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Continental, national and sub-national innovation systems—complementarity and economic growth☆

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Abstract

The purpose of this paper is to discuss the relevance of innovation systems to economic growth rates over the last two centuries. The focus is on complementarity (or lack of it) between sub-systems of society and on models of active learning in catching up economies. The paper discusses variations in rates of growth of economic regions and the extent to which variations may be attributed to "innovation systems". The analysis is applied to Britain in the 18th century, the United States in the second half of the 19th century and the innovation systems of *catching up* countries in the 20th century. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

This paper discusses variations over time in rates of growth of various economic regions and the extent to which these variations may be attributed to "innovation systems". There has been a rapidly growing literature on this topic during the 1990s (see, for example, Lundvall, 1992; Nelson, 1993; Mjøset, 1992; Villaschi, 1993; Humbert, 1993; Freeman, 1995; Reinert, 1997).

Much of this literature (see especially Hu, 1992; Porter, 1990; Patel, 1995) insists on the central importance of *national* systems but a number of authors have argued that "globalisation" has greatly diminished or even eliminated the importance of the nation-state (notably Ohmae, 1990). Other critics have stressed alternatively (or in addition) that sub-national entities, such as provinces, industrial districts, cities or "Silicon Valleys" are becoming, or have already become, more important than the nation-state (see, for example DeBresson, 1989; DeBresson and Amesse, 1991).

Unfortunately, at least in the English language, the same word "Regional" is often used to describe two entirely different phenomena, viz.

1. Geographical areas embracing several nation-states and even entire sub-continents—the "Pacific region", "East Asia", Eastern Europe, Central America, etc.

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Table 1
Comparative growth rates sub-continental regions 1965–1999[a]

	1965–1980	1980–1989	1990–1999 (estimate)
GDP % p.a.			
East Asia	7.5	7.9	7.2
South Asia	3.9	5.1	5.5
Africa (sub-Sahara)	4.0	2.1	2.7
Latin America	5.8	1.6	3.1
GDP per capital % p.a.			
East Asia	5.0	6.3	5.7
South Asia	1.5	2.9	3.4
Africa (sub-Sahara)	1.1	−1.2	0.2
Latin America	3.5	−0.5	1.2

[a] Source: World Bank Development Report (1991); own estimates in 1990s.

2. Geographical areas which are smaller sub-divisions of nation-states, e.g. "states", urban areas, counties, rural areas, etc.

This can be a source of confusion, so for this reason, this paper refers to the wider areas as "continental" or "sub-continental" and the smaller areas as "sub-national".The inter-continental variations in growth rates are indeed very wide, as illustrated in Table 1, but the variations between countries have of course been even wider. In particular, a group of countries, today referred to as "developed" or "industrialised" drew far ahead of the rest of the world (later known as "under-developed") during the last two centuries (Table 2, columns 5 and 6).

Abramovitz (1986) coined the expression "social capability" to describe that capacity to make institutional changes which led to this divergence in growth rates. He was himself one of the pioneers of "growth accounting" but, as he cogently pointed out, the accumulation of capital and increase in the labour force are not in themselves sufficient to explain these varying rates of economic growth. The huge divergence in growth rates which is so obvious a feature of long-term economic growth over the past two centuries must be attributed in large measure to the presence or absence of social capability for institutional change, and especially for those types of institutional change which facilitate and stimulate a high rate of technical change, i.e. innovation systems. As we shall see, attempts by Krugman (1994) and others to go back to the quantitative accumulation of capital and labour as the main explanation of the "East Asian Miracle" are very unconvincing. Institutional changes were essential for the accumulation of capital itself.

Many historians and economists had of course always emphasised the importance of technical and institutional change, as for example, Landes (1970) or Supple (1963). Indeed, going back to the early development of economic theory, List (1841) had strongly criticised Adam Smith and other classical economists for what he perceived as their neglect of technology and skills. In fact, Adam Smith *did* recognise the great importance of science and technology but did not consistently give it the prominence which List thought that it merited.

Table 2
Estimates of trends in per capita GNP (1960 US$ and prices, 1750–1977)[a]

Year	Developed countries		Third World		Gaps	
	(1) Total (billion of US$)	Per capita, US$	(3) Total (billion of US$)	(4) Per capita, US$	(5) = (2)/(4)	(6) Ratio of the most developed to the least developed
1750	35	182	112	188	1.0	1.8
1800	47	198	137	188	1.1	1.8
1830	67	237	150	183	1.3	2.8
1860	118	324	159	174	1.9	4.5
1913	430	662	217	192	3.4	10.4
1950	889	1054	335	203	5.2	17.9
1960	1394	1453	514	250	5.8	20.0
1970	2386	2229	800	380	7.2	25.7
1977	2108	2737	1082	355	7.7	29.1

[a] Source: Bairoch and Levy-Leboyer (1981), pp. 7–8.

The main concern of List was with the problem of Germany catching up with England and for under-developed countries (as the German states then were in relation to England), he advocated not only protection of infant industries but a broad range of policies designed to make possible or to accelerate industrialisation and economic growth. Most of these policies were concerned with learning about new technology and applying it and many of them were applied in catching-up countries over the next century and a half (see Section 5).

After reviewing the changing ideas of economists about development in the years since the Second World War, the World Bank (1991) concluded that it is intangible investment in knowledge accumulation, which is decisive rather than physical capital investment, as was at one time believed (pp. 33–35). The Report cited the "New Growth Theory" (Romer, 1986; Grossman and Helpman, 1991) in support of this view but the so-called "New Growth Theory" has in fact only belatedly incorporated into neo-classical models the realistic assumptions which had become commonplace among economic historians and neo-Schumpeterian economists. Indeed, it could just as well have cited List (1841), who in criticising a passage from Adam Smith said:

> ... Adam Smith has ... forgotten that he himself includes (in his definition of capital) the intellectual and bodily abilities of the producers under this term. He wrongly maintains that the revenues of the nation are dependent only on the sum of its material capital (p. 183).

and further:

> The present state of the nations is the result of the accumulation of all discoveries, inventions, improvements, perfections and exertions of all generations which have lived before us: they form the intellectual capital of the present human race, and every separate nation is productive only in the proportion in which it has known how to appropriate those attainments of former generations and to increase them by its own acquirements (p. 113).

List's clear recognition of the interdependence of domestic and imported technology and of tangible and intangible investment has a decidedly modern ring. He saw too that industry should be linked to the formal institutions of science and of education:

> There scarcely exists a manufacturing business which has not relation to physics, mechanics, chemistry, mathematics or to the art of design, etc. No progress, no new discoveries and inventions can be made in these sciences by which a hundred industries and processes could not be improved or altered. In the manufacturing State, therefore, sciences and arts must necessarily become popular (p. 162).

The recent literature on "national systems of innovation" could be described as an attempt to come to terms more systematically with these problems of social capability for technical change. List's book on "The National System of Political Economy" might just as well have been entitled "The National System of Innovation" since he anticipated many of the concerns of this contemporary literature. The main purpose of this paper is to discuss the relevance of systems of innovation to economic growth rate over the last two centuries. A long-term historical approach is essential for this purpose because of the very nature of technical and institutional change. The enormous gaps between different parts of the world took decades or even centuries to open up and the efforts to close them have also taken many decades.

The analysis starts with the case of Britain in the 18th century because Britain was the first country to open up a major gap in productivity, in technology and in *per capita* incomes, compared with all other nations and city states. The British case is discussed at some length both because it was the first and also because it serves to introduce some basic problems in the theory of innovation systems—notably the complementarity (or lack of it) between various sub-systems of society: science, technology, economy, politics and culture, and the complementarity between national and sub-national systems. The British slow-down and "falling behind" in the 20th century also illustrates the relative rigidity of some *organisational* structures compared with informal institutions, a point emphasised by Edqvist (1997a,b) in his thorough review of national systems theory.

Following this discussion Section 4 then takes up the second major example of a national system forging ahead of the rest of the world—the case of the United States in the second half of the 19th and first half of the 20th century. The remainder of the paper then discusses the innovation systems of *catching up* countries, which have been described by Viotti (1997) in an excellent dissertation as *learning systems*. He makes an interesting distinction between *active* and *passive* learning systems and applies this distinction to the example of South Korea and Brazil, an example which is reviewed in Section 5.

Finally, Section 6 of this paper speculates about the possible course of events in the next century, taking up the question of globalisation and convergence and drawing some conclusions about the role of innovation systems in future economic growth.

2. The concept of national systems

The capacity for technical and social innovations did of course strongly influence economic life *before* nation-states became the dominant form of political organisation. Although Adam Smith's book was entitled "The Wealth of *Nations*" and his main concern was to explain "the different progress of opulence in different *nations*", he nevertheless included a long discussion of "The rise and progress of *cities* and *towns* since the fall of the Roman Empire". The contemporary discussion is therefore certainly not entirely new: changing forms of political organisation and territorial boundaries necessarily changed the nature of the debate. For Adam Smith, it was the widening gap in living standards and in manufacturing industry between Britain and other political units in Europe which most intrigued him. Some of these were powerful nation-states, such as France and Spain, others were still city states or small principalities and still others were Empires.

Adam Smith's discussion marked the transition from policies which were mainly concerned with the promotion and protection of *trade*, with the finance of shipping, trading posts and cargoes, with the shipbuilding industry and naval power to policies which were mainly concerned with *manufacturing industry.*

The city-state innovation systems of the Renaissance had many remarkable achievements in craft industries as well as in financial systems, shipping, the arts, medicine and science. We have nevertheless, started this account with 18th century Britain because this was the time when Britain diverged from its great trading competitors in Spain, Portugal and The Netherlands and when the embryonic innovation systems which had grown up in the period of the Renaissance developed into something new, associated with the predominance of capitalist *industry*.

A distinction has been made (Lundvall, 1992) between "narrow" definitions of national systems of innovation (Table 3) and a broad definition (illustrated in Table 4). The narrow approach concentrates on those institutions which deliberately promote the acquisition and dissemination of knowledge and are the main sources of innovation. The "broad" approach recognises that these "narrow" institutions are embedded in a much wider socio-economic system in which political and cultural influences as well as economic policies help to determine the scale, direction and relative success of all innovative activities. The decisive changes which came about in 17th and 18th century Britain and later in the United States and other European countries, were the elevation of science in the national culture, the multiplication of links between science and technology and the systematic widespread embodiment of both in industrial processes in the

Table 3
National systems: "narrow" institutions (sources of innovations)

17th century	Academies of Science, Royal Society 1662, "Proceedings" and Journals, Internationalism of Science, Science Education
18th century	"Industrial revolution" (factories), Technical Education, Nationalism of Technology, Consulting Engineers
19th century	Growth of Universities, Ph.D. and Science Faculties, Technische Hochschulen, Institutes of Technology, Government Laboratories, Industrial R&D in-house, Standards Institutes
20th century	Industrial in-house R&D in all industries, "Big Science and Technology", Research Councils, NSF, etc., Ministries of Science and Technology, Service Industries R&D, Networks

Table 4
Some characteristics of British national system of Innovation during 18–19th century (broad definition)

Strong links between scientists and entrepreneurs
Science has become a national institution, encouraged by the state and popularised by local clubs
Strong local investment by *landlords* in transport infrastructure (canals and roads, later railways)
Partnership form of organisation enables inventors to raise capital and collaborate with entrepreneurs (e.g. Arkwright/Strutt or Watt/Boulton)
Profits from trade and services available through national and local capital markets to invest in *factory* production and in infrastructure
Economic policy strongly influenced by classical economics and in the interests of industrialisation
Strong efforts to protect national technology and delay catching up by competitors
British productivity per person about twice as high as European average by 1850
Consulting engineers develop and diffuse best practice technology in waterwheels, canals, machine-making and railways
Part-time training, night school, and apprenticeship training for new factory technicians and engineers
Gradual extension of primary, secondary and tertiary education

new workshops and factories (Table 4). The cultural changes associated with the Renaissance were pushed even further in the direction of secular instrumental rationality and its application to industrial investment.

3. The British national system

The decisive differences between the city-state innovation systems of the Mediterranean and the British national system were in the role of science and the role of industry. The role of science is still disputed by historians. Some accounts argue that science in Britain in the 18th century lagged behind other European countries, especially France and that it was not particularly important for the success of the industrial revolution. What these accounts tend to misconstrue is that it was not the location of a particular scientific discovery which mattered. These may have been more frequent outside Britain. What mattered for the industrial revolution was the prevalence of a scientific culture. The treatment of Newton in Britain compared with the treatment of Galileo in Italy exemplifies this point. Newton was revered in Britain by both state and church while the fate of Galileo was altogether different. Bacon (1605) had already proposed an integrated policy for science, exploration, invention and technology at the beginning of the 17th century. There was an exceptionally fortunate *congruence* of science, culture and technology in Britain which made it possible to use science, including Newtonian mechanics, on a significant scale in the invention and design of a wide variety of new instruments, machines, engines, canals, bridges, water wheels and so forth. For example, the British industrial revolution depended on water power (*not* on steam power) for over half a century. It was Joseph Smeaton in his papers and drawings presented to the Royal Society in the 1770s whose experimental work made possible a scientific and technological breakthrough in the design of water wheels more than doubling the productivity of water power. The use of iron rather than wood, first of all for the gears and later for the entire water wheel, was made possible through Smeaton's work as a consulting *engineer* for the Carron Iron Works, by then already the largest iron foundry in Europe.

This is only one example, although a very important one, of the positive interplay between science, technology, culture and entrepreneurship which characterised the British national system of innovation. The *congruence* of these four sub-systems of society extended also to the political sub-system, which promoted all of these. According to many accounts (e.g. Needham, 1954) it was the failure of the Chinese Empire to sustain congruence between these sub-systems which led to the failure of China to sustain its world technological leadership. The conflict between church, state and science (e.g. Galileo) hindered a more fruitful development of both science and technology in the Italian city-states and elsewhere in Europe. The different role of science in Britain and Italy has been especially well documented by Jacob (1988).

This was not the only factor which weakened the city-state innovation systems. Even more decisive were the scale economies made possible by factory production, capital accumulation and specialised division of labour. It was an Italian economist, Antonio Serra who first recognised the extraordinary

Table 5
Labour productivity in cotton: operative hours to process 100 lbs of cotton[a]

	OHP
Indian Hand Spinners (18th century)	50000
Crompton's Mule (1780)	2000
100-Spindle Mule (c. 1790)	1000
Power-assisted Mules (c. 1795)	300
Roberts' automatic Mule (c. 1825)	135
Most efficient machines today (1990)	40

[a] Source: Jenkins (1994), p. xix.

importance of increasing returns to scale but he died in prison whereas Adam Smith was honoured by the British Prime Minister ("We are all your pupils now"). Enterprises and workshops were still very small in 18th century Britain but the shift from cottage industry to factory production and the constant improvements in machinery were still enough to confer a huge advantage on British manufacturing firms. Nowhere was this more obvious than in the cotton industry (Table 5) where the combination of technical inventions, investment in machinery, factory organisation, and entrepreneurship in ever-wider markets (facilitated still by naval power) opened an enormous productivity gap between Britain and all other producers. Some enterprises in the two leading industries, cotton and iron, already deployed hundreds of people by 1800.

Investment in *industry* certainly owed a great deal to profits from *trade* but this could not have taken place without a change in the culture and attitudes of the landlord and middle classes as well as changes in the capital markets. The investment in the transport infrastructure by the British landlord class was unique in Europe and caused Marx to remark that Britain had a bourgeois aristocracy. The bourgeoisie and the landlords in Britain behaved differently following the victory of Parliament over the monarchy and the aristocracy in the English Civil War in the mid-17th century. This victory made irreversible political and social changes despite the restoration of the monarchy in 1660. The investment in trade, transport and industry became even more important than the ownership of land. The local political initiative of landlords in promoting a wave of investment in canals in the late 18th century was exceptionally important in the early take-off of several key industrial districts whose access to national and international markets had hitherto been hindered by poor communications and transport.

Schumpeter always maintained that the spread of innovations was necessarily uneven both with respect to timing and to space and this was certainly the case with the spread of those innovations which comprised the British industrial revolution. They were not evenly spread over all parts of the country, they affected only a few industries at first and they diffused relatively slowly to other European countries. The main centres of innovation, of urbanisation and of the rapid growth of new industries were not in the London region but in the North of England, especially in Lancashire and Yorkshire, in the Midlands and in Scotland. Originally, the reasons for the success of the new "sub-national" industrial regions or districts had little or nothing to do with economic policy at a regional level. The main advantage of the North was probably the more rapidly flowing rivers of the Pennine Hills which provided the consistency and strength of flow for Smeaton's water wheels. The iron industry was obviously also influenced by the location of wood for charcoal and later, coal and iron ore deposits but much iron ore was still imported in the 18th century.

However, although geological factors such as rivers for navigation or water power and deposits of minerals or the lack of them, played an important role in determining the early growth of various industries, these *natural* advantages were soon overtaken by *created* advantages such as the transport infrastructure, the location of ports and access to skills and to markets. Lancashire enjoyed the advantage of the port of Liverpool which was the centre of the North Atlantic trade with North America. Many economists, and especially Marshall, pointed to the external economies which resulted from many firms in the same industry located in the same industrial district where "the secrets of industry are in the air" (Foray, 1991). To this day, these external economies of agglomeration have continued to be extremely important in industries as diverse as semi-conductors, toys, and machine tools. They are an essential part of the argument of Piore and Sabel favouring small firm networks as against large mass production firms. They are also one of the main reasons for some economists to propose that sub-national regional innovation systems have now become more important than national systems themselves.

There is much in the experience of the British industrial revolution which appears at first sight to favour this view. Above all, the accumulated specialised skills in Lancashire were one of the major reasons for the extraordinary success of the Lancashire cotton industry, undoubtedly the leading sector of the British industrial revolution, accounting for 40% of all British exports in 1850 and still for over a quarter of a much larger total in 1900.

In their explanation of the reasons for British dominance in cotton persisting throughout the 19th century, Mass and Lazonick (1990) attribute this "sustained competitive advantage" to a cumulative process in which the development and utilisation of several key productive factors reinforced each other. These affected labour costs, marketing costs and administrative costs. In all of these areas, industry scale economies (Marshall's external economies of scale) were important: In the case of labour:

> During the nineteenth century the development and utilisation of labour resources provided the British cotton industry with its unique sources of competitive advantage. The major machine technologies ... required complementary applications of experienced human labour to keep them in motion. Experience gave workers not only specific cognitive skills (of which a process such as mule spinning was much more demanding ...) but also (and more important over the long run) the general capability to work long hours at a steady pace without damaging the quality of the product, the materials or the machines (Mass and Lazonick, 1990, p. 4).

Mass and Lazonick lay particular stress on the habituation to factory work and cumulative skills of the labour force but they also stress that the trade union organisation at that time and in that sector (surprisingly for some stereotyped ideas of British industrial relations of later periods and other industries), were particularly congruent with incentives to sustain and increase productivity. Great responsibility was given to the more skilled workers (who often had previous experience in domestic craft work) for recruitment, training and supervision of the less skilled.

> Besides the general habituation to factory work that came from growing up in factory communities and entering the mills at a young age, cotton workers developed specialised skills in spinning particular types of yarn and weaving particular types of cloth (Mass and Lazonick, 1990, p. 5).

In common with other historians they point to the economies of agglomeration in relation to pools of specialised skilled labour in various Lancashire towns: Bolton (fine yarns), Oldham (coarse yarns), Blackburn and Burnley (coarse cloth), etc. Similar arguments apply to the availability of skilled mechanics adept at maintaining (and improving) the local machinery. The gains from increasing productivity were generally shared with the skilled workers, whose union power ensured this.

> By the 1870s cotton industries around the world could readily purchase British plant and equipment and even British engineering expertise. But no other cotton industry in the world could readily acquire Britain's highly productive labour force; no other industry in the world had gone through the century-long developmental process that had produced the experienced, specialised and cooperative labour force that Britain possessed (Mass and Lazonick, 1990, p. 8).

Similar arguments apply to the machine-building industry and to mill and machine design. Whereas the early mill-wrights came from the earlier tradition of corn-mills, wind-mills, etc., with the increased specialisation and sophistication of machinery, special and cumulative skills became increasingly important here too. All of this led to high levels of machine utilisation as well as lower initial costs of machinery.

Again in relation to material costs, the highly concentrated Liverpool cotton exchange provided Lancashire with an exceptional advantage. Foreign buyers found it cheaper to buy in Liverpool than anywhere else in much the same way that the Amsterdam flower market re-exports to the entire world today. The Manchester ship canal and the railway from Liverpool from 1830 onwards meant that transport costs for Lancashire were extremely low. Lancashire spinners could avoid the heavy warehousing costs of more distant competitors. It was not quite "just-in-time" but was well in that direction. The Liverpool market gave Lancashire enormous flexibility in grades and types of cotton and spinners took advantage of price changes on a weekly basis. Furthermore, Lancashire had a unique capability to work with inferior grades of cotton for any market in the world and even to cope with the partial switch to Indian cotton at the time of the American Civil War.

The world-wide marketing structure was yet another cumulative advantage of the Lancashire industry, which like all the other factors mentioned provided external economies for the firms in the industry. The structure of the Lancashire industry itself with the very well-informed merchants, converters and finishers meant that it had the capability to deliver whatever product the customer demanded to any part of the world rapidly. Again, inventory, transport and communication costs could be kept low through this industry-wide advantage.

Similar economies of agglomeration applied to other industries such as pottery (Staffordshire), cutlery (Sheffield), hosiery (Nottinghamshire) or wool (Yorkshire). There is no doubt that these sub-national systems of innovation or industrial districts, as Marshall called them, made major contributions to the success of the industrial revolution in Britain. However, it by no means follows that the national system was unimportant or that it was simply the sum of the sub-national systems. Each of the industrial districts could flourish not only because of the specialised *local* advantages and institutions (pools of skilled labour, exchange of experience, trade associations, etc.) but also because of *national* advantages conferred by British political, cultural, economic and technological institutions. Easy access to a large and rapidly growing domestic market as well as to foreign markets, access to the capital market and a legal system which protected property and its accumulation, and access to a national pool of engineering and scientific knowledge. In fact, the national and sub-national systems complemented each other.

It is hard to believe that the British industrial revolution would have been more successful if Britain had been divided into 20 or 30 separate states, cities and principalities as Germany and Italy then were. In fact, Friedrich List and most of those concerned to catch-up with Britain in the 19th century advocated a confederation of German states preceded by a Customs Union (*Zollverein*) and bound together by a national railway network and other national institutions because they perceived the many advantages of a unitary nation-state.

The *national* advantages of Britain which complemented the specialised sub-national industrial districts were admirably summed up by Supple (1963):

> Britain's economic, social and political experience before the late 18th century explains with relatively little difficulty why she should have been an industrial pioneer. For better than any of her contemporaries Great Britain exemplified a combination of potentially growth-inducing characteristics. The development of enterprise, her access to rich sources of supply and large overseas markets within the framework of a dominant trading system, the accumulation of capital, the core of industrial techniques, her geographical position and the relative ease of transportation in an island economy with abundant rivers, a scientific and pragmatic heritage, a stable political and relatively flexible social system, an ideology favourable to business and innovation—all bore witness to the historical trends of two hundred years and more, and provided much easier access to economic change in Britain than in any other European country (Supple, 1963, p. 14).

4. The United States national system of innovation

The economies of scale achieved for British firms and the British industrial districts by the removal of internal trade barriers and by British trading and naval superiority were even more important in the rise of the United States economy. During the second half of the 19th century and the first half of the 20th century it was the United States economy which grew much more rapidly than any other (Table 6).

Not surprisingly, the country whose "national system of innovation" most closely resembled the British system in the 18th century were the former British colonies of USA. However, in the first half of the 19th

Table 6
Relative productivity levels (US GDP per hour = 100)[a]

	1870	1913	1950
UK	104	78	57
France	56	48	40
Germany	50	50	30
Fifteen countries	51	33	36

[a] Source: Abramovitz and David (1994).

century, despite a rich endowment of natural resources and many favourable institutions, growth was still retarded by the lack of an appropriate transport infrastructure to take advantage of the natural endowment and size of the country and its market. It was the advent of railways and the new technologies of the late 19th century which enabled American entrepreneurs to forge far ahead of the rest of the world. At first, the United States imported much of this technology from Europe. Many of the key inventions in cotton spinning and weaving were smuggled out of Britain and across the Atlantic by British craftsmen as it was then illegal to export this technology. Arkwright's water frame was an example of a machine that was carefully memorised and then re-built in America. But from the very beginning American inventors modified and reshaped these technologies to suit American circumstances. By the end of the century American engineers and scientists were themselves developing new processes and products in most industries, which were more productive than those in Britain.

As we have seen, among those institutions most favourable to economic growth in Britain were the scientific spirit pervading the national culture and the support for technical invention. These features were readily transferred to the United States and respect for science and technology has been an enduring feature of American civilisation from Benjamin Franklin onwards. As de Tocqueville observed in his classic on "Democracy in America" (1836):

> In America the purely practical part of science is admirably understood and careful attention is paid to the theoretical position which is immediately requisite to application. On this head the Americans always display a free, original and inventive power of mind (De Tocqueville, 1836, p. 315).

The early immigrants were obliged as a matter of life and death, to learn by doing about agricultural techniques in the American Continent and agricultural research emerged early as an outstanding feature with strong public support. Whereas in Europe, with the partial exception of Britain, feudal institutions often retarded both agricultural and industrial development, the United States never had any feudal institutions either in agriculture or any other part of the economy. Moreover, the relative abundance of land, the westward-moving frontier, the destruction of the native civilisations or their confinement to a relatively small part of the territory, all favoured a purely capitalist form of economic development with a relatively egalitarian distribution of income and wealth amongst the white immigrants in the early period.

The big exception to these generalisations was of course the slave economy of the South. It is difficult to assess the degree to which the economic growth of the South in particular and of the Union in general was retarded by the prevalence of this slave economy but it was in the period which followed the victory of the North in the Civil War that the United States achieved rates of growth well above any previously achieved by Britain. This was a case of the sub-national system of the South *retarding* national economic growth until the victory of the Union and the major institutional changes which ensued, especially the abolition of slavery. Even after its abolition, slavery left an enduring legacy of social and economic problems, some of which persist to this day but the maintenance of the Union meant that the predominantly capitalist path of development in the North and West prevailed in the whole country. In these circumstances an entrepreneurial culture could flourish as nowhere else.

Historians such as Abramovitz and David (1994), who have examined American economic history after the Civil War point to several characteristics of the United States economy which were in combination exceptionally favourable to a high rate of economic growth. These were (i) resource abundance in both land, minerals and forests; (ii) an exceptionally large and homogeneous domestic market facilitating production, marketing and financial economies of scale, especially in the extractive, processing and manufacturing industries.

Abramovitz and David argue that the higher relative price of labour in North America interacted with these advantages to induce substitution of capital and natural resource inputs for skilled labour. This stimulated already in the first half of the 19th century the development of a specific American labour-saving, capital-intensive technological trajectory of mechanisation and standardised production, which at the lower end of the quality range had enabled US manufacturing to surpass British productivity levels already by 1850. As the 19th century advanced, "the engineering techniques of large-scale production and high throughput rates became more fully explored and

Table 7
Comparative levels of capital/labour ratios 1870–1950 (USA = 100)[a]

	Germany	Italy	UK	Average of 13 European countries	Japan
1870	73	–	117	–	–
1880	73	26	106	68	12
1913	60	24	59	48	10
1938	42	32	43	39	13
1950	46	31	46	39	13

[a] Source: Abramovitz and David (1994, p. 8).

more widely diffused. American managers became experienced in the organisation, finance and operation of large enterprises geared to creating and exploiting mass markets (Abramovitz and David, 1994, p. 10).

The extent to which this specific American trajectory of tangible capital-using technology diverged from that of Europe (and Japan) can be clearly seen from Table 7. Until the 1880s the UK still had an overall capital/labour ratio higher than that of the United States but by 1938, like all other countries, the ratio had fallen to less than half that of the United States. The large cost reductions and productivity gains associated with this North American technological trajectory could be illustrated from numerous industrial sectors. The extraordinary productivity gains in mining and mineral processing are emphasised in particular by Abramovitz and David, whilst the productivity gains in agriculture are very frequently cited by other historians. The examples of *steel* and *oil* are particularly noteworthy because of the key role of these commodities in all kinds of tangible capital-using investment projects, in capital goods themselves, in transport and in energy production and distribution. Cotton, iron, canals and water-power were the leading sectors in the early British industrial revolution; oil, steel and electricity were the leading sectors in the huge American spurt of growth from 1880 to 1913.

Viotti (1997) points out that these differences and the case of the chemical industry in Germany mean that catching up in the late 19th century and early 20th century was rather different from what it has become in the late 20th century. The United States and Germany, he suggests caught up by *radical* innovations in new industries, not by incremental innovations in cotton spinning and weaving. Today, the late-comer countries may not have the option of radical innovations in new industries and have no alternative but to pursue the path of imitation and *learning*. However, he makes a distinction between *active* learning systems and *passive* learning systems, taking the examples of South Korea and Brazil to illustrate his point. We shall pursue this example in Section 5.

5. Late-comer catch-up in the 20th century

Very large economies of scale were characteristic of the forging ahead process in the United States, especially in steel, chemicals, oil, minerals and electricity. Even after the Second World War, when the OECD (previously OEEC and ERP) organised many European missions to study the productivity gaps between European and American firms, they frequently stressed scale of plant and size of domestic market as two of the biggest comparative advantages of US firms. This kind of thinking lay behind much of the political impulse to establish first the European Coal and Steel Community and later the European Common Market (Customs Union) and the European Economic Community. Just as the German nationalists, following Friedrich List, believed that a German Customs Union would greatly facilitate catch-up with Britain, so the European federalists believed that a European Common Market would accelerate European catch-up with the United States. This philosophy still influences the debate on EMU today.

Catch-up by Western Europe did indeed take place between 1950 and 1975 although it certainly cannot be attributed uniquely to scale economies and market enlargement. As with the first British industrial revolution, a general capability for institutional and technical change was essential and not merely scale economies. European research and development activities, technology transfer, education and training, and management techniques were all greatly improved. Investment by the United States firms in Europe and by European firms in the USA also facilitated the transfer of technology and management techniques. All these things were necessary even to achieve the scale economies themselves.

Not surprisingly, however, economists who were interested in catch-up by "late-comer" countries were especially impressed by the scale economies of North

American and European firms and when they came to study catch-up phenomena, they stressed this point in particular. Gerschenkron (1962, 1963) studied the catch-up by 19th century German and later Russian firms in the steel industry and argued that the new (late-comer) firms could acquire and use the latest technology, at much lower costs than those in the pioneering countries, by transfer agreements, inward investment and the recruitment of skilled people. Even more important in his view was the fact that the pioneering firms and countries had already established a growing world market so that the catch-up firms did not have to face all the uncertainties, costs and difficulties of opening up entirely new markets. Gerschenkron's theory of *late-comer* advantages stressed that the pioneers could not possibly *start* with large plants, whereas the late-comers could move very rapidly to large-scale production, while their mature competitors might be burdened with smaller plants embodying now obsolete technology.

Jang-Sup-Shin (1995) in his study of the *Korean* steel industry endorsed this Gerschenkronian explanation, pointing out that Posco, the largest Korean steel firm was able to leapfrog European and American firms with respect to plant size and technology and thus enter the world market as a low-cost producer. He extended this analysis to the case of the semi-conductor industry arguing that here too the plant-scale advantages of the Korean producers of memory chips enabled them to leapfrog the European semi-conductor industry and to compete with the most successful Japanese and American firms. However, he accepted that the Gerschenkron late-comer scale economy advantages had to be complemented by a "national system of innovation" explanation of successful catch-up since neither in the case of steel, nor in the case of semi-conductors could catch-up have taken place without many institutional changes, especially in education, training and R&D.

Bell and Pavitt (1993) pointed to another problem with Gerschenkronian catch-up theory: a country which simply instals large plants with foreign technology and foreign assistance will not experience the build-up in technological capability over several decades, which has been characteristic of the leading countries. Consequently, below capacity working and low output capital ratios have often persisted in developing countries. *Active* learning policies of the type prescribed by Bell and Pavitt, by Viotti and by Alice Amsden, will be essential to overcome this disadvantage of late-comers.

Perez and Soete (1988) provided a more general theory of the science and technology infrastructure needed for effective catch-up. They showed that even the costs of *imitation* could be rather high in the absence of an infrastructure which is taken for granted in mature industrialised countries. Even more important, they showed that these costs would vary systematically at different stages of evolution of a product or a technology. Thus, while Gerschenkron could be regarded as the leading theorist of late-comer advantages, Perez and Soete reflected the experience in numerous developing countries of late-comer *disadvantages* and difficulties in catching up the leaders in technology. However, they did also point to "windows of opportunity" in the acquisition and assimilation of technologies, provided the catch-up countries followed appropriate social, industrial and technology policies.

Gerschenkron himself argues that countries could only enjoy late-comer advantages if they could also make innovations in their *financial* system so that the huge scale of investment needed for very large plants could be accommodated. However, there is another important point about late-comer advantages which Gerschenkron did not sufficiently explore: the plant scale economies of a particular historical period were not necessarily characteristic of *all* industries or of other periods. As Perez and Soete showed, scale economies are industry-specific and technology-specific. In a number of industries, such as aircraft or drugs, scale economies in *design* and *development* costs were much more important than *plant*-scale economies in *production*. In still other industries, scale economies in *marketing* may be decisive. In the steel industry itself as well as in semi-conductors, plant scale economies have changed with technology.

Nevertheless, Gerschenkron's theory of late-comer advantages was an important complement to infant industry arguments. The much higher growth rates in some catch-up countries are obviously attributable in part to the fact that costs of technology acquisition and implementation are lower and the risks and uncertainties are less in catch-up situations. Imitation is usually easier and less costly than innovation. A very big gap in technology does provide a *potential* for fast catch-up.

Finally, as traditional international trade theory has always stressed, late-comer countries will usually enjoy labour cost advantages and these may be very large now because of the wide disparities in world-wide *per capita* incomes. These labour-cost advantages may also be reinforced by lower costs of particular materials and of energy, as well as climatic advantages. All of these things as well as the narrow and the broad national innovation systems affect the potential for catch-up and its realisation.

It also seems to be the case that geographical and cultural proximity to nations which have led either in forging ahead or in catching up has a considerable effect on rate of catch-up. It would be difficult otherwise to explain the clear-cut *inter-continental* differences which are apparent. Britain was first caught up and overtaken by neighbouring European countries and by countries partly populated by British and other European immigrants (the United States, Canada, Australia, etc.). The most successful catch-up countries in the late 20th century have been those which are geographically (and in some respects culturally) close to the leading catch-up country of the 20th century—Japan.

Thus, it is not altogether surprising that East Asian countries and some South-East Asian countries grew much faster than Latin American countries in the 1980s and 1990s, despite the fact that the Asian countries started from a much lower level of industrialisation and productivity than most Latin American countries (Table 8). This would appear at first sight to support a simple convergence theorem—the later the faster. But before jumping to any such conclusion it is essential to recognise that not all late-comer countries were catching up; some were falling further behind and some were standing still. The countries and sub-continents making the fastest progress have actually varied enormously both in 19th and 20th centuries. Uneven development is a much more accurate characterisation of growth than convergence. In a well-known paper, De Long (1988) showed that Baumol's (1986) attempt to establish the convergence theorem using Maddison's data was fundamentally flawed:

> . . . when properly interpreted Baumol's finding is less informative than one might think. For Baumol's regression uses an *ex post* sample of countries that are now rich and have successfully developed. By Maddison's choice, those nations that have not converged are excluded from his sample because of their resulting persistent relative poverty. *Convergence is thus all but guaranteed in Baumol's regression*, which tells us little about the strength of the forces making for convergence among nations that in 1870 belonged to what Baumol calls the "convergence club." . . . Because [Maddison] focuses on nations which (a) have a rich data base for the construction of historical national accounts and (b) have successfully developed, the nations in Maddison's sixteen are among the richest nations in the world today (De Long, 1988, pp. 1138–1139, emphasis added).

De Long showed that for another sample of countries, drawn *ex ante*, there was no correlation between starting level of productivity and subsequent growth performance.

Following up De Long's critique of convergence theory, Chabot (1995) showed that for the period 1820–1870 the capacity for income growth varied *directly* not *inversely* with countries' 1820 level of GDP per capita: "The result is directly antithetical to what convergence theory predicts. The case is demonstrated remarkably well by two countries, the United States and the UK. Both were amongst the group of three to four most promising nations in 1820 and both experienced phenomenal subsequent growth rates. Clearly something more than the logic of convergence and catch-up was at work." (p. 60). Sections 3 and 4

Table 8
Starting levels for industry, Latin America and Asia 1955[a]

	Ratio of manufacturing to agricultural net product	US$ net value of manufacturing per capita
Argentina	1.32	145
Brazil	0.72	50
Mexico	1.00	60
Venezuela	1.43	95
Colombia	0.42	45
South Korea	0.20	8
Thailand	0.28	10
India	0.30	7
Indonesia	0.20	10

[a] Source: Maizels (1963).

Table 9
Falling behind-rates of divergence or convergence towards the US labor productivity level, 1870–1950[a]

Country	Rate
Australia	−0.95
Austria	−0.81
Belgium	−0.84
Canada	0.10
Denmark	−0.46
Finland	−0.20
France	−0.37
Germany	−0.88
Italy	−0.37
Japan	−0.30
The Netherlands	−0.87
Norway	−0.15
Sweden	0.04
Switzerland	−0.14
UK	−0.77

[a] Source: Maddison (1995), as quoted in Chabot (1995).

of this paper have attempted to show that the "something more" was specific national innovation systems.

Chabot further showed that for the period 1870–1950, *forging ahead* by the United States in labour productivity took place in relation to all other OECD countries except the Nordic countries (Table 9). Only for the period 1950–1992 did he find some limited support for convergence and he concluded

> in the whole of modern economic history, there is only one period which offers any substantive support for international convergence, and even that is subject to non-trivial qualification (p. 62).

Although Gerschenkron was undoubtedly right to detect some major advantages for late-comer countries and to show that *in some circumstances* late-comers, starting from a very low level of productivity could enjoy growth rates much higher than the established leading countries, it certainly does not follow that late-comers will *always* tend to converge with the leaders. Whether they do so or not depends, as was suggested at the outset, on social capability for technical and institutional change, i.e. on the national systems of innovation and on the nature of the new waves of technology pervading the system. It also depends on a favourable conjuncture of international relationships.

Whilst it is true that most Asian countries were "later" late-comers than most Latin American countries in their industrialisation, their faster growth in the 1980s and 1990s cannot be explained by this alone. Nor indeed can it be explained as Krugman (1994) attempted to do, primarily by fast growth of capital and labour inputs, with technical change playing very little part. Neither is the World Bank Report (1993) on the "East Asian Miracle" entirely convincing in its explanation of the "miracle". Both Krugman and the World Bank Report greatly underestimate the role of technical change and in particular they fail to recognise the degree to which the "Tigers" since the 1970s concentrated their investment, their R&D, their infrastructural development, their training and their technology input on the electronic and telecommunication industries. "Catch-up" is not a spontaneous process associated with late-coming, nor the inevitable outcome of market forces in a liberal economy. By a combination of good fortune and of good judgement, as well as proximity to Japan, the Tigers (and later some other Asian countries) increased their commitment to the manufacture and export of electronic products at a time when they were the most rapidly growing part of world exports.

Clearly, the huge achievements of the Tigers in export performance in the 1980s and 1990s were greatly facilitated by the commodity composition of their exports and imports, both of which were heavily related to the fastest growing sectors of the world economy and of world trade (Table 10). Singapore is the most extreme example of this with electronic and telecommunication products accounting for over a third of total industrial production and nearly two-thirds of exports by the mid-1990s. Hong Kong, however,

Table 10
Exports of ICT equipment[a] to major OECD countries as a share of total manufacturing exports to those countries from each of the following countries

	1970	1980	1992
Japan	21	17	29
Germany	7	5	6
USA	14	15	22
France	6	5	6
The Netherlands	6	7	8
UK	6	7	13
Taiwan	17	16	28
South Korea	7	13	26
Singapore	20	36	65

[a] Computers, office machines, telecommunication equipment and other electronic equipment; source: OECD trade data base.

Table 11
Indicators of national efforts in S&T-Brazil, South Korea, Japan and the United States[a]

	Brazil	South Korea	Japan	The United States
Scientists and engineers engaged in R&D (per million population)	235[b] (1993)	1990 (1992)	5677 (1992)	3873 (1988)
Expenditure for R&D as percentage of GNP	0.4[c] (1994)	2.1 (1992)	3.0 (1991)	2.9 (1988)
Expenditure in R&D by source of funds (%)	1994[c]	1992	1992	1992
Government	81.9	17.2	19.4[f]	43.3[f]
Productive enterprise	18.1	82.4	71.0[f]	51.6[f]
Other	–	0.4	9.6[f]	5.1[f]
Total patents granted in 1991	2479[d]	3741[e]	36100[f]	96514[f]
Patents granted to residents (%)	14[d]	69[e]	84[f]	53[f]
Number of tertiary students per 100,000 inhabitants (1992)	1079	4.253	2340	5652

[a] Source: Viotti (1997). Numbers between parenthesis correspond to the year of the data.
[b] Computed from MCT (1995).
[c] CNPq (1995, p. 23).
[d] MCT (1996, p. 37).
[e] Lall (1992a, p. 197), the statistics of patents for South Korea are for the year 1986.
[f] STA/NISTEP (1995).

transferred much of its electronics manufacturing to China in the 1980s and 1990s. Elsewhere in Asia networks of interdependent suppliers of electronic components, sub-systems and final products were the typical feature of rapidly growing manufacturing industries. Both imports and exports of these products grew extremely rapidly. Not only did the World Bank Report neglect the pattern of structural change in the East Asian economies, it also neglected the changing pattern of research and development activities and of technology transfer.

The World Bank Report *did* recognise the importance of *education*. However, it differed from the earlier work of institutional economists such as Amsden (1989) and Wade (1990) in neglecting the role of government policy in many other areas, such as the protection of certain industries, the promotion of exports, the subsidies to specific firms and the promotion of R&D activities. In general, it ignored *industrial* policy and had little to say about training or technology transfer. In all these respects, the policies of South Korea, Taiwan and Singapore have resembled those prescribed long ago by Friedrich List. In pointing this out, Freeman (1993) made some comparisons and contrasts between Brazil and South Korea.

This comparison has been made much more thoroughly since then by several Brazilian scholars (Villaschi, 1993; Albuquerque, 1997b; Viotti, 1997). Albuquerque distinguishes several different categories of "national innovation systems", while Viotti makes an interesting distinction between "Active" and "Passive" learning systems building on the earlier work of Villaschi (1993) and Bell and Cassiolato (1993) on "learning to produce and learning to innovate". All of these accounts emphasise the role of *active policies* at the national and firm level in the import, *improvement* and adaptation of technology as characteristic of successful catch-up.

Viotti (1997) presents impressive evidence of the contrasts between Brazil and South Korea in the fields of education, and of research and development (Table 11). In presenting this evidence, he points out that the number of tertiary students per 100,000 inhabitants in Brazil (1079) is approximately just a fourth of that of South Korea (4253) and the concentration on *engineering* is much greater in the Korean tertiary education system compared with both science and humanities. Amsden (1989) in her classic work on Korean catch-up, gave some vivid examples of the role of training in the steel and cement industries in the early period of catch-up. This has become even more important in the electronic industry. For example, Samsung not only trains thousands of its own employees at every level but also regularly provides intensive training for its sub-contractors. Such intensive training efforts are essential for an *active* policy

Table 12
Emerging sources of technology in terms of ownership of US patents[a]

Year	Patents granted during 1977–1992	Share	1983–1989	Share	1990–1996	Share
Taiwan	382	0.10	2292	0.41	11040	1.43
South Korea	70	0.02	580	0.10	5970	0.77
Israel	641	0.16	1507	0.27	2685	0.35
Hong Kong	272	0.07	633	0.11	1416	0.18
South Africa	491	0.12	699	0.12	787	0.10
Mexico	245	0.06	289	0.05	314	0.04
Brazil	144	0.04	212	0.04	413	0.05
PR China	7	0.00	142	0.03	353	0.05
Argentina	130	0.03	135	0.02	187	0.02
Singapore	17	0.00	65	0.01	337	0.04
Venezuela	51	0.01	122	0.02	192	0.02
India	56	0.01	96	0.02	204	0.03
East and Central Europe	3444	0.87	2417	0.43	1317	0.17
Sub-total	5950	1.51	9189	1.62	25215	3.26
Others	731	0.19	902	0.16	1494	0.19
Total	393629	100.00	565739	100.00	772927	100.00

[a] Source: Kumar (1997) based on data presented in US Patents and Trademarks Office (1997) TAF special report: all patents, all types—January 1977–December 1996, Washington, DC.

of continuous improvement of technology even more than for simple imitation. Whereas *static* economies of scale can be achieved simply by building a larger plant, the far greater *dynamic* economies of scale depend on such active learning policies and increasingly on engineering activities and in-house R&D at plant level, as shown so clearly by Bell and Cassiolato (1993) and by Bell and Pavitt (1993). The rapid change of product design and the associated change of components characteristic of the electronic industry have further increased the importance of these active learning and training policies.

Viotti has further shown that Korean industry has relied far less on foreign investment than Brazil and has relied more on imports of capital goods and on increasingly active efforts to improve upon imported technology through the *in-house* R&D efforts of Korean firms themselves. Hobday (1995) has pointed to the variety of strategies in the East Asian countries, all designed in different ways steadily to upgrade local technological capability. The contrast between the rapid rise in the performance of in-house R&D in *firms* in both South Korea and Taiwan, and its low level, stagnation or non-existence in firms in most developing countries is especially notable. Table 11 illustrates the contrast with Brazil.

The rise of in-house R&D in the 1970s led to an extraordinary increase in numbers of patents (Table 12) and this is perhaps the most striking confirmation of the *active* learning system in South Korea and Taiwan. Between 1977–1982 and 1990–1996, the number of patents taken out in the USA by Brazil, Argentina, Mexico and Venezuela nearly doubled from 570 to 1106, but in the same period the numbers taken out by the four "Tigers" increased nearly 30 times over, from 671 to 18,763.

In the case of South Korea nearly half of the patents taken out between 1969 and 1992 were in six technical fields in the electronics area (semi-conductors, computers, imaging and sound, instruments, electrical devices and photocopying). In the case of Taiwan the increase in total numbers of patents was even more remarkable but they were spread over a wider technical area, including especially metal products and machinery as well as electrical and electronic devices (Choung, 1995). Firms in both South Korea and Taiwan were so successful in their catch-up that they began to export technology themselves and to invest overseas in older industrial countries like Britain as well as in the less developed countries of South-East Asia.

Although very useful for international comparative purposes, *United States* patent statistics are of course not the only ones which are significant. Since the establishment of the European patent, the European Patent Office (EPO) statistics are increasingly valuable. Even more interesting for catch-up countries are the measures of *domestic* patenting in each individual country. In a pioneering paper, Albuquerque (1997a) analyses these statistics and more interestingly from the standpoint of this paper shows that the number of *Brazilian* domestic patents have shown no clearly increasing trend in the last 15 years after reaching a peak in 1981–1982.

The extraordinary growth of East Asian patenting in the USA is not of course only an indication of active technology improvement. It is also influenced by the commercial and export strategies of firms Hobday (1995) has particularly stressed the key role of learning by exporting in East Asian catch-up. The success of East Asian firms in exports complements their success in obtaining *United States* patents. Moreover, insofar as they continue to make progress towards the world technological frontier, they have encountered increasingly severe competition from the established technological leaders and from the pressures of these leaders to liberalise all aspects of their economic, financial and trading systems.

The dominance of the United States firms in the world software industries and in all the supporting services for the Internet and in world financial services presents some especially acute problems for those catch-up countries which are making good progress in closing the gap in manufacturing.

The liberalisation of capital movements which has already taken place exposes all countries to the instability and shocks which occur in any part of the system. Events in the late 1990s have shown that these shocks can be propagated throughout the system and that however good the narrow innovation system it is always still part of a broader global economic and political system. Trends in the political, cultural and economic sub-systems are influenced very strongly by institutions which are only tenuously related to science and technology. These points are further discussed in Section 7 of this paper.

6. Conclusions

Section 3 of this paper suggested that it was from the time of the British industrial revolution in the 18th century that full *national* systems of innovation emerged. Bairoch's (1993) estimates of the widening gap between developing countries and industrialised countries show this gap growing very rapidly from this time onwards and Sections 3 and 4 of the paper attempted to show that this huge gap between the "forging ahead" countries and the rest could best be explained in terms of such concepts as the "national systems of innovation". Section 5 further showed that this concept is also necessary to explain varying rates of late-comer catch-up and the failure of late-comer catch-up in some circumstances.

Whilst economic historians have had few difficulties in accepting the crucial importance of technical and institutional change in the theory of economic growth, the growth modellers have found this a continuing problem. Some early growth models put the main emphasis on accumulation of (tangible) capital through investment and the growth of the labour force and left all other influences to be subsumed in a "residual factor". Although the so-called "New Growth Theory" broke away from this tradition and moved "intangible investment" in education, research and development to the centre of the stage, the old approach lingers on, as can be seen for example in Krugman's (1994) attempt to debunk the "East Asia Miracle" and to explain East Asian growth mainly in terms of capital and labour accumulation.

The treatment of all the complexities of technical and institutional change in early growth models came in for heavy criticism at the time both from historians and from many economists, especially as most of the models showed that the "Third Factor" apparently accounted for most of the growth. Balogh (1963) dubbed the "Third Factor" the "Coefficient of Ignorance" while Supple (1963) concluded that "it must surely be clear that any discussion of the relationship between capital formation and economic growth necessarily entails the appraisal of a host of other issues. And these in their turn lead to the conclusion that the accumulation of capital is in itself by no means the central aspect of the process of economic growth" (Supple, 1963, p. 22).

In response to this criticism various attempts were made to disaggregate the residual factor in the aggregate production function, notably by Denison (1962, 1967), who used what Dosi (1988) described as an "entire Kama-Sutra of variables" in his efforts to make systematic comparisons of growth rates. Yet none of these efforts could survive the trenchant criticism of Nelson (1981) and others who pointed to the *complementarity* of all these variables. The contribution of capital accumulation to growth depends not only on its quantity but on its *quality*, on the direction of investment, on the skills of entrepreneurs and the labour force in the exploitation of new investment, on the presence (or absence) of social overhead capital and so forth.

A brave and highly original contribution to the growth modelling debate came from Adelman (1963). She recognised early on that the assumption of constant returns to scale in many models raised big problems and in the so-called "New Growth Theory" this assumption has been dropped in favour of Young's (1928) increasing returns to scale (Romer, 1986; Grossman and Helpman, 1991).

These models usually also follow her in attempting to assign a specific role to technical change (or as she termed it "the stock of knowledge from applied science and technology"). In her model Irma Adelman also separated "Natural Resources" from other forms of capital in much the same way as the classical economists separated land. This distinction is likely to become increasingly important with the growing recognition of the importance of ecological factors and resource conservation in economic growth. She also separated technical change from other forms of institutional change. Thus, she specified the production function as

$$Y_t = f(K_t N_t L_t S_t U_t)$$

where K_t denotes the amount of the services of the capital stock at time t; N_t stands for the rate of use of natural resources; L_t represents the employment of the labour force; S_t represents "society's fund of applied knowledge"; U_t represents the "social-cultural milieu within which the economy operates" (Adelman, 1963, p. 9).

Adelman was also unusual in her frank recognition of the immense difficulties in the production function approach and of the interdependence of her variables. For example,

> ... both the quality and the composition of the labour force vary through time and are not independent of the rates of change of the other variables in the system. Specifically, changes in the skills and health of the labour force are directly dependent upon changes in society's applied fund of technical knowledge (S_t).

Like other modellers, she suggests that the conceptual problems "which arise from the heterogeneity and incommensurability of the production factors may be reduced somewhat if we think of each input as a multi-component vector rather than as a single number".

However, this is still not the greatest difficulty with the production function approach. Again, as Irma Adelman so clearly points out:

> Even more difficult than the measurement problems raised by these production factors are those posed by an attempt to quantify our last two variables. S_t and U_t represent heuristic devices introduced primarily for conceptual purposes ... At some time in the future a method may be evolved for the ordinal evaluation of S_t and U_t but such a method does not now exist and accordingly neither variable can be used as an analytical tool (pp. 11–12).

This situation has scarcely changed since 1963 despite some advances in the measurement of R&D and of education and despite the somewhat greater realism about technical and institutional change in the more recent "new" growth models (Verspagen, 1992).

All of this does not mean that the modelling attempts and developments in growth theory of the past half century have been a complete waste of effort. Adelman's argument for the heuristic value of growth modelling still stands and her own attempt to use her production function to illustrate the differences and similarities in the growth theories respectively of Adam Smith, Ricardo, Marx, Schumpeter, Harrod, Kaldor and the neo-Keynesians is an excellent example of these heuristic advantages. But when all is said and done the main conclusion of the whole debate has been to vindicate the contention of many economic historians and neo-Schumpeterian economists that technical change and institutional change are the key variables to study in the explanation of economic growth.

In his fairly sympathetic treatment of neo-classical growth theory Gomulka (1990) concluded that

> The cumulative effect of the theoretical and empirical work has been to highlight more sharply and widely than ever before how really central is the role, in long-term economic growth, of the activities producing qualitative change in the economy. Technological changes have assumed the primary role by virtue of their being typically the original impulses which tend to initiate other qualitative changes. By the same token, the work has also helped to delineate the very limited usefulness of the (standard) growth theory based on the assumption that these qualitative changes are cost free and exogenously given (p. 19).

Sections 1–5 have attempted to justify the view that technical change and the institutions which promoted it played a central role both in the forging ahead process and in the catching up process. This is by no means to deny, however, the role of other influences—economic, political and cultural—which constitute the "broad" national system of innovation. Although the work on national systems has made a promising start on the very complex task of "putting history back into economics" it has certainly not done enough to satisfy the critics, many of whom are uneasy about neo-classical growth models, but also lack confidence in alternative "evolutionary" explanations of economic growth.

Some of the most promising lines of future research on national systems would appear to be in the study of catch-up failure and *falling behind* in economic growth. In cases such as Britain and Argentina, both of which slowed down and fell behind in the 20th century, many of the explanations offered point to the lack of congruence between various sub-systems of society, social institutions which have been favourable to economic growth in one period of technological development may not be so favourable when there are fundamental changes in technology.

Hughes (1982) has shown that Berlin and Chicago forged ahead of London in the applications of electric power in part because of the multiplicity of standards in Britain and mis-management of the new infrastructure. These kinds of points indicate that various "out of synch" phenomena had emerged towards the close of the 19th century in Britain—between technology and culture, technology and politics, technology and the economy and even between technology and science. In the mid-19th century, very few people foresaw this relative British decline. Even Friedrich List, the outstanding exponent of catch-up theory on the Continent of Europe, died believing that Germany could never overtake Britain. Much later on, in the 1960s, the "Dependency" theorists were so impressed by the advantages of the United States and Western Europe that they thought it impossible for countries in Asia, Latin America or Africa ever to catch up.

The advantages of fore-runners may indeed appear overwhelming at first to late-comers. Not only do they apparently command an unassailable lead in technology, but they also enjoy many static and dynamic economies of scale and privileged prestigious positions in world markets. It is for this reason that successful catch-up is often referred to as a "miracle" (The German and Japanese "miracles" of the 1950s, 1960s and 1970s; the Korean and Taiwanese "miracles" of the 1980s and 1990s). But if any process is to be regarded as a "miracle" it should be "forging ahead" rather than catching up.

At the present time (late 1990s) the United States appears to have enormous advantages compared with its principal competitors. The successful catch-up of Japan and other East Asian countries was based on their intensive active learning in *hardware* design, development and manufacturing. Now, however, it is increasingly *software* design, development, production and marketing which is the key to commercial success. Here the United States has some considerable fore-runner advantages. It has by far the strongest software industry in the world with major advantages in scale economies in business applications. This has led in turn to English language domination in software generally and especially on the Internet—a global infrastructure, dominated by US service providers and content providers. Finally, the United States firms also lead in many other service industries and the victory of the USA in the Cold War has established the US as the only "super-power" in a military sense. This power can be used to protect the interests of US firms world-wide including their intellectual property.

It is impossible to predict however how long these advantages can be retained despite the tightening of intellectual property restrictions. Very many countries have rapidly growing young software firms including

Eastern Europe, as well as Eastern Asia, Latin America and countries with strong English language capability, such as India. Moreover, political and social events may predominate over more narrow technological and economic factors.

Social scientists face a more complex problem than biologists because the "selection environment" confronting innovators is not simply the natural environment but also several different sub-systems of human societies—scientific, technological, economic, political and cultural. Each of these has its own unique characteristics and successful diffusion depends on the establishment of some degree of congruence between them.

The growing environmental problems facing the whole world may also impose a rather different pattern of economic and political development than that which has prevailed in the 20th century. The development of environmentally friendly technologies and their universal diffusion may impose a more cooperative civilisation and an entirely new pattern of institutional change and of knowledge accumulation. The great variety of new possibilities in science, technology, economics, politics and culture means that despite the present-day predominance of the United States, permanent convergence based on US hegemony is a rather unlikely scenario. Viotti may be underestimating the feasibility of new clusters of radical innovations in catch-up countries.

The natural environment confronts all living creatures but the accumulation of scientific knowledge and of technological knowledge and artefacts are uniquely human processes even though they may have originated, as with other animals, in the search for food and shelter and the communication associated with this search. There are birds and mammals which also make use of "tools" in the sense of twigs, branches or stones, but the systematic *design* and *improvement* of tools and other artefacts are uniquely purposeful human activities, with their own partly autonomous selection environment. Economists often use a biological analogy to analyse the competitive behaviour of firms in a capitalist economy and the survival of the supposedly "fittest" firms. This is a case of the borrowing back of an analogy which Darwinian theory originally took over from economics. But again the selection environment which confronts firms in their competitive struggle is actually very different from the natural environment confronting animals and plants and this economic environment is itself rapidly changing in ways which are unique. Finally, the political system and the cultural milieu are again uniquely human and powerfully influence the evolution of the economy, as they also reciprocally influence the evolution of science and technology. Evolutionary theories which deal *only* with the survival of *firms* (Alchian, 1951) or *only* with the survival of artefacts or of nations are inadequate for the study of economic growth (Freeman, 1994).

We have no alternative but to confront the unique features of human history, even though we may quite legitimately search for patterns of recurrence and for explanations of recurrence and of non-recurrence. One of the most obvious unique features is the rate of knowledge accumulation in human societies and the varying modes of disseminating this knowledge between individuals and groups. These features are ubiquitous and justify continuous attention by historians of economic growth, searching both for regular patterns as well as for the emergence of new features.

7. Speculations

In this search, economists and other social scientists will need to pay attention to changing systems of innovation at all levels—the global level, the continental and sub-continental levels, the national level and the sub-national level. This paper has concentrated on developments at the *national* level in the belief that the major phenomena of forging ahead, catch-up and falling behind in 19th and the 20th centuries can most plausibly be explained in terms of national systems, albeit in an international context and recognising uneven development at the sub-national level.

All of this may change in the 21st century. In particular, the capacity to use information and communication technology will probably be a decisive factor in world competition and this in turn will lead to the dominance of firms and networks with capability in *service* activities. The models which economists have used have largely been based on *manufacturing* activities, although of course agriculture and services have always been important. Now manufacturing may increasingly be located outside Europe, Japan and the United States. Major manufacturing firms such as General Electric or Ericsson have for some time had a deliberate strategy of increasing the share of *service* activities within their total turnover. Manufacturing employment has already declined substantially in firms such as these and accounts now for much less than half the total, even though they are still often thought of as mainly manufacturing organisations. Financial, marketing, software, design and R&D services may often predominate now in the portfolio of large MNCs.

This does not mean that manufacturing will cease to be important. It will always be important, just as agriculture will always be important even though it occupies a small proportion of the labour force. It may more often be sub-contracted and competitive power will increasingly depend on the capability to manage international networks in production and marketing, with the core activities of research, design and development of software and hardware, based mainly in the national "home" base as long as their base can provide the necessary supporting scientific, technological, educational, financial and communication infrastructure.

Power in these networks will depend on a variety of information services and knowledge-based activities but not only on these. These networks are embedded in social systems where increasing inequality is now the rule and to some degree exacerbated by these developments. Both environmental and social problems are likely to become more acute in these circumstances. Political and cultural changes may then take precedence in the complex interactions between the various sub-systems of society at all levels of the global system. Breadth, enlightenment and social solidarity are essential in the end for any innovation system. Otherwise, as Gomulka has suggested, people may reject the constant turmoil and uncertainty of contemporary competitive innovation systems and insist on the primacy of quality-of-life objectives.

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