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Abstract
Neo-Schumpeterians of the 1970s and 1980s argued for the concept of pervasive technological systems as one way of interpreting creative destruction. Pervasive technologies are basic innovations that find application in a wide variety of sectors in the economy. It has recently been suggested that the period of rapid economic growth in the 1990s in the United States can be explained by the rise of a set of technologies known as Information and Communication Technologies (ICT). Such an interpretation is certainly in broad accordance with the notions of Schumpeterian radical technological breakthroughs, creative destruction and pervasive technological systems. This paper provides an attempt to interpret this ICT 'revolution' from a Schumpeterian point of view, using input-output data and technology flow matrices for the US economy. The paper concludes with a broad discussion of the historic role of ICT in the US and world economy.

Keywords: Technological revolutions, input-output economics, Schumpeterian economics

JEL – codes: O3, O4, C67

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1. Introduction

'We see computers everywhere, except in the statistics on productivity growth' a famous sound bite by Nobel Prize winner Robert Solow that neatly summarizes much popular debate around the issue of Information and Communications Technologies (ICT). The general feeling of an increased presence of ICT that is expressed with this statement has recently given rise to a vision of a society in transformation towards an 'information age'. These debates are surrounded by claims about the growing importance of ICT for the world economy (see, e.g., OECD, 2000), and have led to often-optimistic estimates of the contributions of sectors related to ICT to the overall economy.

Smith (2001) provides a brief review and critical discussion of these contributions, and concludes that much of the debate is not well founded in either sound economic theory, or a systematic conceptual framework for measuring the economic impact of ICT. At the heart of these problems is the supposed so-called pervasive nature of ICT, i.e., the phenomenon that ICT have an impact on a broad range of industries and activities. This implies that there is not a single economic sector that represents ICT.

The (historical) role of such pervasive technologies has been the subject of the Schumpeterian literature on economic growth and structural change. In this literature, which is by no means undisputed (e.g., Smith, 2001 is quite critical), one finds a framework that explains the subsequent rise and fall of pervasive technological systems, and their interaction with the economy. What the theory suggests is that structural change, economic growth and major technological breakthroughs are closely interconnected, and can only be analyzed jointly.

This paper will attempt to use the Schumpeterian framework to make a systematic analysis of the role of ICT in the structural change in the US economy over (most of) the postwar period.[1] The aim of the analysis will be to relate the role of structural change in connection to a specific historical case of a major technological breakthrough. The technological and broad economic background to the analysis will be derived from the existing (neo-) Schumpeterian literature, which will be reviewed briefly in section 2 of the paper.

The main vehicle for analysis is input-output analysis. This technique is well suited to analyze the impact of pervasive technologies, because it provides a broad picture of the interdependencies between sectors in the economy. The Schumpeterian theory on pervasive innovations is essentially an argument about changes in these interdependencies, and the impact this has on structural change and economic growth, hence the idea of using input-output analysis. Section 3 will outline the preliminaries in input-output analysis that are necessary for the analysis.

Section 4 provides the main empirical contribution of the analysis. This section will make use of a database on input-output relations for the US economy for the time span 1958-1998, both for the technological and economic domain. The conclusions of the analysis are summarized in section 5. This section will also provide some conclusions on the contemporary role of ICT that come out of the historical comparisons made in section 4.

2. Structural Change and Technology: A Schumpeterian perspective

The impact of major technological breakthroughs on the economy is the domain of Schumpeterian theory.[2] In his seminal 1939 work *Business Cycles,* Schumpeter outlined a theory about the occurrence of long waves of economic growth driven by radical technological breakthroughs. In the 1970s and 1980s, his work was used as a starting point for a large literature that investigated the Schumpeterian hypothesis about long waves and innovations in an empirical way. One of the main ideas found in this

[1] Gordon (2000) puts this period and the topic of ICT in a broader historical perspective, but his emphasis is largely on productivity growth. Here, structural change will be the main topic of comparison.

[2] The reader may recognize many of the ideas discussed in this section as those that are present in the literature on so-called General Purpose Technologies (GPTs) (e.g., Helpman, 1998). I consider the literature on GPTs as the American counterpart of the Schumpeterian literature that I discuss in this section. The Schumpeterian literature was mainly developed in the European context, and there are few references from the GPTs literature to the Schumpeterian literature summarized here, despite the fact that the latter was clearly leading in time. Since the ideas in the two bodies of literature share many ideas, however, the informed (American) reader may also use the GPTs literature as a frame of reference for the empirical analysis in this paper.

neo-Schumpeterian literature (e.g., Mensch, 1979, Freeman, Clark and Soete, 1982 and Kleinknecht, 1987) is that Information and Communications Technologies (ICT) would be the driver of a new wave of economic growth starting in the 1980s or 1990s.

In the recent context about the rise (and demise) of the so-called New Economy, the Schumpeterian idea is obviously an attractive way of providing a theoretical foundation to the popular debates. In this view, the New Economy would be another upswing in a sequence of five long waves, each one driven by a technological revolution that is related to a 'bunch' of basic innovations.

Schumpeter did not invent the idea of long waves in economic time series. It featured in the work of the Russian economist Kondratief, and even before him there were economists in the Marxian tradition that raised the idea. Long waves are approximately 50-60 years in duration, and there is a (once) vivid literature on the subject of whether or not they exist (see, e.g., Kleinknecht, Mandel and Wallerstein, 1990). This paper will not be concerned with the question whether or not long waves exist. Much of this debate is focused on the idea of a strongly regular rhythm of long waves and strict periodicity. Such an idea of long waves is not important for the current analysis. Instead, the analysis starts from the idea that there may be long-run trend reversals in the rhythm of economic growth, which span decades rather than years, and which are related crucially to technological changes. The question how the economy may be reshaped under the influence of such major technological breakthroughs is what concerns us here.

The starting point of the Schumpeterian wave is the occurrence of one or a number of interrelated 'basic' (or radical) innovations. These basic innovations provide the opportunity for increasing growth rates, i.e., for the upswing of a new long wave to set in. In Schumpeter's original point of view, the basic innovations were introduced by a special class of businessmen he called entrepreneurs. The entrepreneur is an especially visionary businessman, who recognizes the commercial opportunities of the basic innovations at a time when other businessmen, or possible consumers of the products associated to the basic innovations, are still in the dark with respect to the new possibilities. The entrepreneur is also especially skilled in terms of running the type of business that is needed to make the basic innovations into a success, or in the art of invention, or both. One may also think of partnerships of businessmen (managers) and inventors, jointly representing the entrepreneur.

Later in his life, Schumpeter started to put less emphasis on such personal characteristics of the entrepreneur and their importance for basic innovations. This was the result of changes going on in the economy during the period in which Schumpeter was most active in terms of his professional activities. The role of the entrepreneur in the innovation process slowly started to be taken over by large firms, which were much less dependent on the personalities of their managers than had been the case in the past. However, no matter whether the source of basic innovations is a single entrepreneur or a large firm, the role of basic innovations for the process of economic growth remains largely the same.

The opportunities of the basic innovations unleash great commercial potential, and hence attract a swarm of imitators. This why such radical innovations "are not evenly distributed in time, but that on the contrary they tend to cluster, to come about in bunches, simply because first some, and then most firms follow in the wake of successful innovation" (Schumpeter, 1939, p. 75). Such an imitation and diffusion process does not consist, however, of mere copying of the original innovation. It rather takes the form of ever more incremental improvements. There is a bandwagon of such imitations taking place during the phase after the immediate introduction of the innovation. The bandwagon of imitations leads to higher growth rates, i.e., takes the economy into the upswing, because the imitators are able to expand their activities while slowly pushing the radically new technologies into the economy. A multiplier process sets in because this expansion requires investment in capital and workers.

The upswing is not only a process of expansion, however, because productive capital that is specific to the old technology can no longer be used. This includes machinery and equipment installed in factories, skills and experience locked up in human capital, or infrastructural capital used for transportation or energy distribution. Firms that try to hold on completely to the old technology will have increasing problems in surviving in the market, and may eventually be forced to chose between adopting the new technology or go out of business. Schumpeter uses the term creative destruction to illustrate the dual nature of expansion and competition between technologies that takes place during the upswing phase.

The bandwagon of imitation makes the upswing happen but also implies that profit rates of the firms pushing the new technology will gradually be eroded. Initially, when there are only one or a few firms that use the new innovations, profit rates are high due to the large technological opportunities and absence of competition. But when the bandwagon grows, technological opportunities gradually become smaller (when the easiest incremental improvements have already been applied and only the harder-to-achieve improvements remain). The entrance of more and more firms on the bandwagon at the same time increases the level of competition, and this drives down the profit rate. Eventually, this will lead to profit rates and overall growth rates settling down at the high level of the prosperity phase.

Competition and the further erosion of technological opportunities do not stop in the prosperity phase, however. The continuation of these processes eventually leads to a decline in the growth rates. The recession sets in. During the recession, the technology can be considered as mature, and competition between firms mainly takes the form of (intense) price competition. The diffusion of the basic innovations gets saturated at this stage, when all potential users have adopted the technology. Hence, markets are no longer expanding and depend to a large extent on replacement of old and defective products.

The recession turns into a depression when saturation gets almost complete, and the intensity of price competition reaches a peak. Technological opportunities for further improvements of the technological paradigm have dried up completely at this stage. The economy approaches a zero profit level, and the need for a new set of basic innovations becomes very high. This is when the process starts all over again with the next wave of basic innovations that may lead the economy into a new upswing.

This description of the rise and fall of a set of basic innovations is called the primary cycle by Schumpeter. The primary cycle may also be re-enforced by a secondary cycle that is to a large extent driven by investment in financial assets. During the early upswing, (stock market) investors get optimistic about the new technology and are willing to take more risk when investing in the new companies. Such investment facilitates the expansion of the new technology and the companies that have adopted it. However, the large degree of uncertainty associated with the new technology may also lead to failures of firms, and hence investment in the stock market becomes highly risky, but such risk is not perceived by all stock market speculators because of the generally optimistic nature of the booming times. In the same way that such speculative bubbles may facilitate the upswing, they may aggravate recessions and depressions, when sentiments become over-pessimistic

One basic question that can be asked with regard to the original Schumpeterian theory of basic innovations and long waves regards the timing of the swarms of innovations. If these swarms were spread out evenly over time with short intervals of time between them, a smoother pattern of economic growth might easily result because periods of saturation of one innovation would be offset by periods of expansion of others. Kuznets pointed this out in a review of Schumpeter's two volumes on *Business Cycles*. In Kuznets' view, Schumpeter's theory needed an answer to the question as to why the entrepreneurs that were to introduce new radical technologies would get tired every 50 years. Schumpeter did not elaborate on the reasons why swarms of innovations would be spread unevenly over time, although he did point to the pervasive nature of some innovations, i.e., that they affect a large number of sectors in the economy at the same time. This obviously reduces the probability of swarms of innovations in different phases of their life cycle more or less offsetting each other.

While Schumpeter wrote up his theory of long waves and basic innovation during the first half of the 20th century, the role of basic innovations in the economy gained new interest in the 1970s, when the economy in the Western world was slowing down. According to some (Schumpeterian) economists, the depression phase of the long wave had set in, and they were putting their hopes for an upswing in the coming decades on the new technological paradigm of computers and related electronics technology. With such a re-birth of Schumpeter's theory, the need for a more elaborate theory for the timing of swarms of basic innovations became all the more apparent.

It was the German economist Mensch who put forward a new theory of the relation between long waves and basic innovation. Mensch argued that basic innovations cluster during the depression phase of the long wave, contrary Schumpeter's original view that swarms of innovations would occur during the early upswing due to imitation. The theoretical explanation for such Mensch-type clusters of basic innovations was offered in the form of the depression trigger hypothesis. This hypothesis starts from the assumption of bounded rationality, which is particularly appropriate in the case of basic innovations or a radical change of technological paradigm. Mensch argued that firms under bounded rationality would display so-called satisficing behaviour, which means that they will strive to obtain a certain minimal level of profits by trying out new combinations (innovating). After they have reached this minimum level, the firms will focus more on maintaining this level, i.e., exploiting the opportunities that they have found, than on trying to increase the profit level even further by searching for new innovations.

This explains why firms will not be actively searching for new basic innovations during the upswing or prosperity phase of a long wave. In these phases, the increasing or high profit rates will lead to a focus of attention on the existing technological paradigm. Only when profit rates start to soar will the interest in new basic innovations surface again. This will occur during the late stage of the recession and the depression phase. Some time after this, firms start actively searching for basic innovations, and after a while their search will become successful. This explains why basic innovations will cluster in the depression phase.

The neo-Schumpeterian work on basic innovations and long-run economic growth has mainly proceeded along two lines. On the one hand, there is a set of contributions (e.g., Kleinknecht, 1990) that try to establish empirical evidence for the clustering of basic innovations. This entails the identification of such basic innovations using the literature on the history of technological change, and dating them. The second stream of literature consists of a more or less historical approach to the issue (e.g., Freeman and Soete, 1997). This literature attempts to assess the role of basic innovations using historical material, and puts much emphasis on the interaction between technology and the economy.

[insert Diagram 1 around here]

It is this second stream of literature that is of prime interest to the purpose of this paper. The contribution of this literature is twofold. On the one hand, it provides an historical scheme that relates the role of basic innovations to economic history. Such a scheme is reproduced in an elementary form in Diagram 1. The second contribution of this literature is that it introduces a number of working hypotheses and concepts that can be used to analyze the impact of basic innovations. Four of these notions or working hypotheses will be discussed here.

Firstly, the introduction of basic innovations and their diffusion leaves a deep structural impact on the economy in the widest interpretation of this notion. Basic innovations change the sectoral composition of the economy (a narrow interpretation of the notion of economic structure). The historical work shows, for example, the rise and (relative) decline of the textiles sector, the machinery sector, the electric machinery sector, the chemicals sector, and the electronics sector. Key sectors associated with new technological systems slowly rise while the paradigm develops, and such key sectors associated to older technologies see their influence decline at the same time. Thus we see the rise and relative decline of iron, steel, plastic and information, or, in the sphere of energy systems, waterpower, steam power, electricity and fossil fuels.

Secondly, it is argued that the introduction of a new set of radical technological breakthroughs can only proceed with major institutional change (Freeman and Perez, 1988). New technologies generally facilitate and require changes in the organization of firms, the market system, the educational system, the political system, etc. Examples of this are the introduction of the factory system during the Industrial revolution, the rise of managerial capitalism as a result of increased economies of scale and scope, and the Bretton Woods system and the positive impact it had on world trade (Nelson and Wright, 1992).

Thirdly, it is the diffusion of the new technologies that matters for economic growth, rather than the innovation itself. Thus, we observe that the major technological characteristics of the subsequent technological revolutions in Diagram 1 are associated with technical breakthroughs that occurred in a previous wave rather than at the beginning of the current wave. This holds, for example for steam ('invented' in the 1770s by James Watt, but the full impact came only in the period from 1830 onwards), electricity, and for ICT. This finding is an important qualification made by Freeman and others to the original long wave theory proposed by Schumpeter. The resulting picture is thus one in which radical changes of technology are slowly introduced in the economy. The diffusion of basic innovations is a gradual process of incremental change, but one with a tremendous long-run impact. At the same time, this diffusion process is one in which opportunities from various 'basic innovations' are combined in new ways, rather than the spread of a single innovation in isolation.

Fourthly, the new technologies of the type that change the nature and pace of economic growth in a major way can be characterized as *pervasive*. This means that they can be applied in a broad range of other activities or industries, other than just the industries where the innovations stem from originally. As a historical example, one may think of the steam engine, which originated as a device used only to pump water from flooded mines. Changes (many of them incremental) to the original design by Newcomen made it possible to apply the steam engine in a broad range of other industries, such as textiles mills and other factories producing a wide range of products, blast furnaces, railways, and sea-transport. The key factors or sectors associated with a technological revolution find their way through the large majority of economic activities and all actors in the economy have to deal with these key factors in some way or another. It is especially this pervasiveness that makes a basic innovation different from other technological innovations (Freeman and Perez, 1988).

With this general characterization of the neo-Schumpeterian literature, Diagram 1 can be used to put the broad history of technological change in an economic perspective. The sequence starts with the Industrial revolution, which mainly consisted of bringing a number of major technological breakthroughs in spinning and weaving to the factory. This increased tremendously the productivity in the textiles industry, and provided an important stimulus for the development of the whole economy. Other industries such as pottery also started to mechanize.

The second phase runs approximately from 1840 to 1890. During this phase, the pervasive influence of steam power was the driving force. Also, the new system of manufacturing was starting to diffuse from the United Kingdom to the European continent and the United States. During this phase, there were also important technological inventions in the field of, for example, electricity, that would become the drivers of a next phase.

This next phase is characterized as the 'age of electricity and steel' (app. 1890 – 1940). The dynamo was an important innovation that made the application of electricity possible (David, 1990), and Thomas Edison invented many products that took full benefit of this new power source. Again, during this phase, there were a number of main technological inventions, such as the cracking of oil and the application of the assembly belt in a manufacturing system, that would drive the next phase.

Mass production is the characterization of this next phase (app. 1940-1990), which relies on the application of economies of scale and scope, the availability of cheap energy (oil) and new materials (plastics). A number of typical consumer goods, such as the television and the automobile are central to the diffusion of mass production manufacturing methods.

The final phase is called 'the information age', and relies on the application of ICT in the economy. Note that again, the major underlying technology, i.e., automatic data processing, was invented during the earlier phase (in this case, during and early after the second world war, when both the United States and the United Kingdom developed the 'computer'). The technology only came to full exploitation, however, in the 1980s and 1990s, after fusion with telecommunications and the invention of, e.g., the Internet and the Personal Computer.

Research Issues

After this broad introduction to the Schumpeterian idea of technological revolutions and their impact on economic growth and structural change, it is time to outline the main research questions addressed in this paper. The starting point is the notion of pervasiveness of new technologies, and the impact that this has in terms of structural change. The main question is whether or not one may observe the rise (and decline) of the (supposedly) most recent technological revolution (ICT) in the economic and technological data on the structure and growth of the economy. For this purpose, use will be made of a database on US input-output tables, for the period 1958-1998, and of a number of so-called technology-flow tables based on patent citations data for the US (for the period 1968 – 1998). The US is chosen for two reasons: first because it can be seen as the technological and economic leader during most of this period, and second because input-output and patent data for other countries do not provide a comprehensive picture of the type we are interested in. For example, early postwar data are missing in most countries other than the US, and also capital flow tables are missing for most years other than the most recent 2 decades. Patent citations data or other measures on which technology-flow tables can be constructed are available only for the most recent period for other countries than the US.

Specifically, the analysis will be aimed at trying to identify a number of pervasive technological developments in the input-output and technology-flow data, and to relate these to the general Schumpeterian ideas as outlined above. In doing this, it will be possible to draw some general conclusions on the recent debates on the role of ICT in the world economy which were briefly referred to in the introduction.

Given the central role of the notion of pervasiveness in the Schumpeterian theory, it is necessary to operationalize this notion in the specific context of input-output and technology flow tables that will be used here. It is proposed that the concepts of linkages, especially so-called forward linkages, is useful for doing this. The advantage of this is that the idea of linkages is well established in input-output analysis, and hence has a firm conceptual basis.

3. Preliminaries of input-output and technology-flow analysis

Input-output analysis

The input-output approach to analyzing the economy starts from the following representation (see Miller and Blair, 1985, for an overview of input-output analysis):

	Sectors 1..*n*	Investment	Other final demand	Gross Output
Sectors 1..*n*	Intermediate demand Value added	Final demand		
	Gross Output			

A row spanning the intermediate and final demand blocks represents the distribution of the sales of a particular sector. In the case of intermediate demand, goods are delivered to another sector (possibly the same sector), which uses the goods in its own production process. In the case of final demand, goods are either delivered to end users (consumers, export, or government), or to other sectors in the form of investment goods. A column spanning the intermediate demand and value added blocks represents the distribution of the sectors output with respect to origin. In the intermediate demand block, this indicates from which sector intermediate goods come. The value added block gives the sector's contribution to GDP. Column *i* will sum to the same value as row *i*.

In writing the input-output system in terms of equations, uppercase bold letters will denote matrices, lowercase bold letters vectors, and the corresponding lowercase non-bold italic letters elements of these. Then, one may write

$$\mathbf{Ax} + \mathbf{f} + \mathbf{h} = \mathbf{x},$$

where **x** is the vector of gross output, **h** the vector of investment demand, **f** the vector of other final demand, and **A** the matrix of so-called technical coefficients, for which the element a_{ij} is defined as int_{ij} / x_j (int denotes an element in the intermediate demand matrix). Given **A**, **f** and **h**, one may solve for x as follows:

$$\mathbf{x} = [\mathbf{I} - \mathbf{A}]^{-1}[\mathbf{f} + \mathbf{h}],$$

where **I** is the identity matrix. Note that throughout the paper, the intermediate demand block and final demand categories will include imports of goods that are also produced in the domestic economy. The sum of these imports over a row will be subtracted in the column **f**.

The matrix $\mathbf{[I\text{-}A]^{-1}}$ is called the inverse Leontief matrix. This matrix measures the interdependencies between sectors through intermediate demand. It captures the general idea that an increase in the demand for goods of one sector will also increase demand for other sector's goods, because of derived demand for intermediate goods. The inverse Leontief matrix is often used to measure so-called backward linkages. The notion of a backward linkage refers to the amount of gross product generated by a one-unit increase of final demand in one sector. This value can be calculated by summing the elements in the column of the inverse Leontief matrix. Increasing the demand for a sector with strong backward linkages will have a large effect on gross output of the total economy, because of the strong multiplier effects involved. The column sum of the inverse Leontief matrix is often used as an indication of the strength of backward linkages (see Miller and Blair, 1985).

The concept of forward linkages derives from an opposite view on the linkage system. This notion is concerned with the question how important the supply of a given sector is for gross output in the total economy. There are several possible definitions, the simplest of which uses the same inverse Leontief matrix as was used in the calculation of backward linkages. In this definition of forward linkages, one sums per row over the columns of the matrix. The thought experiment associated to this definition is to increase final demand in *all* sectors (rather than a single sector, as in the case of backward linkages) by one unit, and to see how much extra gross output this will generate in sector k (for which the sum over columns is carried out). Among others, Guo and Planting (2000) use this measure of forward linkages.

The problem with this measure of forward linkages is, however, that assuming an increase of one unit of final demand in all sectors is not a very subtle way of quantifying demand. In practice, some sectors have higher final demand than others, and this is not reflected in this method of measuring forward linkages. Therefore, a different method of measuring forward linkages is preferred here. This method was originally proposed in the context of the supply-side input-output model (see Miller and Blair, 1985, for details). However, as was argued by Dietzenbacher (1997), the traditional interpretation of this model as a quantity model is problematic. We therefore interpret our measure of forward linkages in the context of Dietzenbacher's suggestion of a price model.

The first step in the calculation of the indicator for forward linkages is the calculation of a matrix similar to the inverse Leontief matrix. The difference is that each element of the matrix **A** is divided by its row sum rather than its column sum. Thus, instead of technical coefficients (also called input coefficients), we obtain so-called output coefficients, which indicate what proportion of output of a sector goes to which other sector. Let us denote this matrix by **B**, with b_{ij} defined as int_{ij} / x_i. If we now sum columns over a row of matrix **B**, the resulting number gives the increase in total costs for the economy as a result of an increase in costs of primary inputs (labour and capital) in sector k (over which columns were summed in a row). This is the measure for forward linkages used here, as it gives an indication of how widespread (pervasive) the use of a sector's products is.

One drawback of the static input-output model as used so far is that it regards investment demand only as a category of final demand. In a dynamic context, however, investment demand is derived demand, as is intermediate demand. Leontief and Duchin (1986) provide a dynamic input-output model that is based on such an accelerator mechanism. An important input into this model is the capital flow matrix **C**, which gives the deliveries of capital goods from sector i to sector j. The columns of matrix **C** will sum to the elements of **h**.

For the purposes of this paper, however, it suffices to go back to the original work of Leontief on input-output tables, which was reprinted and updated as Leontief (1953). In his original approach, Leontief did not make an attempt to separate intermediate goods from investment goods in the construction of the table. Hence, Leontief's approach constitutes of implicitly adding the elements of **C** to the corresponding elements of the intermediate block in the diagram above. The vector **f** is then removed from the final demand block, so that the row-sum does not change. In order to make columns and rows sum to the same value, investments made by a sector must be subtracted from value added.[3]

The consequence of this procedure is that the contribution of a sector to GDP can no longer be derived directly from the table. But the procedure for deriving output using the (modified) inverse Leontief and final demand vector remains valid. The linkage structure implied in the inverse Leontief matrix then not only represents intermediate demand, but also investment demand. It must be noted, however, that the technical coefficients matrix **A** that is calculated using this procedure has a different interpretation than under the normal procedures. Normally, the matrix is a precise reflection of derived demand under the strict assumption of so-called Leontief technology, i.e., a production function that does not allow for substitution between production factors. When investment is included in the inverse Leontief matrix, the 'technical coefficients' also include an element of expectations, related to the

[3] In fact, in Leontief's original tables for the US economy in 1919 and 1929, rows and columns did not generally sum to the same value. His concept of 'value added' was also not identical to what is common today.

dependence of investment demand on expectations about future sales. A similar argument holds for the matrix **B**.

So far, the input-output table has been presented and used in an industry-by-industry format. This means that both the rows and columns contain industries. However, industries generally produce multiple goods, and a single good may also be produced by more than one industry. This is why so-called make and use tables have been introduced in the analysis (see Miller and Blair, 1985 for more details). The make table has the following structure:

	Commodities 1..*m*	Total industry output
Industries 1..*n* producing commodities		
Total commodity output		

The cells in the industry-by-commodity block indicate how much of each commodity is produced by each industry. The make table can be used to construct a matrix **M**, in which the element m_{ij} is formed by taking the corresponding element in the make table, and dividing it by the sum of the column *j*.

The use table takes the following form:

	Using industries 1..*n*	Using final demand categories	Total commodity output
Commodities 1..*m*			
Industry value added			
Total industry output			

In this table, the commodity-by industry and commodity-by-final demand blocks indicate how much of each commodity is used by these demand categories. The industry value added block is appended to yield industry gross output.

The rows for commodities 1..*m* of the use table together form the matrix **U**. A conventional industry-by-industry input output table can then be formed by calculating **MU**. Note that this method assumes that the origin of a particular commodity used in various sectors is similar. In other words, the distribution of commodities over the rows of the make table as implied in the matrix **M** is assumed to hold for all using demand categories. This procedure can be used for the basic input-output table as well as for the capital flow matrix.

A final issue regarding the input-output tables refers to the use of current prices or constant prices. Generally, input-output tables are presented in current prices. Deflating an input-output table is not an easy task, since the requirement that rows and columns sum to the same values has to be maintained. Although deflating the tables in this way is possible if enough data are available, no attempt has been made to do so in the present analysis. The reason is that the interest is in a description of the current state of the economy, and prices are an essential part of this. Freeman and Soete (1997) have, for example, described how the introduction of basic innovations has gone hand-in-hand with rapid price decreases of materials associated with them. These price falls are part of the diffusion process, and are hardly something one needs to 'correct' for. In addition, it may be argued that if one was going to deflate the tables, it would make most sense to use the most recent year as the base year for the price indices (because this is the year for which the diffusion rate of ICT is highest). Thus, the results for the most recent year would not be changed in any way, because this would be the year for which prices are equal to one. As will be seen below, the results for the most recent year (1998) are indeed quite salient, and form an important part of the main conclusions. This part would not be changed if we use fixed price data instead of current price data.

Technology flow analysis

Input-output analysis has also been applied to the technology domain. The starting point of this type of analysis is the idea that innovative ideas partly spill over to others. Such spillovers may occur as a result of variety of mechanisms. Griliches (1979) made a distinction between so-called rent spillovers and pure knowledge spillovers. Rent spillovers arise when a buyer gets a technologically improved product without paying the full differential in (monetary) value that can be associated with product innovations. This may, for example, happen, because of competitive pressures on the suppliers of the goods for which product innovation is taking place. Pure knowledge spillovers occur independent of market transactions. This type of spillover may, for example, occur when an inventor gets an idea from looking at the invention of another inventor. This may either take the form of imitation, or refer to a completely original idea. Los (1999) provides an extensive discussion of the various types of knowledge spillovers in the context of an input-output analysis.

When spillovers occur between sectors as well as within sectors, there is obviously an intersectoral component to the process. Scherer (1982) gave an early account of this by means of a matrix that indicates the intersectoral knowledge spillovers. His matrix was based on patent statistics, and relied on a method of identifying the sectors in which a patent was produced and in which it was used. Kortum and Putnam (1997) and Verspagen (1997) provide alternative matrices based on slightly different methods, but still using patents as the basic data. Van Meijl (1997) used various types of these patent flow matrices as well as regular input-output tables in an analysis of productivity growth. Evenson and Johnson (1997) provide an overview of some of the methods used in this field.

Patent citations are an obvious way of identifying knowledge spillovers. This idea was first coined by Jaffe et al. (1993). Just like scientific papers, patents may cite other patents, and this may be taken as an indication of a knowledge flow from the cited patent to the citing patent. However, one must keep in mind that patent citations primarily serve the legal purpose of identifying which knowledge can be claimed by the patent, and which knowledge belongs to earlier patents.

For the analysis here, US patent citations were used to construct technology flow matrices for the period 1968 – 1998. The patent citations data were taken from the NBER server, and these are at the level of individual patents. Patent data other than citations were taken from the US Patent Office. A selection was made of patents where the first inventor was an inhabitant of the US, and all citations between these were considered. The US Patent office uses a concordance between technology codes and industrial (SIC) codes in order to assign patents to industries. Using this data, a matrix was set up in which the number found in a cell is equal to the number of patents in industry i (rows) cited by patents of industry j (column). The row-sector can thus be seen as the spillover-generating sector, the column sector as the spillover-receiving sector.

In accordance with the approach followed for calculating forward linkages for the input-output data, each cell in this matrix was divided by the row sum, so that one obtains the fraction of patents in the row sector cited by the column sector. Separate matrices were constructed for five-year periods following 1968, 1973, 1978, 1983, 1988, 1993 and 1998. The year of application of the citing patent was used to date citations.

The matrices constructed in this way provide an overview of the structural changes occurring in the process of technology generation. Generalizing from the Schumpeterian framework introduced above, one could expect that the role of ICT in this system would become more central, i.e., that ICT related sectors would increase their influence on technology developments in other fields. This will be investigated below.

4. Structural change and Schumpeterian dynamics in the US economy

For the US economy, input-output material classified under a (largely) constant and consistent classification system is available for the period 1958-1998, i.e., a span of 40 years. This is ideal for analyzing and detecting the type of long-run structural change that is implied in the Schumpeterian model of technology and economic growth. The analysis here will make use of input-output tables for the years 1958, 1967, 1982, 1992 and 1998. For all those years except 1998, the basic input-output table is available as well as the capital flow matrix **C**. For 1998, a basic input-output table is also available, but no capital flow matrix is available for this year. This problem is solved by using the capital flow table for 1992 to calculate a hypothetical capital flow table for 1998, assuming that the distribution of investment over using sectors did not change from 1992 to 1998. Using the capital flow matrix **C**, one may construct an industry-by-industry output flow matrix that is similar to the prewar

Leontief method, i.e., which includes both intermediate flows and capital flows.[4] It has been argued above that this approach is to be preferred in the present case, because it captures important linkages between sectors that are due to capital flows rather than intermediate flows (normally, capital flows are not included in the calculation of 'technical coefficients').

[insert Figure 1 around here]

Figure 1 gives an overview of the share of three categories of demand in total demand for the various years. Clearly, intermediate demand is rather important, although its impact is declining over time. Final demand (not including investment demand) is the next important factor, while investment is a relatively minor component of demand. Although this may indicate that including capital flows in the calculation of linkages may not be very important, one must not forget that at the level of an individual sector, the picture is often quite different (e.g., sectors such as machinery or aircraft).

The level of aggregation of the tables for the various years differs, but they have all been re-classified into 48 sectors. Two of these, related to local or federal government, will generally be excluded from the tables and figures (although not from the underlying calculations). Hence, 46 industries result in the analysis.

The data for 1958 and 1967 are published in the form of an industry by industry table, while the data for 1982 - 1998 are published in the form of make and use tables (this includes both the basic table and the capital flow matrix). The tables for 1982 - 1998 were transformed to industry-by-industry format using the procedure outlined in section 3.

Postwar linkage structure

The analysis here will only refer to the linkage structure based on the (modified) inverse Leontief matrix that includes investment flows (**C**). Results for a matrix including only intermediate demand were also calculated but there are omitted because of space considerations (available on request). Table 1 gives the results for the various years under consideration.

[insert Table 1 around here]

The immediate postwar period was characterized in section 2 as the period of mass production. Hence, one would expect that sectors related to these technologies would dominate the linkage structure in 1958. The top of forward linkages in 1958 is dominated by metal making sectors, which occupy the first three positions. This is consistent with mass-production in the sense of the importance of metal as a basic material, although one may also argue that this strong position remains from the previous period ('age of electricity and steel'). Industries truly related to mass production are found on ranks six to eight: paper, chemicals and plastic materials. Mass communication (radio and tv broadcasting) is listed on rank five, which also seems consistent. Also machinery (rank 10) and petroleum and natural gas (11) are clearly related to mass production. On the other hand, motor vehicles, a typical mass production good, does not list high on the ranking of forward linkages (rank 28).

In the transition to 1967, linkages do not change very much. The rank correlation between forward linkages in 1958 and 1967 is 0.96. This also holds for the subsequent changes: the rank correlations are 0.93 (for 1967 – 1982, the longest period), 0.96 (1982 – 1992) and 0.98 (1992 – 1998). Thus, in 1998, many of the sectors that were high on the list in 1958 are still high on the list. First is now crude petroleum and natural gas, second and third the two primary metals sectors, and fourth ore mining. Other mining is fifth. Thus, the first five entries on the list of pervasive sectors in 1998 are all clearly related to the 'old economy' rather than the 'new economy'. On the sixth position, one finds the first sector related to the ICT, i.e., electronic components. Two 'old' materials sectors (plastics and glass, stone and clay) are found next, after which follows computers and office machines (rank nine). Thus, although there is clear dominance of 'old sectors' in terms of pervasiveness or forward linkages, one

[4] The term capital flows is used to indicate gross private fixed capital formation, and hence excludes all public investment. This is included in the tables in the final demand block.

can clearly see some of the new sectors associated to ICT rising. Thus, it seems to be the case that the new technologies complement the old ones, rather than substitute them.

A broad view based on Multi Dimensional Scaling (MDS) plots

While the results on forward linkages provide a useful overview of the general trends of pervasiveness of the various sectors and their associated technologies, they do not provide a comprehensive view of the process of structural change over the postwar period. In order to obtain a more general overview of the trends of structural change, a different technique will be applied. This technique starts from the inverse Leontief matrix based on **B**, just as the measure of forward linkages does. However, rather than simply summing over the columns for each row, the information in each of the individual cells of this matrix will be used.

An individual cell in the inverse Leontief matrix (based on **B**) indicates the change in total costs in the column sector as a result of a change in the value of primary inputs of the row sector. The two cells for sectors i and j above and below the diagonal together can thus be taken as an indication of the intensity of the supply links between the two sectors. The higher the value of these cells, the stronger the link between the sectors. For n sectors, one can imagine an n-dimensional space in which the sectors could be plotted in such a way that sectors with strong (weak) links would be plotted close to (far from) each other. Hence (spatial) clustering in such an n-dimensional space would indicate economic clusters in terms of input-output (forward) linkages.

Of course, visualizing an n-dimensional space is nearly impossible for large n, as is the case here. In this case, the technique of multi dimensional scaling (MDS) may be used to reduce the number of dimensions. This technique applies an algorithm that attempts to reduce the number of dimensions in which the n sectors are plotted to a predefined value (usually two or three), while maintaining in the best possible way the original ranking of all possible pairs of sectors in terms of distance. Naturally, while reducing the dimensions, the ranking of pairs of sectors on distance is not maintained perfectly. The mismatch between the original ranking and the ranking based on the reduced dimensions is expressed in a statistic called stress, and this is minimized in the algorithm. The algorithm generally does not find a global minimum for stress, so that the starting configuration of the points may be of influence on the result.

The specific MDS algorithm used here is the PROXSCAL algorithm in SPSS 11.0. One hundred different starting configurations were tried for each case, and the results are averages for these trials. An ordinal scale was use for the distance ranking. Before being used in the MDS algorithm, the inverse Leontief matrix was symmetrized by taking the average of above and below diagonal elements.

[insert Figure 2 about here]

The results for an MDS analysis in two dimensions are in Figure 2. The numbers in the graph correspond to sectors, and the correspondence is given in the appendix. In general, the obtained configurations of sectors make intuitive sense.[5] This is indicated by the lines grouping sectors together (these are, however, admittedly arbitrary). Thus, for example, one can identify a number of broad clusters of sectors: metals and machinery (basic metals, metal ore mining, non-electrical machinery), chemicals (mostly without pharmaceuticals), services, and, indeed, ICT (hardware) sectors. The latter have been defined as computers and office machines; radio, tv and communications equipment; electronic components; scientific and controlling equipment; optical, ophtalmic and photographic equipment; communications except radio & tv broadcasting. These ICT sectors are indicated by a gray shade in the figures. For all the years, they occur relatively close to each other in the figures, although there are also other sectors that are near to this cluster. These sectors include weapons (no. 7), aircraft (no. 30), and radio and tv broadcasting (no. 37).

[5] Note that the general orientation of the sectors in terms of north-east-south-west is variable and does not have a precise interpretation. It is only the relative distance between sectors that has a valid interpretation. It would be possible to rotate the figures in order to fix a particular set of sectors to a constant (approximate) position. Also, the axes of the figures do not have a clear interpretation, which is why they are omitted.

The 'ICT-cluster' starts out in 1958 at a position that is somewhat in the periphery of the figure. This indicates that although these sectors have relatively close forward linkages between themselves (this is why they appear close to each other), but that there are still not interacting to a great extent with the other sectors in the economy to a very large extent (this is why they are at the periphery of the graph). In the following years, this situation is largely the same, although one might argue that in 1998, there is some movement of the ICT sectors towards the core of the figure. This is not a very strong tendency, however.

What is interesting to note is that the ICT related cluster always appears relatively close to a the broad cluster of services sectors. This includes sectors such as finance, insurance and real estate, business services, but also medical services and amusements (the latter only for later periods). For the last two years, computer services is included as a separate sector in business services in the underlying input-output data, and it turns out that this is a rapidly growing subcategory. In order to keep the classification of sectors comparable to the earlier years, this sector has been merged with business services, which appears rather central in 1998. Thus, we may conclude from both tendencies that the main pervasive impact of ICT is felt in services sectors, something that is, again, in broad accordance with the intuition about the 'ICT revolution'.

Concluding, the MDS analysis seems to broadly support the conclusions reached earlier from the analysis of forward multipliers: ICT is clearly a technology on the rise, but this trend takes the form of complementing the 'old economy' rather than substituting it as the core of the system of economic transactions.

Technology flow matrices: an MDS perspective

The MDS method can also be applied to the technology flow matrices, although these have a somewhat different nature than the inverse Leontief matrices considered so far. The same MDS method was applied to the seven technology flow matrices, and these are depicted in Figure 3. Again, the numbers indicate sectors, but the classification for the technology flow matrices is different than for the input-output material. The technology data has a less detailed breakdown for the ICT sectors, a more detailed breakdown for some of the (electrical) machinery sectors, and services are absent because these do not generate technology (patents) in the traditional sense. ICT is now defined as computers and office machines; electronic components and communications equipment (except radio and tv); and scientific and controlling equipment. These sectors are again indicated in gray.

[insert Figure 3 about here]

The general constellation obtained is remarkably constant. One always finds a broad chemicals cluster on one side of the figure, a broad cluster consisting of transport equipment and weapons sectors on the other side, and a set of metal and machinery related sectors in between. The three ICT sectors always appear in this latter cluster, although they are largely in the periphery of this. Relative to each other, the three ICT sectors do not change position in any significant way. Scientific and controlling equipment (no. 41) is always closest to the centre of the figure, then electronic components (no. 32), while computers and office machines (no. 21) is the most far out sector.

What this seems to show is that in terms of technology flows between sectors, the US economy is characterized by a more or less constant constellation since 1968. ICT plays a somewhat central role in this, but it is certainly not the most central sector, and there is no strong evidence for an increasing role of ICT as the supplier of technology flows to other sectors.

5. Conclusions

This paper has applied concepts and techniques from input-output analysis to the Schumpeterian idea of technological revolutions and their impact on the structure and growth of the economy. The US economy over most of the postwar period was the subject of study. The general working hypothesis, derived from a discussion of the Schumpeterian view on technology, structural change and growth in section 2, was that the emergence of technological revolutions should become visible in the linkage structure of the economy, both in terms of economic transactions (input-output data) and technological dependencies captured in so-called technology-flow matrices between sectors. Specifically, the hypothesis was that ICT, as the last of number of technological revolutions, would become visible in terms of increased forward linkages of the key sectors associated with the technology. The evidence in favour of such a hypothesis is mixed. The results point to the following three conclusions.

First, one can indeed identify some sectors related to the previous technological revolution of mass-production at the top of the lists of sectors with forward linkages during the immediate postwar period, as 'predicted' by the Schumpeterian theory. This holds, for example, for sectors such as machinery, chemicals, transportation, and primary metals. During the late 1980s and 1990s, electronic components, computer equipment and related ICT sectors show a rise on the ranking of forward linkages, but this does not lead to an absolutely dominating position. In this period, the top-list of sectors with forward linkages still includes mostly 'old' sectors. Especially primary metals sectors and refined oil are high on the list, even in the 1990s. A more comprehensive analysis of the linkage structure in the form of MDS plots for various periods confirms this picture, both for economic transactions, and for technological dependencies. Thus, overstating the case somewhat, we could paraphrase Solow by saying that 'we see computers everywhere, except in the input-output tables'.

Second, the linkage structure of the US economy is rather sticky. Rank correlations between forward and backward linkages of sectors over periods of roughly 10-15 years are rather high. This also explains why industries related to 'old' technological revolutions dominate the linkage structure for a long time, in fact well into the period where one might expect newer technologies to become dominant.

Third, the structure of technological linkages between sectors as indicated by patent citations is remarkably constant over the period 1968 – 1998. In this respect, the ICT sectors seem to occupy a position in a broader cluster of machinery related sectors that act as a relatively central cluster generating technology spillovers to other sectors. However, the ICT sectors are certainly not at the core of this cluster, indicating that one can certainly not draw the conclusion that ICT is the main pervasive technology of our days in terms of generating technology spillovers.

Finally, a number of conclusions may be drawn regarding the historical role of the ICT revolution. The analysis suggests that even if ICT are a pervasive technology, one should not conclude that they would completely dominate the sectoral linkage structure as a result of this. Although such technological substitution may have been the dominant mode of development in some instances of the history of technology (e.g., one does not travel on steam trains so much these days), it is certainly not the only mode, and probably will never be the mode in which ICT proceeds. The data suggest that ICT will not substitute some of the older technologies completely, neither in the domain of economic transactions, nor in the domain of technology dynamics. Significant parts of the 'old economy' remain to occupy dominating roles in the economy for a long time, both in terms of the composition of output and its growth rate, and in terms of linkages between sectors. In other words, if there (still) is a new economy, it seems to be made of steel, concrete and petroleum just as much as of silicon chips and software. ICT diffuses gradually but decisively, and has a major impact on the economy, but does not change the economic structure in a complete way.

An important question emerging from this conclusion is what is the exact relation between the ICT revolution and the mass production paradigm that preceded it. Here one can point to at least two factors that have implications for the nature of ICT as a technological force, and the way in which it has transformed (or not) the linkage structure of the economy. First, it has to be noted that electronics and ICT in broad are dependent on electricity. Thus, in this respect, the economy does not see any change in the main source of power, as it did, for example, in the transition from steam to electricity, or even a partial transition such as occurred when refined oil was introduced at large scale. Of course, this has consequences for infrastructural investments related to power generating and distribution. This fact shapes to an important extent the nature of ICT as a technological system that is complementary to what is in existence rather than a substitute.

Second, if one regards information as the main raw material of the ICT revolution, there is an important distinction between older technological systems and ICT. The distinction is that even today, a large fraction of information flows is internal to firms and organizations, and is not traded on the market. This is a major difference with previous eras: iron and cheap textiles during the industrial revolution, steel, plastic materials and oil are all examples of raw materials that played an important role in previous periods of rapid technological change, and all of these commodities were intensely traded in the capitalist markets. Obviously then, these trade flows would have a major impact on economic transactions and the linkages structure between sectors as it was investigated here. But information is still largely excluded from the input-output tables that were considered here. The ICT sectors that one can see in the economic data are mainly hardware producing or hardware using sectors, and not information providing or information using sectors. Again, this implies that the existing transactions structure is not substituted by the ICT revolution, but rather complemented.

Of course, one may point to trends that seem to imply that information (or 'content') is now increasingly being traded. The available anecdotal evidence also indicates, however, that the current institutions and markets still have problems accommodating these shifts. This is, for example, evident from the issues surrounding Napster and supposed software- and other forms of piracy. Another example is the issue of electronic trading and payments. This seems to be a field where institutional change associated with the ICT revolution is still in its infancy. When and if these issues are resolved, the ICT revolution may enter into a new phase during which the linkage structure between sectors may be altered in a more drastic way, but this remains mere speculation at present.

What this leads to in terms of a general conclusion is then that although the ICT revolution seems to fit nicely in a Schumpeterian scheme of successive technological revolutions, the case in point also shows that each of these major technological breakthroughs also forms an epoch in itself, with many specific factors that shape its development, and especially its relation to older technologies. Each technological revolution develops in historical time, with contingencies and more systematic factors interacting in a complicated way to shape the development path. No purely deterministic and mechanistic view of these processes will suffice, and in this respect one needs to proceed with caution in order to apply a simplistic scheme of technological substitution in order to predict the future of what was once known as the New Economy.

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Diagram 1. Technological Revolutions – A Schumpeterian scheme

Timing (approximate)	Name	Driving Innovations	Salient institutional changes
1780-1840	Industrial Revolution	Mechanization of textiles	Factory system
1840-1890	Age of steam power and railways	Application of steam power in factories and railways; machinery	Joint stock companies
1890-1940	Age of electricity and steel	Application of electric power, electrical machinery, application of steel	Rise of the R&D lab, managerial capitalism, Taylorism
1940-1990	Age of mass production	Assembly line, cracking, plastic materials, automobiles	Bretton Woods and Pax Americana; institutionalized labour relations ('Fordism')
1990 - ?	Information Age	Information and Communications Technologies	Networks

Source: adapted from Freeman and Soete (1997)

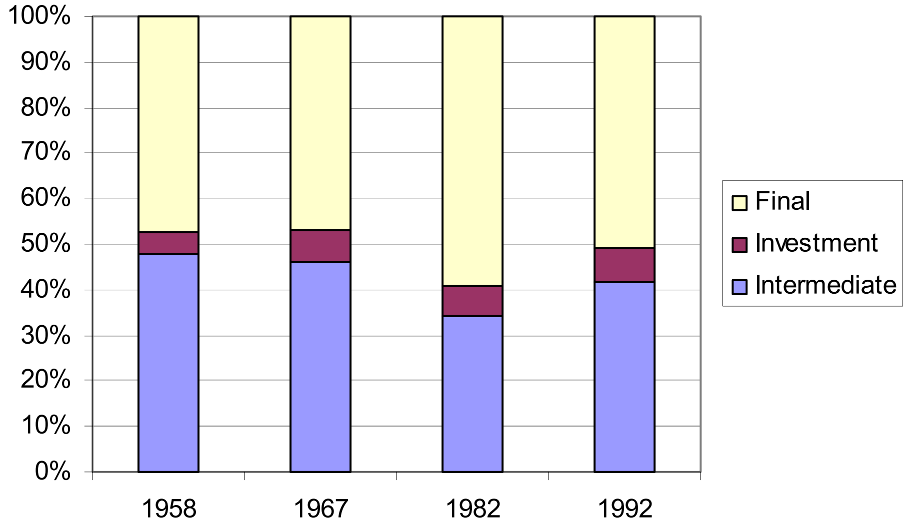

Figure 1. Composition of total flows in the postwar input-output tables, 1958-1992

Table 1. Linkage structure of the US economy, 1958 - 1998

	1958 Forw	Rank Forw	1967 Forw	Rank Forw	1982 Forw	Rank Forw	1992 Forw	Rank Forw	1998 Forw	Rank Forw
Agriculture	2.66	21	2.72	22	2.67	26	2.65	21	2.80	20
Ore mining	4.70	1	4.77	1	7.00	1	4.40	4	4.45	4
Coal mining	3.40	9	3.49	7	3.63	12	3.34	14	3.39	13
Crude petroleum & natural gas	3.27	11	3.30	13	4.46	4	4.75	3	5.28	1
Other mining	3.59	4	3.84	5	4.45	5	4.00	5	4.14	5
Construction	1.95	38	2.47	25	3.00	19	2.51	25	2.59	24
Ordnance	2.07	35	1.27	45	1.27	45	1.21	46	1.23	45
Food	1.48	45	1.49	44	1.67	41	1.56	43	1.63	42
Textiles	2.16	33	2.22	32	2.20	33	2.24	31	2.27	31
Wood	2.86	18	2.96	16	3.44	14	3.14	16	3.25	16
Paper	3.47	6	3.27	14	3.25	15	3.10	17	3.17	17
Printing & publishing	3.02	16	3.03	15	2.52	30	2.49	26	2.47	28
Chemicals	3.44	7	3.36	9	3.91	6	3.52	11	3.63	11
Plastic materials	3.43	8	3.41	8	3.65	11	3.60	7	3.77	7
Drugs, cleaning & toilet prep.	1.65	43	1.57	42	1.58	43	1.44	44	1.51	43
Paints	3.20	12	3.51	6	3.75	8	3.40	13	3.32	14
Petroleum refining	2.23	29	2.32	29	2.70	23	2.41	28	2.44	29
Rubber & plastic products	2.83	19	2.85	18	3.24	16	3.17	15	3.26	15
Leather	1.55	44	1.53	43	1.53	44	1.75	38	2.13	32
Glass, stone & clay products	3.16	14	3.35	10	3.74	9	3.58	8	3.73	8
Primary iron & steel	3.94	2	4.03	3	5.44	2	4.81	1	5.06	2
Primary nonferrous metals	3.87	3	4.06	2	5.26	3	4.79	2	4.97	3
Metal products	3.17	13	3.31	12	3.78	7	3.56	10	3.71	10
Machinery	3.37	10	3.31	11	3.73	10	3.56	9	3.56	12
Office machines & computers	3.08	15	2.77	21	3.02	18	3.52	12	3.71	9
Electric machines	2.78	20	2.82	20	3.11	17	2.98	18	3.16	18
Audio, tv & communications eq.	2.19	32	1.86	39	2.59	28	2.58	23	2.68	21
Electronic components	2.98	17	2.82	19	3.58	13	3.91	6	4.12	6
Motor vehicles	2.26	28	2.29	30	2.68	24	2.55	24	2.56	26
Aircraft	2.05	37	1.90	37	1.76	38	1.93	35	1.92	36
Other transportation equipment	2.45	24	2.48	24	2.22	32	1.64	42	1.65	41
Scientific instruments	2.44	25	2.43	26	2.58	29	2.29	30	2.60	23
Optical equipment etc.	2.27	27	2.33	28	2.65	27	2.58	22	2.56	27
Misc. manufacturing	2.11	34	2.05	34	2.00	35	1.99	33	2.04	34
Transportation	2.50	23	2.56	23	2.67	25	2.48	27	2.57	25
Communications	2.21	30	2.22	31	2.22	31	2.01	32	2.11	33
Radio & tv broadcasting	3.50	5	3.88	4	2.91	21	2.81	19	2.84	19
Electricity, gas & water	2.35	26	2.41	27	2.89	22	2.35	29	2.31	30
Trade	1.81	40	1.76	41	1.96	37	1.85	36	1.90	37
Finance & insurance	2.19	31	1.97	35	2.04	34	1.81	37	1.92	35
Real estate	1.72	42	1.78	40	1.74	40	1.65	41	1.73	39
Hotels and repair services	2.07	36	2.11	33	1.65	42	1.73	39	1.46	44
Business services	2.52	22	2.87	17	2.99	20	2.72	20	2.61	22
Automobile repair	1.90	39	1.97	36	1.97	36	1.33	45	1.89	38
Amusements	1.76	41	1.89	38	1.76	39	1.96	34	1.71	40
Medical, educational services	1.18	46	1.11	46	1.08	46	1.70	40	1.07	46

Source: calculations on input-output data from US official sources

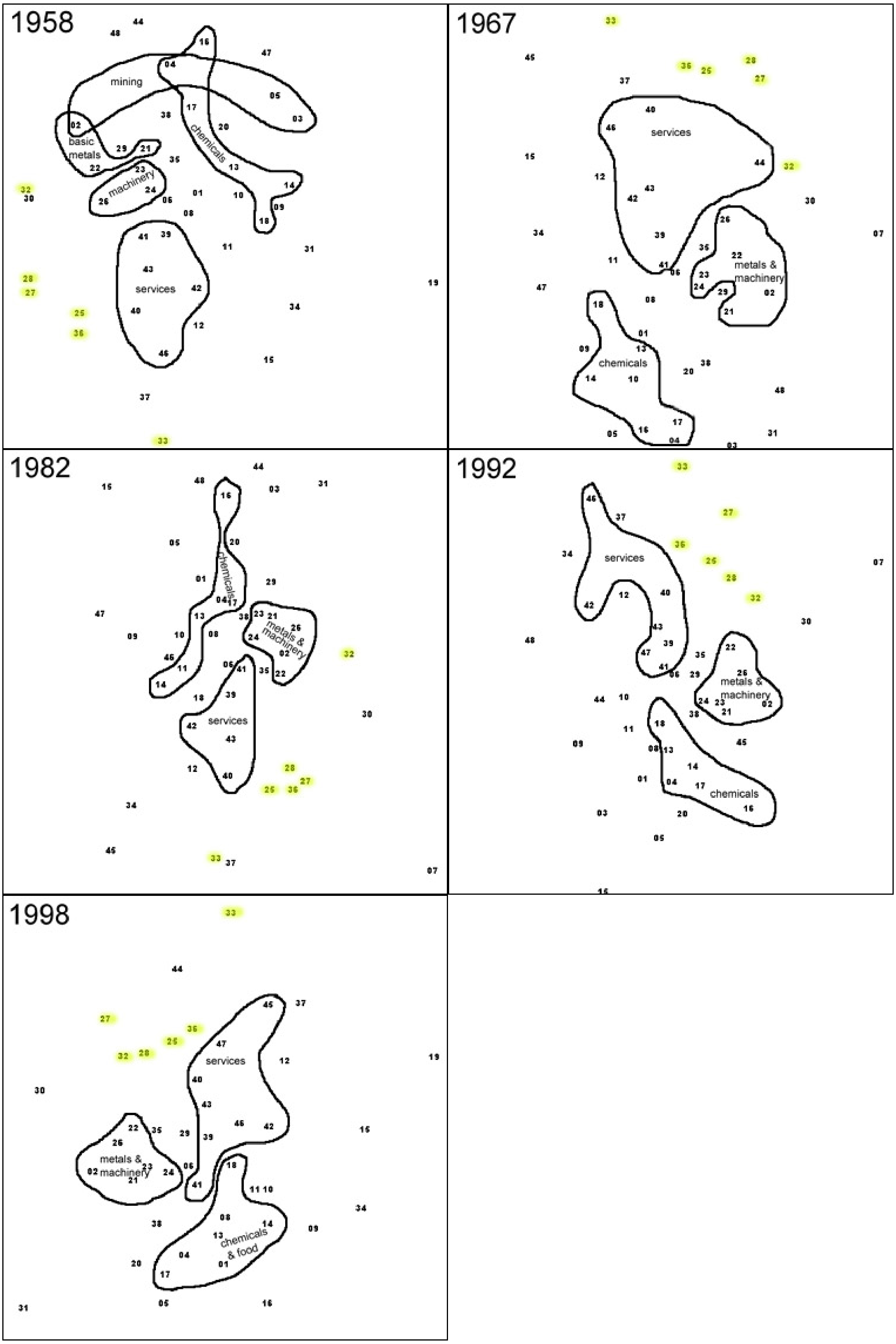

Figure 2. MDS pictures for inverse Leontief matrix based on output coefficients (forward linkages), US economy, 1958 - 1998

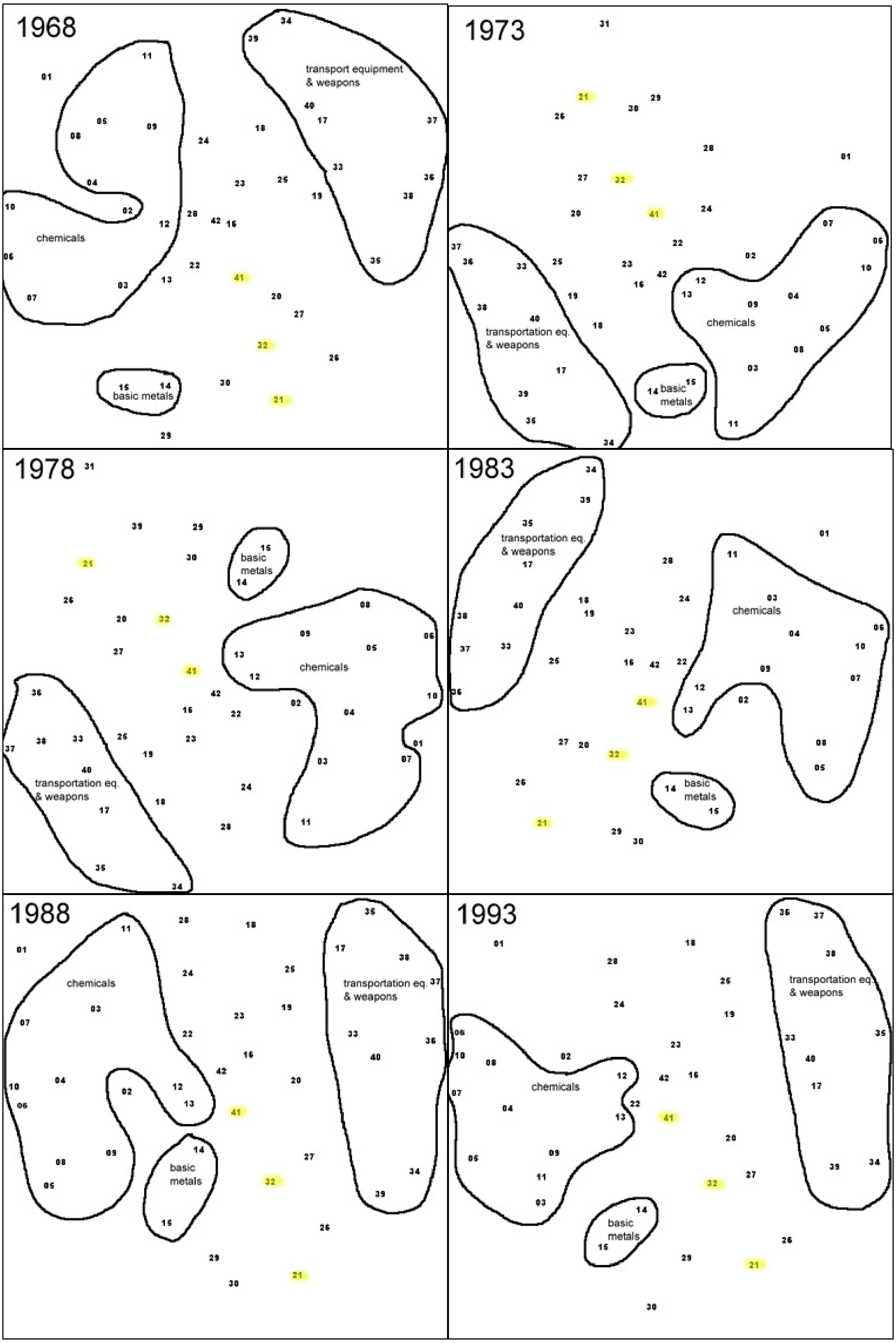

Figure 3. MDS pictures for technology flow matrix based on output coefficients (forward linkages), US economy, 1968 – 1998 (five year periods following the year indicated)

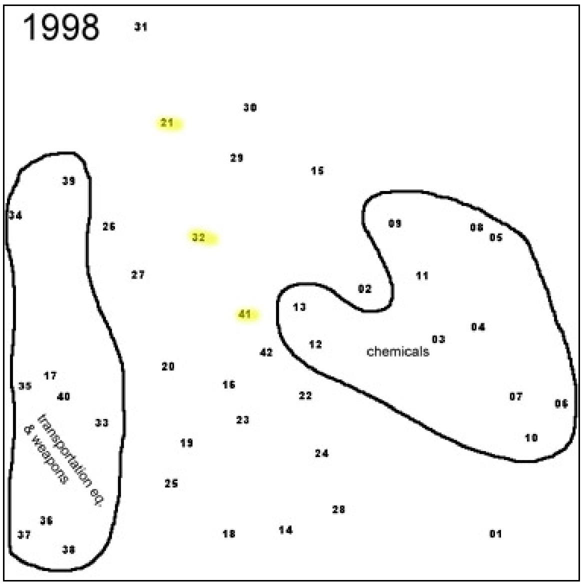

Figure 3. Continued…

Appendix. Sectors used in the analysis

1. Sectors used in the input-output tables (numbers indicate numbers used in the MDS diagrams)

01	Agriculture
02	Ore mining
03	Coal mining
04	Crude petroleum & natural gas
05	Other mining
06	Construction
07	Ordnance
08	Food
09	Textiles
10	Wood
11	Paper
12	Printing & publishing
13	Chemicals
14	Plastic materials
15	Drugs, cleaning & toiler preparations
16	Paints
17	Petroleum refining
18	Rubber & plastic products
19	Leather
20	Glass, stone & clay products
21	Primary iron & steel
22	Primary nonferrous metals
23	Metal products
24	Machinery
25	Office machines & computers
26	Electric machines
27	Audio, tv & communications equipment
28	Electronic components
29	Motor vehicles
30	Aircraft
31	Other transportation equipment
32	Scientific instruments
33	Optical equipment etc.
34	Misc. manufacturing
35	Transportation
36	Communications
37	Radio & tv broadcasting
38	Electricity, gas & water
39	Trade
40	Finance & insurance
41	Real estate
42	Hotels and repair services
43	Business services
44	Automobile repair
45	Amusements
46	Medical, educational services
47	Federal government organizations
48	State and local government organizations

2. Sectors used in the technology flows matrices (numbers indicate numbers used in the MDS diagrams)

01	Food and kindred products
02	Textile mill products
03	Industrial inorganic chemistry
04	Industrial organic chemistry
05	Plastics materials and synthetic resins
06	Agricultural chemicals
07	Soaps, detergents, cleaners, perfumes, cosmetics and toiletries
08	Paints, varnishes, lacquers, enamels, and allied products
09	Miscellaneous chemical products
10	Drugs and medicines
11	Petroleum and natural gas extraction and refining
12	Rubber and miscellaneous plastics products
13	Stone, clay, glass and concrete products
14	Primary ferrous products
15	Primary and secondary non-ferrous metals
16	Fabricated metal products
17	Engines and turbines
18	Farm and garden machinery and equipment
19	Construction, mining and material handling machinery and equipment
20	Metal working machinery and equipment
21	Office computing and accounting machines
22	Special industry machinery, except metal working
23	General industrial machinery and equipment
24	Refrigeration and service industry machinery
25	Miscellaneous machinery, except electrical
26	Electrical transmission and distribution equipment
27	Electrical industrial apparatus
28	Household appliances
29	Electrical lighting and wiring equipment
30	Miscellaneous electrical machinery, equipment and supplies
31	Radio and television receiving equipment except communication types
32	Electronic components and accessories and communications equipment
33	Motor vehicles and other motor vehicle equipment
34	Guided missiles and space vehicles and parts
35	Ship and boat building and repairing
36	Railroad equipment
37	Motorcycles, bicycles, and parts
38	Miscellaneous transportation equipment
39	Ordinance except missiles
40	Aircraft and parts
41	Professional and scientific instruments
42	All other sic's

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