BACK

TECHNOLOGICAL TRANSFORMATION, IPRs AND SECOND BEST THEORY

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by

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I. INTRODUCTION

The research interests of myself and my co-authors have concerned economic growth, technological change and general purpose technologies — pervasive technologies that transform our whole society. Our many publications culminated in *Economic Transformations: General Purpose Technologies and Long Term Economic Growth* by Richard Lipsey, Kenneth Carlaw and Cliff Bekar (hereafter LCB). This work has only incidentally raised issues concerning intellectual property rights. Before I stray into these grounds where I am not an expert, let me say a bit about those things in which I have specialized.

II. THE NATURE AND POWER OF ECONOMIC GROWTH

Economic growth is not just more of the same. Although, for example, people living in the first decade of the 21st century have about 10 times the measured purchasing power as their counterparts living in the first decade of the 19th, they consume it in the form of new products made with new processes and new forms of organizations.

People living in the first decade of the 20th century did not know modern dental and medical equipment, penicillin, bypass operations, safe births, control of genetically transmitted diseases, personal computers, compact discs, television sets, opportunities for fast and cheap world-wide travel, air conditioning, and food of great variety free from ptomaine and botulism, much less the elimination of endless kitchen drudgery through the use of detergents, washing machines, electric stoves, vacuum cleaners, refrigerators, dish washers, and a host of other labour-saving household products that their great grandchildren take for granted—to mention just a few of the most dramatic changes in products. Nor could our ancestors of one hundred years ago have imagined the robot-operated, computer-controlled, modern factories that have largely replaced their noisy, dangerous, factories that spewed coal smoke over the surrounding countryside.

In summary, technological change not only increases our incomes; it transforms our lives through the invention of new, hitherto undreamed of products that are made in new, hitherto undreamed of ways.

III. CAUSES OF GROWTH

There main causes of growth are generally agreed and a fourth is controversial.[1]

[1] Lack of space prevents me from addressing the fourth alleged cause, rising population. The recently popular 'Unified Growth Theories' that attempt to explain changes in output and population simultaneously use a basic assumption that the pace of technological change is an increasing function of the size of a country's population. So sustained growth follows inevitably once the population gets large enough. I mention this here, not only because such models are the current flavour of the day, but because policy

1. *Increases in market size* allow for increased gains from trade based on a finer division of labour and facilitate the exploitation of scale economies. One of the best examples is the transformation of the U.S. economy that ensued when the railroads merged a series of local markets into one national market with the enormous effects analysed by Chandler (1977).
2. *Investment in physical and human capital,* which gives each worker more capital and more of the stock of existing knowledge, tends to increase per capita output.
3. *Technological change* is the third and most important source of growth. In the long term, new technologies in the forms of new products, processes and forms of organisation, are potent sources of economic growth, as emphasised many years ago by Joseph Schumpeter.[2]

New investment without any technological change implies more or the same. If e.g., technologies were frozen at 1900 levels while investment continued, there would be only so much that people could do with more 1900-vintage products such as horses and buggies, bicycles, and holidays at adjacent seaside resorts and these products would have been produced by a host of new 1900-vintage, pollution-producing factories.[3] In contrast, the illustrative list of new products and new processes given earlier shows that new products, production processes and forms of organisation have transformed peoples' standards of living, how and where they work, their social and political ways of life, and even their value systems in ways that mere capital accumulation and expanding markets within the context of unchanging technology could not have done.

Savings and investment do nonetheless matter because most new technologies are embodied in new capital equipment whose accumulation is measured as gross investment. Thus anything that slows the rate of embodiment of new technologies through investment, such as unnecessarily high interest rates, slows the rate of growth.

IV. GENERAL PURPOSE TECHNOLOGIES

Technological change runs the whole gamut from continuous, small, incremental changes, through discontinuous radical inventions, to occasional new general purpose technologies (GPTs) that evolve to transform societies.

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makers are likely increasingly to encounter policy advice derived from such controversial, and in my view unrealistic, theories.

[2] We define technological knowledge, technology for short, as the set of ideas specifying all activities that create economic value. It comprises: (1) knowledge about product technologies, the specifications of everything that is produced; (2) knowledge about process technologies, the specifications of all processes by which goods and services are produced; (3) knowledge about organisational technologies, the specification of how productive activity is organised in productive and administrative units for producing present and future goods and services. (LCB: 58).

[3] Similarly, holding technology constant and expanding market size would have some effect, but could not be the source of exponential growth over the centuries.

IV.1 Characteristics

GPTs begin as fairly crude technologies with a limited number of uses and evolve into much more complex technologies. As they diffuse through the economy, their efficiency is steadily improved. As mature technologies, they are widely used for multiple purposes, and have many spillovers.[4] GPTs expand the space of possible inventions and innovations of new products, processes, and organisational forms. These in turn create other new opportunities, and so on in a chain reaction that stretches over decades, even centuries. An example is the computer, which, among myriad other things, enabled the development of efficient, precisely controlled robots, which in turn enabled the restructuring of many factories along highly automated lines. We use the term 'spillover' to cover all such interrelations.

It is important to note that many of the responses to a new GPT cannot be modelled (for measurement or any other purposes) as the consequence of changes in the prices of flows of factor services produced by the previous GPT. This is because most of the action is taking place in the technological structure of capital. For example, the most profound effects of electricity came not from a fall in the price of power, but in making possible new products and new process that were technically unavailable with steam. For a case in point, the revolution in the layout of factories that led to the mass production assembly line could never have happened with steam driven factories. Also, with the range of household machines that revolutionized household work, no steam engine could have been attached to the carpet sweeper to turn it into a vacuum cleaner, to the ice box to turn it into a refrigerator, or a washing tub to turn it into a clothes washing machine,

As these examples illustrate, GPTs rejuvenate the growth process by presenting new agenda for R&D directed at finding new applications of the main technology and new technologies based on, or derived from, that main technology. Think, for example, of all the myriad applications of both computing power and electricity in today's world.

Any technological change requires alterations in the structure of the economy, what we call the *facilitating structure,* changes that often proceed incrementally, more or less unnoticed. Typically, however, major new GPTs cause extensive structural changes to such things as the organisation of work, the management of firms, skill requirements, the location of industry, and supporting infrastructure. When these occur, we speak of revolutions.[5]

IV.2 GPTs in history

I have little space here to discuss the fascinating history of the couple of dozen GPT that we identify as having had transforming effects over the last 10,000 years. They all fall into five main classes: materials (e.g., bronze), power (e.g., the steam engine), information and communication technologies or ICTs for short (e.g., the computer),

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[4] We call these spillovers because this term covers more than the commonly used term "externalities" (See LCB 100 ff)

[5] Probably the most important modern exception is the laser, which is used throughout the economy for multiple purposes. Lasers caused no revolution because they fitted well into the existing social, economic and institutional structures.

transportation (e.g., the railroad), and organisational technologies (e.g., the factory system). Here is a list of the main ones with the approximate dates at which they came into common use in the West, not when they were first invented.

(1) The domestication of plants (9,000-8,000 BC)

(2) The domestication of animals (8,500-7,500 BC)

(3) Smelting of ore. (8,000–7,000 BC)

(4) The wheel (4,000-3,000 BC)

(5) Writing (3400-3200 BC)

(6) Bronze (2800 BC)

(7) Iron (wide 1200 BC)

(8) The heavy plough[6]

(9) The water wheel (early medieval period)

(10) The three-masted sailing ship (15th century)

(11) Printing (16th century)

(12) The steam engine (late 18th-early 19th century)

(13) The factory system (late 18th-early 19th century)

(14) The railway (mid 19th century)

(15) The iron steam ship (mid 19th century)

(16) The internal combustion engine (late 19th century)

(17) The dynamo to generate electricity (late 19th century)

(18) The motor vehicle (20th century)

(19) The airplane (20th century)

(20) The mass production, continuous process, factory[7] (20th century)

(21) The computer (20th century)

(22) Lean production (20th century)

(23) The Internet (20th century)[8]

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[6] This has all the aspects of a GPT except multiple uses. We list it because the agriculture was transformed by this technology that accounted for possibly 95% of the economy. Among many other things, the induced organisational change from the two to the three field system altered diets greatly and changed social relations because the system required joint village decisions. It also led to a number of important new derivative technologies, the most important of which were an efficient horse collar and horse shoes.

[7] Although continuous process techniques began to evolve with the rationalisation that followed the electrification of factories in the late 19th century, we date the emergence of mass production as a GPT at Henry Ford's innovations in the first decade of the 20th century.

(24) Biotechnology (20th century)

(24) Nanotechnology[9] (sometime in the 21st century)

There is just space for one illustration of the transforming effects of these GPTs. The introduction of bronze in Mesopotamia in the early 3rd millennium BC had profound effects.[10] It revolutionised warfare since large forces armed with interlocking bronze shields and bronze spears could for the first time surround a smaller force and wipe it out with few losses for itself. These 'economies of scale in warfare' allowed the development of multi-city empires and began the era of more or less continuous organized warfare in which we still live. This warfare led to the increasing importance of military leaders compared with the priesthoods and over a couple of centuries kings replaced priests as rulers. Also, since a spatially extended empire could not be controlled by the type of priest-led command economy that characterised the early hydraulic civilisations of Sumer, command economies gave way to much more market orientation. *If introducing multi-city empires and organized warfare, as well as replacing priests by kings, and the command economy by a significantly market-driven one is not a major technology-driven transformation, then I do not know what is.*

V. HOW THE WEST GREW RICH

During most of the middle ages, the West was backward by the standards of China and the Islamic countries. Indeed, Kenneth Pomeranz has argued that even as late as the beginning of the 18th century, there was little to chose between China and the West in terms of economic performance. How then did the West pull ahead of the rest of the world technologically in the 18th and early 19th centuries (and much earlier in many places)? We argue in LCB that the major difference between the West and the rest, including China and Islam, was the presence of Western science in general and Newtonian mechanics in particular. The later was the underpinnings of the First Industrial Revolution.

We trace the origins of Western science and the reasons for its non-emergence in Islam and China back through developments in the Middle Ages to early Christianity and Islam. There were many historical accidents. Two of the most important were that Christianity had to make its way into a sophisticated Greco-Roman civilisation and a well established state. This forced the church fathers to become philosophers and created a pluralism between religion and the state. In contrast, Islam came out of the desert and spread by the sword. This gave rise to theocratic societies with no distinction between state and religion. Also there was no need for the Islamic religious leaders to become philosophers and to great extent they remained ignorant of both philosophy and Greek science. Second, when the Islamic authorities decided to translate Greek learning into

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[8] We list electronic computers and the internet as separate GPTs since that is the common usage and the one we adopted in LCB. But subsequent work has led us to group these two technologies into a single GPT, which we call 'programmable computing networks' (PCN). (See Carlaw, Lipsey and Webb 2007)

[9] Nanotechnology has yet to make its presence felt as a GPT but its potential is so obvious and developing so quickly that we are willing to accept that it is on its way to being one of the 21st centuries most pervasive GPTs.

[10] For a full discussion see Dudley (1991).

Arabic, they encountered Aristotle at the outset and it was difficult to reconcile many of his teachings with that of Judeo-Christian-Islamic beliefs. So they confined Greek science to a lesser status than learning based on the Koran. In contrast, when Western scholars rediscovered Greek learning, they were confined to Latin transactions which emphasised Plato but not Aristotle. By the time the disturbing teachings of Aristotle were discovered, the Western Christian church had become committed to the doctrine that there was no conflict between Greek science and Christian theology. A century of debate ensued with Thomas Aquinas at the centre. Conservatives sought to reject Aristotle and with him much of Greek science while liberals argued, in the end victoriously, that there was no conflict and to discover nature’s laws was a reverent attempt to discover God’s purposes.

A key institutional development in the West during this period was in the concept of treating a body of people as a corporation, separate from the state and distinct from the individuals who compose it. Guilds were first. Later came the universities, and then several cities. The plethora of corporations, each with its own range of authority, was a key development in the West's growing pluralism. The power of corporations created a split between civil and ecclesiastical law on the one hand, and the corporations on the other. Importantly, it produced the concept of *degrees of jurisdiction*.

Once they became corporations, universities set standards and granted licences to become teachers. Within broad limits set by the need to at least appear to conform with church dogma, members of a university were free to pursue virtually any intellectual avenue. Over a couple of centuries, universities came to teach a more or less common agenda across most of Europe. “For the first time in history, there was an educational effort of international scope, undertaken by scholars conscious of their intellectual and professional unity, offering standardized higher education to an entire generation of students.” (Lindberg 1992: 212) Through these universities, “…the West took a decisive (and probably irreversible) step toward the inculcation of a scientific worldview that extolled the powers of reason and painted the universe—human, animal, inanimate—as a rationally ordered system” (Huff 1993: 189).[11]

The concept of a university, as a place where scholars and their pupils gathered to study, was an Islamic invention, which spread to the West. But what never happened in the Islamic world, and what was crucial in the West, was the development of the university as a corporation, an organization that provided a neutral space where new ideas could be developed more or less free from state and religious censure. In Islam, universities were collections of scholars each one of whom issued his own certificate of competence to his students. Because Greek science was suspect, it was largely taught outside of universities by isolated scholars. Thus, as with so many other innovations, the West was not the original inventor; instead it critically improved on technologies and institutions that it had copied from elsewhere.

The universities were critical in culturing science. Many other societies, particularly those of Islam and China, produced many breakthroughs in science and

[11] By the Early Modern period, as is the case with most institutions that gain political power, universities tried to suppress elements of the newly emerging science. As we document in Chapter 6, their attempts were made much more difficult by the existence of the printing press and the production of standardized texts.

technology. However, Europe alone generated the incremental, cumulative advances that were necessary to produce modern mechanistic science, the science of the Industrial Revolution, as well as the more sophisticated sciences that followed and underlay the Second Industrial Revolution in the latter part of the 19th century. All cumulative advances require some form of 'memory' but technology and science require different forms. Artefacts provide a memory for the non-tacit aspects of technological knowledge. They have a physical existence and technological improvements are embodied in better artefacts; they are there for all to use and to improve on in their turn. So, for most of history artefacts have provided an unplanned, and largely unmanaged, technological memory.

In contrast, there is no automatic memory for scientific knowledge. Creating an institutional memory for science was an important contribution of the Medieval Western universities: it was recorded in libraries; it was taught in class rooms; scholars contributed to its evolution. This continuity was lacking in China and Islam where many scientific discoveries were made but subsequently forgotten.[12]

The contrast between physical memory for technologies and institutional 'memory' for scientific discoveries is important in answering the question: Why is it that other regions in the world, especially those with important historical achievements in science and technology, failed to produce modern mechanistic science and the sustained innovation that came to depend on it? An important part of the answer is that they lacked the independent institutions that provided an effective memory needed for cumulative scientific advances.

The Industrial Revolutions in the late 18th and early 19th centuries that pulled the West decisively past the rest of the world technologically did not just happen out of the blue. Instead, it was the culmination of a trajectory of mechanisation of textile production whose program had been laid down by Leonardo di Vinci in late in the 15th century. Early inventions came first and then the harder ones slowly yielded to the desire to mechanise. Finally by the later 18th century, mechanisation had proceeded far enough that it paid to take production out of the cottages (the putting out system) and transfer it to sheds (the early factory system). Those who are unwilling to see the Industrial Revolution as the culmination of a long process stretching over centuries fail in Usher's words "…to recognize the essential cumulative character for mechanical achievements." Importantly, the First Industrial Revolution was a mechanical revolution and built on some of the great engineering works of the 18th century, all of which employed Newtonian science.

> "Brought together by a shared technical vocabulary of Newtonian origin, engineers, and entrepreneurs—like Bolton and Watt—negotiated, in some instances battled their way through the mechanization of workshops or the improvement of canals, mines, and harbors. …[B]y 1750 British engineers and entrepreneurs could talk the same mechanical talk. They could objectify the physical world, see its operations mechanically and factor their common interests and values into their partnerships. What they said and did changed the Western world forever" (Jacob 1997: 115).

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[12] See Qian (1985) for detailed discussion and illustrations of this important point.

The Second Industrial Revolution in the later part of the 19th century was based on more modern science than the first. Chemicals, steel production and electricity led the way, and all of these needed the type of science that was available nowhere outside of the West. With electricity, a long trajectory of scientific advances designed to discover the nature of magnetism and electricity began with the publication in 1600 of Gilbert's *de Magenta,* one of the first works of truly modern science, extended through numerous discoveries and inventions, until finally in 1867 the invention of the dynamo allowed the efficient generation of electricity.

VI MODELLING THE ECONOMY

Economic theory is meant, among other things, to explain, interpret, and offer advice as to how to alter in desired ways, the experience of the real world, including the growth performances that I have briefly discussed above. I distinguish two main branches of the subject that attempt these tasks, *neoclassical* and what I call *structuralist evolutionary*.

VI.1 Neoclassical

Although there is a well developed neoclassical theory of economic growth, most of the policy advice in which I am interested is generated from the static general equilibrium (GE) version of neoclassical economics. In its canonical statement first formalised by Arrow and Debreu, competition is pictured as the *end state* of a competitive equilibrium in which firms maximise under conditions of perfect knowledge, or risk, and the givens are tastes and technology. Desirable market characteristics include:

- all individuals having full access to existing knowledge;
- the absence of market power so that price taking is the typical situation;
- prices are equal to opportunity costs and do not, therefore, allow for any pure profits;
- rents associated with market power of oligopolies, monopolies, and other forms of market power are minimized;
- sources of non convexities such as scale effects and high entry costs are minimal or non-existent.

VI. 2 Structuralist-evolutionary

In what we call the structuralist-evolutionary (S-E) view[13], competition is pictured as a *process* in which

> "...firms jostle for advantage by price and non-price competition, undercutting and outbidding rivals in the market-place by advertising

[13] Neoclassical, general-equilibrium, resource-allocation models, as well as aggregate-production-function growth models, do not include institutions or structures that differentiate one economy from another, and they model technology as flat. In contrast, S-E theories include the economy's institutions and its "facilitating structure" and model technologies as structured.

> outlays and promotional expenses, launching new differentiated products, new technical processes, new methods of marketing and new organisational forms, and even new reward structures for their employees, all for the sake of head-start profits that they know will soon be eroded. ...[in short] competition is an active process." Blaug (1997, p.255-6)

Technology is endogenous and is one of the most important strategic variables in inter-firm competition. Firms operate under conditions of uncertainty (about which more later) and, as a result, they grope into an uncertain future in a profit seeking but not profit maximizing manner. The things that drive the economy towards desirable results are the very characteristics that are seen as undesirable sources of market imperfections in neoclassical economics.

- Given that most private sector R&D is internally financed by existing firms, large profits are the drivers of much technological change and economic growth.
- Price taking is not the most desirable market structure because perfectly competitive industries rarely innovate, instead oligopolies are at the forefront of technological advance.
- Given the uncertainly associated with invention and innovation, large profits are the carrot that induces agents to attempt leaps into the unknown.
- An innovator knows something that his competitors do not and this asymmetric information produces the needed profits.
- Thus, although the special case of an entrenched monopoly that does not innovate because it has a protected market is regarded as undesirable, most other 'market imperfections' are the very forces that drive economic development.
- Scale effects, rather than being imperfections to be offset, are some of the most desirable results of new technologies, particularly those associated with the "historical increasing returns" analysed by LCB (397-401).
- Non convexities associated with entry costs for new firms and development costs for new products are the accepted costs of innovation and the source of some of the rents that drive such behaviour.

VII ECONOMIC POLICY

Because they see different market characteristics as desirable, the two theories have radically different implications for economic policy. According to S-E theory, many of the very market imperfections that are seen as impediments to optimality in neoclassical theory are important sources of growth in a dynamic economy and are to be encouraged not suppressed. In contrast, neoclassical theory stresses the creation of an efficient, or optimal, allocation of resources and derives a unique set of policy prescriptions that apply with equal force to all economies and all activities, whatever their differences.[14] *This is to remove market 'imperfections' or 'distortions' wherever they are found.*

VII.1 The Second Best Problem

The theory of second best shows that the above-stated neoclassical advice does not provide reliable rules for piecemeal improvements in welfare.[15] Although the conditions for a first best optimum are clear, establishing some of these conditions when others go unfulfilled does not guarantee increasing economic efficiency, a proposition proven in Lipsey and Lancaster (1958) and earlier stated by Samuelson (1948) and Pareto (1898).

Things that prevent attaining an efficient allocation of resources are variously called 'constraints' or 'distortions.' Since neither of these terms cover everything with which I am concerned, I use the term "sources of divergence," *sources* for short. I define these as anything that if introduced on its own would prevent the achievement of a perfectly competitive, price-taking equilibrium that was Pareto efficient and otherwise attainable.

The list of the many prevalent *sources* is daunting.[16] Each point in the list is a different type of *sourc*e and each type contains many items.

1. Market structures are rarely competitive enough to make marginal cost equal to price: oligopoly, monopolistic competition and monopoly vastly outnumber cases where firms are price takers. Some price setting behaviour occurs because of technologically determined factors such as scale economies, some because of firm-determined entry barriers and product characteristics[17] and some because of policy.
2. Since most products are differentiated, fixed costs that create significant non-convexities are ubiquitous: e.g., entry costs of new firms, including those needed to establish its distribution networks; development costs of new products, and advertising needed to publicise them.
3. Location in space creates overlapping oligopolies where neither monopolistic nor perfect competition is typically possible (Eaton and Lipsey, 1989 and 1997: Introductory Essay). Fixed costs ensure that space is inhabited by "lumpy" firms located at distinct points in space. This implies that free entry will not drive profits to zero (Eaton and Lipsey, 1978). Furthermore, the Nash equilibrium under

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[14] A distinction is usually made between the purely positive concept of a Pareto efficient allocation of resources and the normative one of an optimum allocation, which requires the value judgments about such things as the relevance of the potential compensation test. Since most of what I say in this paper is applicable to both concepts, I use the terms efficiency and welfare interchangeably.

[15] See Lipsey (2007) for a detailed discussion of second best theory and its critics.

[16] These are quoted from Lipsey (2007).

[17] There is no impersonal market in which the price of a generic version of differentiated products, such as refrigerators, is determined. Individual manufacturers must administer their own prices and take externally determined sales as their market signals. For discussion of the effect of product differentiation on the competitive model see Eaton and Lipsey (1989).

free entry produces a pattern of rectangular markets rather than the efficient pattern of Löschian hexagons (Eaton and Lipsey, 1976).

4. Many labour markets are not auction markets. Wages are often payments on implicit long term contracts, varying with age. Wages are often signalling devices. Labour markets are often internal, employers promoting existing employees rather than searching outside for better candidates. Even where these, and many other similar forms of behaviour, are efficient responses to non-perfectly competitive circumstances, they upset the Paretian conditions in labour markets.
5. Governments intervene in many markets with such things as rules, regulations quantity restrictions, taxes and subsidies, import tariffs and non-tariff barriers.
6. Incomplete and asymmetric information abounds.
7. Positive and negative externalities are attached to many economic activities.
8. There are many missing markets.
9. One of the foundations of welfare economics, the maximisation of utility functions in which the only arguments are the goods and services consumed by the agent in question, is currently being challenged (Sen 1994 and Layard 2005). Modern research confirms that individuals are social animals and what others do enters into their utility functions in myriad ways. This greatly alters set of policies that can increase welfare.

We do not have a GE model of an institutionless, fully uncontrolled market economy with the mix of market forms that characterises a typical industrialised economy, as outlined in point 1 above. Thus, there is no compelling theory or evidence to suggest that such economies are statically efficient. Furthermore, we do not have a model that incorporates the other static *sources* mentioned above. The upshot is that we do not know the necessary and sufficient conditions for achieving an economy-wide, static, first-best, allocation of resources even in a theoretical economy that includes the full array of actual *sources* rather than a few selected ones.

Achieving an economy-wide second best optimum allocation looks even more difficult than achieving the first best. Without a model of the economy's general equilibrium that contains all of the above *sources,* we cannot specify the existing situation formally and so cannot calculate the second best optimum setting for any one *source* that is subject to policy change.[18]

None of this has prevented many economists from trying to develop general rules for making second best improvements — e.g., "reducing the largest 'distortion' must bring gain"[19]. I consider many of these in Lipsey (2007) and

[18] This is an important point since much of the literature that is critical of second best theory assumes that economists know a distortion when they see one and know that the ideal policy is to remove the distortion directly, something that is necessarily welfare improving only in an imaginary one-distortion world.

[19] This particular proposition that occurs in the literature in several variants does not provide operational advice in a multi-*source* economy, since it is impossible to measure and hence rank the size of various items of the sources from all of the nine different types listed above.

argue that they are all open to some, often all, of the following types of objections.

Type 1 objections: Only one type of *source* is considered, such as taxes, and then usually only two items from this *source*, one that is given and one that can be varied by policy. No one knows if the results will stand in models with more items from the one type of *source,* to say nothing of items from the other types of *sources* listed above.

Type 2 objections: Many of the propositions are based on restrictive assumptions not found in reality, and so provide no obvious guide for practical policy — for example, all goods are substitutes for each other, or all have unit elasticities of demand, or the economy is separable into parts that do not interact to with each other,

Type 3 objections: The possible effect on technological change is ignored—a serious shortcoming since small induced changes in the growth rate can have large cumulative effects on GDP.

To consider the great importance of this last type of objection, we first need to consider the economics of knowledge

VII.2 The Economics Of Knowledge

Long before endogenous knowledge entered macro growth theory, micro economists were writing about the economics of knowledge and of endogenous technological change. Smoker (1966) and Rosenberg (1982) were among the first to follow Schumpeter's lead in studying how the economic system generated technological knowledge endogenously. (At the time, both standard micro and macro models treated technology as exogenous.) Paul Romer (1986), who introduced endogenous technological change into macro growth models, argued that what made his new growth theory important was that it pointed to something that really was different, knowledge.

VII.2.i Characteristics of knowledge

Knowledge, which lies behind technology and hence much of economic growth, is unlike ordinary private commodities in that it is non-rivalrous — one person's use of some piece of knowledge does not diminish any other person's ability to use the same knowledge. Consider the 2*x*2 matrix shown in Figure 1. Pure private goods of standard economic analysis are rivalrous—if you eat this apple, I cannot also eat it—and excludable—if I buy it, it is clearly mine not yours. Pure public goods, are non-rivalrous and non-excludable—e.g., everyone benefits when the police protect some public neighbourhood and no one can own that protection in order to exclude others who enter that neighbourhood from gaining the benefit.[20] *Knowledge is different from both of these*. It is non-rivalrous, since one person's use of it does not diminish another person's ability to use it, and it is (at least partially) excludable. The reasons for the latter characteristic

[20] Importantly, what is or is not a public good at any one point in time depends on technology. For example, radio and TV were initially public goods but with the development of cable, satellite, and other types of excludable transmission technologies, they were able to take on the characteristics of a non-rivalrous but excludable technology.

are (1) that much technological knowledge can be patented or copyrighted; (2) some of it can be kept secret—at least for enough time to profit from having access to it; and (3) most of it requires a great deal of acquired tacit knowledge before it can be profitably employed.

Figure 1

	Excludable	Non-Excludable
Rivalrous	NORMAL GOODS Apples Dresses TV Sets Computers A seat on an aeroplane	COMMON PROPERTY Fisheries Common Land Wildlife Air Streams
Non-Rivalrous	KNOWLEDGE All codifiable knowledge pure and applied. (*Partially* excludable.)	PUBLIC GOODS Defence Police Public Information Broadcast signals Some navigation aids

VII.1.ii Implications for efficiency conditions

The upshot according to Romer (1990, 1994) is that the conditions for an optimum allocation of the nation's resources do not apply to knowledge even if all the other optimum conditions could (unrealistically) be satisfied. The optimum condition for any piece of knowledge that already exists is that its price be zero since that maximises its use, but it minimizes the monetary incentives for inventors to risk their time and money on discovering new applied knowledge. In contrast, we could imagine (at least in theory if not in practice) giving perfect protection to inventors and innovators, allowing them to extract rents equal to the full value of their new knowledge. But this would slow the diffusion of this knowledge. Since technologies build on each other in a path dependent manner—what has gone before provides a platform for what can be invented and innovated now—slowing the diffusion of existing knowledge and practices also slows the development of new knowledge and practices. So there is a trade off between more secure property rights to encourage inventions and innovations and less secure property rights to encourage diffusion and consequent downstream inventions and innovations—and there is nothing in the neoclassical model to tell us the optimum position on this tradeoff. So formal analysis alone cannot derive necessary and/or sufficient conditions for an optimum allocation of resources in an economy in which knowledge is being created endogenously. Deciding how to make the invention-diffusion trade off necessarily involves judgments that cannot be derived from formal models.

Using a different line of argument S-E, economists who study the generation of knowledge from a micro point of view come to the same conclusion that there is no unique optimum allocation of resources. The argument starts by distinguishing between risk and uncertainty, as Frank Knight (1921) did long ago. Risky events cannot be foretold with certainty but they have well-defined probability distributions and hence well-defined expected values. Uncertain events have neither well-defined probability distributions nor well-defined expected values. Because innovation means doing something not done before, it always involves an element of Knightian uncertainty. When major technological advances are attempted, it is typically impossible even to enumerate in advance the possible outcomes of a particular line of research, including all of the applications that can be made from some successful breakthrough. Furthermore, the search for one objective often produces results of value for quite different objectives. All this implies that agents will not be able to assign probabilities to different occurrences in order to conduct risk analysis as conventionally defined.

A key characteristic of risky situations is that two agents possessed of the same information and presented with the same set of alternative actions will make the same choice—the one that maximises the expected value of the outcome. A key characteristic of uncertainty, however, is that two equally well-informed agents presented with the same set of alternatives actions may make different choices. If the choice concerns R&D, one may back one line of attack while the other backs a second line, even though both know the same things and both are searching for the same technological breakthrough. No one can say which agent is making the better choice at the time that the decisions are being made.[21] So when technology is changing endogenously, profit seeking in the presence of uncertainty, rather than profit maximising in the presence of risk, implies that there is no unique, welfare-maximizing equilibrium of the sort derived in neoclassical static economics.

> *The concept of an efficient or optimum allocation of resources cannot be defined, even in theory, in a world of constant, endogenously induced technological changes made under conditions of uncertainty because future payoffs can only be discovered after they have arrived.*

Of course, if we could foretell the full future consequences of our current actions, we could maximise the present value of all future consumption. But it is in the nature of uncertainty that this cannot be done.

This in turn has another important implication:

> *There does not exist a unique set of formally determined, optimum public policies with respect to technological change in general and R&D or human capital formation in particular.*

[21] Japanese and American firms have been observed to make different R&D decisions although both are searching for the next advance in some product over which they compete. For examples see Dertouzos, *et al* (1989) and Womack *et al* (1990)

Accepting this conclusion has important consequences for how we view economic policy in the area of growth and technological change. If there is no unique optimum rate of R&D, of innovation, or of diffusion, policies that affect these decisions whether directly or indirectly (*and almost all polices have some such indirect effects*) must be based on a mixture of theory, measurement and subjective judgement. The need for judgement does not arise just because we have imperfect measurements of the variables that our theory shows to be important, but because of the very nature of the uncertain world of knowledge-driven growth in which we live.

VII.2.iii Implications for policy

Rejecting optimality does not imply rejecting policies designed to affect the development of knowledge through R&D or other activities. What is rejected is the idea that we can determine *the* best amount of such activity by comparing the actual amount against some formally derived criteria of optimality. After considering and rejecting attempts in the literature to derive general rules applicable to achieving a full second best optima, or for making piecemeal improvements in welfare in second best settings. I conclude (Lipsey 2007 forthcoming):

> "In all practical circumstances, economists investigate policy issues using methods that omit a potentially significant subset of *sources*. Thus we must of necessity make personal judgments about the applicability of such models when predicting where piecemeal, second-best improvements are possible. This is one of the many reasons why policy advice must use a mixture of formal modelling, appreciative theorizing, relevant evidence and an inevitable amount of judgment — and why it must be context specific (i.e., there are few practical generalisations that apply to each and every set of items in each and every *source*). The task is easier if the objective function is more circumscribed than the whole society's welfare. Although all of this may be obvious to economists with policy experience, it is not a warning typically emphasised in public economics texts."

A typical illustration of many these points is found in the excellent article by Baumol (2004). He argues in favour of parity pricing (or ECRU) for copyright fees, and as he observes later in the paper, his argument also applies to some forms of patents. His objective is to ensure that among agents competing for use of some 'resource' the one who wins is the one revealed by current output and input prices to be the most efficient. This analysis is open to my "objection 1" since, although the objective would be desirable in an otherwise first best world, it is not obviously efficiency or welfare increasing in the real world with the myriad *sources* that he does not consider. Clearly, it is Baumol's implicit judgment that the objective is also desirable in such a world. I do not object to that judgment but only insist that this is a second best problem[22] since the relevant prices are all determined in second best situations and it is thus a matter of

[22] Some confusion was caused by Lipsey and Lancaster's use of terms. A 'second best situation' referred to *any* situation in which the first best was unachievable. The 'second best optimum setting' for any *source* referred to the setting of that *source* that maximises the value of the objective function, *given settings on all the other existing sources*. I follow those usages here.

(implicit) judgment that second best ramifications in other markets do not need to be considered.

Baumol's paper also illustrates another of my points that policy is much more amenable to welfare analysis when the objective function is more circumscribed than maximizing the whole community's welfare. In Baumol's case, although maximising community welfare might be a behind-the-scenes objective, the up-front objective is to ensure that, judged by current market signals, the most 'efficient' agent gets the resource. Various policies to this end *can* be assessed in a formal model, even though such a model *cannot* demonstrate conclusively that the policy will increase the economy's overall economic efficiency and/or welfare.

Unusual in such studies of efficiency, Baumol does not ignore the conditions that lead to my "objection 3". When he considers the objection that parity pricing will protect monopoly profits, he takes a Schumpeterian line saying that since these profits are one of the sources of long run technological advance, we should not necessarily dismiss a policy just because it protects them. I agree, but stress that *how much* profit we allow to encourage *some undetermined amount* of technical progress is a judgment call that cannot be established solely by formal analysis. Even if we could quantify these relations (a very tall order), we still would have no formal way of deciding between those who argued that accepting the high profits as the price of the resulting extra R&D was a good bargain and those who argued that it was not.

VII.3 Technology enhancing policies

I follow the dictionary meaning of intellectual property to include "certain names, written and recorded media, and inventions." I call any policy designed to encourage the generation and use of new technological knowledge a 'technology enhancement policy'.

VII.3.i Alternative policies

The judgment that the unaided market would not produce enough new knowledge both because of its beneficial spillovers and because the degree with which, and the time span over which, it can be appropriated is accepted by both neoclassical and S-E economists. United in the goal of wanting to encourage the creation and diffusion of new knowledge beyond what the unaided market would accomplish, the two schools differ on methods.

The neoclassical view runs as follows. Since all agents are assumed to be maximizing expected values under conditions of risk, the expected payoff from all lines of R&D will be equated. This is an important result because (1) it allows economists to aggregate from the micro level to an aggregate R&D flow which has a well-defined, unique marginal product and (2) it implies that any total amount of R&D expenditure is, in the absence of externalities, optimally allocated among the various lines of research and development. Following Arrow (1962), the non-rivalrous nature of knowledge implies that less than the socially optimal amount will be produced by the unaided market. So there is a justification for encouraging knowledge creation by such policy tools as intellectual property protection and encouragement for R&D in the form of tax credits or subsidies, the exact amount of encouragement being what is required to equate the marginal social benefit of this activity with its marginal social cost. The encouragement of R&D through public policy should be "non-distorting". This can be accomplished by either an equal subsidy on all R&D or appropriate intellectual property rights. The standard theory of the firm predicts that the same increase in knowledge production can be obtained either by shifting its marginal cost downwards (by, e.g., an R&D subsidy) or shifting its marginal revenue upwards (by e.g. increasing patent protection). The neoclassical case is for undifferentiated property rights for all kinds of knowledge creation and/or a general subsidy or tax credit but *not* for specific encouragement of any specific line of activity, which would "distort" market signals and cause a departure from the optimal allocation of resources among the various lines of R&D.

S-E theory emphasizes the lack of an optimum allocation that can be determined by formal analysis alone due to ubiquitous non-fulfillment of the static optimum conditions (Lipsey and Lancaster), the non-rivalrous and partially appropriable character of knowledge (Romer) and the uncertainty associated with the generation, diffusion and application of new knowledge (Lipsey and Carlaw). Any one of these three is sufficient to establish the need for technology enhancing policies to be based on a mixture of theory, empirical knowledge, and a strong element of judgment. The theory also predicts that even if patent protection were the same everywhere, its effects could not be duplicated by an R&D subsidy in a world of uncertainty because there is then no well defined expected marginal returns from R&D.

VII.3.ii Patent protection

In this section, I first discuss a few of the alleged differences between patents and copyrights, and then go on to argue that patent systems cannot be neutral in their impact on different lines of R&D. After that, I consider some of the historical evidence, first, on the relation between patents and inventions and then between patents and the invention-diffusion trade off.

My concern is with the development of new technologies whose intellectual property protection is mainly in the form of patents. Copyrights, which mainly protect the expression of 'ideas' in such forms as books and music, share both similarities with and differences from patents, which I do not have space to consider in detail here.[23] I will, however, observe that the differences are often alleged to include two questionable ones. First, that patents require disclosure. But what is disclosed are things that are already disclosed by publication in the case of copyrights. So the end result is much the same. The second is that copyright protection is not symmetrical between the producer and the distributor, the latter often taking much, even most, of the benefit. But this is a matter of market power not a difference that is inherent between patents and copyrights. Often inventors have little market power and most of the benefit of what they discover then goes to the agent who obtains the patent for their invention. Also, once artists obtain market power, say as the Beatles did, they can bargain for much of the payoff from the copyrights on their new works. But there seems to me to be a vastly more important difference in that, as illustrated in my earlier discussion of GPTs, patents cover new technologies many of which have enormous spillovers that affect the path of

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technological change and the course of economic growth often over decades and sometimes over centuries, while copyrights cover creations that have by comparison miniscule spillovers—when they have any at all. For this reason, the social goals in promoting patents and copyrights must encompass some very different objectives

The general neoclassical ideal is for "non-distorting" policies that do not alter relative price signals. But as is well known a patent system cannot be neutral even in an otherwise neoclassical world. In some areas, such as pharmaceuticals, patents are relatively enforceable. In other areas, particularly where the characteristics of the product are continuously variable, patents are difficult or impossible to enforce. So the strengthening of patent laws does not grant temporary monopoly power equally in all lines. Instead, it changes the signals by shifting the expected marginal revenue curve differentially in favour of those where patent laws are relatively easy to enforce and against those where they are not. In neoclassical terminology, there is no such thing as a non-distorting patent policy.

When asking why the West grew rich as we did earlier, the question arises: How important were patent laws? North and Thomas (1973) make a case for their importance, pointing particularly to the reform of the UK patent law in the 18th century, after which there was a big increase in the number of patents, followed by the beginning of the Industrial Revolution — at least as it is popularly conceived. They make a strong case, but against it must be set some contrary considerations.

First, as already observed, the Industrial Revolution was the culmination of a series of technological trajectories stretching back to the early modern period. This was true of mechanised textiles machines and electricity as already mentioned and also of the steam engine that was the final product of a long period of interaction between science and technology that started with early modern investigations into the nature of air and a vacuum associated with names such as Galileo, Torricelli, Pascal, and Otto von Guericke. The majority of the developments in all three of these trajectories took place before the 18th century patent reform and although the number of patents accelerated after the reform, there is no evidence of an acceleration of the inventions and innovations. So it is arguable that more patents were taken out because it was easier and cheaper to do so, but that the scientific and technological developments were due to human curiosity and the expectations of being able to obtain some of the fruits of one's inventions, just as they had been over the previous three centuries.

Second, there have been other periods when major new GPTs were invented and innovated while the appropriate property rights came after, not before, the invention. In Medieval Europe water wheels were used first as grinders of grain but then to mechanise a host of other activities.[24] There is debate about how extensive this Medieval

[24] From about 1,000 AD onwards, the water-wheel-driven cam was used to replace animate energy sources and to mechanize at least some of the production in a wide range of manufacturing processes. Early uses of water wheels in Europe, together with the dates at which this use of each has been first substantiated, include: making beer (987), treating hemp (1040), falling cloth (1086), tanning leather (1138), sawing logs (1204), paper making paper (1238), grinding mustard (1251), drawing wire (1351), grinding pigments (1348), and cutting metal (1443). There were many other uses. In particular, the iron industry was transformed by water power. Stamping mills broke up iron ore prior to smelting. Mills operated trip hammers for forging the blooms. Water-wheel driven bellows allowed the heat of blast furnaces to reach crucial smelting temperatures, so that iron could be melted and cast in the way that bronze had been for

mechanisation process was but that it occurred is beyond debate. The lakes created by the damming of rivers to establish heads of water strong enough to drive a water wheel created problems for those who wished to do the same up stream. Much litigation ensued and eventually riparian rights were defined.[25] But these came after, not before, the profusion of water wheels. Also, the revolution of bio-technology, in which we are still in the early stages, began without intellectual property rights being well established in the areas of biotechnology. As the developments occurred, property rights issues were raised and eventually settled (although not always to everyone's satisfaction). So the evidence of these two GPT revolutions, and others that I do not have time to mention, suggest that new technologies are often invented and innovated without property right protection but that they typically raise new property rights issues that are subsequently settled. No doubt if these are not settled, progress may be slowed, but the inventions and innovations got well underway without the protection that was subsequently deemed helpful. From this historical evidence it seems that there is at least a strong case that property right are defined more in response to the relevant innovations than as incentives to develop them.

Now consider the invention-diffusion trade off emphasised by Romer. An important historical illustration is provided by James Watt's patent on his steam engine. Early in the last half of the 18th century, the understanding grew that application of the steam engine to a wide set of new uses required engines that worked at more pressure than one atmosphere as did Watt's. Then in the last quarter of the century, improvements in iron manufacturing made possible the production of such engines. But Watt opposed such high pressure engines, believing them to be fatally unsafe. Thus, until his patent expired in 1800, the further development of his engine was prevented. Then within two years of its expiry, Trevithick in the U.K and Evans in the US produced high pressure engines whose favourable power /weight ratio was essential to expanding the uses of steam. The invention of the railway and the iron steam ship, along with many other applications, were held up by Watts' patent, which not only slowed the existing steam engine's diffusion, but, more importantly, stalled the invention of many new technologies that required high pressure engines.

This example illustrates the many studies that show inventions to be interrelated, coming in bundles as one piece of new knowledge contributes to the discovery of another. Furthermore, complex technologies do not come into the world fully developed. New technologies usually begin operation in crude form and, as they diffuse through the economy, their efficiency improves and their range of application expands. Many of these new uses require the invention of additional supporting technologies. (Steam, electricity, lasers, and computers are typical examples of technologies that started in crude form and took decades, sometimes centuries, to develop much of their potential.) Thus patents which slow diffusion, also slow downstream inventions and innovations. This makes the overall effects of patents on invention and diffusion indeterminate in the absence of detailed case-by-case knowledge. The important conclusion for policy is that we cannot assume that by strengthening property rights we will always accelerate invention and innovation. Since doing so slows diffusion of any given *pre-existing set* of inventions, we

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millennia. [24] Cast iron became an important new product with many uses.

[25] For details see Gimple (1993) and Gies and Gies (1994).

cannot know in general what it will do to future inventions, many of which depend on the diffusion of existing inventions, nor what it will do to the total amount of future diffusion. Deciding on this trade off is a judgment call, one that, like other similar ones, can be assisted by theory, empirical knowledge and welfare economics but in the end requires an irreducible and significant element of judgement.

VII.3.iii R&D subsidies and tax credits

In the neoclassical model, a generalized R&D subsidy is neutral with respect to private incentives. Since, as we have already observed, the expected value of the payoffs to the last dollar's worth of R&D will be the same in all lines of activity before the subsidy, they will remain so after the introduction of a non-distorting R&D subsidy or tax credit, which is the optimal type of encouragement.

As S-E theorist might observe, however, that given that it is agreed that patents cannot be neutral in their effect (since the degree of enforceability differs greatly among industries), it is not clear why so much emphasis should be placed on having 'non-distorting' R&D policies. The nature of patents places the issue of intellectual property protection squarely in a second best situation and enforcing first best conditions for R&D subsidies is not obviously desirable, even in an otherwise neoclassical world. For example, it might in principle be welfare improving to adopt a scheme in which R&D subsidies were negatively related to the degree of protection provided by patents.

More generally, in contrast to this neoclassical search for 'neutrality', S-E theory stresses that, given pervasive uncertainty, there are no well defined expected values and hence no expectation that the allocation of R&D to different lines will equate their expected payoffs, however these are defined.

Also, since most R&D is internally financed out of profits, R&D is more closely related to the profitability of past efforts than to the expected future profitability of current ones. One implication is that there is no unique optimal R&D policy. Neither is there such a thing as a neutral or non-distorting policy. The various instruments of R&D policies will have different effects on the amount of R&D performed, depending on both the technological and the structural contexts within which they operate. Thus there is no general presumption against policies that are focussed on specific technologies, industries or activities. Indeed, since we inhabit a second best world, focussed policies that seek to redress some of the existing imbalances are in principle more desirable that 'neutral' policies that leave these imbalances unchanged.

Because most private sector R&D is internally financed by existing firms,[26] the profits of monopolies and oligopolies that look socially unnecessary in a static context *are the very source of the R&D that produces the new technologies that underlie most economic growth*. So the text-book deadweight loss due to monopoly power would be better called 'the creative soil in which those with market power sow the seeds of economic growth'.

Because there is no clear distinction between innovation and diffusion, much activity that is related to the development and use of new technologies may not appear to

[26] Start ups matter but their R&D is small in relation to the total volume undertaken by established firms.

be basic R&D. Small firms do little recognisable R&D but spend a lot of time monitoring what larger firms are doing and adapting their findings to their own uses. Although this activity may be just as important as upstream R&D, it is not typically covered by such broad polices as R&D tax credits or subsidies. Thus special focussed measures may be useful.

What about the historical evidence on the use and effectiveness of 'neutral' versus 'distorting' policies? Although neoclassical theory is opposed to policies that focus on specific sectors or technologies, in practice, a very large number of important technologies have been encouraged in their early stages by public sector assistance worldwide. US policy provides many examples of this important point with the Department of Defence taking the lead in many cases. Because I do not have time to list the many US examples, I will merely quote Vernon Ruttan's major study (2001), in which he concluded that "…the public sector had played an important role in the research and technology development for almost every industry in which the United States was, in the late twentieth century, globally competitive." No one who has studied his 2001 book, and its 2006 successor, should be willing to pronounce the common thought-suppressing dictum "governments cannot pick winners." Clearly, governments have picked and backed some spectacular winners. Indeed, the US list is a long one including, among many other things, computers, aircraft, and the internet. The list shows that knowing when and how to use public funds to encourage really important new technologies in their early stages is an important conditions for remaining technologically dynamic, at least in many areas of advance. I hasten to add that this is no easy task. The field is strewn not only with many government successes but with many spectacular failures. So the operative debate should not be on the sham issue of whether or not governments always can or cannot pick winners but the real issue of conditions that favour success or failure in such government initiatives. This is what many economists have tried to do including Mowery and Nelson and (1999) and Lipsey and Carlaw (1996, 1998)

For just one example, the belief that civil servants know better than the private sector agents, and can efficiently dictate R&D decisions to them, seldom if ever achieved good results, either in catch-up or leading-edge economies. But many countries have championed consultative processes whereby the government agency and the main private sector agents pool their knowledge and come to a consensus on where the next technology push should be. (For further discussion see Lipsey and Carlaw 1996 and Lipsey and Wills 1996.) The parties then jointly finance the required research. This policy worked well in catch-up economies and it still works well when all private agents are pushing for a *fairly well defined* small-to-intermediate advance in pre-competitive technology.

VIII REPRISE

Economic growth, which raises material living standards over the centuries, is largely driven by technological change that creates new products, new process, and new forms of organisation. New technologies are generated endogenously by public and private sector activities. Because firms seek to create and innovate new technologies under conditions of uncertainty (not just risk), they are better seen as profit-oriented entities groping into an uncertain future and learning by their failures as well as their successes, rather than as entities that maximize the expected value of future returns based on a knowledge of the probabilities associated with alternative lines of action.

When the West surpassed China in the 18th century, the major difference between these otherwise quite similar economies was that the West had early modern science, particularly Newtonian mechanistic science. This provided the intellectual basis for the First Industrial Revolution which was almost exclusively mechanical. Institutions such as the separation of church and state, the concept of the corporation, the collective memory for scientific advances provided by the universities, provided much of the basis for the technologically superior performance of the West.

In analysing economic performance, theories that stress static efficiency often produce different perspectives from theories that stress evolutionary growth. Indeed, some of the main conditions that contribute to static inefficiencies, such as oligopolistic market forms and the existence of pure profits, are those that contribute to technological change and economic growth. So the different theories often produce different policy prescriptions.

Although the knowledge that is generated by endogenous economic activity is non-rivalrous, it is at least partially excludable (and is, therefore, not a pure public good). Formal analysis alone cannot determine the conditions for an optimum allocation because of (1) the ubiquitous non-fulfillment of the static optimum conditions, (2) the non-rivalrous and partially excludable character of knowledge and (3) the uncertainty associated with the generation, diffusion and application of new knowledge. Indeed when technological change is produced endogenously under conditions of uncertainty, the concept of an optimum allocation of resources is not even defined because future payoffs can only be discovered after they have arrived. It follows that all economic policies directed at increasing efficiency or growth, including technology enhancing policies, must be based on a mixture of theory, empirical knowledge, and a large element of judgment.

Virtually all governments, and most economists, are revealed to accept the judgment that the unaided free market would produce an undesirably small flow of new technological knowledge due both to the spillovers caused by non-rivalrousness of such knowledge and the disincentives of being only partial excludable. They thus accept the desirability of technology enhancing policies. However, S-E and neoclassical theories differ on the means of encouraging such technological advance. Neoclassical economists tend to emphasise the desirably of ‘neutral’ or ‘non-distorting’ policies while S-E theorists argue that in a second best world of uncertain outcomes policies that are focussed on particularly technologies or types of activity are often desirable.

There cannot be a neutral patent regime since the ability to enforce patents varies greatly among products and industries. By raising the payoffs to R&D, patents are assumed to increase the amount of technological knowledge that is generated and embodied in new innovations. Historical evidence is unclear on how important this is, since many important inventions and innovations occurred when there was little relevant patent protection. Historically, intellectual property protection often seems to have followed rather than proceeded major new GPTs. Historical evidence also shows that the concern that patent protection can slow the development of new technologies that use or build on the patented technology is not without support. There thus seems to be a trade off between increased protection of newly developed technologies and their diffusion and subsequent use in downstream inventions and innovations. Formal analysis cannot establish conditions for making this choice optimally, and it must remain a judgment call for which theory and evidence can help but not fully determine.

Under conditions of risk, enforceable patents and R&D subsidies can have the same effects in encouraging the generation of new technological knowledge (either by reducing the marginal cost or increasing the expected marginal revenue of R&D). But given uncertainty and the differential ability to enforce patents, these are not equivalent policy tools. Neoclassical economists often call for 'neutral' or 'non-distorting' measures for R&D support in the form of either a subsidy or tax credit available to all. S-E theorists argue that focused policies, directed at specific sectors, such as small businesses or start-ups, or to specific technologies, such as an emerging GPT, can be effective in many circumstances. So in their view, what is judged to be the best policy is highly context specific. They also argue that whatever is said in theory, focussed policies have in practice been widely and successfully used. For example, few if any of the technologies in which the US was dominant in the 20th century were developed without significant public support in which the public sector picked and backed what turned out to be big winners. Such selective policies are fraught with pitfalls. Experience shows that successful ones usually take the form of some type of private-public sector partnership rather than being the sole initiatives of the public sector.

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