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A NEW TAXONOMY OF ECONOMIC SECTORS WITH A VIEW TO POLICY IMPLICATIONS

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Abstract

This paper is an attempt to tease out a taxonomy of economic sectors based on a systems approach to innovation and economic growth that may be useful for policy analysis. The taxonomy explored here revolves around novel products rather than ethereal knowledge-producing entities. This insight goes back to Allyn Young (1928) and Joseph Schumpeter (1934) who argued that the introduction of new goods was the engine of economic growth. More precisely, our taxonomy of sectors focuses on novel products which are efficiency-enhancing within and between sectors through the market mechanism. The scheme revolves around the relationship between 'Enabling' and 'Recipient' sectors (which gives the taxonomy its name: ER), and offers a lens for viewing and interpreting a substantive part of the mechanics of modern economic growth. The last part of the paper briefly discusses a few immediate policy implications, although it has the potential for greater use and value in this regard.

Key words: innovation, economic growth, enabling linkages approach, knowledge-based economies, novel products, efficiency-enhancing innovations

J.E.L. Classifications: L60, O38

1. INTRODUCTION

Although all economic sectors[1] are to some extent separated, most of them are also interrelated, and generally speaking, the economy can be thought of as a *system* with interconnected parts. The idea that the economy is a system with interconnected sectors goes back at least to Quesnay's *Tableau Economique* (constructed by Francois Quesnay in 1758)[2], and is important as a conceptual basis for understanding of the process of economic growth.

Ideally, a systems approach to innovation and economic growth would contemplate all of the linkages (interactions and interdependencies in all directions) between the various sectors of the economy. However, taking into account all of the linkages is not feasible if we want to say something more than 'everything depends on everything'. A workable systems approach to innovation and economic growth should recognize that as a rule every sector interacts with every sector, but should also accept that in the real world some linkages between sectors matter more than others because they *enable* the evolution of the system as a whole. For lack of a better term, we will call this methodological stance the *key linkages approach to innovation and economic growth* or *enabling linkages principle.*

Recent – and very influential, especially at the OECD level - developments on the theoretical front are in line with the enabling linkages principle. For example, the model developed in Romer (1990b) revolves around the existence of a "knowledge-producing sector" and its linkages with other sectors, and suggests that the knowledge sector is strategically significant as an engine of enabling technologies for other industries. However, this latter approach faces the very difficult problem of empirically identifying knowledge-producing sectors.

The literature concerning innovation-related classifications of industries is surprisingly scant and tends to be dominated by the Pavitt's (1984) taxonomy and the OECD's popular High-tech/Low-tech dichotomy[3]. The use of Pavitt's taxonomy is understandable because his classificatory scheme has merit, but the use of the High-tech/Low-tech dichotomy is unfortunate because it has only limited scope. Carroll et al, (2000).

The present paper is an attempt to tease out a taxonomy of economic sectors based on the enabling linkages principle. The taxonomy explored here focuses on novel products rather than ethereal knowledge-producing entities. This insight goes back to Allyn Young (1928) and Joseph Schumpeter (1934) who argued that the introduction of new goods was the engine of economic growth. More precisely, our taxonomy of sectors focuses on novel products which are efficiency-enhancing within and between sectors through the market mechanism. Furthermore, our taxonomic scheme revolves around the relationship between 'Enabling' and 'Recipient' sectors (which gives the taxonomy its name: ER), and offers a lens for viewing and interpreting a substantive part of the mechanics of modern economic growth. As will become apparent, the proposed ER taxonomy is independent of R&D intensities, innovation rates, and the technological complexity of the products involved. In addition, the ER taxonomy circumvents the awkward problem of identifying 'knowledge-based' sectors. Finally, we believe that the ER taxonomy provides insight into the evaluation of the following innovation policy principle: 'enabling sectors and only enabling sectors should be the target of government initiatives'. Our policy interpretation of the ER taxonomy, based on the existence of *complementarities* between enabling and recipient sectors, calls into question this principle.

The rest of the paper is organized as follows. In the next section we consider the notion of knowledge-based sector introduced by the OECD and the corresponding identification problem. In section 3 we define 'Enabling' and 'Recipient' sectors and put forward the ER taxonomy of economic sectors. Section 4 briefly explores a few policy implications emerging from the ER taxonomy. Section 5 offers a summary and concluding remarks. The paper also contains a terminological appendix designed to facilitate interdisciplinary communication between policy makers (many of whom come from the hard sciences and social sciences excluding economics) and economists.

2. THE KNOWLEDGE-BASED ECONOMY AND THE IDENTIFICATION PROBLEM

It is generally agreed that the systematic search for profitable new ideas lies at the core of the knowledge-based economy. To quote a recent influential OECD document at length,

> OECD science, technology and industry policies should be formulated to maximise performance and well-being in "knowledge-based economies" – economies which are directly based on the production, distribution and use of knowledge and information. This is reflected in the trend in OECD economies towards growth in high-technology investments, high-technology industries, more highly-

> skilled labour and associated productivity gains. Although knowledge has long been an important factor in economic growth, economists are now exploring ways to incorporate more directly knowledge and technology in their theories and models. "New growth theory" reflects the attempt to understand the role of knowledge and technology in driving productivity and economic growth. In this view, investments in research and development, education and training and new managerial work structures are key.
>
> OECD (1996, p.3, quotation marks in original)

However, the definition of a knowledge-based economy (henceforth KBE) as one which is "directly based on the production, distribution and use of knowledge and information" does not help us to identify a KBE in the real world, as all industries depend to some extent on the *use* of knowledge.

2.1 Knowledge-based Economy and New Growth Theory

To gain further understanding of the meaning of a KBE a rapid look at the theoretical base underlying the preceding OECD quotation is useful. The unifying thread running through New Growth Theory (NGT) is the view that technological change is essentially an economic phenomenon, or at least explicable in economic terms[4]. In fact, technological change is considered as the result of intentional investments in R&D and of R&D spillovers. Furthermore, the mechanics of economic growth emphasized by NGT captures the traditional idea of *uneven* growth: some sectors generate more economic growth than others, for example through the creation of new knowledge.

The basic NGT approach can be described as follows.

• Technological change is largely stimulated by the profit motive and comes from a *knowledge-producing sector* which generates efficiency-enhancing ideas.

• Ideas created by that knowledge-producing sector are used by firms in the intermediate-goods sector, which produces product outputs which may be consumed or invested.

• The final-goods sector uses labor, human capital, and the set of capital goods to produce final output.

• An equilibrium gives the paths for prices and quantities corresponding to a preassigned set of parameters such as the stock of human capital and final output elasticities.

• The free market mechanism does not lead the economy to an optimum because knowledge will be generated privately only if its dissemination is limited by (for example) patents thus allowing those who generate knowledge to sell it for a positive price.

• The *existence* of the knowledge-producing sector is central to the NGT approach because it renders increasing returns to scale in the economy as a whole inevitable. Intuitively, an increase in 1% in all inputs results in an increase in output by more than 1% because, by definition, nonrival inputs (somewhat roughly, profitable ideas) can be used over and over again simultaneously by many people.

It should be stressed, again, that the foregoing theoretical approach has a major empirical limitation concerning the *identification* of the knowledge-producing sector. The first economist who made this point forcibly was Nicholas Stern:

> There are problems with this approach, however, if we try to tell empirical stories. It is extremely difficult to identify

anything approximating to a knowledge-producing sector
in real economies. (…) Stern (1991, p.127)

To summarize, NGT emphasizes the importance of new ideas in producing knowledge-driven growth, but the difficulty in making the insight operational centers around the identification of the leading growth sector.

2.2 Knowledge-based Sectors and High-technology Industries

In the mid-1980s the OECD invented a classificatory scheme based on R&D intensity: high-technology, medium-technology, and low-technology industries. Table 1 shows the latest OECD classification. This table is reminiscent of the *Tableau Economique* 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 1 *Tableau Technologique.* The idea of classifying sectors on the basis of their level of technology while interesting, is plagued with difficulties. Carroll et. al (2000).

TABLE 1 HERE

The OECD's dichotomy of high-tech/low-tech industries has recently been applied with regard to the concept of KBE. As mentioned before, the notion of KBE revolves around the tripod "use-production-distribution of knowledge". The OECD (1999) has focused on the first leg of this tripod and has not only adopted a working definition of *knowledge-based sectors* based on the intensity of inputs of technology and human capital but also has *empirically* identified the set of knowledge-based sectors. The OECD *defines* knowledge-based sectors as "those industries which are relatively intensive in their input of technology and/or human capital", and *identifies* the set of knowledge-based sectors with High-technology industries, Communication services, Finance insurance, real estate and business services, and Community, social and personal services. (OECD, 1999, p.18)

Any identification of sectors, in this fashion, even if offered as a suggestive rather than a substantive scheme must meet some minimum requirements to ensure its validity. The distinction, for example, between the group of knowledge-based sectors (for short, group A) and other types of sectors (nonknowledge-based sectors or group B) has to be based on the assumption that we can study the characteristics of group A most effectively if they are not merged with the characteristics of group B. In claiming that group A is distinct from group B, the OECD is saying that the characteristics commonly found in A are so distinct from those in B that it is methodologically improper to mix the two indiscriminately.

The essential distinguishing feature between a sector belonging to group A, say 'Office and computing machinery', and another sector contained in group B, for example, 'Non-ferrous metals', is, the OECD asserts, the intensity of the use of knowledge characterizing the firms in each sector. However, knowledge in this context, is an ordinal (not cardinal) variable involving 'more' or 'less' knowledge, but not how much. When we say, for example, that 'Radio, TV and communication equipment' is a knowledge-based sector and 'Non-ferrous metals' is not, we imply that the former uses more knowledge that the latter. This prompts the question: can we confidently say that Micron Technology (developing a new generation of memory chips) or Microsoft (developing the "universal canvas" technology[5]) are using more knowledge than ALCOA (developing the “inert anodes” technology[6]) or Rio Tinto (developing the “wettable cathodes” technology[7])? The basic answer is that we cannot. The data do not exist. But, what we do know is that according to the OECD allocation of industries ALCOA and Rio Tinto are not included in the group of knowledge-based sectors. This assertion is, to say the least, debatable.

The line of division between groups A and B is blurred. Given this fuzziness in delimiting ‘knowledge-based sectors’ from ‘nonknowledge-based sectors’ and in formulating their distinctive characteristics, the identification problem remains unsolved. Consequently, there is *no* solid ground for using the OECD classification of knowledge-based sectors for policy analysis.

As a first approximation, the problem of making a conceptual framework for policy analysis is a problem of consistent taxonomy of economic sectors guided by theoretical contributions and qualitative evidence derived from direct inspection of the growth process. The second approximation consists of a ‘reality check’, that is, the taxonomy should be quantifiable, so that the linkages underlying the scheme can be empirically tested. Hopefully, it should be useful in understanding patterns of activity in individual firms. Finally, the taxonomy should be simple enough for policy makers to visualize their role in the taxonomic system. In the next section, we offer the basis for what may be a useful taxonomy for policy makers in this area.

3. A TAXONOMY BASED ON A SYSTEMS APPROACH TO INNOVATION AND ECONOMIC GROWTH

The present section is conceptual, not empirical. We suggest an organizing tool to look at the mechanics of economic growth, rather than trying to derive specific stories from empirical data. It starts with a pictorial description of the beneficial flows emerging from the innovation process, and then reverts to the enabling linkages principle. Specifically, the aim here is to isolate qualitatively a few stylized linkages between sectors in a way that is tractable and suggests a new taxonomy of economic sectors.

3.1 A Qualitative Matrix of Beneficial Flows

In general, the formulation of any analytical framework is constrained by a trade-off between 'tractability' and 'generality', and the present paper is not an exception to this general rule. Hence, because of the extreme difficulty of directly observing actual knowledge spillovers, our focus is on the creation and distribution of novel products (either new products or existing products with new quality attributes) which are in turn producer goods[8]. It is assumed that when the inputs purchased by one sector from another (or from the same sector) embody efficiency gains or quality improvements, the benefits are fully appropriated by the selling sector.

Ideally, it would be desirable to construct an economy-wide qualitative matrix in order to map the beneficial effects of novel products. A pictorial description of such a matrix of beneficial flows is given by Table 2, where (a) sectors originating novel products comprise the rows; (b) sectors (including end consumers) using those novel products comprise the columns; and (c) the symbols $\oplus$ and $\varnothing$ indicate the existence and non existence, respectively, of beneficial effects[9].

Considerable insight into the role of the various sectors as growth-stimulating entities can be found by measuring the magnitudes implicit in this qualitative matrix. However, the word 'idealization' in Table 2 reminds us that much of the required factual information does *not* exist at the product level.

TABLE 2 HERE

Even though the level of abstraction of the qualitative matrix is very high, this visual model illuminates the separation between those sectors sending beneficial flows through novel products and sectors receiving those flows. A glance at Table 2 suggests the following starting point: there may be sectors able to enhance the economy-wide ability to produce through the creation of novel products because of their particular impact on other sectors.

3.2 The Enabling/Recipient Taxonomy

Inevitably, terminology will play a crucial role in the formulation of the taxonomy, so that we must begin with two definitions: (a) an economic sector is termed *enabling sector* if the principal purpose of the innovative endeavors of the firms operating in that particular sector is to create novel efficiency-enhancing products for use as producer goods in other sectors or eventually in the same sector; and (b) a sector buying novel efficiency-enhancing products is termed a *recipient sector*. The distinction between enabling and recipient sectors is not a mere terminological quibble. It will become apparent that it makes a substantial difference for analysis and policy if firms are included in one class of enabling sectors rather than another.

It follows from the preceding definitions that the very existence of an enabling sector presupposes the existence of at least one recipient sector. Or, to put it differently, in correspondence with each enabling sector there will be one or more recipient sectors. This correspondence between sectors is established through a host of linkages between enabling and recipient firms.

It should be noticed that the demand for novel products from the recipient sectors is essentially a *derived* demand, that is, demand for products not for their own sake but in order to use them in the production of goods and services. It should also be noticed that causation does not just run one way, from enabling to recipient sectors. There are also feedback effects. For example, cost-reducing products may be created on the basis of the insights provided by recipient sectors. These ideas are shown in Fig.1.

FIGURE 1 HERE

It seems reasonable to base the ranking of enabling sectors on the number of their associated recipient sectors because the larger the number of receiving sectors the greater the impact of an enabling sector on the growth performance of the economy as a whole. For example, electronics has an enabling role in a large number of industries, including food processing, automotive manufacturing, precision engineering and defence, medical and health services, information technology, and telecommunications. By contrast, novel products originated in the food processing industry, do not appear to have a magnifying effect on the growth rate of other sectors. To begin with, we formulate a crude separation into two polar classes:

• *High-powered* enabling sectors (those that influence most of the recipient sectors); and

• *Non-enabling* sectors (economic sectors whose novel products do not have perceptible influence in the efficiency of other sectors).

High-powered enabling sectors (such as ‘Office and computing machinery’) and non-enabling sectors (such as ‘Wood products and furniture’) are at opposite extremes of the scale. But there is an area between these two classes where the degree of impact of novel products on other sectors may be more or less noticeable. We describe them as 'strongly' and 'weakly' enabling sectors. Since it is difficult in practice to draw a precise line as to where these two *intermediate* classes begin and end without specific empirical research, the sector members of the two classes '*Strongly* enabling sector' and '*Weakly* enabling sectors' should be considered only as tentative.

Thus, our classification of manufacturing industry consists of four classes:

- Class 1: High-powered Enabling Sectors;
- Class 2: Strongly Enabling Sectors;
- Class 3: Weakly Enabling Sectors; and
- Class 4: Non-enabling Sectors.

The enabling/recipient taxonomy (ER taxonomy for short) emerges through the allocation of the manufacturing sectors mentioned in Table 1 to these classes. The ER taxonomy is presented in Table 3. Even though each class of sectors contains variety, these categories appear to offer a useful alternative scoping view on a rough-and-ready basis.

TABLE 3 HERE

Given its high level of aggregation, Table 3 has its limitations. In particular, it is necessary to carry out field studies in order to validate the groupings of sectors presented in the Table. Similarly, the rank order within each class of sectors cannot be established without detailed empirical research. However, even at this level of aggregation it has some value.

A comparison of Tables 1 and 3, for example, shows that there is no one-to-one correspondence between the High-tech/Low-tech classification of industries given by the OECD's *Tableau Technologique* and the ER taxonomy of sectors. It is true that there are sectors such as 'Office and computing machinery' or 'Radio, TV and communication equipment' that are both High-tech and High-powered enabling sectors, and similarly, we can find sectors that are both Low-tech and Non-enabling, e.g. 'Textiles, apparel and leather' or 'Woods products and furniture'. But the correspondence collapses for several sectors. For example, 'Aircraft' and 'Pharmaceutical products' are High-tech, but not High-powered enabling sectors.

The industries at the bottom-half of the OECD list (Low-tech or 'mature' industries) have a long history and their technological evolution mainly depends either on the creation of novel products in the enabling sectors or on relatively low R&D effort within the industry. All these mature industries are included in Class 3 or in Class 4 in Table 3.

The ER taxonomy is related to the classificatory scheme developed by Pavitt (1984). Pavitt's taxonomy proved a fruitful framework for understanding patterns of industrial innovation through the identification of supplier dominated firms, specialized equipment firms, scale intensive firms and science based firms. The ER taxonomy, on the other hand, aims at mapping sectoral links based on the creation and distribution of novel products that allow producers to carry out their productive activities more efficiently. As a result, the ER taxonomy can be thought of as a complement to the Pavitt's taxonomy, not a substitute for it.

Before advancing to the policy consequences of the ER taxonomy, three points should be emphasized. First, it is not the purpose of the suggested taxonomy to capture the totality of the rich picture of the complex interdependencies among industries underlying the process of technological change, nor the intra and interindustry technological externalities. In particular, Table 3 makes the tacit assumption that the efficiency-enhancing effects emerging from the acquisition of novel products work through the price mechanism, and therefore, can only constitute pecuniary externalities. In other words, novel products are just that, products, not technological externalities.

Second, the ER view highlights certain aspects of the mechanics of innovation and economic growth and put others in the background. It stresses the flows of efficiency enhancing products, but the demand side of the growth process (e.g. income elasticities of demand) and other macroeconomic parameters (such as company tax rate, tariff rates, and tax concession rate) are obscured. The fact that such aspects are left out of the picture does not imply that they are irrelevant, merely that they are not the central focus of the taxonomy.

Finally, the ER taxonomy is based on stable distinguishing features of the various economic sectors (the enabling role of a sector does not appear to fluctuate significantly, except under technological revolutions), and thereby, constitutes a departure from the standard dimensions used to classify innovative industries such as R&D intensities, innovation rates, and technological complexity of products. In addition, a corollary advantage stands out, namely: the ER taxonomy does not depend on the identification of knowledge-based sectors.

4. POLICY IMPLICATIONS

Conventional economic theory looks at the world through the lens provided by the frictionless, perfectly competitive, constant returns to scale paradigm, and implies what may be called the "equipollent postulate', namely: "all sectors are of *equal* value to the domestic economy." It asserts, also, that government support should be limited to providing a satisfactory economic environment, with policy intervention justified only when free markets are subject to market failure.

One of the fundamental tenets of NGT is that perfect competition is logically inconsistent with economic growth. To be more precise, Romer (1990a) has shown that under perfect competition it is *impossible* to remunerate nonrival inputs, and therefore, the assumption of price-taking competition must be abandoned. In this context, while the NGT has provided a useful formal framework and a number of important insights, it has not yet been very helpful on the question on how policy might influence growth. As indicated in section 2.1, NGT rejects the equipollent postulate and appears to suggest that there is scope for government intervention beyond deregulation. The neo-Schumpeterian dimension of NGT places innovation at the centre of long-run economic growth, and focuses attention on R&D expenditure as a key policy variable.

Essentially, the NGT view is that a country's economic prosperity depends on its capacity for innovation, for which technological innovation is a key driver in advanced countries. In rough outline,

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*. These implications, simple as they are, seem to have played an important role in guiding public technology policies in several OECD countries, for they have focused on the stimulation of R&D expenditures. A variety of tax benefits, for example, are provided in several countries in order to achieve the desired stimulation.

Apparently, some countries seem to have accepted the 'black box' without a full understanding of its contents. There is uncertainty as to whether R&D expenditures are a reliable proxy for technological innovation, and importantly, as to the specific roles played by R&D investment in relation to some mature industries. Faced with this uncertainty, what should policy makers do? A range of possibilities exist, including, but not restricted to the following four:

1) Do nothing and let markets rule, at least until and if economists provide more useful advice.
2) Accept the neo-Schumpeterian NGT argument and provide support for those sectors that engage in R&D, on the assumption that R&D does drive innovation and, thus, economic growth. As already indicated, the problem here is that all sectors undertake some R&D and, similarly, are to some extent knowledge-based, so that this 'shotgun' approach is likely to have uncertain impacts. If all sectors receive such support, this amounts to an endorsement of the equipollent postulate.
3) Accept the neo-Schumpeterian NGT argument and encourage weakly enabling and non-enabling sectors to mimic the innovation behavior of the firms in the other two classes by, for example, increasing their R&D expenditure. Unfortunately, as Pavitt (1984) points out, in some industries such as textiles and wood products, novelty has occurred primarily on the basis of innovation undertaken in other sectors, rather than having been 'developed in-house'. Hence, would encouragement of innovation in

these sectors have any effect? Would it better directed to sectors that, in our terminology, have ‘enabled’ innovation in textiles and woods products?

4) As tends to be the case in practice, constituting almost the conventional, OECD-inspired wisdom, restrict support to the ‘High-tech’ industries that undertake high levels of R&D. This would run foul of the difficulties noted earlier.

We conclude this section by identifying where we think the ER taxonomy provides insight into the current policy debate in OECD countries, especially Australia. To this end, we will proceed by first providing a plausible interpretation of Table 3, and then considering what it means in policy terms.

One of the key features of the so called ‘new economy’ is the interaction between ‘old’ or ‘mature’ sectors performing bulk processing of resources, such as foodstuffs, metal and ores, and relatively ‘new’ sectors, e.g. office and computing machinery, yielding efficiency-enhancing products for use in a variety of industries. In other words, a ‘new economy’ consists of two interrelated worlds: a traditional part (bulk processing of resources) and a newer part (creation of enabling products). The two worlds are not neatly split at the macro level, but it would be always possible to say whether a particular company is mature or enabling. Table 3 is a telescopic view of these interlaced worlds[10].

In the course of the shift from the ‘old economy’ to the ‘new economy’ policy makers have become obsessed with the magic incantation of the enabling sectors. The rapid growth of these sectors appears to revive the Say’s law of markets which can be paraphrased as “the supply of efficiency-enhancing products across industries creates its own demand” and underpin the current conventional wisdom, namely ‘enabling sectors and only enabling sectors should be the target of government initiatives’.

The problem with this principle is that it overlooks the simple, yet fundamental insight that there may be low growth were it not for the activities of 'new economy' firms, but there would be no growth were it not for 'old economy' firms. We believe that the policy message conveyed by the shift from the 'old economy' to the 'new economy' has been deciphered incorrectly for at least two reasons. First, enabling and non-enabling sectors are *complementary* rather than substitutes. Human beings cannot survive by eating 'digital food' or protect their health from cold weather by wearing 'virtual clothes'. Second, the economic dynamics of the enabling sectors operating in countries where the fundamentals for technological change are in place[11] suggests that the 'new economy' firms will remain on the innovation treadmill irrespective of *additional* incentives.

Due to the existence of fierce competition, the firms included in classes 1 and 2 will normally operate on their innovation possibilities frontier, determined by the stock of human capital and the endowment of physical capital. Therefore, it would be really difficult to stimulate *additional* R&D expenditure through government incentives in these classes. Undiscriminating subsidies, for example, would give rewards for R&D investment that would have happened anyway.

'Create destructively or perish' is the golden rule for most new economy firms. In contrast, creative destruction does not appear to be the predominant form of non-price competition for firms operating in classes 3 and 4. The crucial role of these firms from the point of view of aggregate growth is to *defray* a substantial proportion of the fixed innovation costs incurred by firms operating in groups 1 and 2. Or, to put it differently, a substantial, perhaps key part, of the demand for innovation that drives firms in groups 1 and 2 originates in groups 3 and 4, the mature sectors in an economy.

In essence, we believe that it is neither necessary nor desirable to focus government incentives to economic growth *only* on classes 1 and 2. The firms operating in these sectors are obliged by the forces of competition and increasing returns to scale to invest in innovation to the *maximum* possible in order to survive. What these sectors basically need is a world class endowment of human capital and science and technology institutions addressing their needs. Government support for the science base in universities and research institutes is important for both classes (High-powered and strongly enabling sectors). In particular, government funding for cooperative research (collaboration between enabling sectors, universities and research institutes) to maintain (and attract) 'new economy' firms is not only important but imperative.

The relative theoretic and policy neglect that mature sectors have faced in recent decades, especially in countries that are dominated by such sectors is evident. Our view is that classes 3 and 4 (mature sectors) deserve more attention, or at least attention comparable to that devoted to classes 1 and 2. For a small economy such as Australia's, the enhancement of the absortive capacity of mature sectors through technology importation and dissemination may be just as important as R&D for domestic enabling sectors.

It is a mistake to think that the newer part of the economy will completely dislodge the traditional part of the economy. In the foreseeable future mature sectors will occupy a sizable proportion of the economy because the existence of enabling sectors presupposes the existence of recipient sectors. More precisely, a substantial part of the market size for enabling sectors is given by the demand for innovation from mature sectors. Hence, the end result is that the level (and rate) of innovation of the ‘new economy’ companies strongly depends on the performance of the ‘old economy’ firms.

5. SUMMARY AND CONCLUDING REMARKS

People intuit that innovation in one enabling sector may enlarge the size of the market for output in other sectors. For example, developing and integrating satellite technology may allow new commercial and military applications, and thereby, extend the market size of whole sectors that revolve around them. We have put forward a systematic way of looking at economic sectors from the innovation-growth prism capturing this intuition. What we have done is qualitative and conceptual. Our main objective has been to provide a clear conceptual framework for further interpretation and quantitative work. To this end, we have used the enabling linkages principle.

Economic sectors have been grouped in four classes on the basis of their attributes to enhance the economy-wide ability to grow. In essence, Enabling sectors provide novel products that are efficiency-enhancing across sectors, and Recipient sectors are the beneficiaries of the corresponding pecuniary externalities. The ER taxonomy is independent of R&D intensities, innovation rates, and technological complexity of products, and circumvents the awkward (and unresolved) problem of identifying ‘knowledge-based’ sectors.

The ER taxonomy involves logic, facts, and policy implications, as in all economics. The logic is simple: new ideas incorporated in efficiency-enhancing novel products lead to increasing returns not only because the ideas can be used repeatedly and simultaneously by many people, but also because these novel products generate cost-savings across sectors. In a nutshell, increasing returns are *magnified* by the enabling role of some economic sectors. The questions of fact are related to the ranking provided by Table 3. Detailed empirical analysis will shed light not only on the ranking within the classes but also on the reasonableness of the allocation of sectors to the different groups.

To answer policy questions economists have to separate what is relevant from what it is not in relation to the policy issue under consideration. An important point is the complementarity between enabling sectors and mature industries: innovation in enabling sectors influences the size of the market for output in mature sectors, but there is also a reverse influence in that the market size for enabling sectors hinges on the demand for innovation from mature sectors.

One can view the ER taxonomy as arguing for the importance of mature industries in the growth process because these industries help defray the (fixed) innovation costs incurred by the enabling sectors. Specifically, our policy interpretation of the ER taxonomy is that governments should put less emphasis on targeting specific enabling sectors (classes 1 and 2) and concentrate more on enhancing the absorptive capacity of the mature industries (classes 3 and 4). This interpretation reverses the predominant conventional wisdom.

We plan to extend our qualitative approach in a number of directions. First, we are aware of the need of quantification of the enabling linkages principle underlying the ER taxonomy[12]. Our second goal will be to explore in depth the role of government in coordinating economic activity, particularly through market-friendly measures, in the light of the ER taxonomy.

Appendix: Nomenclature Employed in this Paper

Because this paper will be of interest for policy makers and other analysts who are not necessarily economists, we believe it may be useful to have some kind of terminological discipline, and describe the most important technical terms employed in this paper.

Beneficial effects of Innovation

The concept of innovation comprises both technological innovation (creation of novel products or new production processes[13] by means of R&D effort or other forms of creative effort) as well as organizational (or managerial) innovation. Novel products are sold to others –either to other enterprises or to consumers. Normally, if a novel product is a producer good, it should serve to improve either the efficiency or the quality of output in the buying sectors, while if it is a consumer good, it should presumably enhance the quality of life directly. A new process is a technical improvement in one's own production methods and can have productivity effects by reducing input prices or consumer good prices. Organizational innovations are changes to the business' strategies, structures or routines which aim to improve the performance of the business.

Some innovations may have only a direct impact on growth (the creation of digital games), while others may also have indirect repercussions through productivity-enhancing effects (new technologies that reduce input prices) or through efficiency-enhancing effects (new software labor-saving products). These beneficial effects can happen either within the sector where the innovation occurs or across sectors or at the consumer level. Furthermore, the beneficial effects of an innovation can be either transmitted through the market mechanism, and thereby, the beneficial effect is paid for, or can percolate through the economy without full compensation due, for example, to reverse engineering.

It is worthwhile mentioning here that an R&D project ends when the innovation has been materialized, that is, when the work is no longer experimental and pre-production begins. Even when a research endeavor turns out to be unsuccessful (and by definition, there is no innovation), an R&D project may yield valuable information, and the returns to this kind of knowledge can often not be excluded. For example, a drug that fails to obtain the FDA approval may leave fruitful insights for new drugs, but the unapproved drug cannot be considered as an innovation from the economic viewpoint.

Splitting Innovation Spillovers

In the most recent line of empirical research technological change is also considered as the result of the existence of both intentional investments in R&D and R&D spillovers. Estimates of innovation spillovers started with Griliches (1958), and today we have at our disposal a number of papers where estimations of the magnitudes of R&D spillovers can be found. These include Adams (1990), and Bernstein and Nadiri (1988), (1989). The measurements of spillovers suggest that there are substantial intra and interindustry R&D spillovers. Notwithstanding, the econometric evidence is plagued with unresolved questions concerning the existing estimates[14].

It is generally agreed that the term ‘R&D spillovers’ refers to the fact that firms undertaking R&D are unable to appropriate all of the benefits from their R&D activities. This standard characterization of the notion of spillovers may be termed *weak* (or catchall) definition of R&D spillovers, because it implies that the spillover effects occur through two quite distinct channels. One is "knowledge spillovers", which refer to the effect of R&D performed in one firm in improving technology in a second firm without compensation for the former. The other refers to inputs purchased by one ('beneficiary') firm that embody efficiency- enhancing attributes and quality improvements, and these beneficial effects are not fully appropriated by the selling (or 'source') firm.

It should be emphasized that the weak definition of R&D spillovers encompasses two different mechanisms of transmission: while knowledge spillovers are not transmitted through the market mechanism, the inputs purchased by the beneficiary firms are obviously transacted in the market place. Or, to put it differently, the weak definition encapsulates both technological externalities (knowledge spillovers) and pecuniary externalities (efficiency gains through the acquisition of novel products)[15].

It should also be emphasized that the second channel postulates that the source firm is, at least to some extent, "unfairly" treated by the market mechanism because it provides benefits to other firms without getting the corresponding piece of the action. This prompts the question: why are source firms willing to do a "favor" to beneficiary firms? The answer may well be that source firms introduce new inputs to gain competitive advantage and are totally satisfied with the premium price received for their novel products. In other words, in a free market economy transactions presumably occur because both the beneficiary firm *and* the source firm are willing to exchange the items in order to maximize their profits. In brief, no one is doing a favor to anyone.

The foregoing leads naturally to a *strong* definition of the notion in question, namely: R&D spillovers are knowledge spillovers originated by firms undertaking R&D activities. Clearly, the strong definition constitutes a proper subset of the weak definition.

The partition between the weak and the strong definition leaves us with a ‘residual’ of innovation spillovers, namely beneficial spillovers originated either by efficiency-enhancing novel products or by reductions in the input prices. This residual category is useful to visualize one of the simplifying assumptions underlying the ER taxonomy: Table 3 focuses *only* on innovation spillovers that constitute pecuniary externalities stemming from efficiency-enhancing novel products.

For the sake of completeness, we finally make contact with the nomenclature used in Kettle et al. (2000, esp. pp. 485-486): the ‘weak’ and the ‘residual’ definitions of innovation spillovers correspond to ‘pure knowledge spillovers’ and ‘rent spillovers’, respectively.

TABLE 1
THE TABLEAU TECHNOLOGIQUE
(LATEST 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*	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

* 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.

TABLE 2

QUALITATIVE MATRIX OF BENEFICIAL EFFECTS OF NOVEL PRODUCTS (IDEALIZATION)

Sector **making** the novel products ↓	Sector **using** the novel products →				
	Sector1	Sector 2	. . .	Sector n	Consumers
Sector 1	$\oplus$	$\oplus$	. . .	$\varnothing$	$\oplus$
Sector 2	$\varnothing$	$\oplus$	. . .	$\oplus$	$\oplus$
.					
.					
.					
Sector n	$\varnothing$	$\varnothing$	. . .	$\varnothing$	$\oplus$

<u>Legend</u>

$\oplus$: Existence of beneficial effects

$\varnothing$: Nonexistence of beneficial effects

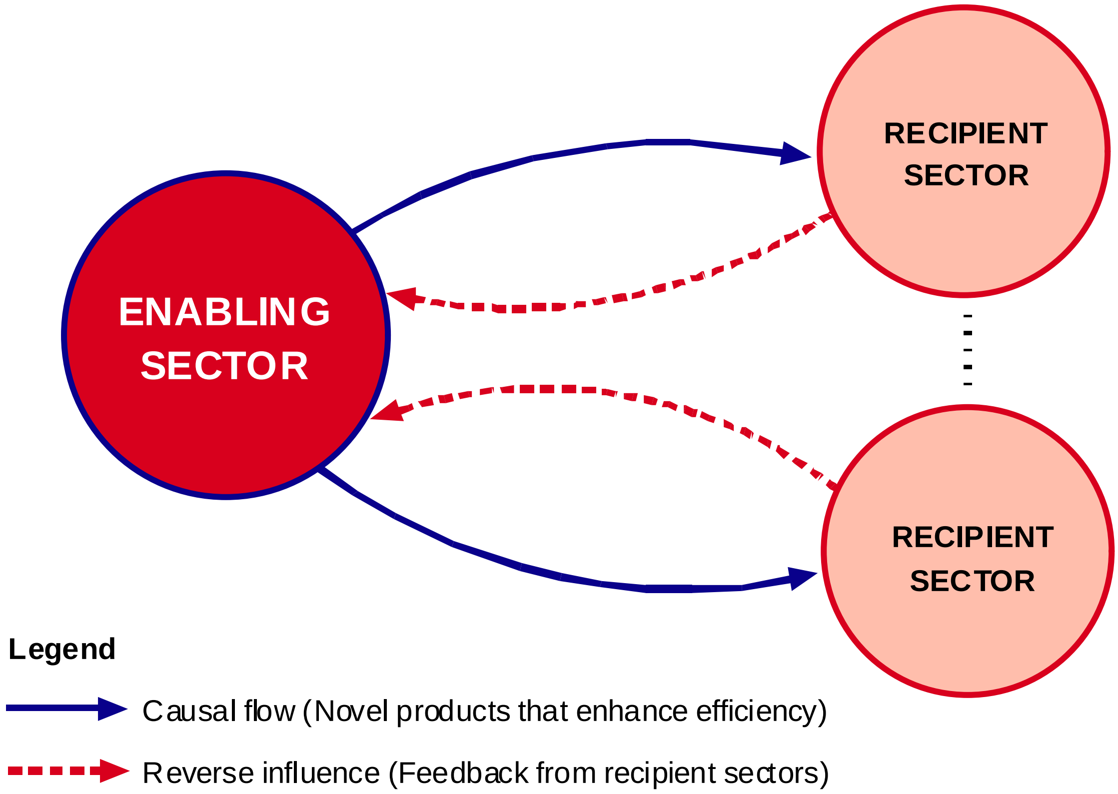
ENABLING SECTOR
RECIPIENT SECTOR
RECIPIENT SECTOR
Legend
Causal flow (Novel products that enhance efficiency)
Reverse influence (Feedback from recipient sectors)

FIGURE 1

TABLE 3
THE ENABLING/RECIPIENT TAXONOMY

Economic Sectors	Enabling	Recipient
Class 1		
• Office and computing machinery	⊗ ⊗	®
• Radio, TV and comm. equip.	⊗ ⊗	®
• Professional goods	⊗ ⊗	®
• Electrical machinery	⊗ ⊗	®
• Non-electrical machinery	⊗ ⊗	®
Class 2		
• Aircraft	⊗	®
• Motor vehicles	⊗	®
• Shipbuilding and repairing	⊗	®
• Chemicals	⊗	®
• Pharmaceutical products	⊗	®
• Other transportation equipment	⊗	®
Class 3		
• Non-ferrous metals	θ	®
• Non-metallic mineral products	θ	®
• Metal products	θ	®
• Iron and steel	θ	®
• Petroleum products	θ	®
• Other manufacturing	θ	®
Class 4		
• Rubber and plastic products	θ θ	®
• Paper and paper products	θ θ	®
• Food, beverages and tobacco	θ θ	®
• Textiles, apparel and leather	θ θ	®
• Wood products and furniture	θ θ	®

<u>Legend</u> (Table 3)

⊗ ⊗: High-powered enabling sector
⊗: Strongly enabling sector
®: Recipient sector
θ: Weakly enabling sector
θ θ: Non-enabling sector

References

Adams, James D. (1990): "Fundamental Stocks of Knowledge and Productivity Growth", *Journal of Political Economy*, 98, pp.673-702.

Aghion, P. and P. Howitt (1992): "A Model of Growth through Creative Destruction", *Econometrica*, March, 60, pp. 323-351.

Bernstein, Jeffrey, and M. Ishaq Nadiri (1989): "Research and Developmentand Intra-Industry Spillovers: An Empirical Application of dynamic Duality", *Review of Economic Studies*, 56, pp. 249-269.

Bernstein, Jeffrey, and M. Ishaq Nadiri (1988): "Interindustry R&D Spillovers, rates of Return, and Production in High-Tech Industries", *American Economic Review*, 78, pp. 429-434.

Carroll, Peter, Eduardo Pol, and Paul L. Robertson (2000): "Classification of Industries by Level of Technology: An Appraisal with Some Implications", *Prometheus* (forthcoming).

Griliches, Zvi (1958): "Research Cost and Social Returns: Hybrid Corn and Related Innovations", *Journal of Political Economy*, 66, pp. 419-431.

Grossman, Gene M. and Elhanan Helpman (1991): *Innovation and Growth in the Global Economy*. Cambridge, MA: MIT Press.

Kettle, Tor J., Jarle Moen, and Zvi Griliches (2000): "Do Subsidies to Commercial R&D Reduce Market Failures? Microeconometric Evaluation Studies", *Research Policy*, April, 29, pp.471-495.

OECD (1996), *Science, Technology and Industry Outlook: Part V – Special Theme: The Knowledge-based Economy*. Directorate for Science, Technology and Industry, March, pp.1-42.

OECD (1999), *OECD Science, Technology and Industry Scoreboard 1999. Benchmarking Knowledge-Based Economies*, pp. 1-178.

Pavitt, Keith (1984): "Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory", *Research Policy*, 13, pp. 343-373.

Quesnay's Tableau Economique (1972), Kuezynski, M. and R.L. Meek, eds., London, Macmillan.

Romer, Paul M. (1990a): "Are Nonconvexities Important for Understanding Growth?", *American Economic Review*, May, 80, pp. 97-103.

Romer, Paul M. (1990b): "Endogenous Technological Change", *Journal of Political Economy*, October, 98 (5), pp. 71-102.

Schumpeter, Joseph, A. (1961): *History of Economic Analysis*. London, Allen & Unwin.

Scitovsky, Tibor (1954): "Two Concepts of External Economies", *Journal of Political Economy*, April, pp. 143-151.

Stern, Nicholas (1991): "The Determinants of Growth", *Economic Journal*, 101, January, pp. 122-133.

Young, Allyn (1928): "Increasing Returns and Economic Progress", *Economic Journal*, 38, December, pp.527-542.

Endnotes

1 In this paper we follow the standard practice of using the terms 'sector' and 'industry' synonymously.

2 According to Schumpeter (1961, esp. pp. 241-243), the *Tableau Economique* can be thought of as a pictorial description of a system of simultaneous equations, and thereby, a precursor of the input-output system and modern general equilibrium analysis.

3 Although the latest OECD classification of industries consists of four groups of industries, (High tech, Medium-high tech, Medium-low tech, and Low-tech industries), it is customary to refer this as the OECD's "dichotomy" of high-tech/low-tech industries.

4 For the sake of definiteness, NGT is identified here with the line of formal reasoning inaugurated by Romer (1990b), and the contributions of Grossman and Helpman (1991), Aghion and Howitt (1992), and others.

5 Compound document that blends information from an internet browser with information from a Microsoft application like Excel spreadsheet.

6 New cost-reducing technology expected to be introduced into aluminium plants in a year or two.

7 New technology expected to double the savings of the inert anodes technology and to be introduced into aluminium plants in four or five years.

8 The relationships between knowledge spillovers, R&D spillovers and externalities is not free of subtleties, and they are discussed in a brief appendix at the end of this paper.

9 The allocation of the symbols $\oplus$ and $\varnothing$ that appears in Table 2 is for illustrative purposes only.

10 In passing, we note that the use of language about the "old" and the "new" economy is confusing because it opens the possibility of a play on words. In fact, a new economy is characterized by the *coexistence* of old (mature) and new (enabling) sectors, and therefore, an integral part of a "new" economy is still the "old" economy.

11 The fundamentals for technological change are: a stable and predictable political environment; credible macro and microeconomic policies; secure property rights; an appropriate endowment of human capital; suitable technology distribution power (i.e. science and technology institutions that address the industry needs); and government support for innovation.

12 We are designing a large scale field study to quantify the enabling linkages underlying the ER taxonomy.

13 In many cases the creation of a novel product is linked to new manufacturing processes, that is, process development turns out to be an integral part of product development.

14 Kettle et al. (2000) contains a detailed discussion of the difficulties associated with measurement of R&D spillovers.

15 The partition of external economies into technological externalities (external influences in the technological possibilities of a firm) and pecuniary externalities (external economies operating through the market mechanism) is due to Scitovsky (1954).