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Classification of Industries by Level of Technology: an Appraisal and some Implications[1]

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ABSTRACT *Modern growth theory acknowledges that a country's economic prosperity depends in large part on its capacity for technological innovation. Empirical evidence, however, supports the view that not all sectors are equally innovative. As a result, it seems desirable from a public policy perspective to identify and promote sectors displaying both a high innovation rate and, in an increasingly competitive international economy, a high degree of international competitiveness. It is frequently argued that the high-tech industry sectors, in contrast to low-tech sectors, satisfy both conditions, with the clear implication that public policy should be directed to enhancing the performance of high-tech sectors.*

This approach raises at least two important issues. The first is whether such classifications can be meaningfully constructed given both the intractability of the concepts involved and the difficulties in data collection. A second issue is the basic assumption that policy emphasis should be placed on technology-intensive industries because they have a greater impact on growth. In this paper, we argue that while it may be possible to construct indices of technological intensity that are useful for some purposes, the ones that are currently proposed do not, in fact, address questions of economic growth and firm performance very well. In part, this is a reflection of the technicalities involved in formulating and operationalising the indices, but it also reflects problems in the underlying premise, namely technology-intensive sectors are more growth-inducing than low-tech sectors. We call, therefore, for the adoption of a more sophisticated and detailed approach that would provide a sensible classification of industries and new policy insights.

Keywords: high-tech/low-tech industries, R&D intensity, innovation, economic growth, policy implications.

1. Introduction

It is commonly argued that technological change and in particular innovation, is a major engine of long-run economic growth.[2] This means that a nation's economic prosperity depends in large part on its capacity for innovation, for which technological innovation is a key driver in advanced countries. Empirical evidence, however, suggests that some industries are more innovative than others.[3] Hence, it would be desirable from a public policy perspective to identify and promote sectors displaying both a high innovation rate and, in an increasingly competitive international economy, a high degree of international competitiveness. It is frequently argued that the high-tech industry sectors, in contrast to low-tech sectors, satisfy both conditions, with the implication that public policy should be directed to enhancing the performance of high-tech sectors.[4] As the author of a recent OECD working paper has put it, '… technology is a key factor in enhancing growth and competitiveness in business'.[5] Furthermore, he argues that:

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> Firms which are technology-intensive innovate more, win new markets, use available resources more productively and generally offer higher remuneration to the people that they employ. High technology industries are those expanding most strongly in international trade and their dynamism helps to improve performance in other sectors (spillover).[6]

If this is true, both government policy and firm strategy need to be informed by reliable indicators of technological characteristics. Again, in Hatzichronoglou's words, 'In order to analyse the impact of technology on industrial performance, it is important to be able to identify those industries and products which are most technology-intensive, through criteria allowing the construction of special internationally harmonized classifications'.[7]

This approach raises at least two important issues. The first is whether such classifications can be meaningfully constructed given both the intractability of the concepts involved and difficulties in data collection. A second issue is the basic assumption that policy emphasis should be placed on technology-intensive industries because they have a greater impact on growth. In this paper, we argue that while it may be possible to construct indices of technological intensity that are useful for some purposes, the ones that are currently in use and proposed are of limited scope. In part, this is a reflection of the technicalities involved in formulating and operationalising the indices, but it also reflects problems in the underlying premise, namely that technology-intensive sectors are more growth-inducing than low-tech sectors.

In the next section, we establish the link between economic growth and 'high-tech' industries, and pose two basic questions implied by the typical policy response to this relationship. In Section 3 we discuss the standard one-dimensional indicators designed to classify industries according to their level of technological intensity and provide a robust classification of industries. Section 4 describes multidimensional attempts to separate high-tech from low-tech industries. In Section 5 we critically evaluate the latest OECD industry classification by level of technology from a macroeconomic perspective. Section 6 discusses some limitations of industry policies focusing only on high-tech industries. Section 7 argues that R&D intensity is not a strategic variable at the firm level. Finally, we summarize our findings and also sketch an alternative approach that may be more useful in generating sound national economic policies and firm strategies. We use Australia as a country of reference, but the methodology is applicable to other countries.

2. 'High-tech' Sectors and Economic Growth

In the past decade, a number of studies have investigated the problems associated with operationalising technological innovation as a tool in economic policy formulation. One of the most important is the *Oslo Manual: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data*, which was published by the OECD in 1997. Although relatively brief, the *Oslo Manual* canvasses the important issues associated with the use of innovation data. As the subtitle indicates, the recommendations are not firmly prescriptive, but rather intended to provide a series of suggestions for looking at varied issues as the authors concede that there is no single indicator that meets all needs.

> Ideally, a comprehensive information system should be constructed that covers all types of factors within the innovation policy terrain. This would place governments in a strong position to deal appropriately with any particular policy issues that might arise. In practice, only parts of such a system can be covered by indicators, while other parts call for qualitative information. Moreover, as policy and indicator analysts are well aware, indicators will only occasionally relate neatly to a single

> factor or issue, and more often than not will relate to a range of matters and only partially to each. Any broad information or monitoring system will also need to be supplemented with case studies where specific in-depth analysis is required. As far as possible, it will also be important to consider a range of indicators and other information wherever possible—even if attention is to be directed to a highly specific issue or a relative narrow range of issues.[8]

In acknowledgement of these considerations, the OECD's own tables on innovation look at the question from many different points of view. As the variety of indicators is so wide, we will concentrate in this paper on the classification of sectors by their degree of technological intensity.

There are two general rules about the design of definitions for analysing practical problems that are particularly relevant for this topic. As we have seen, few empirical researchers would deny that useful definitions are always somewhat *arbitrary*. In particular, empirical work requires the use of 'working definitions' which are not excessively broad or narrow for analytical purposes.[9] To illustrate this general rule, it suffices to consider a familiar example. Defining the concept of an 'industry' focusing on product substitutability appears to be a simple task. Almost everyone would accept that an industry is a collection of firms that sell highly substitutable products. Close substitutes are in the 'industry'; other products are outside the 'industry'. However, this definition is not free of difficulties as products are rarely homogeneous and are therefore not highly substitutable. For example, large luxury cars are not perfect substitutes and do not trade in the same markets as small family cars. Is it more appropriate, therefore, to talk about the 'family car industry' and the 'luxury car industry' rather than the 'automotive industry'? In essence, the answer depends on the purpose of the research project, but even this way of proceeding can be problematical since the choice of data may well be restricted to categories established for other purposes.

The ideal definition of an industry would not only require a precise measurement of substitutability between products but would include all producers. Other industries may be considerably harder to analyse than automobiles. 'Instruments and controls' are divided into a wide range of types. Furthermore, as Patel and Pavitt have shown,[10] more than half of the large firms for which they have patent information are engaged in research into 'instruments and controls' even though their main activities are in other industries. As a result, information on any particular type of device is likely to be widely dispersed. Since cross-elasticities are nearly impossible to measure accurately, because markets are not laboratories in which experiments can be carried out, we face the following alternative: either we work with industry classifications that are somewhat arbitrary or we cannot address practical problems.

Working definitions are important because they are usually embedded in conceptual frameworks used to derive policy implications, and the policy recommendations themselves are affected by the conditions imposed on the definitions. One specific illustration of this (second) general rule will lead us directly into the point we want to make in this paper. The neo-Schumpeterian branch of the New Growth Theory (or NGT) places innovation at the centre of long-run economic growth.[11] The intuition behind this vision is that a country's economic prosperity depends on its capacity for innovation, for which technological innovation is a key driver in advanced countries. Somewhat roughly, the point made by NGT takes the following form:

R&D expenditure $\Rightarrow$ increased knowledge and new products/processes
$\Rightarrow$ economic growth.

In the context of NGT, R&D expenditure is both a proxy for technological innovation and a *black box*. How policy makers should best interpret and respond to the role of this insight is understandably a matter for debate. A typical policy response consistent with NGT is as follows. Empirical evidence indicates that some industries are more innovative than others. It would, therefore, be desirable to bolster those sectors that are highly innovative and highly competitive internationally. It is frequently argued that high-tech sectors meet both conditions. Hence, a country must have strong high-tech sectors in order to sustain economic growth.

Two basic questions for a policy maker immediately suggest themselves. What is a high-tech sector? Can we empirically identify high-tech sectors? The term 'high-tech industry' became fashionable in the mid-1980s. According to the generally accepted perception, the robotics, telecommunications, semiconductor and computer industries fall into the category of high-tech industries.[12] In recent years, the Internet and biotechnology have also assumed considerable importance as high-tech sectors in the context of the Nasdaq Stock Exchange. Often quoted examples of low-tech industries are textiles and furniture. But what makes an industry high-tech or low-tech? Is it the nature of the technological inputs involved in the production processes or the technological complexity of the outputs of the industry? Are high-tech industries those operating on the cutting edge of technology developments and producing outputs heavy in know-how and light in raw materials? Are low-tech industries those displaying technological stagnation?

It is tempting to identify 'high-tech industry' with 'knowledge-intensive industry', where the latter means 'industry involving significant techno-scientific inputs'. The problem with such an identification is that technological change is a ubiquitous phenomenon. Given flexible manufacturing, information systems, and other technological advances, almost every modern industry is knowledge-intensive. In particular, industries such as textiles, food processing and furniture are being technologically transformed by new production procedures and distribution strategies.

In summary, the line between 'high-technology' and 'low-technology' industries is not at all easy to draw. Even though there has been a number of attempts to deal with the problems associated with the classification of industries on the basis of 'technology levels', no agreed definition exists.

3. Classifying Levels of Technology: One-dimensional Criteria

A taxonomy of industries based on only one distinguishing feature is a *one-dimensional* classification. There are three standard classificatory criteria for distinguishing industries in terms of technological intensity. Each criterion generates a classification of industries by levels of technology. We developed the corresponding empirical tables that follow using data from the second Australian Bureau of Statistics (ABS) innovation survey and test for consistency between the tables regarding the level of technology in which industries are placed.

3.1. Criterion 1: R&D Intensity

This commonly used empirical classification, which was pioneered by the OECD,[13] is based primarily on R&D intensity as measured by expenditure on R&D as a proportion of output. The original work included R&D intensities emerging from a sample of 11 countries and led to a listing that places industries in three categories: industries that spend more than 4.5% of sales on R&D are classified as high-tech; industries that spend between 1.0 and 4.5% of sales, as 'medium-tech', and sectors that spend less than 1%,

Table 1. Classification of industries by level of technology (Criterion 1: R&D intensity)

High-tech industries (R&D intensity: 3% or more)	**R&D intensity**
Radio, TV and communication euipment	7.8
Pharmaceutical products	3.1
Office and computing machinery	3.0
Low-tech industries (R&D intensity: less than 3%)	
Non-electrical machinery	2.5
Professional goods	2.4
Motor vehicles	1.7
Chemicals	1.2
Other transport equipment[a]	1.2
Iron and steel	1.2
Non-ferrous metals	1.1
Electrical machinery	0.9
Paper and paper products	0.8
Non-metallic mineral products	0.5
Textiles, apparel and leather	0.5
Other manufacturing n.e.c.	0.4
Food, beverages and tobacco	0.4
Metal products	0.3
Wood products and furniture	0.3
Petroleum products	n.p.
Rubber and plastic products	n.p.

[a] Includes aircraft and shipbuilding.
n.p.: not available for separate publication.
Source: Data provided by the *Australian Bureau of Statistics* (ABS) originated in the Second ABS Innovation Survey. A summary of the general findings can be found in *1996–97 Innovation in Manufacturing*, ABS, Catalogue No. 8116.0.

as low-tech. The R&D data employed derive from the OECD's *Analytical Business Enterprise Research & Development* (ANBERD) Database.

The OECD classification of industries by technological intensity has been extensively used by many countries. In particular, a slightly improved version of the original OECD classification of manufacturing industries has been used in Australia by Keith Bryant *et al.*, where different cut-off points and four categories of industries ('high technology', 'medium-high technology', 'medium-low technology' and 'low technology') are presented.[14]

As there is always some degree of arbitrariness in selecting cut-off points between technology classes, for our present purposes it is immaterial as to whether we use four, three or two technology categories. To simplify matters, we merge 'medium high-tech industries' and 'high-tech industries' into one category and 'medium low-tech industries' and 'low-tech industries' into a second, and reformulate the first criterion as follows: any industry exhibiting R&D intensity of 3% or more is a high-tech industry while any industry displaying less than 3% of R&D intensity is a low-tech industry. This rearrangement allows us to allocate Australian manufacturing industries into two groups. Table 1 provides a classification of industries on the basis of Criterion 1 using Australian innovation data.

It should be clear that this OECD derived taxonomy is an *input* based classification of industries that completely overlooks the technological characteristics of the final product. If, for example, R&D intensity in the milk industry were to rise to 12%, this sector would qualify as a high-tech industry regardless of the fact that its output does not change. In addition, it is based on *direct* inputs of R&D and does not include research findings that originate outside the industry and that have been captured indirectly, perhaps through the purchase of equipment embodying R&D activities or perusal of the trade press. Thus, in common with the other indicators that we shall discuss, this measure masks variations across firms that may be of considerable magnitude, and as a result is of limited use in formulating either government policy or firm strategy (a point that we shall return to in detail).

A number of authors have proposed classifications that are, in essence, similar to the OECD's. Medcof, for example, appears to believe that there is a clean line separating high-tech from low-tech industries:

> Unambiguous identification of HTIs (high-technology industries) must begin with a clear definition. A simple one that strips away many side issues is: a high-technology industry is one whose business activities are heavily dependent upon innovation in science and technology. (…)
>
> A good way to operationalize our definition of HTIs is with the research intensity metric. This is the ratio of the R&D expenditures of an industry to its total sales, and is conceptually a logical way to measure 'heavy dependence on science and technology innovation'. Research intensity also has the virtue of being calculated with data that are readily available from a number of sources and can be calculated at both the industry and firm levels. Research intensity is probably the most frequently used measure for identifying high-technology industries and firms.[15]

Medcof also defines a 'super-technology' industry as one displaying both high total R&D expenditure and heavy dependence on science and technology innovation, and identifies five of them as the 'non (sic) plus ultra of high technology': biotechs, semiconductors, software, pharmaceuticals, and telecommunications equipment.[16] As what Medcof calls 'research intensity' is nothing but 'R&D intensity', however, his definition leads us back to the OECD one-dimensional classification and its limitations.

3.2. Criterion 2: Innovation Rate

Further insight into the conditions defining high- (or low-) tech industries could be gained by taking into account the *rate of technological innovation*, defined as the proportion of businesses undertaking technological innovation in a given industry. To illustrate this approach, the following typical description is useful:

> A high-technology industry is, loosely speaking, an industry in which the success of companies depends largely on their ability to keep up with rapid innovation in products, production processes, or both. (…)[17]

In this schema, the essential distinguishing feature of a high-tech industry is a high rate of technological innovation. Low-technology industries are defined by contraposition.

Of the (estimated) 55,000 Australian manufacturing firms, only 26% had undertaken one or more technological innovation activities over the 3-year period July 1994–June 1997.[18] We use this percentage to draw the border line between low-tech and high-tech industries. Table 2 provides an empirical classification of industries on the basis of Criterion 2 using data stemming from the second Australian Bureau of Statistics (ABS) innovation survey.

Table 2. Classification of industries by level of technology (Criterion 2: rate of technological innovation)

High-tech industries (innovation rate: more than 26%)	Rate of technological innovation (%)
Radio, TV and communication equipment	70
Pharmaceutical products	61
Office and computing machinery	58
Petroleum products	49
Chemicals	44
Rubber and plastic products	39
Non-electrical machinery	38
Non-metallic mineral products	36
Food, beverages and tobacco	36
Professional goods	34
Electrical machinery	33
Iron and steel	31
Non-ferrous metals	29
Low-tech industries (innovation rate: 26% or less)	
Paper and paper products	26
Other manufacturing n.e.c.	26
Other transport equipment[a]	25
Motor vehicles	23
Metal products	20
Textiles, apparel and leather	15
Wood products and furniture	15

[a] Includes aircraft and shipbuilding.
Source: Data provided by the *Australian Bureau of Statistics* (ABS) originated in the Second ABS Innovation Survey. A summary of the general findings can be found in *1996–97 Innovation in Manufacturing*, ABS, Catalogue No. 8116.0.

3.3. Criterion 3: Technological Endowment of the Final Product

The paper by Hatzichronoglou contains a list of high-tech products derived from calculations of R&D intensity by groups of products in a few advanced countries.[19] According to this list, the main categories of high-tech goods are aerospace, computers–office machines, electronics–telecommunications, pharmacy, scientific instruments, electrical machinery, chemistry, non-electrical machinery, and armaments. Each category contains sub-categories, for example, pharmacy is unfolded into 26 subcategories (antibiotics, penicillins and their derivatives, pituitary (anterior) or similar hormones, etc.).

Some of the limitations of the product approach are mentioned by the author, e.g. it is difficult to construct a product hierarchy in terms of their level of technology content. In passing, we note that Hatzichronoglou does not give any information about low-tech products. The biggest problem, however, appears to be related to products such as pharmaceuticals or chemicals where the R&D input is very high, but the technological complexity of the final product reduces to a mere combination of raw materials. For example, antibiotics and assembly line robots are both R&D intensive products, but the latter is an intelligent device[20] and the former is not.

Without striving for rigor, we use an alternative classificatory scheme. As will become apparent in a moment, our practical criterion to allocate industries on the basis of the technological endowment of the final product to different technology classes has the advantage of simplicity, but it is not equivalent to the one adopted by the OECD. For lack of a better expression, a product made up of raw materials and endowed with intelligent devices is termed 'technologically equipped'. A product is said to be 'technologically void' if it consists only of raw materials.[21] Both kinds of products can be either consumed as final products or used as inputs within and between industries. We use the following dichotomy (Criterion 3): high-tech industries produce technologically equipped products while low-tech industries produce technologically void products. According to this criterion, pharmaceuticals and chemicals are low-tech products.

Table 3 provides a (rough) classification of industries based on Criterion 3. It is hardly necessary to add that the ideal classification of industries according to Criterion 3 would require an accurate evaluation of the technological content of each product, a task that is virtually impossible.

Table 3. Classification of industries by level of technology (Criterion 3: Technological endowment of the final product)

High-tech industries (technologically equipped products)
Aircraft
Office and computing machinery
Radio, TV and communication equipment
Professional goods
Motor vehicles
Electrical machinery
Non-electrical machinery
Other transport equipment
Shipbuilding & repairing
Low-tech industries (technologically void products)
Chemicals
Pharmaceutical products
Petroleum products
Non-metallic mineral products
Rubber and plastic products
Non-ferrous metals
Iron and steel
Metal products
Food, beverages and tobacco
Paper and paper products
Textiles, apparel and leather
Wood products and furniture

3.4. *Robustness Test*

There appears to be no logical reason to expect consistency (one-to-one correspondence) between classifications. For example, the fact that a sector has a high innovation rate does not (logically) imply that its R&D intensity is also high or that the sector in question produces technologically endowed products. To systematically assess the *empirical* compatibility of the aforementioned classifications, some terminology and a piece of notation are needed.

An industry (say) 'metal products', is said to pass the *robustness test* (is *robust*) if 'metal products' is included repeatedly in the same level of technology (say, 'low-tech') irrespective of the criterion employed. Superimposing Tables 1, 2 and 3 we obtain a classification of the robustness of industries (see Table 4). When an industry is high-tech and robust, e.g. 'radio, TV and communication equipment', we write ⊗. To identify industries that are low-tech and robust (e.g. 'wood products and furniture') we employ the symbol □. The message conveyed by Table 4 can be condensed as follows. At the extremes, the distinction between high-tech and low-tech industries is clear, but in the middle (14 industrial sectors out of 20) there is *no* sharp dividing line, as indicated by the symbol ¤. The implication for policy seems to be that the 'robust classification' afforded by Table 4, as with the indicators upon which it is based, should be used as a policy guide only for the unambiguous cases and is of little or no value for the bulk of industries, and as it will become apparent in Section 5, the number of unambiguous cases is even smaller than Table 4 shows.

Table 4. A robust classification of industries by level of technology

	High-tech	Indeterminate	Low-tech
Radio, TV and communication equipment	⊗		
Office and computing machinery	⊗		
Pharmaceutical products		¤	
Professional goods		¤	
Motor vehicles		¤	
Chemicals		¤	
Electrical machinery		¤	
Non-electrical machinery		¤	
Other transport equipment		¤	
Petroleum products		¤	
Rubber and plastic products		¤	
Non-metallic mineral products		¤	
Food, beverages and tobacco		¤	
Iron and steel		¤	
Non-ferrous metals		¤	
Other manufacturing n.e.c.		¤	
Metal products			□
Paper and paper products			□
Textiles, apparel and leather			□
Wood products and furniture			□

Source: Tables 1, 2 and 3.
Legend: ⊗ means 'it satisfies all the three one-dimensional criteria for "high-tech" industry'. ¤ means: ' it does not meet at least one of the three criteria'. □ means: 'it satisfies all the three one-dimensional criteria for "low-tech" industry'.

4. Multidimensional Classifications

The foregoing suggests—correctly—that one-dimensional indicators do not adequately capture the complexity of the real world. We now describe several classifications based on more than one distinguishing feature and point out that the available multidimensional classifications of industries by level of technology also have limitations.

4.1. The Shankling and Ryans Scheme

An early explicit definition of a high-tech industry was presented by two marketing analysts who wrote:

> 'High tech' has become a buzzword to describe everything from the space shuttle to the electric frying pan. In our judgement, businesses must meet three criteria to be labeled 'high technology':
>
> 1. The business requires a strong scientific-technical basis.
> 2. New technology can quickly make existing technology obsolete.
> 3. As new technologies come on stream, their applications create or revolutionize markets and demand.[22]

All three conditions are questionable, at least on an individual basis. The first condition resembles the requirement discussed earlier that a high-tech industry is a knowledge-intensive industry. Condition 2 incorporates an element of 'creative destruction' in the Schumpeterian sense (somewhat roughly, that innovation kills off its predecessors). The problem here is that sometimes innovations are complementary with their predecessors. The last condition can be disposed of more brusquely by considering the example of the soft drinks industry, where the introduction of Coca-Cola fits nicely into condition 3 but few people believe that soft drinks are high-tech products.

4.2. The Felsenstein and Bar-el Scheme

A more rigorous classification is due to Felsenstein and Bar-el.[23] These authors provide a classification based on 'technological profiles'. A *technological profile* is an ordered collection of the following three variables: (1) labour technological intensity (or *human capital intensity*), i.e. the share of scientists and engineers in the work force; (2) capital technological intensity, i.e. the nature (sophisticated or simple) of the machinery used in the production process; and (3) product technological intensity, i.e. investment in the development of new products and processes.

Assuming that each variable can take only one value, say 1 = high or 0 = low, a technological profile is specified as an ordered collection of three values. For example, (0,1,1) = (low, high, high) is a technological profile identifying an industry that develops innovative products with sophisticated production processes and low employment of qualified labour. It is clear that the industry (1,1,1) is more technologically intensive than the industry (0,0,0). But it is also clear that excepting these extreme cases, it is conceptually awkward to rank technological profiles. For example, is the industry (0,1,1) more technologically intensive than the industry (1,0,1)? Moreover, certain technological profiles are counterintuitive even if conceivable, e.g. the industry (0,0,1) develops new products without using highly qualified labour or sophisticated machinery.

4.3. The Keeble Scheme

To study the geographical distribution of high-tech industries in Great Britain during the period 1981–1987, David Keeble designed the following (catch-all) definition:

> High-technology industry can be defined as those activities in which rapid technological change and high inputs of scientific research and development expenditure and employment are producing new, innovative and technologically advanced products. Industries (iron and steel, vehicles) which are increasingly using these products (computers, robots) as key ingredients in their own manufacturing processes, are however, excluded. Classic high-tech products include computers, semiconductors (silicon chips), lasers, space rockets and body-scanners. Research-intensive services such as telecommunications and computer also qualify.[24]

The basic problem with this multidimensional schema is that Keeble does not define the concept of a 'technologically advanced product', which makes the allocation of industries to the high-tech category logically impossible.

4.4. The Hatzichronoglou Scheme and the Tableau Technologique

The OECD classification of industries on the basis of the degree of technology intensity (also referred to as the *ANBERD classification*) has recently been revised in order to improve the classificatory scheme.[25] Since we have already considered the product approach in sub-section 3.3, we concentrate here on the sectoral approach. As it is more sophisticated than the other methodologies described, it merits detailed discussion.

The new version of the sectoral approach distinguishes between 'producing ideas' and 'using ideas'. To this end, two basic concepts are introduced:

1. direct technological intensity (DTI), reflecting the *production* of technology, and
2. indirect technological intensity (ITI), reflecting the *use* of technology.

The two central notions are lumped together to generate 'overall technological intensity' (OTI), defined as $OTI = DTI + ITI$. These are quantified employing the following indicators:

1. direct R&D intensity (R&D expenditure divided by production or R&D expenditure divided by value added in the sector), and
2. indirect R&D intensity or 'embodied technology', defined as acquired technology (i.e. technology embodied in intermediate and investment goods *used* in the sector) divided by production.

Coefficients derived from an input–output table are used to determine the weights used in the sectoral calculations. The latest version of the OECD classification of industries by level of technology revolves around direct and indirect R&D intensity.[26] For reasons that will become apparent in a moment, this classification requires careful scrutiny.

The 1997 OECD classification was constructed using 1980 and 1990 as benchmarks because for these years industries allocated to a higher category have higher OECD-average intensity for all indicators than industries in a lower category, with the single exception of 'petroleum products'. Table 5 shows the 22 ANBERD manufacturing sectors dispersed within four categories of technology intensity. This table is reminiscent of the *Tableau Economique* (constructed by Francois Quesnay in 1758) in that it is a primitive map of an extraordinarily vast and complex collection of facts. It is for this reason that we call Table 5 *Tableau Technologique.*

An important question that naturally arises at this point is: what is the use of the OECD classification of sectors by level of technology? The allocation of manufacturing sectors into categories of technology intensity provides a *grand view* of the distribution of the OECD-average technology contents across manufacturing industry as a whole. The 1997 classification is an important improvement on the original OECD one-dimensional sectoral approach that was based only on direct R&D intensity and did not take into account the technology *embodied* in purchases of intermediate and capital goods (indirect R&D intensity). This is, of course, better than nothing, but there still remains the policy question: how can the *Tableau Technologique* be used to draw policy recommendations?

In principle, we can use the *Tableau* to implement international comparisons of overall technological intensity ('benchmarking'), assuming availability of data. As it happens, both variables, direct and indirect R&D intensity, are very highly correlated to

Table 5. OECD classification of industries by level of technology

	OTI	**Direct R&D intensity**	
		R&D/ production	R&D/ value added
High-tech industries			
Aircraft	17.30	14.98	36.25
Office and computing machinery	14.37	11.46	30.49
Pharmaceutical products	11.35	10.47	21.57
Radio, TV and comm.. equip.	9.40	8.03	18.65
Medium high-tech industries			
Professional goods	6.55	5.10	11.19
Motor vehicles	4.44	3.41	13.70
Electrical machinery	3.96	2.81	7.63
Chemicals	3.84	3.20	8.96
Other transport equipment	3.03	1.58	3.97
Non-electrical machinery	2.58	1.74	4.58
Medium low-tech industries			
Rubber and plastic products	2.47	1.07	3.02
Shipbuilding and repairing	2.21	0.74	2.13
Other manufacturing	1.76	0.63	1.52
Non-ferrous metals	1.57	0.93	3.48
Non-metallic mineral products	1.44	0.93	2.20
Metal products	1.35	0.63	1.39
Petroleum products[a]	1.33	0.96	8.43
Iron and steel	1.10	0.64	2.48
Low-tech industries			
Paper and paper products	0.88	0.31	0.76
Textiles, apparel and leather	0.78	0.23	0.65
Food, beverages and tobacco	0.73	0.34	1.14
Wood products and furniture	0.65	0.18	0.47

[a] Includes refineries.

Legend: OTI = direct R&D intensity (measured by R&D/production) + indirect R&D intensity.

Source: OECD, 1999, p. 106.

Note: The *Tableau Technologique* refers to the year 1990. The corresponding data for 1980 can be found in OECD, 1999, p. 106.

each other, suggesting that the production of technology and the use of technology change in the same direction. When considered for the OECD as a whole, the inclusion of indirect R&D intensity does *not* affect a sector's classification in any of the four categories, although it may alter its ranking within a given technology category.[27] From a policy-making standpoint, however, the inclusion of indirect R&D intensity enables discussion of important options that are not covered by direct intensity on its own.

5. Technological Intensity from a Macroeconomic Perspective

It is reasonable to expect that the level of technological intensity for particular sectors varies from country to country and differs from OECD averages. If we compare the data for Australia in Table 1 with the middle column in Table 5, the contrast is instructive (we concentrate on DTI since data for ITI are not available for Australia). As the comparison makes clear, the levels of DTI for most industries are *substantially* lower in

Australia than for the OECD considered more broadly. This prompts an awkward question. Does this striking difference in technological intensities mean that high-tech industries are surprisingly rare in Australia? The answer appears to be in the affirmative, unless one cares to believe that the magnitude of ITI for Australia is so big that the situation could be reversed by introducing the use of technology into the picture.

The distinction between direct and indirect R&D inputs, while a valuable insight, does not, unfortunately, provide much assistance for policy makers. If country A, for example, has a highly technology-intensive pharmaceutical industry, indicated by an OTI well above the OECD average ($= 11.35$, according to Table 5) and country B has a pharmaceutical industry that is only slightly technology-intensive, does it mean that the pharmaceutical industry in country A has overinvested in OTI and that in country B has underinvested in OTI?

Hatzichronoglou's paper indicates that the degree of OTI in an industry should be taken as an international standard.[28] If we assume that the *Tableau* provides OTIs representing international benchmarks, it follows that shortfalls in, for example, a country's DTI relative to the international classification must be compensated for by larger than average amounts of ITI. This assumes that countries may be able to import technologies as efficiently as they can produce them *ab origine*. Although this is a sensible conclusion that meshes well with empirical data, it renders *indeterminate* any policy advice that might be offered on the basis of the *Tableau*.

The reason is not hard to find. Let us make the (heroic) assumption that the OTIs given by the *Tableau* are optimal in some sense. This automatically implies that for a given sector a policy maker can fix one of the remaining two variables more or less arbitrarily and determine the corresponding unknown. Or, to put it differently, given the optimal value for the pharmaceutical sector $\mathrm{OTI} = 11.35$, a policy maker has one degree of freedom in the sense that he can fix one variable and determine the value of the other so as to satisfy the equation $\mathrm{DTI} + \mathrm{ITI} = 11.35$. Quite obviously, the problem lies in the fact that for each sector the *Tableau* gives only one equation for two unknowns, and thereby, the division between DTI and ITI becomes *moot*.

To sum up, we are still unable to answer the following policy questions: should governments encourage firms to make or buy their technology, to become first movers or rapid second movers? Should educational systems and research facilities be directed towards the generation of knowledge or the cultivation of absorptive capacity? The answers to these questions vary from case to case and are empirical, not conceptual. Moreover, they are difficult to predict, yet predictive ability is what policy formulation requires.

6. Sectoral Diffusion and Product Innovation

While the distinction between direct and indirect technological (or R&D) intensity is useful, it does not track one vital aspect of innovation and diffusion—the embodiment of an innovation in other products.[29] This is a major problem for at least two reasons. First, it is entirely possible that the total effects, say in terms of overall productivity gains throughout the economy, from the introduction of an innovation originating in a sector that does not rank highly in terms of technological intensity, but whose impact is widespread, will exceed those of an innovation that is highly rated on technological intensity but has few uses. Second, the relative weights of the sectors deemed to be high-tech may be significantly smaller than those of other, less R&D intensive, sectors. Therefore, improvements in productivity in lesser R&D intensive sectors may have substantially greater effects on the economy than those in high-tech areas. As a consequence, not only is a blinkered preoccupation with high-tech sectors and products by policy makers likely to be counterproductive, but the *meaningfulness* of the high-tech/low-tech distinction for policy purposes is itself called into question. As Michael Porter recently put the matter,

> In the new economics of competition, what matters most is not inputs and scale, but productivity—and [this] is true in all industries. The term *high-tech*, normally used to refer to fields such as information technology and biotechnology, has distorted thinking about competition, creating the misconception that only a handful of businesses compete in sophisticated ways. (…) In fact, there is no such thing as low-tech industry. There are only low-tech companies that fail to use world-class technology and practices to enhance productivity and innovation.[30]

The overall economic impact of an innovation depends directly on the proportion of the economy that is affected as well as on the productivity gains that result in each of the fields which the innovation touches. To consider a crude example, a 20% improvement in productivity in a sector accounting for 5% of national income will have less effect on overall growth and welfare than would a 5% improvement in productivity in sectors that account for a quarter of national income. Before proceeding further, however, time needs to be brought into the analysis. Over even short periods, the magic of compound interest will necessarily increase the weights of sectors that have above average rates of growth at the expense of those that are growing more slowly. If trends continue, relatively small sectors will become large and relatively large ones will lose ground or even disappear. The logic that Hatzichronoglou presents to support attention for high-tech sectors, which we have already quoted, is based on the plausible assumption that (at least some of) the sectors classed as high-technology and medium-high-technology will continue to grow quickly and that they will dominate the best performing economies of the future. It would be idle to deny that transformative sectoral change has occurred in the past or to posit that it will not continue to take place. The chemical, electrical and electronic, steel and motor vehicle sectors, which were very small in 1870, later grew to dominate the industrial economies of Europe, North America and Japan. By contrast, the share of output in the same economies attributable to textiles and agriculture has diminished considerably, despite being propped up through subsidies.

Nevertheless, over shorter (but still very substantial) periods traditional sectors continue to retain great importance in terms of both output and employment. The need for these sectors does not disappear quickly and important gains are to be made through improvements in both their process and product technologies even if these occur incrementally rather than transformationally. In addition, many of the most important results associated with the growth of high-tech industries may be felt through their impact on other, older sectors. To cite just two obvious examples:

1. Improvements in land, sea and air transport have greatly (and differentially) affected the prices at which suppliers of other goods and services can deliver *their* products, in the process greatly increasing the affordability of tens of thousands of different items.
2. The enormous economic impact resulting from electrification did not originate only, or even principally, from the new electrical products that became available, unquestionably important though these were, but from the improvements in productivity than resulted from the application of electricity to production processes for existing goods and services.

Systemic innovations, such as the spread of steam, electrification, and the use of semi-conductors do not occur quickly but may take half a century or more to work themselves out.[31] In the long run, it is necessary to make sure that new sectors are not starved of funds, but it is also necessary to encourage incremental (and sometimes transformational) improvements to existing sectors, especially since the major impact arising from the new sectors may well result from their effects on older industries.[32] Unless we make the unlikely assumption that investment funds in modern industrial economies are too limited to support investments in R&D in both high-tech and other sectors, then it is possible that both long- and short- to medium-term growth may be stunted through a misallocation of investment resources to industries that are presumed to have a bright future at the expense of those that currently provide prosperity. The situation is well-expressed by Mowery and Rosenberg[33] in the course of a recent critique of the concepts of Simon Kuznets. They write that Kuznets

> tends to understate the importance of the adoption of new technologies by mature industries, which has sparked productivity growth and even the appearance of new products (e.g. synthetic-fiber radial tires) in these industries. In fact, many older industries have experienced significant productivity growth as a result of the *intersectoral flow of new technologies*. This intersectoral flow is a fundamental characteristic of 20th-century innovation in the U.S. economy—for example, innovations in the chemicals and electronics industries have been truly pervasive, being incorporated into a staggering array of consumer and capital goods. In addition, the rise of the automobile and commercial aircraft industries significantly increased the demand for advanced products (e.g. jet fuel, composite materials, gasoline) from other industries, thereby creating additional incentives for increases in scale and efficiency.[34]

In short, innovation and industry policies require attentiveness to all sectors of the economy because the evolution of the various sectors is inextricably linked.

7. Technology Intensity and Firm Strategy

As the *Oslo Manual* acknowledges,[35] basic innovative behaviour takes place at the level of individual firms. Therefore, it is legitimate to inquire to what extent concepts of technological intensity might be useful in determining technology strategy by firms. The appropriate answer seems to be that their value depends on the context.

In one sense it would be easy for firms to achieve high-tech status. All that they need to do is to devote enough resources to research and development to meet the threshold figure; yet there is a basic flaw here. It does not make sense to spend large amounts on R&D to attain high-tech status, simply because the R&D effort is an input to be optimally determined, *not* to be maximized. Moreover, the fact that R&D intensity varies so greatly across sectors indicates that there are characteristics of various industries (such as the stage of the product and process life cycles and the nature of competition within the industry) that strongly affect research intensity.

One complicating factor is that most firms produce goods or services that are composites of varied components that are often of different technological vintages. Following Mowery and Rosenberg, we may argue that much of the innovation in low-technology sectors results from the introduction of high-technology artefacts into existing technological systems. The *Oslo Manual*[36] lists a number of examples of the application of innovations in service industries, such as the introduction of cellular telephones by road transport companies to improve routing, or the use of e-commerce by wholesalers of machinery, equipment and supplies.

It is questionable, though, that these should be termed to be high-tech, or indeed *any*-tech, strategies. Incremental improvements of this type rarely lead to substantial increases in the technological status of the employing firms, except perhaps in a slow and evolutionary fashion. For one thing, nodes of innovation may remain exactly that: isolated areas in which products with high levels of (often indirect) technological intensity form part of a production chain that is otherwise largely unaffected by change at any given moment. In addition, increases in ITI, as through the use of cellular phones, may involve very little learning within the using industries. Even the development of e-commerce may require more in the way of organisational learning to make efficient use of new opportunities than of increased technological skills *per se*. Systemic improvements, on the other hand, will by definition have more far-reaching effects on existing technologies, particularly if they are competence-destroying.[37] Again, however, even systemic change may not involve high levels of R&D intensity.

The modern automobile is one of the many possible examples that helps to illustrate the uncertainty involved in applying classifications of technological intensity at the firm and product level. Hatzichronoglou[38] notes that the classification of motor vehicles as a high-tech *product* would clash with the classification of the automotive industry as a medium-high-tech *sector*. When automobiles are considered on a component-by-component basis, however, they may not embody much high technology at all even if the degree of R&D and the use of scientific and engineering labour are high. In fact, automobiles are a classic example of a product and a sector that have changed steadily but without large numbers of major changes over a period of several decades. Despite innumerable improvements, for instance, the basic concepts that underlie the power train have remained similar for a century. Other more recent changes, such as the substitution of plastic components for metal ones, have led to dramatic reductions in weight but have not altered the function of most of the components. Similarly, the use of electronic components has frequently entailed the substitution of one component for another without substantially changing the way in which automobiles as a whole perform. It is arguable that, despite the indicators that show that R&D resources are used intensively in the automotive sector, automobiles are not basically a high-tech product and that many of the resources are devoted to rearranging existing technological building blocks in more-or-less predictable ways rather than to pushing back the frontiers of knowledge. This could be explained by the nature of competition in the industry, which relies on frequent, if often cosmetic, changes to a complex mechanical/electronic product. If competition were based less on cosmetic product differentiation and if the major firms produced fewer models, the level of R&D intensity in the sector might be reduced without commensurate reductions in the pace of technological change. As matters stand, however, firms must continue to invest heavily in R&D in order to achieve competitive levels of change (which are not the same thing as levels of improvement).

8. Summary and Proposal

Our survey has yielded a number of findings. First, in spite of the high level of aggregation, we have found that only 30% of the Australian industries pass the robustness test, that is, 14 industrial sectors out of 20 cannot be unequivocally classified as high-tech or low-tech. For example, inspection of Tables 1 and 2 shows that 'iron and steel' is low-tech according to Criterion 1 (R&D intensity), but high-tech when looked at from the angle of Criterion 2 (innovation rate), and consequently 'iron and steel' is not a robust industry. Surprisingly industries typically regarded as unimpeachably high-tech, such as pharmaceuticals and chemicals, or as low-tech (e.g. food, beverages and tobacco) also fail to pass the test. Second, the existing multidimensional criteria cannot provide unambiguous classifications of industries because either the conditions imposed are questionable such as 'new technologies make existing technology obsolete' or their key concepts are defined in the penumbra of fuzzy expressions such as 'capital technological intensity' or 'technologically advanced products'. Third, a comparison of the latest OECD classification of industries by level of technology (what we call here the *Tableau Technologique*) with the data originated by the second ABS innovation survey strongly suggests that high-technology industries do not meet high-technology criteria in their Australian operations. This confirms that the dividing line between high-tech and low-tech industries is blurred at best.

At this point one might well ask: what is the difference between a 'camel' and a 'high-tech industry' from a semantic viewpoint? After all both terms can be found in the dictionary. A camel is called a camel because a satisfactory criterion has been generally accepted asserting that a creature with certain characteristics will be called (once and for all) a camel. Researchers have not been able to identify a set of characteristics that would allow us to call an industry high-tech on the basis of generally accepted rules. It is tempting to argue here that in the same way that we can define a camel or a tiger or an elephant by pointing to a specimen of the class denoted by the concept, we could define a high-tech industry by mentioning a particular sector without any additional qualifications. The problem still remains, however, because it would be extremely difficult to reach consensus about arbitrary classifications of industries in this psychological sense. If we are unable to state clearly why we call an industry high-tech, then we are not dealing with science but with obscurantism.

Another finding of our survey has to do with the use of the *Tableau Technologique* to draw policy implications. From the viewpoint of policy makers, the usefulness of any classificatory scheme of industries lies in the light it throws on the way public policy can be performed in order to improve economic performance. One strong implication of the arguments that we have presented is that the OECD classifications of industries based on levels of technology fail to unambiguously inform decision makers about policy actions conducive to better sector performance.

To compare the international standards provided by the *Tableau Technologique* with the overall technological intensities (OTIs) of a particular country is fraught with difficulties. Are the OTIs afforded by the *Tableau* technologically optimal in some sense? Even under the extremely unrealistic assumption that the *Tableau* affords optimality, discrepancies between 'optimal' OTIs and OTIs observable in a particular country imply *indeterminateness* of policy actions because there is a choice of using direct technological intensity (DTI) or indirect technological intensity (ITI) to move to the international standards. For example, assuming that for a given sector (say aircraft) the OTI provided by the *Tableau* (= 17.30) is greater than the observable OTI in a particular country and in the same sector: should we choose DTI expansion to move to the 'optimal' level 17.30? Or should we choose ITI expansion to reach the desired 17.30? Or should we pick a policy mix of (e.g.) reducing DTI and substantially increasing ITI? Or should we let the market work and forget about the *Tableau*?

We believe it is appropriate to *avoid* the dichotomy high-tech/low-tech when designing innovation and industry policies. This taxonomy has been used in many senses, none of which is quite satisfactory. The complexity and multiplicity of technological factors (e.g. in many industries products are amalgams of old and new, and simple and sophisticated, technologies) make the dichotomy *intractable*. Instead of chasing a will-o'-the-wisp, we suggest a change of focus.

How, then, might technologies be treated and quantify in order to search for a sensible classification and new policy insights? The way to solve this problem which would suggest itself more naturally would be to compare 'technological configurations' at the firm level (somewhat roughly, knowledge bases necessary to efficiently produce the core products), and thereby draw conclusions on the way technology evolves in particular product fields.

In other words, a meaningful approach to the issue would be to consider technological *change* rather than *levels* of technologies at the firm level or product field. In many cases, improved performance results from changes (autonomous or systemic) to the technologies of existing products and processes. Whether these changes involve large investments in R&D is not essential, nor is the vintage of the improvements essential. Change alone is significant—if one accepts the assumption that changes that persist are efficiency-enhancing in some respect.

Thus to evaluate technological change at the micro level it is necessary to compare two technological configurations. All firms and sectors possess technological configurations that may be mapped satisfactorily answering the following question: what is the required technological endowment for a firm to be able to produce the goods located in a given product area and/or position itself for the next generation of products?[39] Although this would be a difficult and lengthy task, it would provide a benchmark against which subsequent changes could be judged and their effects measured.

The important consideration would be the outcomes of the changes, as measured by (say) increases in productivity or the introduction of new products or processes rather than their technological intensities. Technological intensity could also be considered, but without the presumption that high levels of R&D or of employment of scientific and technical personnel necessarily lead to superior results. Similarly, improvements in productivity should not be taken in isolation as an indicator of the viability of a firm or industry since superior substitutes may be available.[40]

This is not to say that these issues are easy to think through. The results of this type of study would not be cut-and-dried and would have to be used with care. Close attention would need to be given to the definition of the scope of the issue under consideration because (a) some changes are bound to be difficult to separate from others, while (b) changes in some aspects of an industrial chain may not have discernable repercussions in other parts of the chain. As a result, different maps may be derived for different firms or for different parts of an industry or sector, but these may need to be analysed in the context of other maps covering competing firms or larger segments of the industry or sector.

Notes and References

1. An earlier version of this paper was presented at the workshop on Low Technologies Industries held in Oslo, 7–8 April 2000.
2. See, for example, the arguments that run through the OECD's *Science, Technology and Industry Scoreboard, Benchmarking Knowledge-Based Economies*, OECD, Paris, 1999.
3. *Ibid.*, p. 60
4. *Ibid.*
5. T. Hatzichronoglou, 'Revision of the high-technology sector and product classification', *STI Working Papers*, OECD/GD (97)216, 1997, p. 4.
6. *Ibid.*, p. 4.
7. *Ibid.*
8. *Oslo Manual: Proposed Guidelines for Collecting and Interpreting Technological Innovation Data,* OECD, Paris, 1997, p. 30.
9. An example of the arbitrariness needed to reach working definitions is the repeated use of 'significant' in the *Oslo Manual.*

10. P. Patel and K. Pavitt, 'The wide (and increasing) spread of technological competences in the world's largest firms: a challenge to conventional wisdom', in Alfred D. Chandlers, Jr., Peter Hagström and Örjan Sölvell (eds), *The Dynamic Firm: The Role of Technology, Strategy, Organization, and Regions*, Oxford University Press, New York, 1998, pp. 192–213. See also: O. Granstrand, P. Patel and K. Pavitt, 'Multi-technology corporations: why they have "distributed" rather than "distinctive core" competences', *California Management Review*, 39, 4, 1997, pp. 8–35.
11. The unifying thread running through NGT is the view that technological change is itself an economic phenomenon. See, for example, P. M. Romer, 'The origins of endogenous growth', *Journal of Economic Perspectives*, 8, 1, Winter 1994, pp. 3–22.
12. See, for example, J. K. Paul (ed.), *High Technology, International Trade and Competition*, Noyes Publications, New Jersey, 1984.
13. *The Measurement of High Technology*, Note by the Secretariat, Directorate for Science, Technology and Industry, OECD, Paris, 1988.
14. K. Bryant, L. Lombardo, M. Healy, L. Bopage and S. Hartshorn, *Australian Business Innovation. A Strategic Analysis*, Science and Technology Policy Branch, Department of Industry, Science and Technology, Australian Government Publishing Company, Canberra, 1996.
15. J. W. Medcof, 'Identifying super technology industries', *Research Technology Management*, July–August 1999, pp. 1–2.
16. *Ibid.*, p. 3.
17. Paul R. Krugman and Maurice Obstfeld, *International Economics Theory and Policy*, Addison-Wesley, New York, 1996, p. 279.
18. *Innovation in Manufacturing*, Australian Bureau of Statistics, Canberra, 1998, p. 8116.0.
19. Hatzichronoglou, *op. cit.* This paper draws on methodological work carried out at the OECD and presents two new classifications or 'lists', one for the manufacturing industries (termed sectoral approach), and other for manufacturers (termed *product approach*). The sectoral approach is a two-dimensional classification that will be considered in detail in sub-section 4.4.
20. An intelligent device is defined as one that is capable of exercising discretion according to a set of predetermined rules.
21. We are aware that this classification may be problematic and contentious, but it appears to work exceedingly well at a relatively high level of aggregation.
22. W. L. Shankling and J. K. Ryans, 'Organizing for high-tech marketing', *Harvard Business Review*, November–December 1984, p. 166.
23. D. Felsenstein and R. Bar-el, 'Measuring the technological intensity of the industrial sector: a methodological and empirical approach', *Research Policy*, 18, 1989, pp. 239–52.
24. D. Keeble, 'High-technology industry', *Geography*, 1990, p. 361.
25. Hatzichronoglou, *op. cit.*
26. Cf. *Ibid.*
27. *Ibid.*, p. 5.
28. Whether this is a reasonable proposition depends on the way in which a sector is defined. The pharmaceutical industry in country B may be confined to the production of established products such as aspirin, using traditional processes, and without R&D for the development of new drugs. In this case, the sector would operate very differently than in a country such as Switzerland and we might question if it should even be called the same sector. However, the availability of pharmaceuticals to the residents of country B, and their approximate cost, might be the same as in Switzerland as a result of imports. If the sector is defined to include the distribution network as well as actual production, the level of OTI would therefore be the same in both countries.
29. ITI is based on the embodiment of R&D from other sectors of the economy in the technology employed in a given sector, but it does not indicate the extent to which innovation in that sector has been transmitted elsewhere.
30. M. E. Porter, 'Clusters and the new economics of competition', *Harvard Business Review*, November–December 1998, pp. 85–6.
31. P. A. David, 'Computer and dynamo: the modern productivity paradox in a not-too-distant mirror', in *Technology and Productivity: The Challenge for Economic Policy*, OECD, Paris, 1991.

32. Moreover, the best customers for high-tech products may well be in low-tech sectors, in which case policies that impede innovation in the latter will also retard the growth of the former.
33. D. C. Mowery and N. Rosenberg, *Paths of Innovation: Technological Change in 20th-Century America*, Cambridge University Press, Cambridge, 1998.
34. *Ibid.*, p. 5, italics in original.
35. Albeit without making clear the mechanisms that connect a firm's behaviour with various aspects of the environment. OECD, 1997, *op. cit.*, pp. 31–7.
36. *Ibid.*, pp. 50–1.
37. M. Tushman and P. Anderson, 'Technological discontinuities and organizational environments', *Administrative Science Quarterly*, 31, 1986, pp. 439–65.
38. Hatzichronoglou, *op. cit.*, p. 8.
39. Exploratory work to answer part of the posed question has been carried out by K. Smith, 'Industrial structure, technology intensity and growth: issues for policy', paper presented to the *METU Conference in Economics III*, Economic Research Center, Middle East Technical University, Ankara, Turkey, 8–11 September 1999.
40. J. M. Utterback, *Mastering the Dynamics of Innovation: How Companies Can Seize Opportunities in the Face of Technological Change*, Harvard Business School Press, 1994, pp. 158–60, argues that the emergence of substitutes actually spurs increases in innovation in established products.