THE KUZNETS CURVE AND THE LIFE CYCLE ANALOGY

by

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Abstract

The growth and, especially, the successions of industrial sectors strongly suggests an "aging" phenomenon. In fact, the Kuznets curve was originally based on this notion. More recently, the aging idea has been more fully elaborated into a 'life cycle' scheme (conception, birth, childhood, adolescence, maturity and senescence) which corresponds quite closely with the observed stages of development of a new technology or product. The question arises: is the life cycle analogy sufficiently general to constitute a set of "stylized facts" around which a theory could be developed? In particular, is the life cycle reversible? If so, under what circumstances? The paper addresses these questions and concludes with some observations about the environmental Kuznets curve (EKC) and its applicability to the question of whether economic growth is compatible with long-term sustainability.

The Historical Background

The observed pattern of economic growth offers significant justification for "stage" theories. The key element of such theories is a critical threshold of some sort, often couched in terms of savings and capital accumulation. When this threshold is reached and passed, the economy is ready for a sharp acceleration of growth, analogous to a takeoff [e.g. Rostow 1960].

But another stylized fact of economic growth is that after growth accelerates (the takeoff), it reaches a maximum, and subsequently it declines.[1] British growth rates declined after 1870 or so. U.S. growth slowed markedly after 1972. Western European growth has generally slowed since 1990 (although Britain slowed earlier and is now growing a bit faster again). Japan managed to keep it up through the 1960s and 1970s. Taiwan and Korea have done as well or better in the 1970s and 1980s. Malaysia, Indonesia and Thailand followed by a few years. Most recently, China has grown very rapidly throughout the 1990s and the Philippines seem poised to follow suit. Meanwhile the Japanese economy has come to a virtual standstill in the 1990s. South Korean growth has slowed from 10% per annum to around 6% now and the decline seems likely to continue.

This growth acceleration followed by a slowdown pattern has a certain superficial resemblance to the aging process in a biological organism. It appears that the first economist to suggest an industrial aging process was a German, Julius Wolff. "Wolff's Law" asserts that the cost of incremental improvement rises as a technology approaches its long-run limiting performance level. Simon Kuznets, for whom the famous curve was named, extended Wolff's work [Kuznets 1930]. In brief, the Kuznets curve suggests that as an economy develops, the share of agriculture in GNP will decrease, the share of industrial output will increase and then decrease, and finally the share of services will increase. It follows, of course, that consumption of primary resources and commercial energy (and pollution) will increase at first, then reach a peak, and finally decrease [World Bank 1992].

The standard explanation is given in terms of stages of structural change [e.g. Syrquin 1988; OECD 1992]. The stages correspond rather well to stages of the life cycle. Can the life cycle analogy offer any further insights? In the first stage of development (childhood) a developing economy is dominated by primary production, primarily agriculture, forest products and mining. During this period the commercial energy industry is not very important compared to the use of biomass, either from agriculture or forests.

Assuming there is some economic surplus available for investment, the next stage is industrialization (adolescence). During this period the economy is building infrastructure and accumulating capital goods, which are materials and energy intensive.

Finally, in the third stage (maturity) demand for material products begins to saturate. Having already achieved some degree of comfort and security, there is less incentive to save and invest for a better future. Moreover, the requirements for replacing depreciated capital soak up an increasing share of savings. Thus the rate of investment driven growth decelerates. At this time there is also a shift toward consuming services, which are less materials and capital intensive, hence less pollution intensive.

In the following sections I expand on these observations. However, before offering a more elaborate discussion of the life cycle analogy, it is useful to introduce a related notion (also with a biological analog), namely that of succession.

The Sequence of Technological Succession

The process of industrial succession — analogous, in some respects to the succession of dominant species in an ecosystem — can be most easily understood in terms of an underlying technological succession. This technological succession, in turn, arises from increasing human ability to modify ambient natural conditions, or states of nature, at least locally and temporarily. These states are measured by physical and thermodynamic variables. Examples include temperature, pressure, tension, illumination, electromagnetic fields, friction, chemical composition of the surroundings, and so forth. Temperature is the first variable that became controllable by humans, at least in the upward direction, via atmospheric combustion of natural fuels. (Temperatures of the order of 600 degrees Celsius, enough to melt lead and make bricks and tiles, were achieved in prehistoric times). Higher temperatures were reached only gradually, by enclosing increasing the size of the furnace, adding forced air, drying and preheating the fuels, modifying the fuel (e.g. acetylene, hydrogen), modifying the oxidant (pure oxygen instead of air). By these means it became gradually possible in historic times to melt zinc, copper, silver and gold and pig iron. Before the 1780s carbon steel could only be made in tiny quantities by a laborious process of repeated heating and hammer forging — as exemplified by Damascus swords. Cort's puddling process and Huntsman's crucible process changed that and made wrought iron and crucible steel industrial commodities. But only in the 1850s did the Bessemer process (an air jet through molten pig iron to burn out the excess carbon) make it possible to reach the temperature at which pure iron and carbon steel melts (1550 °C) and can be cast into slabs or beams for structural purposes.

By the end of the 19th century much higher temperatures (up to 2500° C) were reached in electric arc furnaces, making it possible to utilize harder alloys, such as chromium, cobalt, molybdenum, nickel and tungsten steels. But, of course, electric arc furnaces were only possible after large-scale electric power generators were available to serve industry. That only occurred after 1890 or so, thanks to the development of electrotechnology. Aluminum, too, only became available as an industrial material after this time, because the only economically feasible large scale aluminum smelting process (Hall-Heroult, 1886) is electrolytic and consumes a great deal of electric power.

Higher temperatures made possible harder tools, which permitted faster and more accurate cutting. Thus machine tools and high-speed machining of metals, as an industrial process, could not have been introduced before high-temperature alloys to make the tools with. Complex machine parts, such as the crankshafts of piston engines, depend on high speed machining. Thus, the mass production of automobiles could not have preceded the availability of hard high speed tool steels and abrasives for grinding. Subsequent progress in machine cutting speed has depended largely on the availability of even harder materials, such as silicon carbide, tungsten carbide and others, also produced in electric furnaces.[2] Needless to say, aircraft technology was dependent on the availability of both high speed machine tools to produce critical parts of piston engines and aluminum for structural parts.

Higher (and lower) than atmospheric pressures have become continuously available only since large, fast mechanical pumps could be produced, largely after the turn of the century. Pumps are needed for both compression and evacuation. Continuous high pressures are needed, for instance, to synthesize ammonia — for fertilizers, as well as explosives — on an industrial scale (Haber-Bosch 1910). A number of other important chemicals (e.g. methanol) also depend on high pressure synthesis. Pressure casting is now becoming important in metallurgy. Much higher pressures are needed for some processes, such as the manufacture of industrial diamonds, although they can now be produced only in tiny volumes or for very short times. But progress in this area will undoubtedly open the door to new and unsuspected capabilities in other areas. High vacuum was also the key to several important industries, beginning with electrotechnology; radio, TV, high voltage discharges, electron microscopes, X-rays, etc. Modern applications notably include micro-electronics which requires ultra-pure materials and ultra-clean surfaces to achieve exacting performance standards.

It would be possible to go on in this vein, describing how various technologies, and industries, became possible only after some technological threshold had been reached in the domain of temperature, pressure, tensile strength, malleability, rigidity, transparency, low thermal or electrical resistance, high thermal or electrical conductivity, or any of a score of other performance measures. For instance, physicists are now actively seeking to develop practical (manufacturable) superconductors that can operate at temperatures above the temperature of liquid nitrogen — which would then be useable as a coolant. This would open a new range of applications, including magnetic suspension. A related one would be a material light enough and strong enough to make flywheels, capable of operating at extremely high speeds, in a vacuum, on frictionless magnetic bearings, for electromechanical energy storage. For more along these lines see [Ayres 1989a, 1994].

Evidently the domains of most current interest are micro-electronics and semi-conductors (still), information processing and artificial intelligence, and genetic engineering. In these domains it is more difficult to identify future thresholds along a single performance dimension. One can, however, easily identify several multi-dimensional performance targets, such as protein synthesis, methanol or hydrogen from cellulose or lignins, or a cheap and easily manufacturable fuel cell. In the information processing domain it is even more difficult to clearly identify future milestones, or even trajectories. I do not propose to make the attempt.

The Sequence of Industrial Succession

Large-scale industrial activities have developed, historically, following the achievement of critical new technological capabilities, along lines suggested briefly in the last section. Thus, in a typical pre-18th century economy most products in trade were largely biological in origin and the role of humans merely plant, harvest, select, cut and shape, assemble and — in some cases — perform simple transformation processes using low temperature heat (such as cooking or baking clay). In such an economy food was (and, in many places still is) mostly consumed fresh or preserved by simple means such as pickling, baking, drying or salting; structures were (and are) made of natural materials or crude bricks and tiles; mechanical work was done by humans, animals, watermills, and windmills or sails; and metals tended to be scarce and used mainly for cutting tools and weapons. Trade was (and is) largely local.

The next step in the technological succession of Europe was the building of canals (18th century), followed by railways (19th century), and much later by paved roads and airlines (20th century). This sequence has been short-circuited in the developing countries, which tend to depend far more at an early stage on aircraft and roads and do not invest in canals or railroads. This leap-frogging has contributed to the developmental acceleration noted earlier.

Large-scale manufacturing in Europe and North America developed along two parallel tracks. One was textiles, starting with woolens (which supported a large sheep farming activity in Britain) and then cotton cloth (which supported slavery in the cotton plantations of North America). But the woolen and cotton-based textile industry of Europe and North America peaked long ago and finally declined. All that is left is a very "high tech" mass production industry based almost entirely on synthetic fibers derived from petrochemicals. This industry probably has no long-term future in the industrialized world, however.

Textiles and clothing were long regarded by development economists as the natural first step of industrialization for a developing country, because of its use of low cost unskilled labor. This was "confirmed" by the fact that India built a significant textile manufacturing sector in the late 19th century, and Japan and Hong Kong later followed the same path. But this sector is also one of the first to experience saturation. Moreover, when synthetic fibers were introduced to the textile markets in the 1950s there was no straightforward way for developing countries without a sophisticated chemical industry to restructure their cotton or silk based textile industries appropriately.

The other manufacturing track in Europe and America was metal products (such as muskets and pistols, cutlery, pocket watches and clocks), machinery (such as steam engines and railway locomotives), water pumps and pipes, and ships. It was demand for these products that created induced demand for iron and steel. The steel industry of Europe and North America received its greatest impetus from the needs of railway construction. Now it is bridge-building, ferroconcrete construction, pipelines, military equipment and motor vehicle manufacturing that consumes most of the steel. Some of the simpler products (such as re-bars and I-beams) are made in small electric mini-mills from recycled scrap. Automobile engine blocks are simple iron castings, also made from recycled scrap. The most sophisticated products, such as very thin sheet for auto bodies, forgings and specialized alloys for machine tools, steam turbines, jet engines, nuclear reactors and equipment for chemical processing industries, require a high level of metallurgical and engineering expertise and experience. This keeps the steel industry of Europe, North America and Japan competitive, for the moment.

In the developing countries of today there is little local scrap, as yet, so local markets (e.g. in Latin America and Asia) are still served by integrated mills, or by imports. Such mills tend to export much of their output of raw steel because local demand is restricted largely to the unsophisticated products needed by the construction sector.

Even so, the development process for developing countries today is much faster than it was for Europe and North America, because some stages can be skipped over. Steel mills can be built almost anywhere with rail transport and access to ore and coking coal. Alumina plants and aluminum smelters can be located anywhere with access to bauxite and, in the case of smelters, electricity. Paper mills can be located anywhere with access to pulpwood and transport. Cement plants need only limestone and coal. Refineries need only oil. The same is true of many other primary products industries.

Chemicals, plastics and synthetic fibers, rubber, pharmaceuticals, and mechanical and electrical machinery manufacturing, on the other hand, are too complex and interconnected to transplant piecemeal into countries with small domestic markets or without primary materials industries. It is nearly impossible for auto parts manufacturers, for instance, to compete for sales to big multinational automakers whose assembly plants are located in other countries far away. Generally speaking, developing countries must first attract assembly plants belonging to multinationals, after which various parts manufacturers will begin to cluster around them. Thus partially integrated mechanical and electrical engineering (including electronics) sectors have been late-comers to most developing economies, except for South Korea, Brazil and now China and India.

The Technology/Product Life Cycle

As noted earlier, a number of the key stylized facts of technological progress constitute a coherent pattern that can be termed the "technology life cycle". The phenomenon is easily identified by its resemblance to the biological life cycle. A technology, like a product, has characteristic stages of development: conception, infancy, adolescence, maturity and senescence. While metaphoric, these stages are so widely applicable that the metaphoric language is almost universally used. Technology in the very broadest sense is always progressing. But the growing tip of rapid progress is always moving from sector to sector. At present, the areas of rapid scientific and technological progress are high energy physics, computer science and bio-chemistry. A few decades ago solid state physics, micro-electronics, nuclear physics and polymer chemistry were very active. In the late 19th century and early 20th century organic chemistry, electrochemistry, electrometallurgy and electromagnetic radiation were the hot subjects.

Technologies have recently followed where science led. Like science, it progresses unevenly. The spotlight moves irregularly from sector to sector. At first, some major new application of a scientific discovery is conceived. A harder or stronger material enables a better tool, for instance. This translates into a more efficient manufacturing process. Or it permits higher combustion temperatures or smaller and faster engines. Or a new compound or alloy displays different and unsuspected electronic properties permitting higher photovoltaic efficiency or higher speed or stronger magnetic fields, or higher current density, or more powerful lasers, or better superconductors, or greater/lower electrical/thermal resistance, or greater or less infra-red absorbtivity, etc. The possibilities and combinations are indeed endless.

But, it is also a fact that fields of technology do *not* remain equally active forever. No more do economic sectors grow rapidly and proliferate new products or services indefinitely. The pattern is different. During the infancy stage of a technology, applications do proliferate, as do (mainly) new enterprises hoping to capture new markets. They attract venture capital and invest heavily in R&D. In consequence, the performance level of the technology increases rapidly. Products are likely to be expensive, and sold on the basis of performance. If the new product is not competing directly with an established one, change is rapid, so standardization and large scale production are not possible.

But during the adolescent stage, proliferation of product variants and firms slows and stops. Standardization and consolidation begins, as one or two variants begin to dominate.[3] The firms producing the dominant variants become more profitable and begin to enjoy increased market power. They are in a position to increase capacity, and to exploit economies of scale in manufacturing. Prices then begin to fall and smaller producers are pushed out. The result is commonly called a "shakeout". This phenomenon has occurred dozens of times in different sectors of the economy, from typewriters and bicycles to automobiles and aircraft manufacturing to computers, PCs, and airlines.

The mature phase follows the shakeout. During this phase the rate of progress in terms of performance slows down, the product becomes more and more standardized, economies of scale in manufacturing become more and more important, the production process becomes much more capital-intensive — which slows technical change still further — and the industry consolidates still further. Typically it becomes an oligopoly, if not a monopoly. Finally, in the senescence phase, the product becomes a commodity. Technological change slows further.

During this entire sequence underlying economic relationships are changing. For instance, the capital/labor ratio increases steadily, from infancy through maturity. The elasticity of substitution changes too. The return on R&D, and the investment in R&D decreases throughout the cycle. The price elasticity of the product decreases as the product changes from being a high-priced luxury to a low-priced commodity. During the early stage of the life cycle, the product is new and is probably competing, at the margin at least, against some established product. At the end of the cycle it is established and competing, at the margin, against would-be substitutes.

Is the Life Cycle Analogy a Useful Analytical Tool?

The biological life cycle, for organisms, is deterministic, irreversible and immutable. It is a pattern of development that is genetically determined for each organism. An organism may not survive to its maximum lifespan, but morphology and function are definitely functions of age. The pattern is somewhat less rigidly deterministic in the case of ecosystems, or biomes, of course. The classic sequence of "old field" colonizations that follows a forest fire, for instance, can be varied, within limits, by external conditions, including the possibility of human intervention. But the pattern is clear enough to be a good basis for prediction and, if necessary, for policy.

In the case of a technology or a product, the sequence is much less rigid. It is not absolutely irreversible, for instance. There are cases where sectors have, to all intents and purposes, been rejuvenated. When this has occurred it has usually resulted from the impact of another more rapidly changing technology. Or it may be the result of a new constraint, such as a sudden and unexpected scarcity. Or it could result from a sudden increase in competition due to the removal of trade barriers. On the other hand, it is also possible for an industry to skip directly from childhood to maturity, or from adolescence to senescence, in certain circumstances. Nevertheless, it is plausible to argue that the life cycle is the most *natural* pattern, and that if exceptions are desired, for any reason, they will have to be induced by policy.

For instance, the world steel industry was mature by 1920 and senescent by 1950. But it went through a second adolescence in the 1960s and 1970s, thanks to rapidly growing demand, declining trade barriers encouraging global competition, changing raw-material availabilities (more scrap), and the introduction of two important new technologies, the basic oxygen furnace (BOF) and continuous casting. The world steel industry appears to be once again mature and perhaps approaching senescence. A second rejuvenation is unlikely to take place spontaneously.

The world nuclear industry faces seems to be an example of the second kind. In the first place, it skipped the normal childhood stage, leaping from infancy to late adolescence. This happened because the R&D was almost entirely supported by the military nuclear submarine program, and only a few large military contractors had access to that technology. They, in turn, obtained an insurmountable advantage over any would-be competitor. So the nuclear industry never experienced the usual proliferation of different and competing design approaches. Design standardization was enforced, prematurely, by government agencies. The industry was already a government-nurtured oligopoly in the U.S. and a monopoly in most other countries, from the very start. Lacking natural dynamism, such an industry will quickly be overwhelmed by more dynamic competitors, unless it is actually protected by the government (as in France). The highly publicized accidents at Three Mile Island and Chernobyl were enough to stop the growth of the industry in the U.S. Its future depends on external forces; under some scenarios the industry could face extinction; under others, it could be rejuvenated.

The computer industry is a very interesting case. At the beginning, it was supported by government R&D and, for its first two decades the government was the major customer. This was particularly true for UNIVAC, created by the developers of the first electronic computer, ENIAC. But it was also true for IBM, which became the major contractor for an enormous system of early-warning air-defense and missile defense radars (NORAD), which pushed the state-or-the-art of computers enormously. Thus, even though other large electrical engineering firms and office equipment firms (GE, RCA, Honeywell, NCR, Burroughs, Phillips, Thompson, Siemens, Fujitsu, Hitachi, NEC) saw the promise of the technology and invested heavily in it, the conditions existed for a government-nurtured oligopoly, as in the nuclear case. Indeed, this is exactly what did occur. IBM held 70% or more of the so-called mainframe market, worldwide, from the late 1950s through the 1980s. It still does.

But the two factors that have prevented the industry from fossilizing (and has even rejuvenated it in recent decades) are (1) the dynamism of micro-electronics, which IBM could not dominate, and (2) the convergence of information processing technology with information transmission and distribution (i.e. telecommunications) technology. As regards the first factor, series of radical innovations in micro-electronics has essentially preempted computer design and shifted the scene of the action to chip design on the one hand, and software development on the other. The computer is now essentially a collection of peripherals built around a microprocessor chip and some memory chips, with a set of software packages included. Mainframes are a declining subsector of the industry, with personal computers (PCs) linked into networks, becoming more and more dominant. There are, of course, other niches, including mini-computers, engineering workstations, supercomputers and so on.

The second factor that has kept the computer industry from becoming mature, in the life cycle sense, is the advent of computer networking via telephone lines. The Internet and the World Wide Web are the visible evidence of this. Indeed, there is no longer any useful distinction between computer technology and telecommunications technology. The whole field is now called "information technology".

Despite the extremely dominant position of many companies in their niches the interconnections among the niches are so prolific and the dynamism of this technology is so great that new niches are being created by entrepreneurs every year, while others are becoming obsolescent. Since the most important criterion of childhood is relative ease of entry, it would appear that the information industry as a whole has been rejuvenated. Whereas most telephone companies were national or regional monopolies twenty years ago, competition for the long distance market, and innovation in the field of telephone-based services, have exploded. Completely new products, such as mobile phones, have become best-sellers. New systems have been created. New telephone services (like "call-back") have appeared.

Monopolies have not yet disappeared. Telephone companies still monopolize local service over fixed lines. IBM still dominates the corporate and government mainframe computer market, thanks to the enormous investment in system-specific software. Intel has over 90% of the current market for microprocessors for PCs but not in other kinds of computer chips. Japanese and Korean firms are the dominant producers of memory chips in the merchant market, though IBM and Siemens manufacture their own. Compaq is now the biggest PC manufacturer, with IBM only one of the pack. Sun Microsystems dominates the engineering workstation market. Cray was the first and dominant maker of supercomputers, but Cray is already past its prime, having been bought by Silicon Graphics. Cisco Systems has a near monopoly on system switching routers hardware. Microsoft now has a near monopoly on operating PC systems (Windows), and a strong position in word processing, spread sheets and other applications software. Yet, Netscape suddenly appeared out of nowhere to dominate the field of Internet "browsers" and access from PCs.

Evidently, in the information businesses, no monopoly is secure for long — for the present. AT&T was broken up into seven regional companies and a long distance company, which was immediately challenged by a new entrant (MCI) and a formerly minor regional competitor (Sprint, an offshoot of GTE). The local U.S. telephone markets are being opened to competition from both cellular systems and long distance companies. The U.S. and trans-Atlantic long-distance markets are already highly competitive. Europe is in the throes of deregulation. Competition will surely intensify during the next few years. Yet the Telecoms, IBM, Lucent Technologies (formerly AT&T), Siemens, Phillips, Fujitsu, Hitachi, Toshiba, and NEC, and probably several of the Korean conglomerates nevertheless retain the technological, financial and marketing capability of re-entering or increasing their market share in almost any area of hardware, or systems, once the technological rate of change has slowed down to the point where manufacturing and marketing become more critical than design. The life cycle analogy suggests that this will occur eventually.

In the software area, as in the hardware area, standardization is the key to monopoly power. The Microsoft monopoly based on links to PC hardware standards established originally by IBM may be almost over, however. Sun Microsystems' new Java language operates on almost any machine, regardless of operating system or microprocessor. Java has already become the standard for cross platform network-based applications and has opened the door according to some experts to the network computer. Over 100 companies including IBM, Apple and Oracle have committed themselves to its commercialization and 200,000 individual software developers, are now using it. Most industry executives now see Java as a great threat to Microsoft's current dominance of PC software. Nevertheless, though the time may be far in the future, the life cycle analogy suggests that the software sector, too, will eventually become mature.

The economy can be regarded as a collection of sectors in different stages of the life cycle. During the 19th century, most sectors were infant or at most adolescent. Only a very few (like coal, steel and railways) had matured by the end of the century. But a number of new sectors were still infant in 1900 (automobiles, aluminum, electrical engineering, radio) and some of today's most important sectors (aircraft, TV, micro-electronics), were still well in the future. Today, by contrast, most manufacturing sectors are clearly mature. Even semiconductor and computer manufacturing are now essentially mature, having duly experienced their shakeouts notwithstanding the possibility of a new round of competition sometime in the future. On the other hand, telecom and network systems, having been mature a generation ago, have been effectively rejuvenated and are again in the adolescent phase. But the only truly pre-adolescent sectors are biotechnology and the new network-based "multi-media" industry (for lack of a better name).[4]

To answer the question posed at the beginning of this section, I believe that the life cycle provides helpful insights into what is likely to happen next, at least qualitatively. It obviously cannot be used mechanically, because the technological life cycle is not as deterministic or as irreversible as the biological counterpart. Nevertheless, I believe the analogy — allowing for differences — is a useful analytical tool, or meta-model [Ayres 1988, 1989].

The Environmental Kuznets Curve (EKC)

In 1992 the World Bank introduced the so-called environmental Kuznets curve in the context of a rather elaborate argument to the effect that economic development is essentially good for the environment. The empirical backing for the argument was largely based on scatter charts showing that certain categories of pollution (notably water pollution and urban air pollution, especially smoke and sulfur oxides), tended to increase with GNP/capita, at low levels of GNP, but tended to decrease with GNP/capita at high levels. Obviously this is consistent with the standard "stage" view of economic development, where increasing pollution per capita corresponds to the early industrializing stage and decreasing pollution per capita corresponds to the late stage of slower growth and shift toward services. It is also partially explained by the tendency of wealthier countries to shut down energy intensive and materials intensive industries (which also tend to be "dirty" industries) and purchase their products instead from resource rich but poorer countries. A very good example of this is the leather tanning industry, which has now moved almost entirely away from western Europe and North America, to places like Brazil and India.[5]

There is also an economic argument to support the environmental Kuznets curve (EKC) thesis. In brief, it is reasonable to suppose that higher income people will put a higher value on environmental amenities, and will therefore be willing to pay more for pollution prevention and/or control.

Since the theoretical argument seems to support the empirical observations, the World Bank accepted the entire package as gospel truth and pushed it hard as an argument against environmental constraints on economic development. Most mainstream economists found no fault with this. However, a number of environmentalists did see serious flaws in the EKC argument, and economists have begun to take a second look, especially since the publication in *Science* two years ago of an article raising some deep questions about it. This article, based on a Workshop held under the auspices of the Beijer Institute in Stockholm, was signed jointly by a number of well-known economists and ecologists. Since then the Journal *Ecological Economics* has published a special issue of commentaries on the *Science* article. Currently (winter 1996-1997) the Journal *Environment and Development Economics* is planning another special issue on the EKC, for which it is soliciting contributions. In short, the subject is currently "hot".

I do not propose to repeat criticisms of the EKC thesis that I have made elsewhere [Ayres 1996]. But it is appropriate to ask whether the Life Cycle analogy, as elaborated above, offers any special insight on the question of whether economic growth is environmentally benign or not. In particular, the crucial question boils down to relative rates of change. On the one hand, rapid growth in the so-called tiger economies of East Asia, most of which are still in the adolescent stage of increasing materials/energy use, will drive up global materials/energy use per capita and per unit GNP. This accelerates the environmental impact of that use. On the other hand, industrialized Western countries, well into the mature stage of economic development, tend to exhibit a tendency to reducing energy and materials use per unit GNP *but not per capita*. These adverse trends are clearly documented in many publications [e.g. WRI, World Watch Institute, various years].

In short, dematerialization is the key. But in the recent past dematerialization has not been occurring fast enough to compensate for increased consumption, even in the slow-growing West. So the question can be rephrased: does the life cycle analogy offer any clue to tell us whether the desirable trend toward dematerialization of the economy — already very noticeable in the information technology sector — is likely to spread and accelerate? The answer depends on what happens in the mature and senescent sectors, especially housing, transportation and energy supply.

The two examples, steel and information, I discussed above suggest, first, that rejuvenation is possible and second, that there are several ways it can come about. In the case of steel, it was the sudden burst of demand for steel in the rebuilding postwar economies —

especially Japan — together with the coincidental availability of a significantly improved technology, and falling barriers to international trade, that were responsible. The net effect was that Japanese steel-makers were able to overcome their initial disadvantage of smaller market size and obsolescent plant and equipment. By exploiting low cost labor, low cost capital enabling them to invest in newer technology, and free entry into the U.S. market they quickly grew into international leaders.

In the case of information technology, it was technological convergence and deregulation that have been responsible for the rejuvenation. Of the two, technological convergence was probably more important in creating new niches that enabled new players to grow quickly into giants able compete successfully with old monopolies on the global scale.

In the cases of housing, transportation and energy supply, the only plausible drivers of technological convergence on the horizon would have to be information technology. So, one might ask: is it plausible that housing systems, transportation or energy supply systems could be restructured by the imperatives of information technology? As regards energy supply, it is housing and transportation that will drive any market-driven (as opposed to government induced) changes. In the case of housing, it is easy to foresee wideband interactive entertainment/communications systems, perhaps with holographic displays, resulting from a convergence of telecom and TV cable networks. One can perhaps foresee a more distant day when climate control, lighting and security systems will be autonomous (solar powered) and controlled by artificial intelligence.

But unless the trend toward dispersed individual houses in low-density areas were reversed, or such systems were standardized enough to permit factory production of major modules, it seems unlikely that significant per capita reductions in materials/energy use would follow. On the contrary, if greater wealth per capita results in further decentralization of cities, as has been happening for many decades, information technology will not induce significant dematerialization of housing. Indeed, the much-touted trend toward "telework" would probably encourage still more decentralization.

In the case of automotive transportation, the omens are slightly better. Information technology has already become a major part of the automobile. It seems but a minor step further to include electronic locks and satellite based geographical location systems — already available for commercial fleets — as standard equipment. The auto industry foresees electronic highways interacting via special-purpose telecom systems with "smart" vehicles, to increase highway capacity, avoid accidents and reduce congestion. Others view this program as the civil analog of the "star wars" missile defense project. But the same technology would easily permit other applications, notably efficient car-sharing systems, both private and commercial.

However, it is clear that information technology is unlikely to result in significant dematerialization of the transport sector *unless* it contributes to inducing people to use less personal transportation services, and/or to use them much more efficiently. This is conceivable, but far from inevitable.

Summing up I would therefore have to conclude that the EKC offers no basis for confidence that economic growth is or will be environmentally beneficial. On the other hand, I think that the life cycle analogy is modestly helpful in terms of extracting useful clues for purposes of scenario development.

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Endnotes

1. The maximum appears to have increased over time, suggesting an overall acceleration of global growth. However that is another problem.

2. Contrary to intuition, a small increase in the hardness of the cutting tool allows a dramatic increase in metal cutting and grinding speeds, which have increased several orders of magnitude since the beginning of this century.

3. Economists tend to assume that the dominant is invariably the "best" one in some not-very-well-defined sense. But it may be simply the variant that happens to be chosen by a large and powerful firm that has decided to compete for the new market, as in the case of IBM's PC. Or it may be the variant selected by a large and powerful customer in a hurry to standardize, as was the case with nuclear reactor designs, which were prematurely standardized by the US Navy in order to push forward with the nuclear submarine program.

4. In fact, the technological life cycle may be responsible for the so-called Kondratieff, or long cycle that has repeated itself at least four times since the industrial revolution. Three of the cycles seem to have been correlated closely with clusters of technologies associated with a new dominant source of energy (coal, oil and electric power, natural gas) although the fourth substitution — which was widely expected to be nuclear power — seems to have been aborted.

5. When Lawrence Summers was chief economist at the World Bank a few years ago he precipitated a major controversy by a leaked memo, which argued that perhaps some of the less-developed countries are under-polluted in the sense that both they and the wealthier countries would benefit by moving dirty industries to poor countries.