing economic cares, how to occupy the leisure, which science and compound interest will have won for him; to live wisely and agreeably and well". This is an optimistic prophecy, which brings us back to philosophical subject matters. As a prophecy, it has not been fulfilled yet, but it is still helpful in highlighting the vision of economics as a moral science that Keynes professed.

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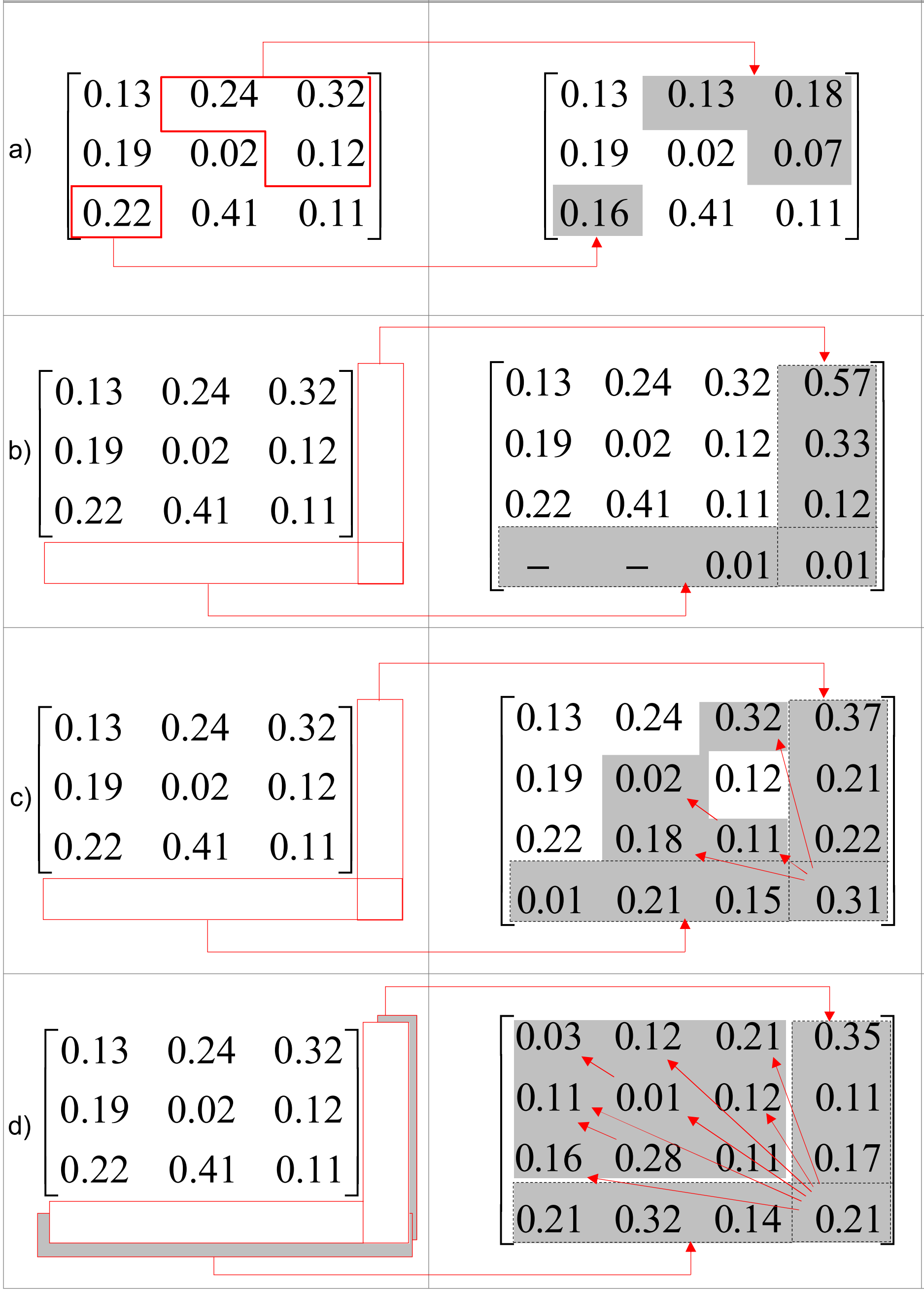
Figures and Tables for the paper:
Something new under the Sun
by GianPaolo Mariutti

Figure 1. Taxonomy of innovation in an input-output framework



Input-output matrix before innovation	Input-output matrix after innovation	Type of innovation
a) $\begin{bmatrix} 0.13 & 0.24 & 0.32 \\ 0.19 & 0.02 & 0.12 \\ 0.22 & 0.41 & 0.11 \end{bmatrix}$	$\begin{bmatrix} 0.13 & 0.13 & 0.18 \\ 0.19 & 0.02 & 0.07 \\ 0.16 & 0.41 & 0.11 \end{bmatrix}$	Incremental innovations: • Input output matrix of same size • Reduction of technical coefficients across different sectors
b) $\begin{bmatrix} 0.13 & 0.24 & 0.32 \\ 0.19 & 0.02 & 0.12 \\ 0.22 & 0.41 & 0.11 \end{bmatrix}$	$\begin{bmatrix} 0.13 & 0.24 & 0.32 & 0.57 \\ 0.19 & 0.02 & 0.12 & 0.33 \\ 0.22 & 0.41 & 0.11 & 0.12 \\ - & - & 0.01 & 0.01 \end{bmatrix}$	Radical innovations: • Input output matrix with an additional column and row • Column almost full of coefficients • Row almost empty of coefficients
c) $\begin{bmatrix} 0.13 & 0.24 & 0.32 \\ 0.19 & 0.02 & 0.12 \\ 0.22 & 0.41 & 0.11 \end{bmatrix}$	$\begin{bmatrix} 0.13 & 0.24 & 0.32 & 0.37 \\ 0.19 & 0.02 & 0.12 & 0.21 \\ 0.22 & 0.18 & 0.11 & 0.22 \\ 0.01 & 0.21 & 0.15 & 0.31 \end{bmatrix}$	New technology system: • Input output matrix with an additional column and row • New row starts to spread inputs • Cluster of sectors are affected and a wave of incremental innovations have been generated
d) $\begin{bmatrix} 0.13 & 0.24 & 0.32 \\ 0.19 & 0.02 & 0.12 \\ 0.22 & 0.41 & 0.11 \end{bmatrix}$	$\begin{bmatrix} 0.03 & 0.12 & 0.21 & 0.35 \\ 0.11 & 0.01 & 0.12 & 0.11 \\ 0.16 & 0.28 & 0.11 & 0.17 \\ 0.21 & 0.32 & 0.14 & 0.21 \end{bmatrix}$	Technological revolution: • Input output matrix with additional column(s) and row(s) • Row full of inputs • Any sector (column) is affected with a generalized storm of incremental innovations

Figure 2. Stages of development through a technological revolution

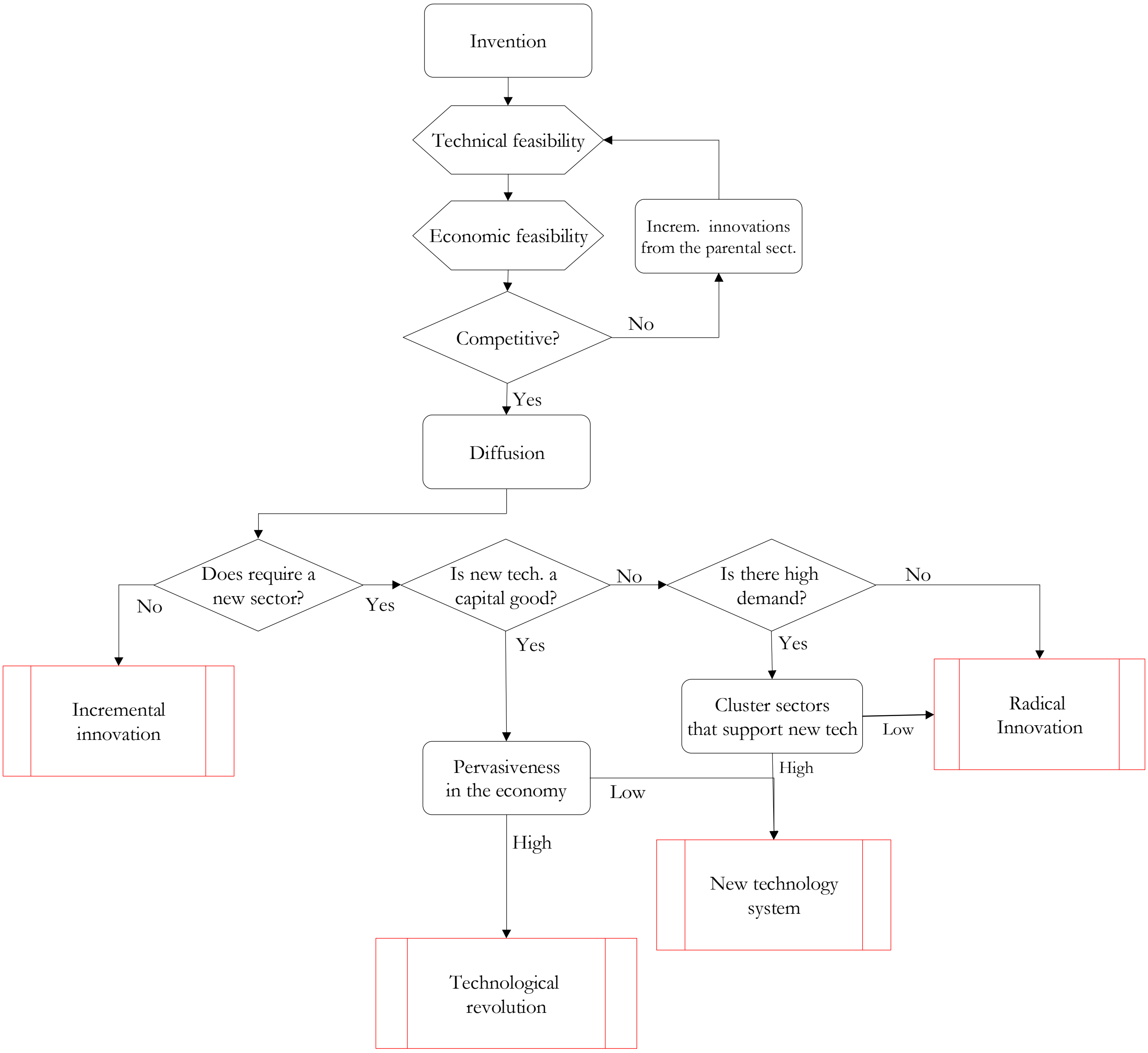
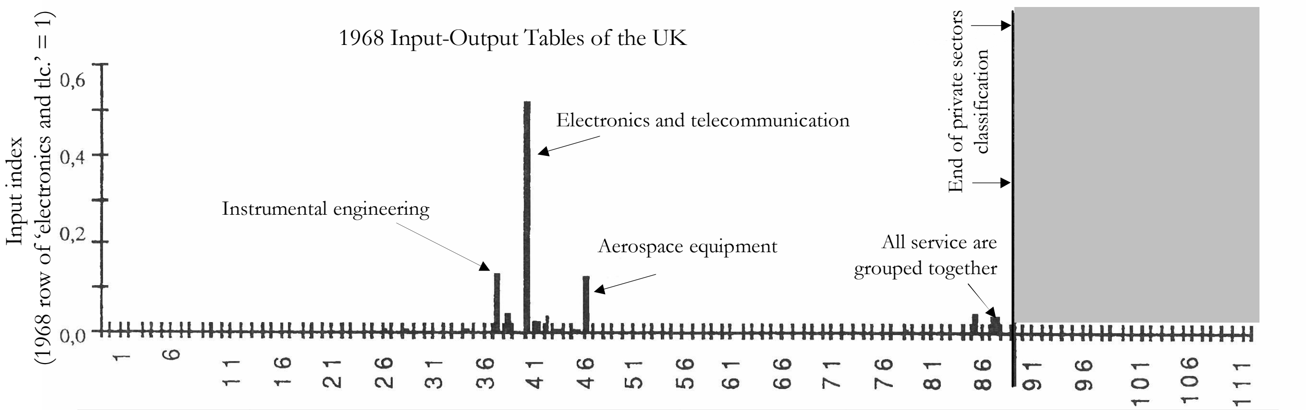


Figure 3. Inputs given to the economy by the row of 'electronics and telecommunication'

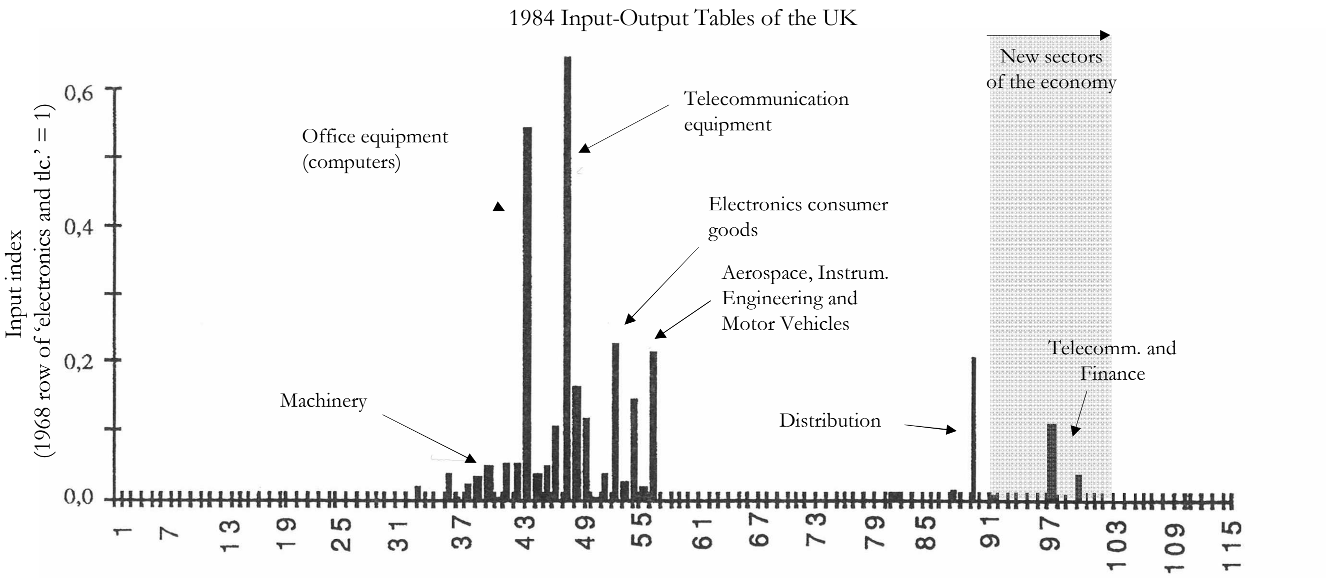


Number of sectors	Type of sectors in the economy	Number of sectors	Type of sectors in the economy
0-10	Primary sector	61-80	Food, cloths and paper processing
11-30	Heavy and chemical sectors	81-88	Energy supply and transport
31-60	Light sectors	89-90	Distribution and Miscellaneous services

Source: Elaborations from data of the Central Statistical Office (1968-1995).

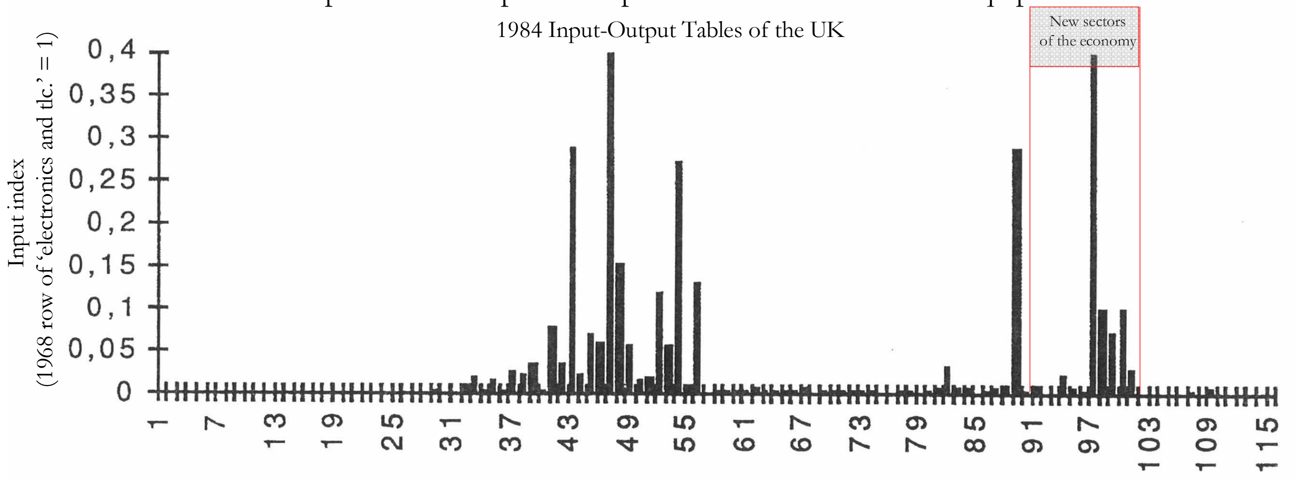
Legend: Electronic inputs (*j*) to the other sectors (*i*) are normalized as follows:
1968: a_{ji} is the share of input *j* in sector i: $\Sigma\, a_{ji} = 1$
1984, 1990: a_{ji} is the normalized share of input *j* in sector *i* (as above), times the ratio between *b* and *c;* where *b* is the share of value added of sector *j* in the economy at time t, and *c* is the share of value added of sector *j* in the economy in 1968 at constant prices.

Figure 4. Inputs given to the economy by the row of ‘electronics components’



Number of sectors	Type of sectors in the economy	Number of sectors	Type of sectors in the economy
0-10	Primary sector	61-86	Food, cloths and paper processing
11-30	Heavy and chemical sectors	**87-101**	Distribution and service sectors
31-60	Light sectors		

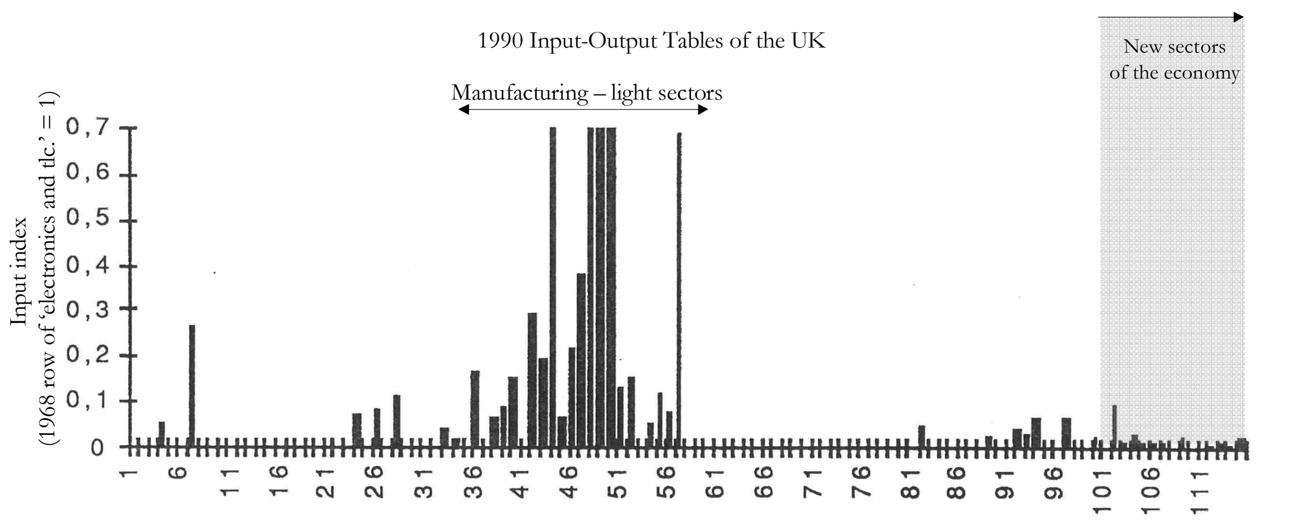
4b. Inputs as above plus ‘computers+telecommunication equipment’



Source: Elaborations from data of the Central Statistical Office (1968-1995).

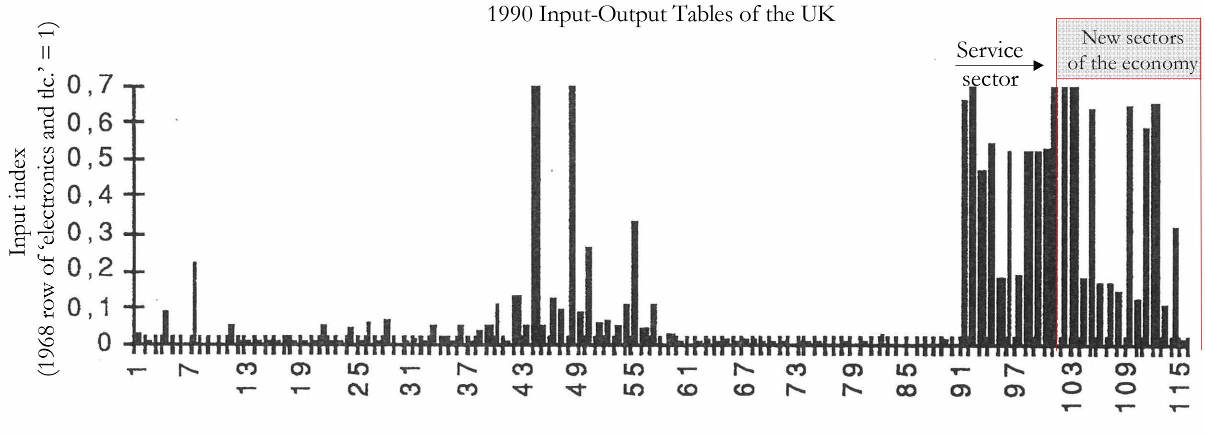
Legend: Electronic inputs (*j*) to the other sectors (*i*) are normalized as follows:
1968: a_{ji} is the share of input *j* in sector i: $\Sigma a_{ji} = 1$
1984, 1990: a_{ji} is the normalized share of input *j* in sector *i* (as above), times the ratio between *b* and *c;* where *b* is the share of value added of sector *j* in the economy at time t, and *c* is the share of value added of sector *j* in the economy in 1968 at constant prices.

Figure 5. Inputs given to the economy by the row of ‘electronics components’



Number of sectors	Type of sectors in the economy	Number of sectors	Type of sectors in the economy
0-10	Primary sector	61-90	Food, cloths and paper processing
11-30	Heavy and chemical sectors	**91-120**	Distribution and service sectors
31-60	Light sectors		

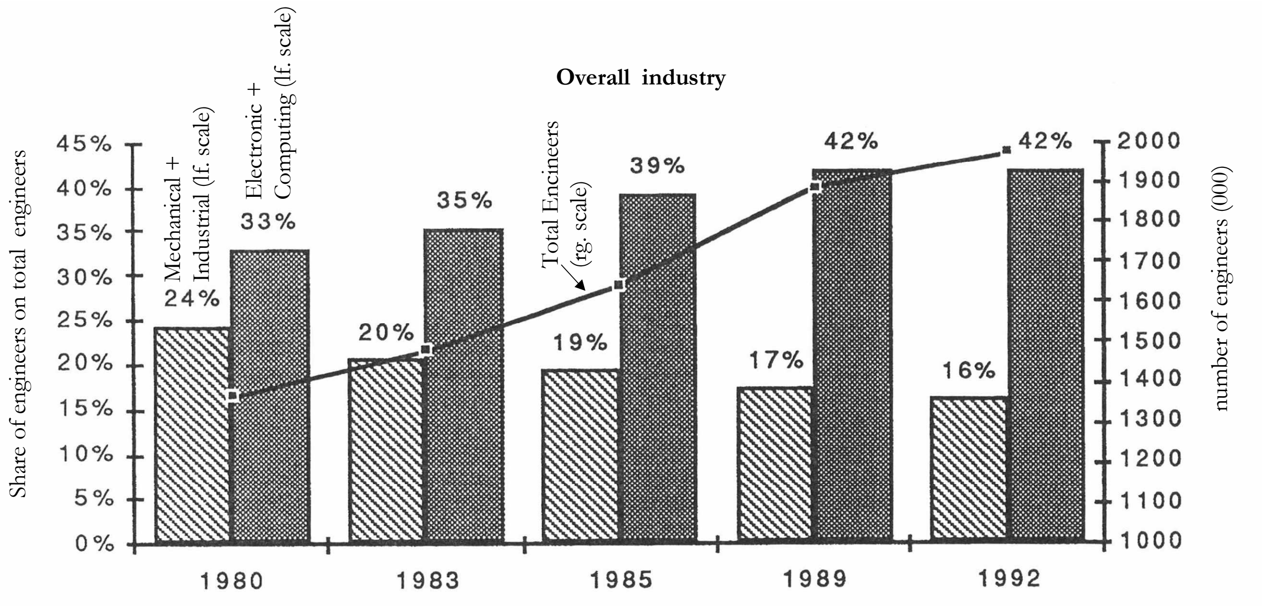
5b. Inputs to the economy by the rows ‘electronics+computers+telecommunication equipment’



Source: Elaborations from data of the Central Statistical Office (1968-1995).

Legend: Electronic inputs (*j*) to the other sectors (*i*) are normalized as follows:
1968: a_{ji} is the share of input *j* in sector i: $\Sigma a_{ji} = 1$
1984, 1990: a_{ji} is the normalized share of input *j* in sector *i* (as above), times the ratio between *b* and *c;* where *b* is the share of value added of sector *j* in the economy at time t, and *c* is the share of value added of sector *j* in the economy in 1968 at constant prices.

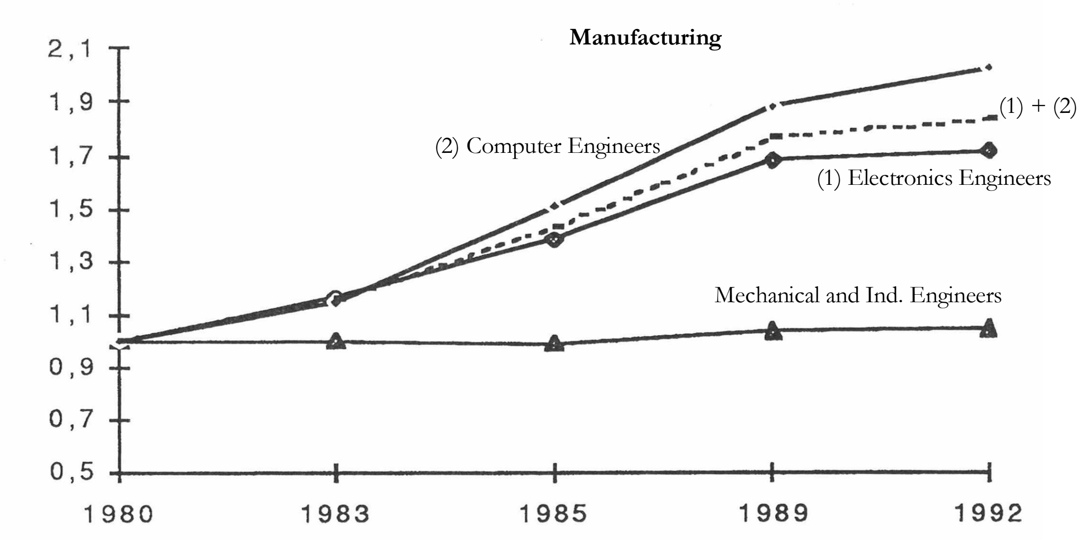
Figure 6. Number of total engineers and shares of Electronic and Computer engineers vs. Mechanical and Industrial engineers in the US industry

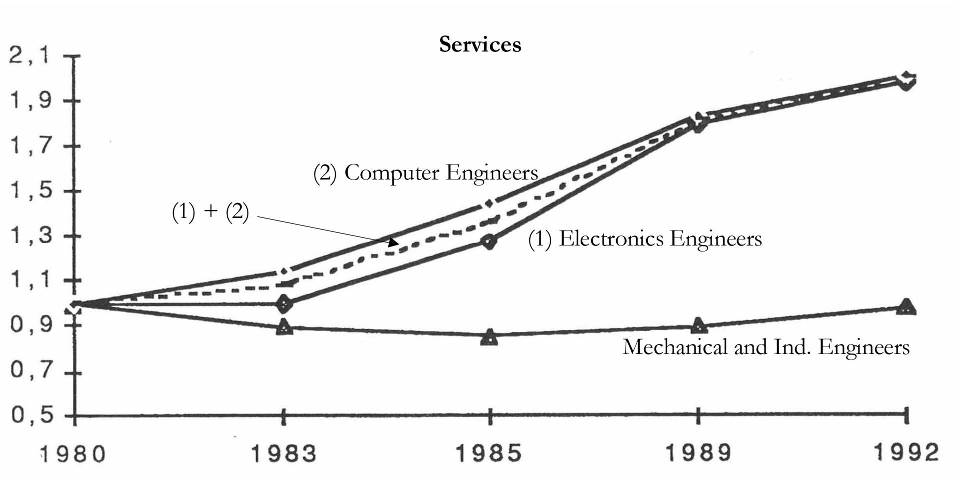


Source: Elaborations from data of National Science Foundation (1996).

Figure 7. Number of Engineers of Electronics, Computers and Mechanics in manufacturing and service sectors for the US

(index numbers, 1980=1)



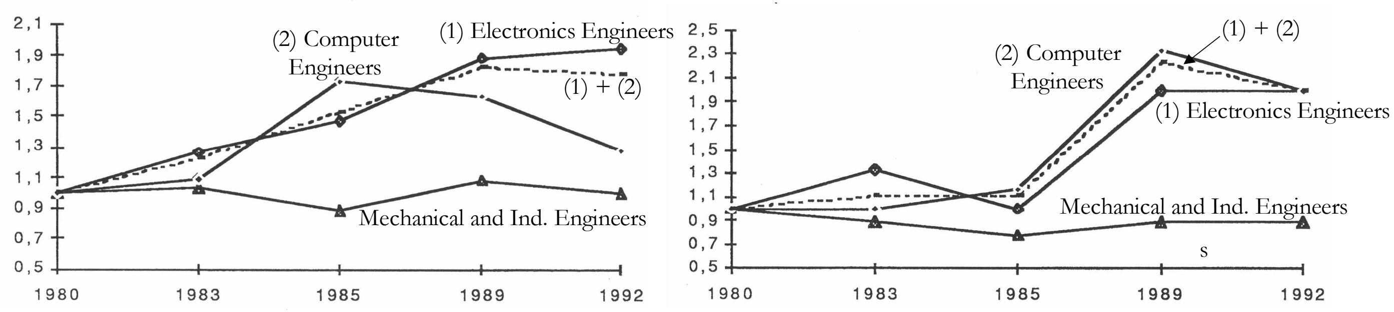


Source: Elaborations from data of National Science Foundation (1996).

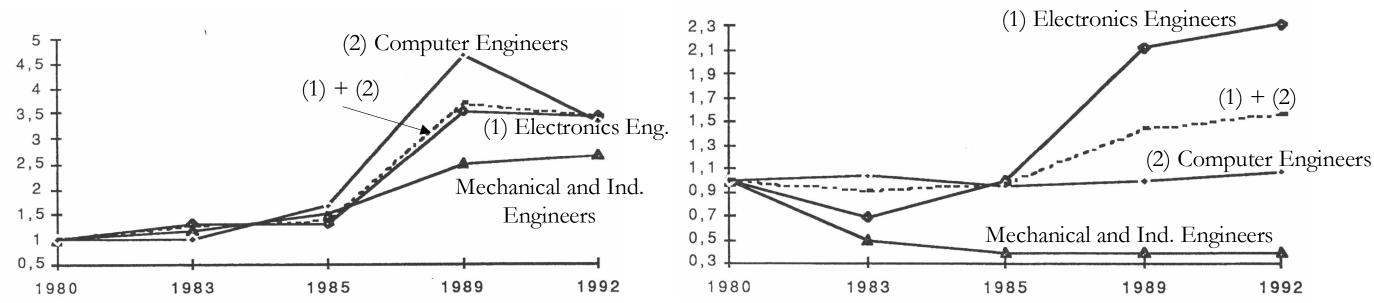
Figure 8. Number of Engineers of Electronics, Computers and Mechanics in six different economic sectors for the US

(index numbers, 1980=1)

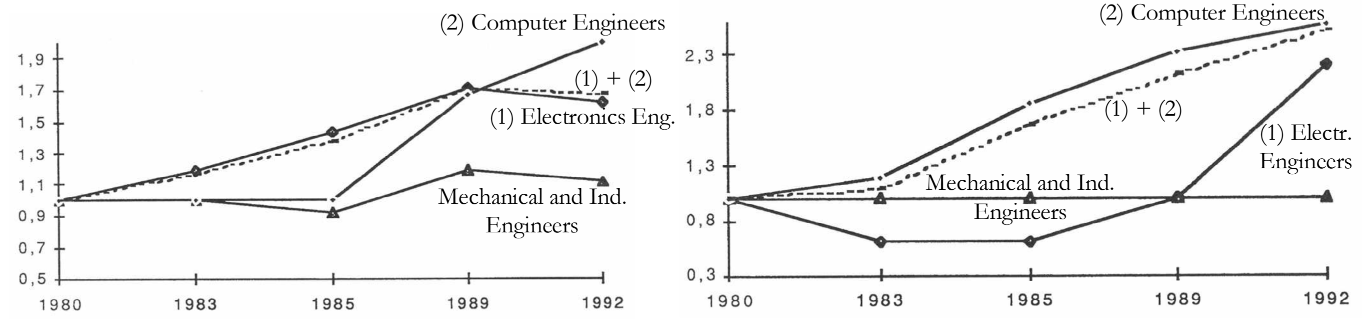
Machinery **Chemicals**



Scientific Instruments **Trade**

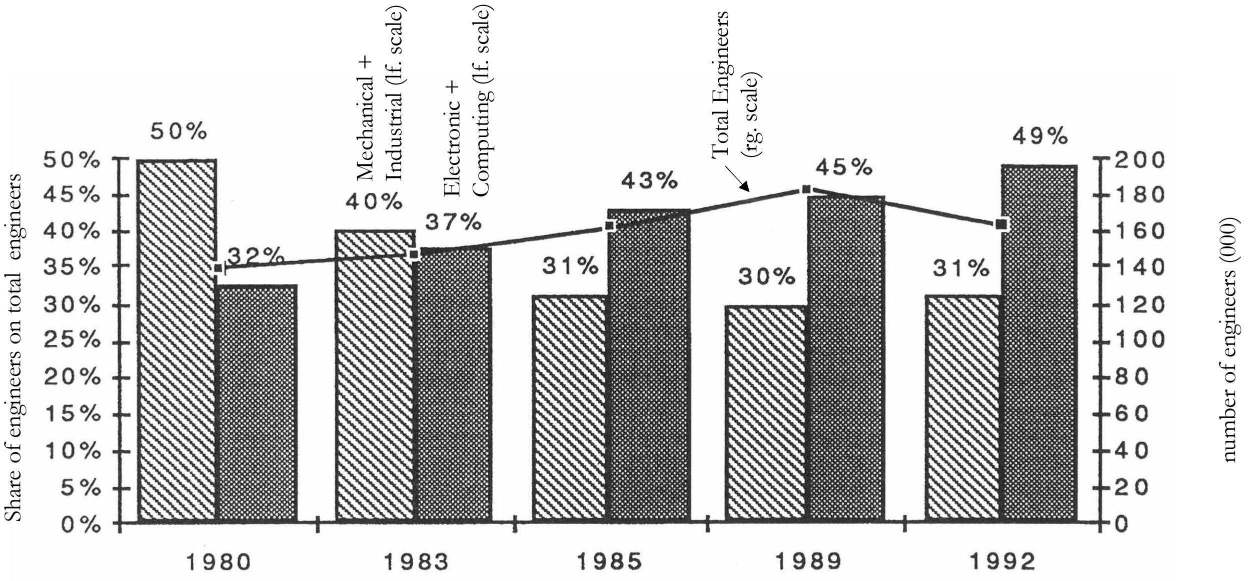


Engineering Service **Finance**



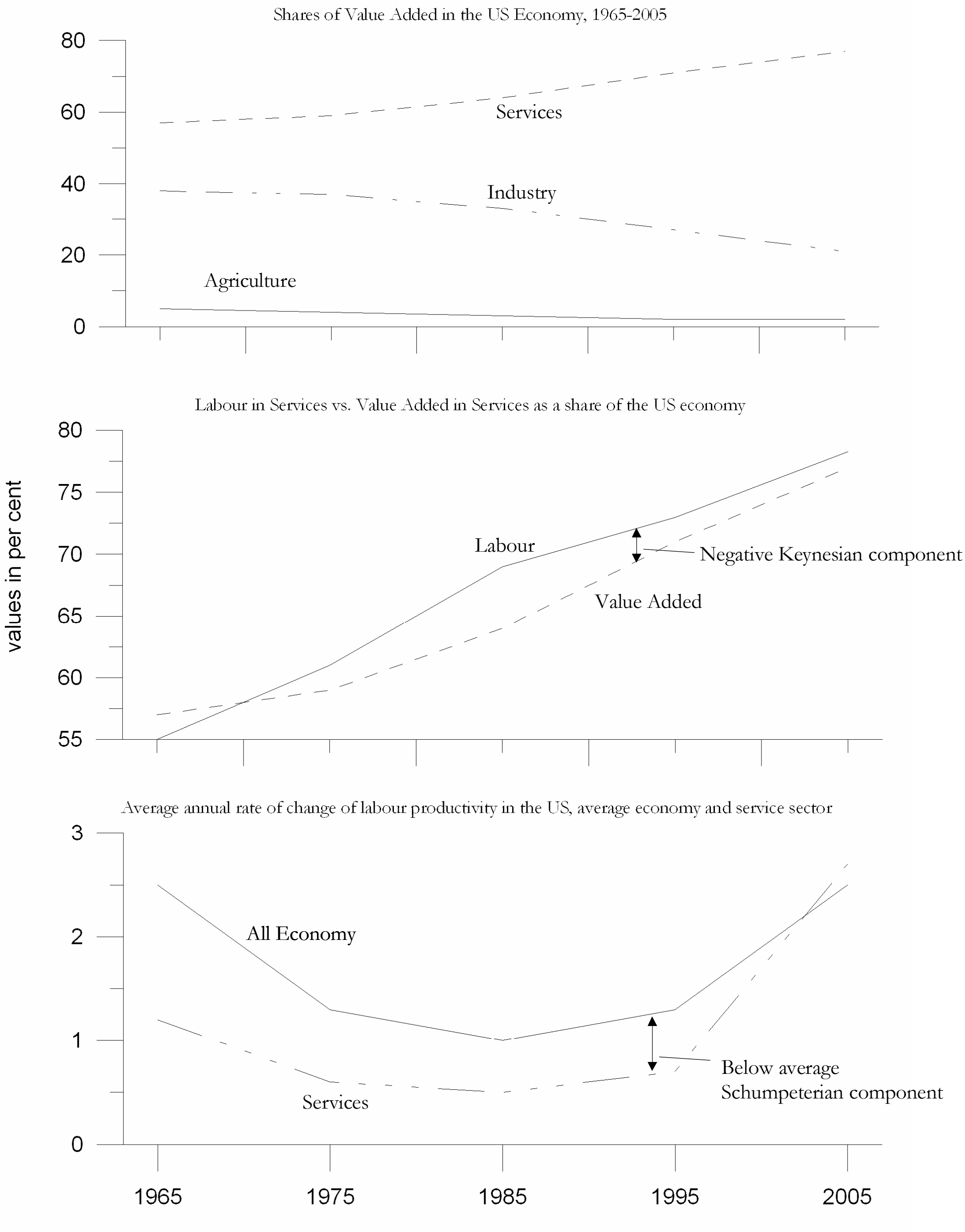
Source: Elaborations from data of National Science Foundation (1996).

Figure 9. Number of total engineers and shares of Electronic and Computer engineers vs. Mechanical and Industrial engineers in the US machinery sector



Source: Elaborations from data of National Science Foundation (1996).

Figure 10. Structure of the US economy and contribution of the Service sector to the rate of growth of labour productivity



Source: Elaborations from data of World Development Indicators (World Bank 2006) and the US Census of Bureau (2008) and Bureau of Labor Statistics (2007).