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*Graciela Chichilnisky**

The Golden Age of Industrial Society

Since World War II, the world economy expanded at an impressive pace, and world trade increased three times more than world production. During this period industrialisation became an irresistible trend, made global by the dynamics of international markets. This was the golden age of industrial society.

Today, the industrial society faces the risks created by its own success. Its growth has been accompanied by a voracious use of natural resources and by increasing inequalities between industrial countries and the rest of the world (World Resources: People in the Environment, 1994-1995). Industrialisation to date has been based on energy. It has been, and continues to be, based on the burning of fossil fuels, and the attendant emission of carbon dioxide. Recent discoveries indicate that carbon emissions can cause climate change. In addition to burning fossil fuels, the process of industrialisation has involved massive clearing of wooded lands, such as forests, where most of the world's biodiversity has been found. Today the extent of a country's industrialisation can be measured directly by the amount of energy and natural resources that it uses.

While only 20 per cent of the world's population lives in industrial societies, through global trade the success of industrialisation has magnified the use of fossil fuels and other natural resources world-wide. The international

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market mediates the relationship between industrial nations and developing countries—the North and the South. With few exceptions, economic development can be read from the composition of a country's exports. The developing South specialises in resources, which account for 70 per cent of the exports of Latin America and almost entirely for those of Africa, while the industrial North specialises in products that are intensive in capital and knowledge. By contrast, the most successful industrialising nations in East Asia have swiftly moved into technology-intensive products, and have shaped their markets to fit their development needs. On the whole, however, the extraction and use of natural resources across the world has reached a scale that is unprecedented by historical standards.

The world's use of resources is not even. The gap in energy and natural-resource use between industrial and developing nations is striking: the average person in an industrial nation consumes 10 times as much energy as a person in the developing world. People in developing countries are more parsimonious in their use of energy: they produce more economic output from each unit of energy they use: in 1991 the industrial (OECD) countries accounted for 37.4 per cent of the world's output, but they used about 52.4 per cent of the world's energy.[1] In this sense, developing countries' energy use can be said to involve less waste.

Today, the pattern of resource use in the world economy is clear: most resources are used in the industrial countries which house 20 per cent of the world's population.[2] For example a single country, the United States, uses about 25 per cent of the petroleum produced in the world, although it has less than 4 per cent of the world's population. This may be traced to resource patterns of resource use and consumption that have been encouraged by institutions created and led by today's Western industrial societies. Since the end of colonialism, development policies encouraged by the Bretton Woods institutions (The World Bank, the IMF) have perpetuated a pattern of development in which the world's less advanced countries play the role of resource producers and exporters, resources which are then imported and over-consumed in the industrial nations. This pattern of trade, and the attendant lo resource prices, is in great part explained by the historical difference property rights between the North and the South in the context of a rapid expansion of global markets (Chichilnisky, 1994a). Countries in the latter hold most resources as common property, while in industrial economies these are on the whole private property. Differences in property rights have been invoked successfully in explaining the fact that the South extracts natural resources for the international market, selling these below real costs (Chichilnisky, 1994a). As a result, the North over-consumes resources and the

South over-extracts them. *In a world where agricultural societies trade with industrial societies, global markets magnify the extraction of natural resources and as a result world exports and consumption of resources exceed what is optimal* (Chichilnisky 1994a).

These facts have led to the view that today's global environmental problems, such as climate change and extensive biodiversity loss, are due mostly to the patterns of consumption and resource use in industrial nations. This view has merit in the short run. In the long run, however, the fate of the world's resources is likely to depend on the developing world. *For these reasons this paper concentrates on today's patterns of development for industrial nations, and on future patterns of development for the rest of the world.* It advances a vision of a new society in which humans live in harmony with each other and with nature, and describes the transition to this new society as a 'knowledge revolution'. This refers to a swift period of change, that is already partly underway in industrial nations, but requires new institutions and policies in order to reach a sustainable outcome.

I propose here the introduction of new institutions and policies which can lead the transformation of industrial society into a sustainable society through the knowledge revolution. As part of these institutions, I propose the creation of a new type of market organisation, involving markets that trade a mixture of private and public goods. These new markets require new regimes of property rights, also proposed here, and carry with them the seed of a human oriented society, which, by its own functioning, encourages a better distribution of knowledge and of natural resources.

A similar vision is proposed for the future of developing nations, which, through their own knowledge revolution, could be transformed into sustainable societies in the future, often bypassing the stages of heavy industrialisation that are damaging to people and their environment.

The arguments proposed here are supported by economic theory, presented in Appendix I, and by empirical evidence, presented in various figures and tables across the paper and explained in Appendix II. The vision is global, and is oriented to transforming today's economies ~~into an instrument~~ of human welfare and knowledge creation, leading to sustainable patterns of consumption and resource use.

Global Patterns of Consumption and Resource Use

Biodiversity destruction and climate change are two pressing problems in the global environmental agenda. Economic activity is the driving force of climate change and biodiversity destruction. Both originate in current patterns of consumption and resource use. As already explained, the economic activity of industrial nations, which house less than 20 per cent of the world population, originates 60 per cent of global emissions of carbon dioxide that could potentially change the global climate. Industrialised countries consume, on average, 10 times more copper, three times more roundwood, 15 times more aluminium, and 10 times more fossil fuel per capita than developing countries (*World Resources: People and the Environment*, 1994-1995, and Chichilnisky, 1995-1996). The destruction of forest ecosystems that accompanies industrialisation is believed to be the main source of global biodiversity loss (*World Resources: People and the Environment*, 1994-1995).

Fossil fuels and forest destruction are at the root of the global environmental problems. Industrial society depends on fossil fuels, and industrialisation has led to most of the destruction of the world's forests in contemporary society. From this perspective, without changing industrial countries' patterns of consumption and resource use there would be no solution to the world's most important global environmental problems. The main issue is the North's use of resources and its patterns of consumption today. It is useful to reflect on the fact that the problem originates from industrialisation rather than from political organisation. Environmental problems are certainly not restricted to capitalism. Some of the worst examples of environmental overuse are found in planned economies, such as in the countries which used to be part of the Soviet Union.

The contribution of developing countries is more ambiguous and complex. Many developing countries are embarked on, and aspire to, their own process of industrialisation. If, however, they were to replicate the pattern of resource use of industrial countries, 50 years from now they could become the major source of global environmental damage; this could spell disaster. Another aspect is that the developing countries are the source of most exports of natural resources used in the world. Indeed industrial countries' extensive use of resources are associated with resource-intensive patterns of economic growth in many developing countries, patterns that have prevailed since the end of colonial rule 50 years ago. The situation has been summarised as th developing countries overexploitation of resources which are exported a over-consumed in the industrial countries. A case in point is the petroleum market, which accounts for most of the energy used in the world (*World Resources: People and the Environment*, 1994-1995). The mineral fuel category of merchandise trade provides an extreme case of delivery of a primary, non-renewable item from developing to industrialised countries. By 1990 nearly three fourths of all Southern exports in this category were sent to OECD countries (*World Resources: People and the Environment*, 1994-1995, p. 14).

Sustainable Development and the Knowledge Revolution

Today the world faces a major challenge: to find practical paths for sustainable development. This means finding ways to reorient consumption patterns and use of natural resources in ways that improve the quality of human life, while living within the carrying capacity of supporting ecosystems.[3] It requires building economic systems where basic needs[4] are satisfied across the world, while protecting resources and ecosystems so as not to deprive the people of the future from satisfying their needs. It requires building a future in which humans live in harmony with nature. We are far from this goal: indeed in many ways the world economy is moving in the opposite direction. The task is daunting.

Just as the environmental problems generated by industrial society are becoming a threat to human welfare, industrial society is in the process of transforming itself. The rapid pace of this process of change has led me to call it a revolution. The change is centred in the use of knowledge and, for this reason, I call it the 'knowledge revolution'.[5] What characterises this so-called knowledge revolution?

The question is best answered in a historical context, by contrasting the current situation with the agricultural and the industrial revolutions, two landmarks in social evolution. Neither of the two previous revolutions is complete. Across the world today we find pre-agricultural societies populated by nomadic hunters and gatherers, and most of the developing world is still living within agrarian societies. While the two previous revolutions are still working their way through human societies, knowledge is becoming a leading indicator of change.

There is nothing new in knowledge leading to and anticipating change. Both the agricultural and industrial revolutions involved new knowledge. The agricultural society evolved from new knowledge about how to use seeds, leading to larger sedentary human societies that exploited agriculture. Land is the most important input of production in the agricultural society, the determinant of economic progress and of wealth, and the labour that powers agricultural production is the most important fuel of agricultural society. The next major social change was the industrial revolution, which emerged from the discovery about how to harness energy through the steam engine and the internal combustion engine. Capital in the form of machines then became the most important input of production, and the most important determinant of wealth and economic progress. Fossil fuels, such as coal and petroleum power engines, and became the most important fuel of industrial growth. The next major change was also driven by knowledge: the discovery of electronic means of processing, organising, storing and communicating information. This discovery is leading to the knowledge revolution.

Knowledge means the ability to choose wisely what to produce, and how to produce it. This ability is becoming the most important input of production, and the most important determinant of wealth and economic progress. It resides mostly in human brains rather than in physical entities such as machines or land.

It is worth pointing out that the important input is *knowledge* rather than information. This is the difference between the computer industry, which is based on information technology, and other sectors such as the telecommunication, biotechnology and financial sectors, which involve knowledge. *In a nutshell: knowledge is the content, information is the medium. The content is driving change, facilitated by the medium.*

Information technology is nevertheless a *fuel* for knowledge. Its abundance and inexpensive supply helps fuel the growth of sectors such as communications, biotechnology and finance. It does so the same way that inexpensive and abundant human power (animals and often slaves) fuelled agriculture in the agrarian society, and that inexpensive and abundant fossil deposits (of oil and coal) fuel machines and economic growth in the industrial society.

Information technology fuels knowledge sectors because it performs the important role of allowing the human brain to expand its limits in the production, organisation and communication of knowledge. However, in the knowledge society, the most important input of production is not information technology itself, but knowledge.

Characterising the Knowledge Revolution

What distinguishes the knowledge revolution from the two previous revolutions, both of which originated also in the discovery of new knowledge? The knowledge revolution is distinctive because in it knowledge itself has become the most important input to production. In previous revolutions the prima inputs were private goods rather than knowledge: goods such as *land* *machines*, that were better utilised because of the new knowledge.

We may characterise the knowledge revolution as a period of rapid transition at the end of which *knowledge* becomes the most important input of production, the most important factor of economic progress and wealth. By analogy, in the agricultural revolution land became the most important input, and in the industrial revolution capital became the most important input. This change is already taking place. There are some indications: the value of a corporation in the stock exchanges of the world is increasingly measured by its knowledge assets, namely discoveries, patents, brand names and innovative products, rather than from its capital base or its physical assets. This means that knowledge-type assets (such as patents) are increasingly regarded as the most important source of economic progress in the corporation, and of its value. In terms of economic progress: knowledge of mathematics and sciences has become a good predictor of national economic progress across the world, see table 1 and figure 3 below.[6] Today, more Americans make semiconductors than construction machinery. The telecommunications industry in North America (U.S. and Canada) employs more people than the auto and the auto parts industries combined. The U.S. health and medical industries alone have become larger than defence, as well as larger than oil refining, aircraft, autos, auto parts, logging, steel and shipping put together. More Americans work in biotechnology than in the entire machine tools industry. Most U.S. jobs in the last 20 years were generated in smaller, knowledge-intensive firms driven by risk capital.

In advanced countries such as the U.S., one-third of the nation's growth is accounted for by the knowledge sectors below,[7] so that knowledge is an increasingly important determinant of economic progress. The knowledge sectors of the economy already are growing much faster than the rest of the economy, and account for most of the dynamics of economic growth (see figure 4 below). This is despite the fact that current systems of accounting undervalue the contribution of electronics, which are extraordinarily productive and offer rapidly lowering costs for their products, so their weighting factor in GDP (market prices) decreases with time. In a nutshell: in the U.S. knowledge products are rapidly becoming the most important input of production, source of value and economic progress. Similar statistics hold in most of the OECD nations. However, development of knowledge sectors is slower in Europe because European financial markets and property rights systems are not so flexible and well developed and regulated. This is discussed further below.

Knowledge as a Privately Produced Public Good

As we have already seen, the knowledge revolution is distinctive because in it *knowledge itself* becomes the most important input to production, as land and machines were in the agricultural and industrial revolutions. This matters because knowledge is a special type of good. Knowledge is called a *public good* by economists, not because it is produced by governments but because it is not 'rival' in consumption. This means that we can share knowledge without losing it. Certainly land and machines do not have this property. They are private goods because they are 'rival' in consumption: If I use a piece of land others cannot; if I use a machine others cannot use it. Knowledge is different. The same knowledge can be used by me and by others simultaneously. This is what is meant when one says that knowledge is not 'rival' in consumption: it can be shared without losing it. This is a physical property of knowledge, not an economic property, and, as such, it is quite independent from the organisation of society. Nevertheless, it is clear that the economic rules governing the use knowledge—for example, whether patents can be used to restrict its use—can have a major impact on human welfare and organisation. More on this below.

Knowledge is also different from conventional public goods of the type that economists have studied for many years, such as law and order or defence. These are also public goods, since they are not rival in consumption. However, they are naturally supplied by governments, in a centralised fashion. The work of economists such as Lindahl, Bowen and Samuelson analyses them in the context of a government policy. What is unique about knowledge is that, although it is a public good at the level of consumption, it is supplied by *private* individuals who are its creators. At the level of production, knowledge is like any other private good: costly to produce, and the resources used to produce knowledge often cannot be used for other purposes. Knowledge requires human time to produce, and human time is certainly a private good in the sense that if used for one purpose it cannot be used for others.

Producing knowledge requires economic incentives similar to those for producing any other private good.

A Service Economy?

It is important to differentiate the knowledge revolution from the concept of a service economy, which used to be thought the latest stage of the industrial society. A service economy is characterised by the production of services more than goods, and it is similar to a knowledge economy in that knowledge sectors often involve services (such as finance).

It is true that services now make up the largest part of advanced industrial economies. However the analogy ends there. The inevitable concern about the service economy is that it could lead mostly to service-oriented labour, such as that employed in the food services or in bank processing, requiring little skill and achieving lower wages.

An important difference between the service economy and the knowledge society is that in the latter the typical worker is highly skilled and generally well paid. Furthermore, the worker's knowledge resides in her/

himself and her/his brain and life experience, rather than in the machines that complement labour. Therefore the knowledge economy could result, with proper institutions, in a society that is more human oriented than the industrial or the service society. Humans could achieve a new form of economic organisation where the most important input of production is no longer machines, as in an industrialised society, but rather human knowledge.

From the environmental perspective, instead of burning fossil fuels to power machines, the knowledge society 'burns' information technology to power knowledge. Information is, in principle, a much cleaner fuel than coal and petroleum, and one that puts humans, rather than machines or land, at the centre of economic progress. The data shows that knowledge sectors are becoming an increasingly important part of economic output (see figure 5). Furthermore, the data shows that these sectors use progressively fewer materials, indirectly and directly, than the old industrial sectors (figure 6). In fact, the total material use of advanced economies such as the U.S. is decreasing through time despite the fact that economic growth is increasing; indeed the (direct and indirect) use of all natural resources has decreased in the U.S. in total despite increasing economic output (figure 7). Notable exceptions to this rule are petroleum and paper (see *World Resources: People and the Environment*, 1994-1995). An empirical analysis of resource use in the U.S. economy and the evolution of biotechnology, finance, computers and telecommunications sectors is attached.

A Vision of the Knowledge Society

A distinct possibility is that in the next century a new society will develop, a society that is centred in human creativity and diversity, and which uses information technology rather than fossil fuels to power economic growth. The vision is a human-centred society which is deeply innovative in terms of knowledge and at the same time very conservative in the use of natural resources. The patterns of consumption and resource use may not be as voracious as those in the industrial society, and may be better distributed across each society and across the globe. The knowledge society may achieve economic progress that is harmonious with nature.

This vision is distant. It is only a possibility at present. Without developing the right institutions and incentives this possibility may never come to pass, and a historical opportunity may be lost.

The following analyses the practical alternatives and the economic institutions that seem needed to bridge the gap between a grim present and a bright and positive future.

The Paradox of Knowledge

As already discussed, knowledge is often produced privately. Therefore the incentives to the production of knowledge are as crucial to the knowledge society as the incentives to produce machinery in the industrial society. Innovation is the most critical part of knowledge production.

To produce new knowledge, economic incentives are necessary. This could involve restricting the use of the knowledge by others, so the creator can benefit. Patents on new discoveries work in this fashion: by restricting others' use of knowledge. This creates a problem. Any restriction in the sharing of knowledge is inefficient, because knowledge could be shared at no cost and by doing so it can better others. So restrictions on the use of knowledge are inefficient after knowledge is created. However, without some restrictions there may be no incentive to create *new* knowledge. I call this the paradox of knowledge. This paradox is at the heart of the success of the knowledge society, of its ability to bring human development for many and not only wealth for a few.

Introducing New Property Rights Regimes

My solution to the paradox of knowledge is to propose new systems of property rights that can deal simultaneously with the need to share the use of knowledge for efficiency, while at the same time preserving private incentives for production. These systems ensure and encourage widespread use of knowledge, such as, for example, software products or the information contained in biodiversity specimens, while at the same time offering incentives to private individuals, the knowledge creators, to produce new knowledge. The appendix contains a technical summary of how this would work in practice: a new regime of property rights on knowledge and how this would work in a competitive market.

In practical terms, I propose substituting patents by a system o *compulsory negotiable licences* which are traded in the market compe itive along with all other goods in the economy. In this new scheme, the right to knowledge is unrestricted; however, users must pay the creator each time they use their knowledge. Since the licences are traded in competitive markets, they ensure that the creators of knowledge are compensated for their labour in a way that reflects the demand for their products and therefore their usefulness for society. Since licences are compulsory, they make knowledge available to all. In this sense they differ fundamentally from patents which, in principle, can restrict the use of knowledge.[8] No restriction in the use of knowledge is allowed in the system I propose. However, a key issue is the distribution, use and applicability of the licences, to which we now turn.

It is clear that a system of licences on knowledge products (e.g. operating systems for software, biological information, how-to-do-it systems) could preserve or even worsen today's uneven distribution of wealth in the economy. This is because the knowledge economy has a built-in incentive for the creation of monopolies. Indeed, any knowledge based corporation is a 'natural monopoly', because the cost of duplicating knowledge products (such as a software products) is very small, and, therefore, the larger the firm the lower its costs. This is an extreme case of 'increasing returns to scale' where larger firms have an advantage over their competitors, and hence can prevent entry by newer and smaller competitors. Such natural monopolies are characteristic of the knowledge society. How to avoid their effects in concentrating welfare in the hands of very few?

The system of property rights proposed here takes into account these possibilities. It establishes how the distribution of licences is a crucial element in achieving efficient solutions. It shows that markets with knowledge operate differently than the standard markets, because knowledge is a public good that is privately produced. The solution is to achieve a distribution of property rights on licences that is negatively correlated with the property rights on private goods. The results in Appendix I make this rigorous.

How can such a system of property rights become accepted? There are already economic incentives for corporations to accept such systems of property rights, even though more economic thinking and education is needed before this acceptance becomes widespread. For example, those producers that benefit in principle from increasing returns to scale could support a system of licences in which the lower income segments of the population are given proportionately more rights to use knowledge than the rest. Consider as examples worker training schemes and school subsidies. Because knowledge is so important for the productivity of society as a whole, and produces positive 'externalities' on all producers, there is an incentive to develop a skilled pool of workers. Corporations know that skilled workers are essential to the success of knowledge industries.

All this is formally established in a proposition presented in the Appendix, establishing that for an efficient market solution, namely one that cannot be improved so as to make everyone better off, lower income traders (individuals or, in the case of international trade, nations) should be assigned a larger endowment of property rights in the use of knowledge.

In practice, this means a larger amount of licences to use knowledge are assigned to such groups. This scheme is new but realistic. Similar systems are already in place in most industrial societies within the educational system. Examples are school subsidies that offer access to education to lower income groups. Another example is the auctioning of airwave use by the U.S. Federal Government; in Washington D.C., minorities and women are given substantial discounts when they participate in auctions for the purchasing of property rights on the airwaves. In certain cases this involves a 40 per cent discount of the auction prices.

Licences: We Make It, We Take It Back

The system of property rights proposed here, while unique in its economic formulation, is reminiscent of a development that is already taking place in the U.S. corporate world. Leasing vehicles and electronic equipment is now a thriving business that hardly existed 20 years ago. One of the largest packaging companies in the world, Sonoco Products Co., started taking its used products off customer's hands after its chief executive officer, Charles Coker, made a pledge in 1990: 'We make it, we take it back'. The policy has already been adopted by the car industry in Germany, where car manufacturers are responsible for disposing of vehicles that customers return at the end of their useful life. An Atlanta-based corporation, Interface, the largest maker of commercial carpeting, has set as a goal the creation of zero waste while making a healthy profit, and takes back the used products that it sells to recycle them. The mission of their businesses, these people say, is to sell *services*, not products; in other words selling viewing services rather than TVs, selling transportation services rather than vehicles. Licensing has the advantage that producers have an incentive to minimise waste and environmental damage—for example, the waste produced by wrapping or by defunct car bodies—as they will be responsible for it. These business people see licensing services as the way to the future.

There is implicit in this a new system of property rights which shares with us the idea of *licensing the use of services* rather than *owning the products that deliver those services*. The products in the corporate examples ju described share another common characteristic with our approach: they ha some of the characteristics of public goods in that they produce negative environmental 'externalities'. Knowledge, as we saw, also produces externalities, though positive.

Knowledge, as we saw above, has much in common with environmental assets: it is a privately produced public good. Knowledge products have been licensed for many years, although this has been done in a case-by-case manner, without securing the competitiveness of the market for licences, and without securing the distribution of property rights that would ensure efficient outcomes. In this sense, the new developments in industry reported here move in the same direction as the system of property rights, involving licences, proposed in Appendix I and discussed above. *The new systems of property rights that I propose can be thought of as a drastic improvement, an institutionalisation and an economic formalization of licensing and leasing systems that have become widely used in advanced industrial economies.*

Human Impacts of Property Rights on Knowledge

The rules that govern the use of knowledge in society are all important because they can lead to threats and opportunities for human development, both directly and through the possible changes in the patterns of consumption of goods and services. They can determine the impact of human societies on the environment and on resource use, as well as determine inequalities across the world economy. The way we use and distribute knowledge casts a very long shadow on human societies. How does this occur?

A historical comparison helps to explain this process. In agricultural societies the way humans regulated the ownership of land, which was then the most important input to production, led to social systems such as feudalism. Ownership of land had, therefore, a major impact on human welfare and on economic progress. Similarly, in industrial societies the way humans organise the use of capital, which is its most important input of production, leads to very different social systems such as socialism and capitalism. Indeed, these two systems are defined by the rules on ownership of capital. In socialism ownership is in the hand of the government or other public institutions, and in capitalistic systems capital is in private hands. Property rights on capital have mattered a great deal, and have even led to global strife in most of this century.

Since capital is the most important input of production in industrial society, it is clear that property rights on capital had an enormous impact on the organisation of society, on economic progress and on people's welfare. Similarly, in the knowledge society the way humans organise the use of knowledge will determine human welfare and economic progress across the world. This means that human institutions that regulate the use of knowledge, such as property rights and markets for knowledge, will become increasingly important. However, as we saw, knowledge is a different type of commodity than land or capital: it is a public good. Markets with public goods, and other economic institutions such as property rights on public goods, are still open to definition and require much economic analysis. Markets themselves will operate differently in the knowledge economy, because the nature of the goods traded is different. There will be new challenges and new opportunities.

Comparing East Asian, Latin American and African Development: Knowledge-Intensive vs. Resource-Intensive Growth

In order to focus the analysis, it is useful to distinguish two patterns of economic growth, two extreme cases within which there is a spectrum of possibilities: economic development that is *knowledge-intensive*, and that which is *resource-intensive*. The former simply means achieving more human welfare with less material input. The latter means achieving more production by means of more material use. These two categories were introduced in Chichilnisky (1995a, 1994b).

There are excellent historical examples of the two patterns of development, and of the differences they induce on economic growth. East Asian nations fit the knowledge intensive paradigm, while Latin American countries and those in Africa, fit well the pattern of resource-intensive growth. On the whole, knowledge-intensive development strategies succeeded, while resource-intensive development patterns lost ground. It is worth examining why.

Those now called the Asian Tigers, including Japan, Korea and Taiwan, and later those called the Small Tigers, such as Singapore, Philippines, Hong Kong and Malaysia, focused on exports of technology-intensive products such as consumer electronics and technologically advanced vehicles. They overturned the traditional economic theory of 'comparative advantages'. In so doing they overcame the bias towards resource-intensive exports based on unskilled labour that was implicit in the recommendations governing Anglo-Saxon economics and the policies of the Bretton Woods institutions since their inception after World War II. In reality, the East Asian nations competed with the advanced industrial nations on their own turf, and won. They succeeded in developing beyond any expectations during the last 20 years.

Resource-Intensive Development in Latin America and Afric

As already mentioned, in contrast with East Asian nations, Latin America and Africa followed a resource-intensive pattern of development. The question is why?

Both Latin America and Africa were deeply influenced in their economic policies by Europe and North America during the period of colonial rule which ended after World War II. During the colonial rule, these regions were used as a source of inexpensive resources, both natural and human resources (slaves). Since the end of colonialism, international markets have perpetrated a pattern of economic development in Latin America and Africa in which the world's less advanced countries play the role of resource producers and exporters. This pattern of trade has been explained by the historical difference in property rights regimes between the North and the South actively trading resources in global markets (Chichilnisky, 1994a). Countries in the South hold most resources as common property; in industrial economies these are, on the whole, private property. Differences in property rights on resources have been invoked successfully in explaining the fact that the South over-extracts natural resources for the international market, selling these below social costs: As a result, the North over-consumes resources and the South over-extracts them. It was established in Chichilnisky (1994a, 1993b) that in a world where agricultural societies trade with industrial societies, international markets magnify the extraction of resources, and exports of natural resources exceed what is optimal.

The other pattern of development that became deeply ingrained during colonialism and in the post-colonial development was the export of labour-intensive products based on abundant and unskilled labour. This was a pattern that was initially used in the East Asian nations, but rapidly abandoned in those nations in favour of technology-based products and skilled labour. Latin America and Africa remained, however, within the conventional paradigm, emphasising unskilled labour, and lost ground. Differences in technologies between the North and the South, and abundant labour in the South, have been invoked successfully in explaining the failure of export-led development based on trade of labour intensive commodities (see Chichilnisky,1981, 1995a, 1994b). The pattern of development based on resources and unskilled labour does not work as had been predicted by traditional theories of competitive advantages. The latter is the pattern of development followed by Latin America and Africa. Even today more than 70 per cent of Latin American exports are resources; Africa's exports are almost exclusively resources. Technology-intensive development followed by the East Asian countries, by contrast, succeeded in the last 20 years beyond anybody's expectations. This pattern is global.

Different Scenarios of Development in the North and the South

The most dynamic sectors in the world economy today are not resource-intensive; they are, rather, knowledge-intensive, such as software and hardware, biotechnology, communications and financial markets (Chichilnisky, 1994b, 1995a). These sectors are relatively friendly to the environment. They use fewer resources and emit relatively little CO_2. Figure 8 demonstrates this in the U.S. economy. Knowledge sectors are the high-growth sectors in most industrialised countries.

Some of the most dynamic developing countries are making a swift transition from traditional societies to knowledge-intensive societies. Mexico produces computer chips, India is rapidly becoming a large exporter of software, and Barbados has recently unveiled a plan to become an information society within a generation (Fidler 1995). These policies are an extension of the strategies adopted earlier by the Asian Tigers, Hong Kong, the Republic of Korea, Singapore and Taiwan (Province of China), who have achieved extraordinarily successful performance over the last 20 years by relying not on resource exports but rather on knowledge-intensive products, such as consumer electronics. By contrast, Africa and Latin America emphasised resource exports and were less successful (Chichilnisky, 1994b, 1995a, 1995-1996).

The lessons of history are clear: resource exports should not be relied upon as the foundation of economic development. African and Latin American nations must update their economic focus. Indeed, the whole world must shift away from resource-intensive economic processes and products. In so doing, fewer minerals and other environmental resources will be extracted, and their price will rise. This is as it should be because today's low resource prices are a symptom of overproduction and inevitably lead to over-consumption. *Not surprisingly, from an environmental perspective one arrives at exactly the same answer: higher resource prices are needed to curtail consumption.*

Producers will sell less, but at higher prices. This is not to say that all will gain in the process. If the world's demand for petroleum drops, most petroleum producers will lose unless they have diversified into other products that involve fewer resources and have higher value. Most international oil companies are investigating this strategy. Indeed British Petroleum and Shell are already following such policies.

The main point is that nations do not develop on the basis of resource exports, and, at the end of the day, development can make all better off. As the trend is inevitable, the sooner one makes the transition to the Knowledge Revolution, the better. The data and a conceptual understanding of ho markets operate leads to the same conclusion. Economic development cannot mean, as in the industrial society, doing more with more. It means achieving more progress with fewer resources.

The Knowledge Revolution in an OECD Context

The U.S. leads the world in the Knowledge Revolution because it has two crucial ingredients: (1) a system of property rights on knowledge, such as licences and patents, which is actively enforced and (2) flexible financial markets, including risk markets such as venture capital, that are needed to support the creation of knowledge-based firms.

Property rights matter. A powerful country such as Japan lost the software race because it does not enforce property rights on knowledge. Therefore, a Japanese software producer does not reap the fruits of his/her labour. Despite a technology-driven economy, Japan has no presence in the software sector today. Nor will any of the East Asian nations that are technology-oriented but have no systems of property rights on knowledge. China, an extraordinary example of rapid economic growth which has reached an unprecedented average of 10 per cent yearly during the last decade, has no property rights on knowledge at present. This may be convenient for easier duplication of technology today, but will handicap the ability of the country to develop its own technology in the future. The example of Japan is clear.

Flexible financial markets matter. European nations have the knowledge base to excel in knowledge industries. However, their financial markets are dominated by large and somewhat inflexible banks (Credit Lyonnais, Deutsche Bank, etc.) who are not active in risk capital. Venture capital in the U.S. has been crucial in the development of the knowledge industry, because most knowledge products emerge from new and smaller firms that are partly financed by venture capital. Such sources of capital are not available in Europe, and therefore the development of knowledge firms is handicapped.

Most of the new employment generated in the U.S. in the last 20 years is in smaller, innovative firms in the knowledge sector of the economy. Correspondingly the U.S. rate of unemployment is the lowest in the world right now at 4.7 per cent, certainly much lower than that of the European Union nations where unemployment routinely reaches the double digits.

The Winners and Losers in a North-South Context

The data and the analysis offered above suggest who will be the winners and who the losers as the world economy progresses towards the knowledge revolution.

The winners are the regions that have

- skilled and productive human resources,
- well developed and flexible financial markets and
- appropriate regimes of property right for knowledge.

These three characteristics are the infrastructure of the knowledge revolution, as much as the railroads and the road system were the infrastructure of the industrial revolution. The regions will need the infrastructures that can support communication, such as telecommunications networks, but if the economic and legal systems are in place the physical infrastructure is likely to emerge. Electricity may no longer be necessary if technologies involving other forms of power for communications and processing systems become widespread; recently, simple but promising technologies were developed that utilise spin angular momentum to power computers, radios and telecommunications in areas that have no electricity.

The Anglo-Saxon nations are in an advantageous position in developing the infrastructure of the knowledge revolution because their legal systems are constructed around the 'case law' which is the most flexible in terms of allowing the introduction of new financial instruments. Many European nations use the Napoleonic code, which is Cartesian in the sense that the introduction of any financial innovation must come from the central government, rather than from private initiative as in the U.S. and the U.K. For example, in France and in Turkey any new instrument requires government action. Turkey, partly for this reason, has no mortgage market to date. Case law may become an important asset for developing nations in a period of rapid change.

In the developing world, those countries that develop good systems of property rights for knowledge will be at an advantage in innovating and in profiting from their innovations. Their ability to innovate is crucial in their moving away from the heavy period of industrialisation in which some of them are already embarked, 'leapfrogging' directly to the knowledge society. Countries such as Barbados and Cuba are already charting this course, and so are parts of Sao Paolo, Brazil. Regions of India such as Bangalore have achieved great gains already, becoming an important presence in software export markets in the short period of 10 years. Presently, Bangalore exports about US$2 billion worth of software yearly, and is the fastest growing exporter of software.

Countries such as China would be in a better position in the future if they were to introduce and monitor property rights regimes for knowledge goods such as for software and entertainment, rather than remaining in the present situation in which they benefit from being able to duplicate those products without paying licence fees. Encouragement for innovation and commercialisation is more important in the long run than the ability to use such products without paying fees. The same is true in Japan and the rest of the East Asian economies.

In the coming decades, the winners will be the regions that have well developed human resources, with the corresponding educational skills in mathematics and sciences, and that develop and implement the economic and legal infrastructure needed for a swift transition to the knowledge society. They will be those that have better regimes of property rights, and a new type of market, based on trading of knowledge products and based on efficient systems of property rights as well as the initial distribution of the use of knowledge, such as those that are detailed in Appendix I.

People-Centred Development: Opportunities and Threats

The knowledge revolution could develop in different ways, depending on the way our institutions and policies unfold. As already explained, knowledge has the capacity of amplifying current discrepancies in wealth, because knowledge sectors can lead to natural monopolies such as those that arise due to the adoption of operating systems (Microsoft's *Windows* operating system is a case in point) or other standards. In the North-South context, knowledge sectors could amplify the differences in wealth between the North and the South. If this occurs, then the low resource prices from developing countries will persist, since they are caused in part by these countries' necessity to survive at low income levels within a difficult international market climate. It has been shown that with current institutions of property rights, anything that leads to more poverty will lead to increased resource exports from developing countries (Chichilnisky, 1994a).

On the other hand, knowledge sectors will flourish in those nations that have skilled labour. Several developing nations are, or could soon be, in that position. For example, the Caribbean and Southeast Asia are a case in point, as are many areas in Latin America (Harris, 1994).

The main issues here are

- to abandon the resource intensive development patterns that these nations have followed for the last 50 years, with the support and encouragement of the Bretton Woods institutions, and
- to seek to establish the institutions (property rights, financial structures) that could lead hem to overcome the 'comparative advantages' mirage and thus avoid the heavy stages of industrialisation, moving directly to the knowledge society.

Heavy accumulation of capital (financial or physical) is not needed for most knowledge sectors. What is needed is highly skilled labour, of the type that does not require expensive machinery or heavy capital investment in plants, and good managerial ability. These are knowledge inputs that rely on a pool of abundant skilled labour. A good example is Bangalore's software industry.

Notes

[1]See *World Resources: People and the Environment*, 1994-1995, pg 167.

[2]See *World Resources: People and the Environment*, 1994-1995, chapter 1, and Chichilnisky, 1995-1996.

[3]The normative definition of sustainable development is explored fully in *Caring for the Earth*, a joint publication of The United Nations Environmental Programme and the World Wildlife Fund.

[4]The concept of development based on the satisfaction of 'basic needs' was introduced and developed empirically in Chichilnisky, 1977.

[5]The term "knowledge revolution" is a trademark of the author.

[6]Data from TIMSS: Third Mathematical and Science Study, American Federation of Teachers, American Department of Education.

[7]See also *Business Week*, 'The New Economy: What it really means' by Stephen Shepard, Editor-in-Chief, November 17, 1997, p. 40, last paragraph.

[8]Patents *can* be negotiated, but they do not *have* to be. Owners of patents are legally entitled not to negotiate them, effectively creating a 'monopoly' during the period of the patent's life. Compulsory licences do not have this feature.

Table 1

13-years old average score in TIMSS* (int average = 500)				
	Maths		Science	
1	Singapore	643	Singapore	607
2	South Korea	607	Czech Republic	574
3	Japan	605	Japan	571
4	Hong Kong	588	South Korea	565
5	Belgium (F)	565	Bulgaria	565
6	Czech Republic	564	Netherlands	560
7	Slovakia	547	Slovenia	560
8	Switzerland	545	Austria	558
9	Netherlands	541	Hungary	554
10	Slovenia	541	England	552
11	Bulgaria	540	Belgium (F)	550
12	Austria	539	Australia	545
13	France	538	Slovakia	544
14	Hungary	537	Russia	538
15	Russia	535	Ireland	538
16	Australia	530	Sweden	535
17	Ireland	527	United States	534
18	Canada	527	Canada	531
19	Belgium (W)	526	Germany	531
20	Thailand	522	Norway	527
21	Israel	522	Thailand	525
22	Sweden	519	New Zealand	525
23	Germany	509	Israel	524
24	New Zealand	508	Hong Kong	522
25	England	506	Switzerland	522
26	Norway	503	Scotland	517
27	Denmark	502	Spain	517
28	United States	500	France	498
29	Scotland	498	Greece	497
30	Latvia	493	Iceland	494
31	Spain	487	Romania	486
32	Iceland	487	Latvia	485
33	Greece	484	Portugal	480
34	Romania	482	Denmark	478
35	Lithuania	477	Lithuania	476
36	Cyprus	474	Belgium (W)	471
37	Portugal	454	Iran	470
38	Iran	428	Cyprus	463
39	Kuwait	392	Kuwait	430
40	Colombia	385	Colombia	411
41	South Africa	354	South Africa	326

* Third International Maths and Science study
Source: TIMSS

Figure 1

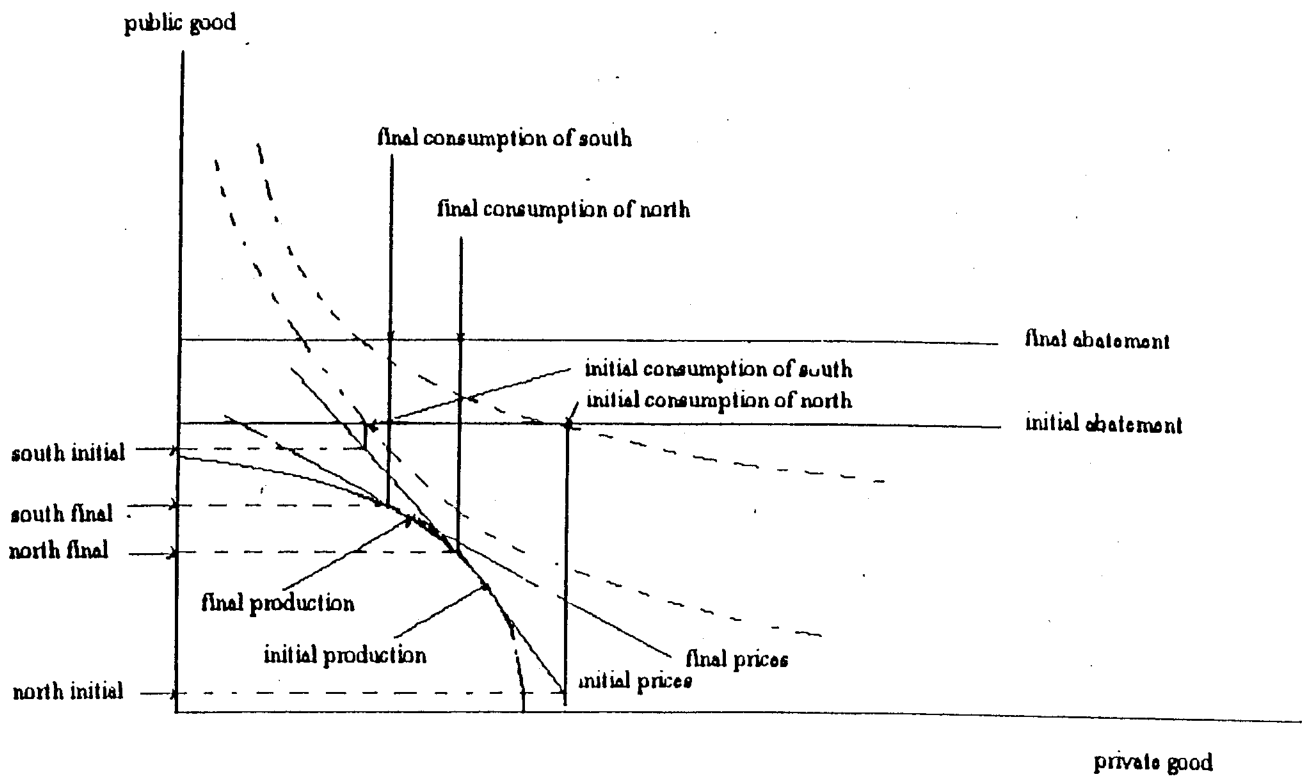
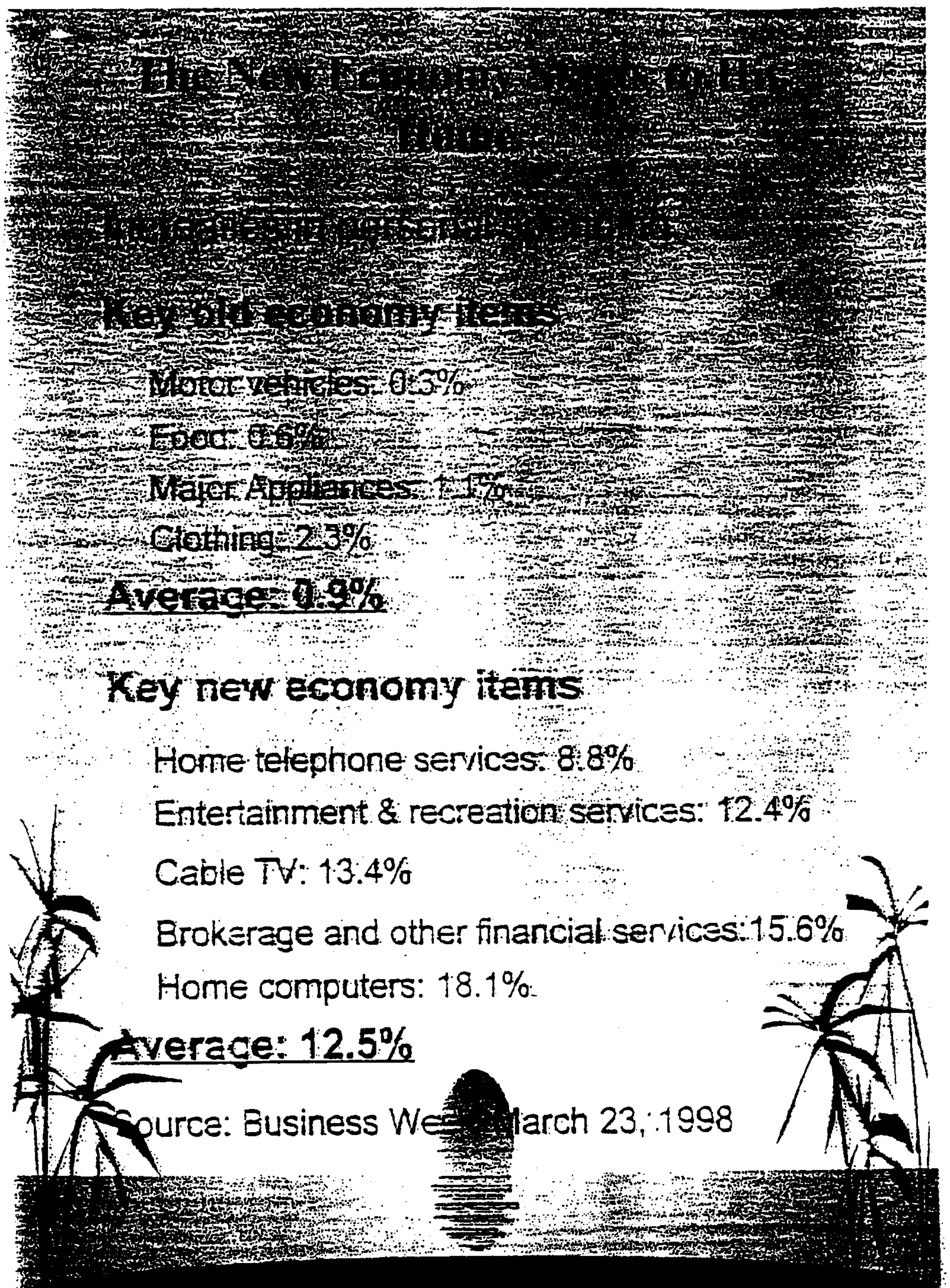

public good
final consumption of south
final consumption of north
final abatement
initial consumption of south
initial consumption of north
initial abatement
south initial
south final
north final
final production
initial production
final prices
initial prices
north initial
private good

Figure 2


Key old economy items
Motor vehicles: 0.3%
Food: 0.6%
Major Appliances: 1.1%
Clothing: 2.3%
Average: 0.9%
Key new economy items
Home telephone services: 8.8%
Entertainment & recreation services: 12.4%
Cable TV: 13.4%
Brokerage and other financial services: 15.6%
Home computers: 18.1%
Average: 12.5%
urce: Business We
arch 23, 1998

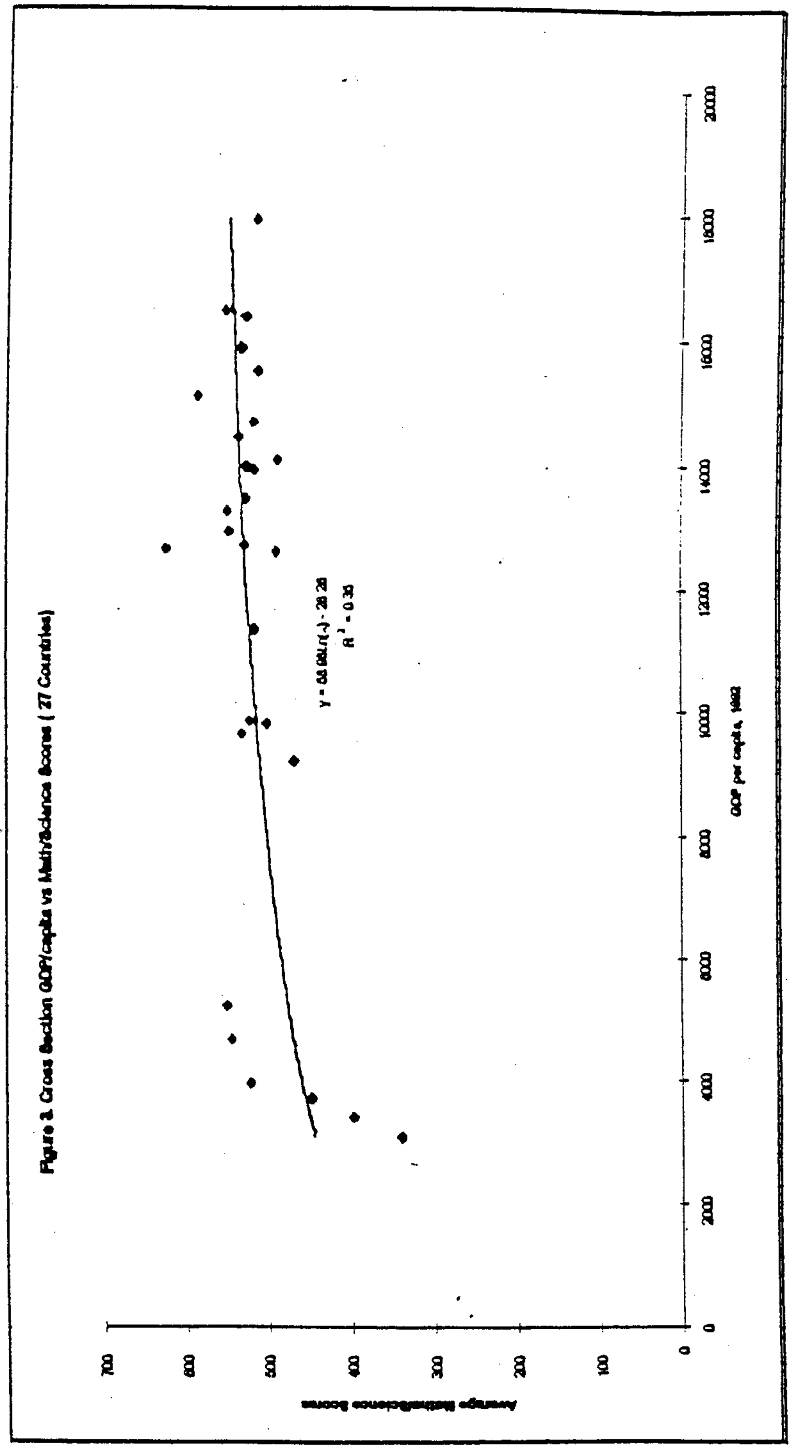


Figure 3. Cross Section GDP/capita vs Math/Science Scores (27 Countries)

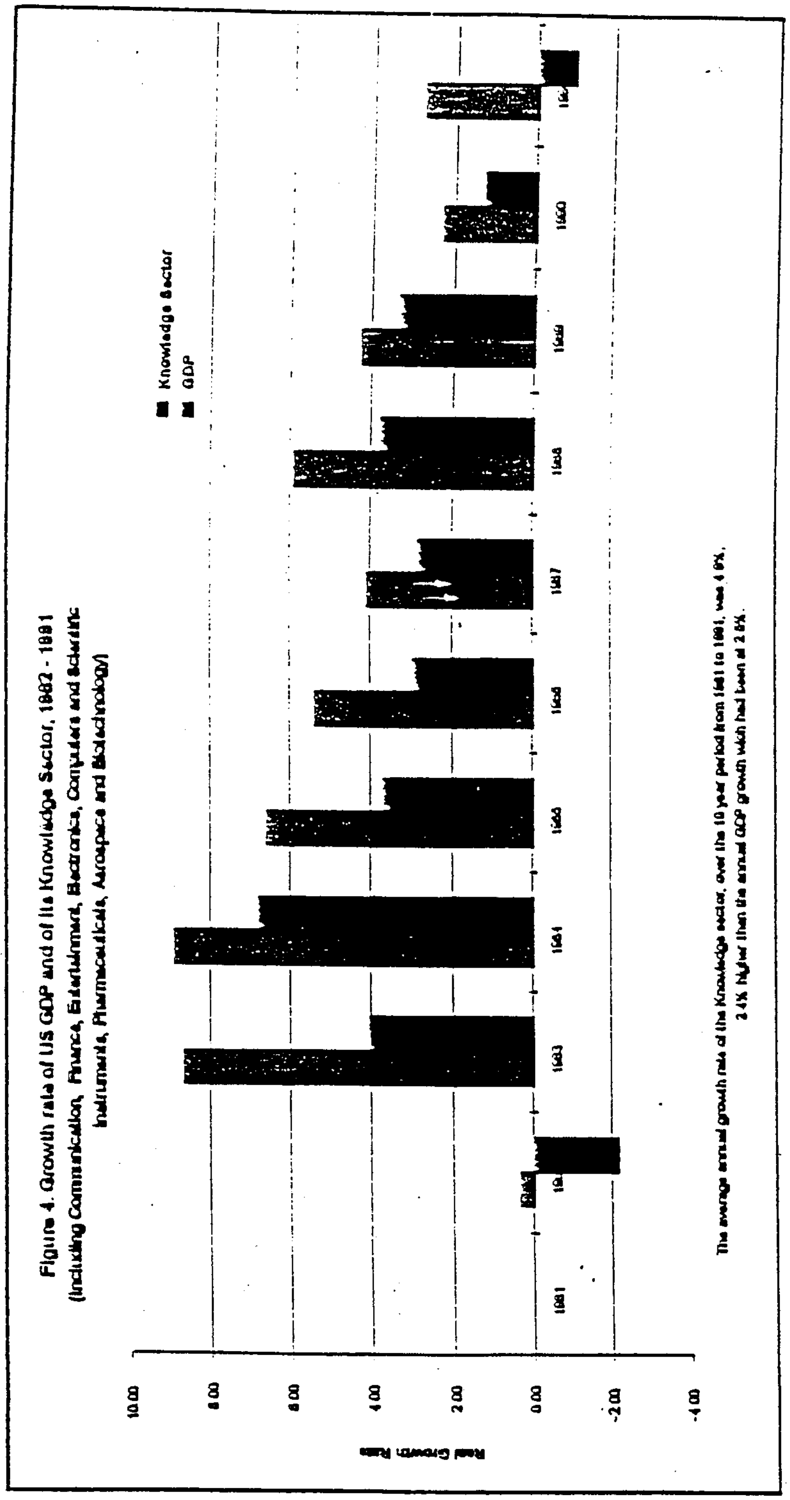


Figure 4. Growth rate of US GDP and of its Knowledge Sector, 1982 - 1991
(Including Communication, Finance, Entertainment, Electronics, Computers and Scientific Instruments, Pharmaceuticals, Aerospace and Biotechnology)

The average annual growth rate of the Knowledge sector, over the 10 year period from 1981 to 1991, was 4.9%, 2.4% higher than the annual GDP growth which had been at 2.5%.

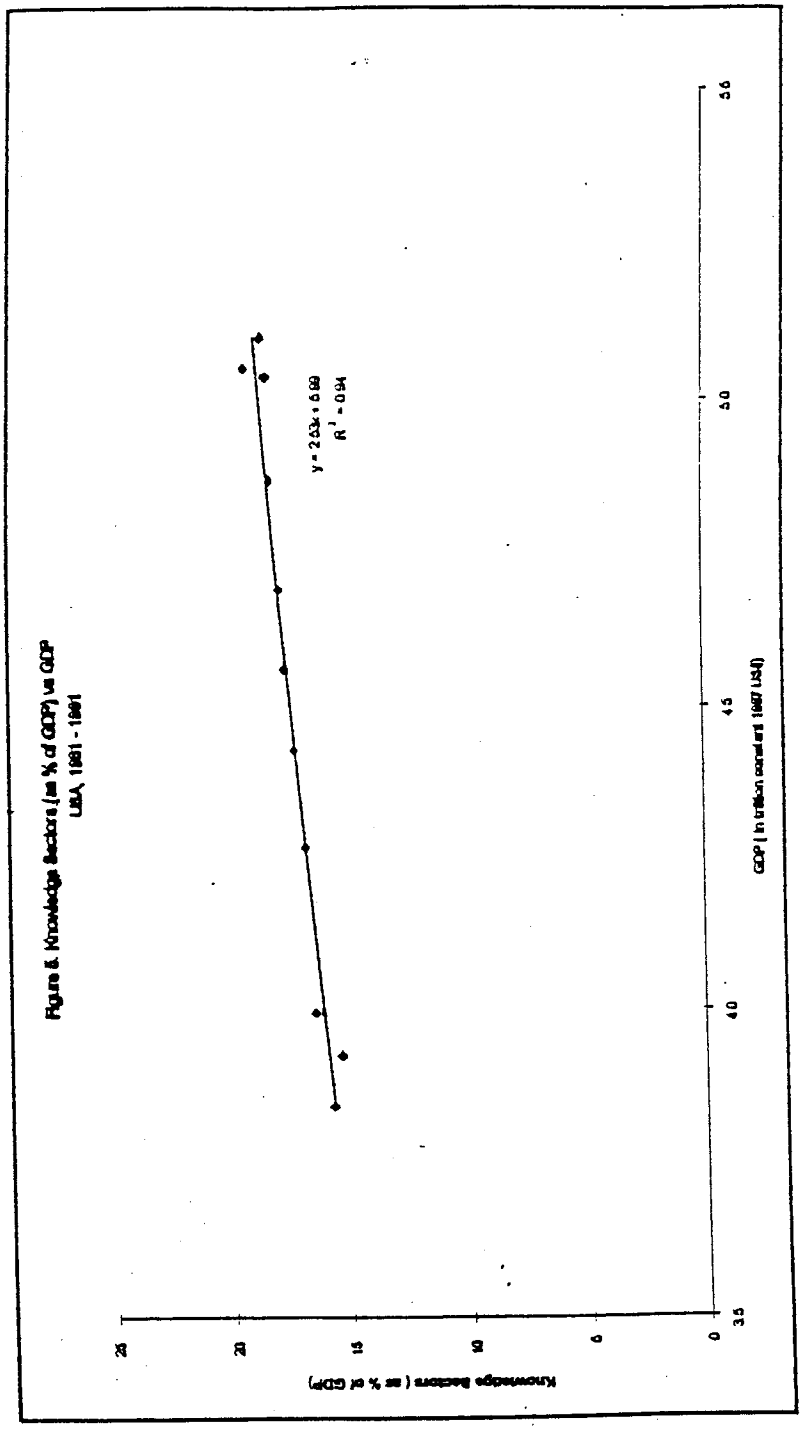


Figure 5. Knowledge Sectors (as % of GDP) vs GDP
USA, 1981 - 1991
$R^2 = 0.94$
Knowledge Sectors (as % of GDP)
0
5
10
15
20
25
3.5
4.0
4.5
5.0
5.5

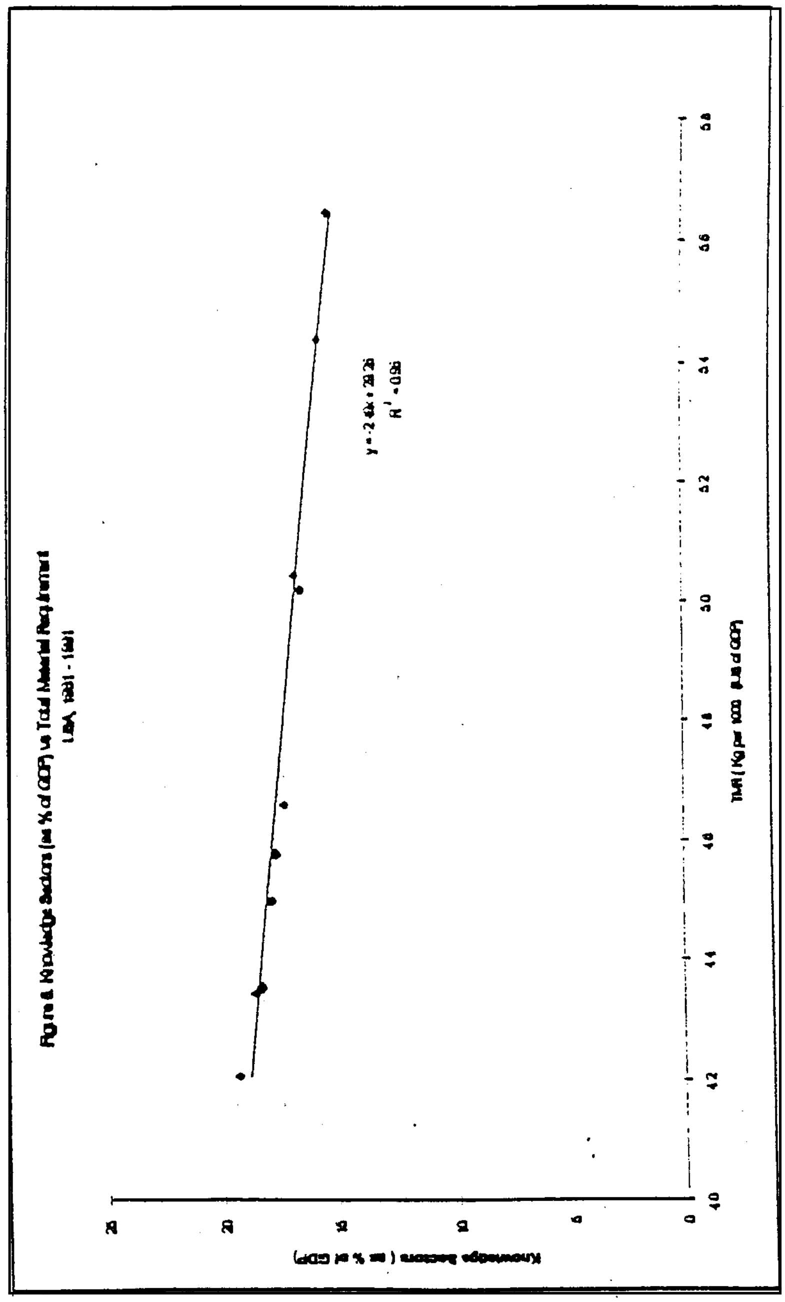
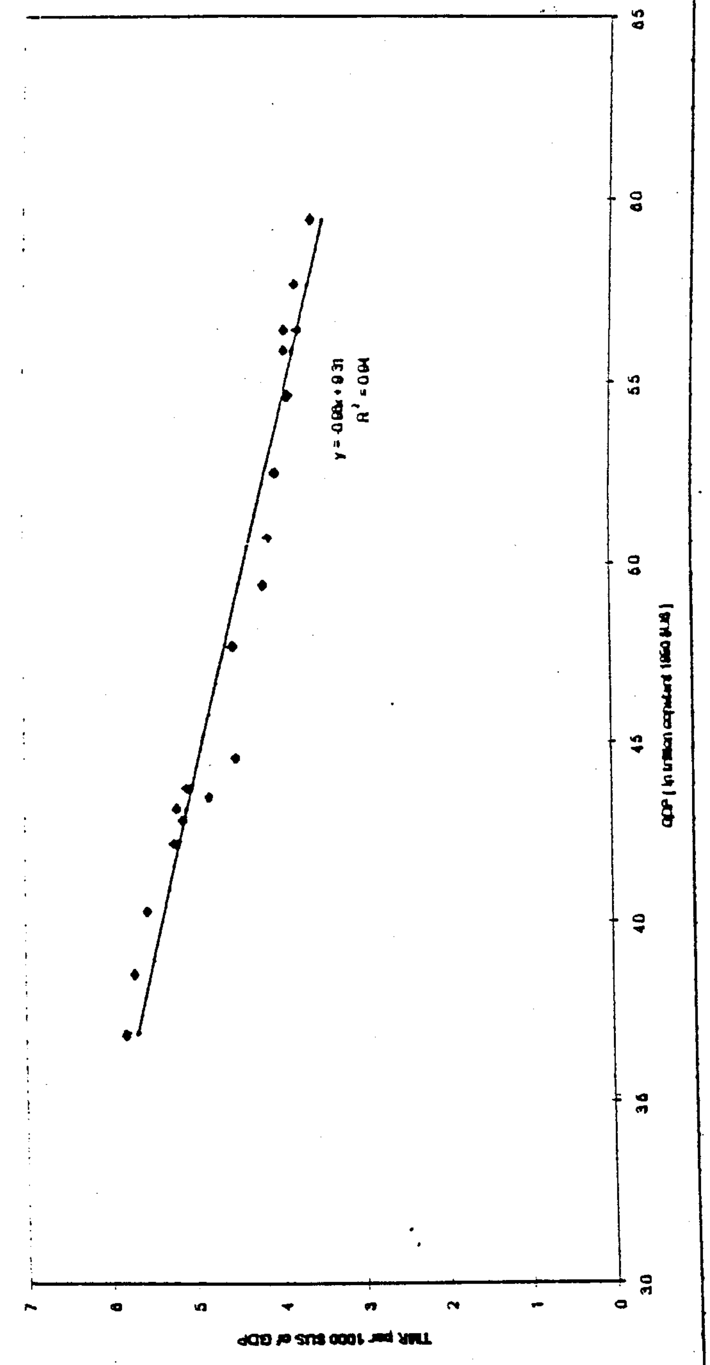


Figure 7. Total Material Requirement vs GDP
USA, 1975 - 1993



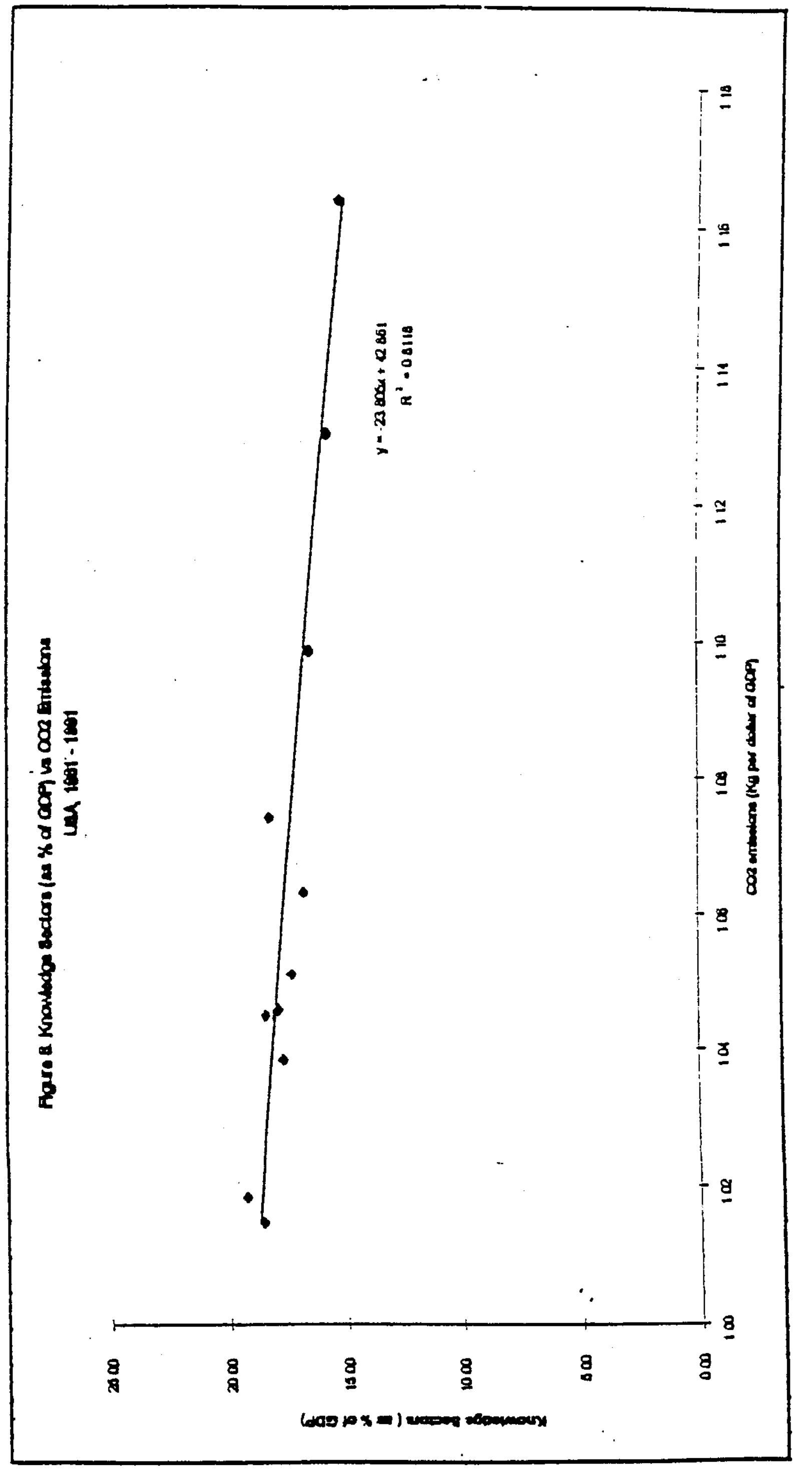


Figure 8. Knowledge Sectors (as % of GDP) vs CO2 Emissions
USA, 1981 - 1991
y = -23.805x + 42.851
R² = 0.8118
Knowledge Sectors (as % of GDP)
25.00
20.00
15.00
10.00
5.00
0.00
1.00
1.02
1.04
1.06
1.08
1.10
1.12
1.14
1.16
1.18
CO2 emissions (Kg per dollar of GDP)

Appendix I

Markets with knowledge

This section presents a general equilibrium model of a market with knowledge. As explained above, knowledge is a privately produced public good. In this sense the model presented below represents a model of a market that trades private goods as well as a privately produced public good, in this case, knowledge.

Markets that trade private goods as well as privately produced public goods have been studied recently by the author and other co-authors in the context of environmental markets where the privately produced public good instead of knowledge is an environmental asset. Typical examples are the quality of the atmosphere measured by its concentration of greenhouse gases. The model presented in this section is a simplified version of the general equilibrium model in Chichilnisky (1997a). The model and the results are an extension of earlier model and results in Chichilnisky (1995a), Chichilnisky and Heal (1994) and Chichilnisky, Heal and Starrett (1993). The reader is referred to the latter for a general result of the theorems reported below in the case that the privately produced public good is an *environmental asset*, such as atmospheric quality, measured by the concentration of carbon dioxide gases in the atmosphere. The difference with the latter model is that here the public good is *not* in the utility function; it induces instead externalities in production.

A general equilibrium model with knowledge

There are two traders, North and South, denoted by the index $i=1,2$ respectively, each producing two goods: one private good (x) and another a privately produced public good (a) representing *knowledge*. Each trader h has finite resources (24 hours a day) which are allocated to produce either private goods or knowledge. For each trader $i=1,2$ there is a trade-off between producing more private goods and producing more knowledge. However, more knowledge leads to higher productivity. Formally for $i=1,2$:

$$x_i = g_i(a_i, a), \text{ with } \partial g_i / \partial a_i < 0, \text{ and } \partial g_i / \partial a > 0.$$

where

$$a = \sum_{i=1,2} a_i, \text{ (or } a = \sup_{i=1,2} (a_i)).$$

Each trader or region has property rights $\Omega_i \in R^2$ on private goods and owns licences that allow use of knowledge, $a_i \in R$. Traders derive utility from the use of private goods x:

$$u_i\,(x_i),$$

Through compulsory negotiable licences, knowledge is available to *all*. Traders may use their licences to access knowledge or may sell their licences in the market. If they wish to use more knowledge than their licences allow, they buy more licences in the market.

Markets for licences are competitive: everyone pays the same price for the same licence; prices are determined by equating supply and demand, and no trader can influence market prices.

Market equilibrium with knowledge

The equilibrium of the market is defined as follows. It consists of

- A price π^*, the relative price between private goods and licences to use knowledge,
- For each trader i=1,2 a level of initial allocation of property rights on licences to use knowledge in the economy $\overline{a_1}$, $\overline{a_2}$,
- For each trader i a level of consumption x_i*of private goods,
- For each trader i a level of knowledge production a_i*,

so that:

- Each trader i allocates time optimally between the production of knowledge and the production of private goods,
- Each trader maximises welfare within a budget defined by prices and property rights:

$$Max\ u_i\,(x_i)$$
$$s.t.\ x_i = g_i\,(a_i^*,\, a^*) + \pi^*\,(\overline{a_i} - a_i^*),$$

i.e. the value of consumption equals the value of production plus the value of licences bought or sold, and

- Markets clear

$$a^* = a_1^* + a_2^*.$$

A competitive equilibrium determines endogenously:

- the initial allocation of property rights on knowledge in each trader or region;
- the level of production and of consumption of private goods and of knowledge by each trader or region,
- the level of trade of private and knowledge between the parties, as well as
- the terms of trade between the private good and knowledge, π, which is the market price of the licences.

The price π can be thought of as a market determined licence fee on using knowledge, since it is a monetary value that must be paid for using knowledge above the level allowed by the initial allocation of property rights.

Adam Smith's invisible hand

The most attractive feature of competitive markets is the efficiency with which they allocate resources, requiring minimal intervention once an appropriate legal infrastructure is in place. This was Adam Smith's vision of the 'invisible hand', and was formulized in the neo-classical theory of competitive markets that has prevailed in the Anglo-Saxon world since the 1950s.

The efficiency of markets is summarised *in the first welfare theorem of economics*. This theorem establishes that the prices and the allocation of goods and services that arises in a competitive market equilibrium are efficient, in the sense that there is no other allocation that can make everyone better off. It is interesting, and somewhat surprising to the non-economist, that this classic theorem bears no connection with the initial allocation of property rights in the economy. Whatever the initial allocation of property rights, for example, even if all goods are owned by two traders and nobody else owns any, the competitive market allocation is efficient. This is due to the fact that the concept of Pareto efficiency is relatively weak: an efficient allocation is one that cannot be improved for everyone in society. A main insight underlying this result is that if everyone chooses within their budget freely, according to their tastes, and keeps on trading until satisfied with their consumption mix, an efficient solution will be reached for everyone. This requires that markets act competitively and that each individual may choose freely, so that each individual's consumption is divorced from that of the rest. It requires, therefore, that traders trade *private goods*. This condition is definitely not satisfied in environmental markets and in markets for knowledge where an individual's production or consumption is linked to, and affects, others. This is the problem of 'externalities', a word that refers to situations where the private actions of one trader, such as production or consumption, affect those of others.

The first welfare theorem has practical importance. It has a major impact on the functioning of market-oriented economies such as that of the U.S. It underlies much of its *anti-trust legislation*, as well as its *insider trading laws*, the laws that restrict *price discrimination*, and other forms of *market discrimination*, including gender and age discrimination. The rationale is simple and compelling. Since, according to this theorem, competitive markets ensure an efficient allocation for society, it follows that competitive markets perform a 'public service'. Economic actions that undermine the ability of the market to act competitively therefore detract from the public service. It is on this basis that the extensive legislation on antitrust and insider trading is enforced. The first welfare theorem has had a major practical impact in the U.S. economy, leading to the break-up of some of its largest corporations such as AT&T. Currently, it underlies the examination by the U.S. government of Microsoft's contractual behaviour.

Equity and efficiency in markets with knowledge

It turns out that the first welfare theorem is no longer valid in markets in which in addition to traditional goods (private goods, such as apples or machinery) one trades public goods, such as the rights to use the planet's atmosphere, or to use knowledge. There is, however, a new first welfare theorem, reported below as the *first welfare theorem for privately produced public goods*, that establishes that the market reaches efficiency, but only for certain allocations of the rights to use knowledge, or licences.

The results are quite general, and apply to any competitive market in which, in addition to private goods, trading involves privately produced public goods. Therefore, they apply to environmental markets as well as markets with knowledge. In the case of environmental markets, in the special case considered in those works, the licences involved permits for the use of the atmosphere of the planet as a sink for the emission of greenhouse gases.

The main results are as follows (for environmental markets rather than markets with knowledge see also Chichilnisky 1993a, Chichilnisky and Heal 1994 and Chichilnisky, Heal and Starrett 1993):

Theorem 1 *(Chichilnisky, Heal and Starrett). Given a total global level of emissions a, there exist a finite number of ways to allocate property rights on emissions among the two regions, i.e. there is a finite way of distributing emissions rights (or permits to emit)* $\overline{a_1}, \overline{a_2}$ *with* $\Sigma_{i=1} a_i = \overline{a}$, *so that at the resulting competitive equilibrium, the allocation of resources in the world economy,* a_1, a_2, x_1, x_2 *is Pareto efficient. For distributions of permits other than these, the competitive market equilibrium is inefficient. When both traders have the same preferences, the region with more private goods should be given fewer property rights on the public good.*

This theorem is illustrated in figure 1, provided above. The figure shows a starting distribution of permits that gives proportionately more rights to emit to the North, and computes the corresponding competitive market equilibrium allocation. In a second step, by redistributing the permits in favour of the South and at the same time tightening the emission targets on the whole world, the competitive market achieves a new equilibrium allocation which increases the welfare of the North and the South. This illustrates the potential efficiency gains obtained by redistributing permits in favour of the poorer countries.

Theorem 2. *By allowing world emissions* $\overline{a}$ *to vary, one obtains a one-dimensional manifold of property rights from which the competitive market with permits trading achieves a Pareto efficient allocation of the world's resources. For allocations of property rights different from these, the competitive market does not achieve Pareto efficient solutions.*

Proof (See Chichilnisky, 1996f and 1997c). The following result applies also to the model presented above, which is different from the model of environmental markets in that the privately produced public good is *knowledge*. The model with knowledge is different from the model of emission markets, because knowledge does not enter in the utility function (as the environmental asset does), but does enter into the production function to improve productivity (the environmental asset does not).

Theorem 3. *First welfare theorem of economics for markets with knowledge. There exists a one-dimensional manifold of property rights allocations from where the market with knowledge achieves an efficient allocation of resources. For allocations of property rights other than these, the competitive market does not achieve Pareto efficient equilibria.*

Proof (See Chichilnisky, 1996f and 1997c). Theorems 2 and 3 identify the set of all 'efficient' allocations of property rights on t use of knowledge, i.e. all allocations of licences to use the available knowledge products in society from which the competitive market achieves efficient allocations of resources as in the case of private goods. It turns out that the allocations that yield efficient solutions provide more property rights to those traders who have less property of private goods. As an example, this would involve proving for people to lower income free access to a number of software programs, a number that is larger than the corresponding number would be for someone with larger income.

The intuition behind these results is simple. Competitive markets in which public goods are traded have more stringent criteria for efficiency than markets for private goods. In addition to the standard marginal conditions (i.e. marginal rates of substitution must equal the marginal rates of transformation), the allocations must also satisfy the Lindahl-Bowen-Samuelson conditions for efficient levels of the public good, requiring that the sum of the marginal rates of substitution equals the (common) marginal rate of transformation between the private and the public good. Since more conditions are needed, the standard competitive allocations are not generally 'first best', i.e. they are not generally Pareto efficient. Often, they are not 'second best' either, where second best means that they are Pareto efficient conditional on a total level of world emissions which does not exceed the given target. Generally, the total amount of the public good is lower in competitive markets than the 'first best' or Pareto efficient level.

There is another way of looking at the same problem. Lindahl showed that efficiency in such markets requires the use of so-called 'personalised' prices, i.e. ones that require as many market prices as the number of people times the number of goods. In our simple example, rather than two markets, one would need four. If the population is large, the number of markets required by Lindahl would be unrealistically large, and in addition would lead to 'arbitrage opportunities' across traders. Traders with lower prices would buy on behalf of others, reselling to others at a profit or 'arbitrage'. Because such prices would be unrealistic, the model and example presented above deal solely with competitive markets in which everyone pays the same prices. But according to Lindahl's theorem, this means that there are not enough markets to achieve efficiency. Lacking markets, in our case the solutions of competitive markets are typically inefficient, as pointed out above.

These results have proved surprising to those who interpret Coase's propositions because they believe that allocating property rights always leads to efficient markets. Nothing in Coase's work ensures such a result when one of the goods traded is a privately produced public good, as happens here. Coase's results, in addition, explain that Pareto efficient allocations are the rest point of trading activity when all possible Pareto improving positions are traded. There is nothing wrong with his result, but it is not applicable to markets in which all traders face the same prices and trade according to competitive market rules. Coase's proposition does not involve competitive market trading, in which, by definition, all trades trade simultaneously at the same prices, but rather all sort of bargaining between any subset of traders, at the same or at different prices. The framework proposed by Coase is therefore different than a competitive market. Nevertheless, with private goods the first welfare theorem does ensure that the competitive equilibrium is Pareto efficient. There is in this sense a consistency between competitive markets and Coase's propositions in this case. But not generally. In brief: nothing in Coase's work ensures the Pareto efficiency of competitive equilibrium in markets which trade private goods and privately produced public goods, as those formalized here.

The results presented above have been surprising also to general equilibrium theorists, but for the opposite reasons. They establish that a judicious selection of property rights can recover first best efficiency in markets with public goods. In the general equilibrium literature it is well understood that markets with public goods are generally inefficient. Indeed our results show that one can replace personalised markets, which is Lindhal's solution, by the appropriate choice of property rights. This is an innovative result which can lead to a society in which the use of knowledge is better distributed. The property rights and market institutions proposed here, by encouraging the creation and better distribution of knowledge, could lead to a society in which humans live harmoniously among themselves and with their environment.

Appendix II

The Knowledge Sectors of the U.S. Economy 1981 - 1991

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Description of the variables

We define the **knowledge sectors** of the U.S. economy as follows:

COMMUNICATION: Telephone and telegraph, radio and television
FINANCE: Banking, credit agencies other than banks, security and commodity brokers, insurance carriers, insurance agents, brokers and services.
ENTERTAINMENT: Motion pictures, amusement and recreation services.
ELECTRONICS, COMPUTERS AND SCIENTIFIC INSTRUMENTS: Computers and office machines (ISIC 3825) - Electronic and telecom equipment, radio, TV (ISIC 3832) - Scientific instruments (ISIC 385).
PHARMACEUTICALS (ISIC 3522)
AEROSPACE (ISIC 3845)
BIOTECHNOLOGY: Medicinals and botanicals (SIC 2833), diagnostic substances (SIC 2835) and biological products ex diagnostic (SIC 2836).

Data sources

Communication, Finance and Entertainment are from the Bureau of Census data base.

Aerospace, pharmaceuticals and electronics are from the European scientific report, which takes the data, with calculations, from the OECD STAN-database.

Software is taken from 'the computer revolution' (see Sichel, 1997). The data are taken from the Phister's database and from the bureau of Census. Because this Series was not complete, we find data for 1981, 1982 and 1983 by extrapolation, using the trend of the rest of the Series.

Communication, finance and entertainment are from the Bureau of Census database.

Biotechnology: Department of commerce, Bureau of the Census. For Diagnostic substances, medicinals and botanicals, because we had not the data for 1981 to 1984, we have completed the series by extrapolation.

The Gross Domestic Product (**GDP**) is taken from the Bureau of Census database.

All those variables are given in constant 1987 US dollars.

The Total Material Requirement (TMR), measured in tons, is taken from the World Resources Institute database.

The Math/Science Scores are from the Third International Maths and Science Study (TIMSS).

Description of the results

Regression 1: Knowledge sectors - GDP

The Knowledge Sector represents a growing share of the US Economy. We find a positive and strongly efficient relation between the Knowledge sector (as % of the GDP) and the GDP.

The R squared is close to one (0.9364) and the T parameter indicates that the estimated positive coefficient of the regression is strongly efficient.

Regressions 2 and 3: Knowledge sector - TMR and CO2

The estimated negative relations between the Knowledge sector and the Total Material Requirement of the economy (TMR is here expressed in kg per dollar of GDP) and between the Knowledge sector and the total CO_2 emissions in the economy are significative.

As those sectors are growing, there are decreases in needs and in emissions, showing that the production is becoming cleaner and more effective.

Regression 4: Cross Section GDP - Maths/Science Scores

The estimated positive coefficient of the relation is efficient. Countries with better scientific education for their children seem to perform better economically.

Regression 5: TMR - GDP

The estimated negative relation is strongly efficient.

Results

Knowledge Sectors - GDP

NUMBER OF OBSERVATIONS: 11

	Mean	Std Dev.	Minimum	Maximum
SUM	17.44749	1.22675	15.39207	19.32254
GDP	4524157.00000	468726.28384	3841022.00000	5099609.50000

	Sum	Variance	Skewness	Kurtosis
SUM	191.92237	1.50492	-0.31587	-0.75949
GDP	4.97657D+07	2.19704D+11	-0.21775	-1.51578

Method of estimation = Ordinary Least Squares

Dependent variable: SUM
Current sample: 1 to 11
Number of observations: 11

Mean of dependent variable = 17.4475
Std. dev. of dependent var. = 1.22675
Sum of squared residuals = .957273
Variance of residuals = .106364
Std. error of regression = .326134
R-squared = .936390
Adjusted R-squared = .929323
Durbin-Watson statistic = 1.46186
Wald nonlin. AR1 vs. lags = .652005 [.419]
Augmented Dickey-Fuller = -2.75432 [.221]
ARCH test = .058794 [.808]
CuSum test = .500537 [.641]
CuSumSq test = .304617 [.289]
Chow test = .144702 [.868]
LR het. test (w/ Chow) = -2.33196 [1.00]
White het. test = 3.16710 [.205]
Jarque-Bera normality test = .098663 [.952]
F-statistic (zero slopes) = 132.488 ** [.000]
Akaike Information Crit. = .759951
Schwarz Bayes. Info. Crit. = -2.00558
Log of likelihood function = -2.17973

Variable	Estimated Coefficient	Standard Error	t-statistic	P-value
C	5.98964	1.00028	5.98793	** [.000]
GDP	.253259E-05	.220028E-06	11.5103	** [.000]

Knowledge Sectors - Total Material requirement
NUMBER OF OBSERVATIONS: 11

	Mean	Std Dev.	Minimum	Maximum
SUM	17.44749	1.22675	15.39207	19.32254
TMR	4.73852	0.48086	4.20533	5.64333

	Sum	Variance	Skewness	Kurtosis
SUM	191.92237	1.50492	-0.31587	-0.75949
TMR	52.12373	0.23123	0.86257	-0.46648

Method of estimation = Ordinary Least Squares

Dependent variable: SUM

Current sample: 1 to 11
Number of observations: 11

Mean of dependent variable = 17.4475
Std. dev. of dependent var. = 1.22675
Sum of squared residuals = .674000
Variance of residuals = .074889
Std. error of regression = .273658
R-squared = .955213
Adjusted R-squared = .950237
Durbin-Watson statistic = 1.11203
Wald nonlin. AR1 vs. lags = .107305 [.743]
Augmented Dickey-Fuller = -1.42967 [.633]
ARCH test = .300310 [.584]
CuSum test = .941088 [.053]
CuSumSq test = .504806 * [.025]
Chow test = 8.02011 * [.015]
LR het. test (w/ Chow) = 10.4644 ** [.001]
White het. test = 2.07921 [.354]
Jarque-Bera normality test = .635896 [.728]
F-statistic (zero slopes) = 191.953 ** [.000]
Akaike Information Crit. = .409093
Schwarz Bayes. Info. Crit. = -2.35644
Log of likelihood function = -.250010

Variable	Estimated Coefficient	Standard Error	t-statistic	P-value
C	29.2623	.856746	34.1551	** [.000]
TMR	-2.49335	.179964	-13.8547	** [.000]

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