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Ecology and the Knowledge Revolution*

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1 The golden age of industrial society

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

Today the industrial society faces the risks created by its own success. Its growth has been based on a voracious use of natural resources,[1] the rapid burning of fossil fuels to produce energy, and massive clearing of wooded lands and other ecosystems where most of the world's biodiversity is found. Economic activity is the fundamental driving force of the two most pressing global environmental problems: climate change and biodiversity destruction.

While only 20% of the world's population lives in industrial societies, through global trade the success of industrialization magnified the use of fossil fuels and other natural resources worldwide. Industrial nations originate 60% of global emissions of carbon dioxide that could precipitate global climate change; they consume on average ten times as much copper, three times more roundwood, fifteen times more aluminum, and ten times more fossil fuel per capita than the developing countries.[2] The international market mediates the relationship between industrial nations and developing countries, the North and the South. The developing South specializes in resources, which account for 70% of the exports of Latin America and almost entirely for those of Africa, while the industrial North specializes in products that are intensive in capital and knowledge.[3] The South

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[1] *World Resources: People and the Environment*, 1994-5, Chichilnisky (1995-6).

[2] *World Resources: People and the Environment* 1994-1995, and Chichilnisky 1995-1996. The destruction of forest ecosystems that accompanies industrialization is believed to be the main source of global biodiversity loss, (*World Resources: People and the Environment* 1994-1995).

[3] 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 ten times as much

houses most of the world's biodiversity, and this pattern of trade is contributing to its destruction.

The trend is global. Since the end of colonialism, the Bretton Woods institutions (e.g. The World Bank and the IMF) have encouraged a pattern of resource-intensive development for the world's less advanced countries. Developing countries play today the role of resource producers, overextracting resources that are traded below their real costs and thus overconsumed in the industrial nations (Chichilnisky 1994a). This pattern of trade, and the attendant low resource prices, has been explained by the historical difference in property rights between the North and the South in the context of a rapid expansion of global markets: *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, leading to rapid biodiversity loss.* (Chichilnisky 1994a).

Today's global environmental problems are therefore connected with the role of global markets in magnifying unsustainable patterns of consumption and resource use in industrial nations.[4] However in the long run the fate of the world's resources may depend on the developing world. *For these reasons this paper therefore concentrates in today's patterns of development in 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 underway in industrial nations, a change that requires new institutions and policies in order to reach a sustainable outcome. I analyze a new type of markets that will play a crucial role in tomorrow's societies, markets trading knowledge and environmental assets, and analyze the property rights regimes that are needed in these markets to achieve efficient, equitable and sustainable development.

2 The new global markets

Markets are a dominant institution in the global economy. As the century turns, however, the market itself is evolving. Two major trends are markets for knowledge and global environmental markets. Markets for knowledge hold the key to the dynamics of the world economy: telecommunications and electronics, biotechnology and financial products, all involve trading products that use knowledge rather than resources as the most important

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 account for 37.4% of the world's output but they used about 52.4% of the world's energy, see *World Resources: People and the Environment* (1994-1995), pg 167. In this sense, developing countries' energy use can be said to involve less waste.

[4]The problem originates from industrialization rather than from political organization. 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.

input. The first global environmental market is about to emerge: following our earlier proposal (Chichilnisky 1993a, 1995,1995b, 1996 and 1996b) the 166 nations who are parties to the Framework Convention for Climate Change (FCCC) agreed in Kyoto, December 1997, to create an international framework to trade carbon emission credits among industrial nations.[5]

Markets for knowledge and environmental markets are different because they trade different type of goods, which I call *privately produced public goods* (PPP goods), rather than the private goods that characterize traditional markets. Private goods—such as apples or machines—are chosen by each trader independently from each other, and are 'rival' in consumption. Not so with knowledge and environmental goods: the carbon concentration in the planet's atmosphere is one and the same for all, and knowledge can be shared without losing it. Such goods may lead to the most important markets of the future. Knowledge and environmental resources are key trends in the world economy, trends that lead the transformation that I call the knowledge revolution.

Focusing on these new markets, I analyze here the introduction of new institutions and the policies that can lead the transformation of industrial society into a sustainable society through the knowledge revolution. I propose the creation of a new type of economic organization, 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 the creation of knowledge, as well as a better use of knowledge and the world's natural resources.

3 Ecology 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 improves the quality of human life, while living within the carrying

[5]These are the so called Annex I countries, see Article 6, paragraphs 1 and 5 of the Kyoto Protocol. Chichilnisky (1993a) advanced the proposal for the creation of an international framework for trading emissions permits at an international OECD conference in Paris, and in 1994 at a Workshop of Joint Implementation and Beyond organized under the auspices of the Global Environment Facility (GEF) with the participation of the members of Bureau of the International Negotiating Committee of the Framework Convention on Climate Change (FCCC), at Columbia Business School, May 1994. Chichilnisky (1995b) advanced officially the proposal for the creation of an International Bank for Environmental Settlements (IBES) that would organize and regulate emissions trading, in a keynote address to the Annual Meetings of the World Bank, and in 1996 various publications proposed blueprints for this trading regime, see Chichilnisky (1996,1996b). In November 1997 The Rockefeller Foundation and the Global Environment Facility organized a workshop to discuss the creation of the IBES in Bellagio, Italy. Finally in December 1997, Article 6 of the Kyoto Protocol formalized the creation of this institution. The modalities, regulation and monitoring of the trading of emissions will be decided at the next Conference of the Parties (COP4) of the FCCC, to take place in Buenos Aires, November 1998. Columbia Earth Institute is organizing a follow up conference for the FCCC members in New York, April 1998.

capacity of supporting ecosystems. It requires building economic systems where the basic needs of today's people are satisfied across the world, while protecting resources and ecosystems so as not to deprive the people of the future from satisfying their own needs.[6] This 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.

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 change has led me to call it a revolution. The change is centered in the use of knowledge and for this reason I call it the "knowledge revolution." What characterizes 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 we find today pre-agricultural societies populated by nomadic hunters and gatherers, and most of the developing world is still within agrarian societies. While the two previous revolutions are still working their way through human societies, knowledge is becoming a leading indicator of change. Knowledge means the ability to choose wisely what to produce, and how to do 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 telecommunication, biotechnology and financial sectors, which involve knowledge. The value of biodiversity resides on its knowledge content, according to ecologists such as E. Wilson and T. Lovejoy. *In a nutshell: knowledge is the content, information is the medium.*

The content (knowledge) is driving change, and this is facilitated by the medium (information). Information technology is the *fuel* for knowledge. Its abundance and inexpensive supply fuels the growth of sectors such as communications, biotechnology and global finance. Information technology fuels knowledge sectors because it performs the important role of allowing the human brain to expand its limits in the production, organization and communication of knowledge. The most important input of production today is not information technology itself: it is knowledge.

[6]This is the definition of sustainability adopted by the Bruntland Report, and is anchored in the concept of development based on the satisfaction of "basic needs," a concept that was introduced and developed empirically in Chichilnisky, 1997a and b. Sustainable development is explored also in Caring for the Earth, a joint publication of IUCN, UNEP and WWF.

4 Characterizing the knowledge revolution

We may characterize the knowledge revolution as a period of rapid transition[7] at the end of which *knowledge* itself becomes the most important input of production, the most important factor of economic progress and wealth. For example, the knowledge content of biodiversity is important for improving public health and human welfare, and is identified as a crucial source of its economic value. By contrast, in prior revolutions the most important actual inputs of production were land (in the agricultural revolution) and machines (in the industrial revolution), inputs that became better utilized because of new knowledge.[8] Knowledge differs fundamentally from land and machines in that it is not rival in consumption, so that the knowledge revolution is based on a radically different type of input of production. Property rights on inputs of production matter a great deal: for example property rights on capital determine the difference between socialism and capitalism, and have even led to global strife in most of this century. Property rights for knowledge are now becoming equally important. More on this below.

The process of change that I call the knowledge revolution is already taking place. There are some indications, including the fact that the value of corporations in the stock exchanges of the world is increasingly measured from their knowledge assets, such as discoveries, patents, brand names and innovative products, rather than from their capital base or 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. At the level of the economy as a whole, knowledge of mathematics and sciences has become a good predictor of national economic progress across the world, see table 1 and figure 3 below.[9] In this period of change the USA leads the pack. Today more Americans make semiconductors than construction machinery. The telecommunications industry in North America (USA and Canada) employes more people than the auto and the auto parts industries combined. The US health and medical industry alone have become larger than defence, and also 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 US jobs in the last twenty years were generated in smaller, knowledge intensive firms driven by risk capital. In the US, one third of the nations' growth is accounted for by the knowledge sectors, see figure below,[10] so that knowledge is an increasingly important determinant of economic progress. The knowledge sectors of the US economy already grow much faster than the rest of the economy, and

[7] The rapid rate of change is read from the fact that the knowledge sectors are growing at more than twice the rate than the rest of the economy, see Figure .

[8] Capital, in the sense of economic value, also shows the same trend: capital was associated mostly with land holdings in the agricultural society, with machinery in the industrial society, and with ideas in the knowledge society.

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

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

therefore account for most of the dynamics of economic growth, see figure 4 below.[11]

A key issue is that knowledge sectors consume less resources and have less ecological impact than the rest; thus they could decrease environmental damage once they become dominant in the economy. This is partly because of our new knowledge about the consequences (costs) to the environment of our economic behavior. The question is whether the pace and scope of this process of change will foster a sustainable society in a timescale that matters. it is therefore important to encouraging and accelerate this transition. The economic transformation depends among other things on the evolution of the new markets for knowledge and for environmental assets. These require special analysis since, as already mentioned, knowledge and environmental assets are privately produced public goods, leading to new types of markets with new challenges and new opportunities for action.

5 A service economy?

It is important to differentiate the knowledge revolution from a service economy which used to be though to be the latest stage of the industrial society. A service economy is characterized 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 labor, such as the labor employed in the food services or in bank processing, requiring little skill and achieving lower wages. The 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 labor. Therefore the knowledge economy could result, with proper institutions, in a society that is more human oriented than the industrial or the service society. This society would involve more human connection and there would have different values, being more sensitive to others' needs and the impact of our actions on them..

[11]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 US 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. Development of knowledge sectors is slower in Europe than in the US because their financial markets and property rights systems are not so flexible and well developed and regulated. This is discussed further below.

6 Knowledge as a privately produced public good

As *knowledge itself* becomes the most important input to production, economic behavior changes because knowledge is a special type of good. It 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. This is a *physical* property of knowledge, not an economic property, and as such it is quite independent from the organization of society. Nevertheless 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 organization. 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, which are supplied by governments, in a centralized fashion.[12] What is unique about knowledge among public goods is that it is typically supplied by *private* individuals who are its creators. At the level of production, therefore, knowledge is like any other private good: costly to produce, and the resources used to produce knowledge (human time) often cannot be used for other purposes. Producing knowledge requires economic incentives similar to those for producing any other private good.

7 A vision of the knowledge society

A distinct possibility is that in the next century a new society will develop, a society that is centered in human creativity and diversity, and which uses information technology rather than fossil fuels to power economic growth. The vision is a human-centered 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 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 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; we need institutions to bridge the gap between a grim present and a bright and positive future. The rest of this paper will address this issue, for which an economic analysis of knowledge is required.

[12] Classic work in the area of public goods by Lindahl, Bowen and Samuelson, as well as modern work on the subject, analyze public goods in the context of a government policy rather than in the context of competitive markets.

8 The paradox of knowledge

To produce new knowledge creators need economic incentives. This could involve restricting the use of the knowledgeby others. Patents on new discoveries work in this fashion: by restricting others' use of knowledge. This creates a problem because any restriction in the sharing of knowledge is inefficient, since knowledge could be shared at no cost and by doing so it can make others better off. 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.

9 New property rights regimes

New regimes for property rights are needed to deal simultaneously with the need to share the use of knowledge for efficiency, while at the same time preserving private incentives for production. Appendix I contains a technical summary of such regimes and how they could would work within competitive markets.

I propose substituting patents by a system of *compulsory and negotiable licences which are traded in the market a competitive fashion along with all other goods in the economy.* In this new scheme, the right to use knowledge is unrestricted and, by law, everyone should have access to it. However users must pay the creator each time they use this knowledge. Since the licences are traded in competitive markets, this ensures that the creators of knowledge are compensated for their labor in a way that reflects the demand for their products and therefore their usefulness for society. Furthermore, the prices paid for the use of licences are uniform and determined by competitive markets. Since licences are compulsory, they make knowledge available to all. In this sense this regime differs fundamentally from patents because, in principle, patents can restrict the use of knowledge.[13] Furthermore, even if traders, there is no requirement that the market for patents should be competitive. 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 property rights for 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" a technical term used to indicate that the cost of duplicating knowledge products (such as a software products) is very small, and

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

therefore the larger is the firm the lower are its costs. This is an extreme case of "increasing returns to scale" where larger firms have an advantage over their competitors, and therefore 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 within competitive markets 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 a distribution of property rights on licences that is negatively correlated with the property rights on private goods, and beyond this a regime that ensures that markets for licences are competitive. The results in Appendix I make this proposal rigorous within a standard model of a market economy.

How will such a system of property rights become accepted? This parallels the introduction of laws to ensure fair trade, a matter on which natural monopolies have offered and continue to offer much resistance, yet were eventually adopted by society as a whole.

In reality there are substantial economic incentives for corporations to accept fair trading and the systems of property rights that we propose, although it is clear that more economic thinking and business education is needed before the acceptance becomes widespread. For example, even 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 an example the case of worker training schemes, school subsidies, etc. 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, one that cannot be improved so as to make everyone better off, lower income traders (individuals or 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 lower income countries or groups.

The regime I propose is new but realistic. In fact, similar systems are already in place in most industrial societies within educational systems. Examples are school subsidies, that offer subsidized access to education to lower income groups. Another, admittedly differnt, example is the auctioning of use of airwaves by the US 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% discount of the auction prices.

10 Licences: we make it, we take it back

The system of property rights proposed here, while unique in its economic formulation, is reminiscent to a development that is already taking place in the corporate world, a development that is also connected with environmental issues that have a public good aspect: the disposal of materials involved in heavy industrial products, such as vehicles and electronic equipment. Leasing vehicles and electronic equipment is now a thriving business that hardly existed twenty 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 CEO 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 the vehicles that the customers return at the end of their useful life, due to environmental concerns. Another example arises in the floor covering industry. Ray Anderson, CEO of Atlanta-based corporation Interface, the largest maker of commercial carpeting, has set up as a goal to create zero waste while making a healthy profit, and takes back the used products that it sells to recycle them. The mission of their businesses, all these business people say, is to sell *services*, not products. In other words: rather than selling TVs, selling viewing services; rather than selling vehicles, selling transportation services, rather than selling carpets, selling the comfort and visual services that they provide. Licencing has the advantage that the producers have an incentive to minimize 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 licencing services as the way to the future, particularly when consumers must pay for the disposal of industrial waste.

Implicit in this a new system of property rights is the idea of *licencing the use of services* rather than *owning the products that deliver those services.* The products in the corporate examples just described share another common characteristic with our economic approach: they have some of the characteristics of public goods in that produce negative environmental "externalities". Knowledge, as we saw, also produces externalities, although positive.

Knowledge, as we saw above, has much in common with environmental assets: it is a privately produced public good. Knowledge products have been licenced 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. *These new systems of property rights that I propose can be thought of as an improvement, an institutionalization and an economic formalization of licencing and leasing systems that have recently emerged in advanced industrial economies.*

11 Property rights regimes for biodiversity

The Biodiversity Convention faces a controversial issue with respect to property rights on the knowledge contained in biodiversity samples obtained from developing nations. The pharmaceutical industry faces difficult ethical and business issues on how to involve and compensate developing countries, and how to price newly discovered drugs on which much R&D has been spent, yet should be available as widely as possible for reasons of human welfare (such as newly found AID's medication). The regime suggested above can deal with these issues since it ensures the widest possible use of the knowledge, while at the same time providing compensation for the discoverer and developer. In essence, patents would be replaced by ongoing, long lived, compulsory licences on the use of the implicit knowledge that would be traded in competitive markets. This regime would expand maximally the use of the products without however depriving the creator from due rewards. Initial fixed costs may be recovered from the appropriate use of initial allocations that favor the low income groups, while recovering fixed costs from higher income groups, as indicated in the model presented in Appendix I.

12 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 organize 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 governments 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 organization of society, on economic progress and on people's welfare. Similarly in the knowledge society the way humans organize the use of knowledge, which is the most important input to production, 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 privately produced public (PPP) 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 of the nature of the goods traded is different. There will be new challenges and new opportunities.

13 The ecological impact of 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 of which 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 fits the knowledge intensive paradigm, while Latin American countries and those in Africa, fit well the pattern or resource-intensive growth. On the whole knowledge intensive development strategies succeeded, while resource intensive development patterns lost ground. Chichilnisky (1997a) studies the historical patterns focusing on East Asian nations that are 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. These focused on exports of technology-intensive products such as consumer electronics and technologically advanced vehicles, and overturned the traditional economic theory of "comparative advantages." In contrast with East Asian nations, Latin America and Africa followed a resource intensive pattern of development and lost ground.

14 Difference 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 shows this for the US economy. Knowledge sectors are the high-growth sectors in most industrialized 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, Republic of Korea, Singapore, and Taiwan (Province of China), who have achieved extraordinarily successful performance over the last twenty years by relying not on resource exports but rather on knowledge intensive products such as consumer electronics. By contrast, Africa and Latin America emphasized resource exports and lost ground (Chichilnisky 1994b, 1995a, 1995-1996).

The lessons of history are clear: not to rely on resource exports as the foundation of economic development. Africa and Latin America 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 overconsumption.

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 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 how market 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.

15 People centered 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[14] 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 the necessity to survive at low income levels within a difficult international market climate. It has been shown

[14]Microsoft *Windows* operating system is a case in point.

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 labor. Several developing nations are, or could be soon, 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 fifty years, with the support and encouragement of the Bretton Woods institutions such as the World Bank and the IMF, and
- to seek to establish the institutions (property rights, financial structures) that could lead them to overcome the "comparative advantages" mirage and thus avoid the heavy stages of industrialization, moving directly to the knowledge society.

Heavy accumulation of capital (financial or physical) is not needed for most knowledge sectors. Indeeed, most new technologies were developed in small firms within the US (the proverbial "garages" in Silicon Valley), and software production in developing nations is very labor intensive and requires little capital. Bangalore is a typical example having become in 10 years one of the world's most active exporter of software, involving today US$2 billion of exports yearly. What is needed is highly skilled labor, of the type that does not require expensive machinery or heavy capital investment in plants, and good managerial ability, all knowledge inputs that rely on a pool of abundant skilled labor. A good example is Bangalore's software industry.

16 Appendix I

16.1 Markets with knowledge

This section presents a general equilibrium model of a market with knowledge.[15] As explained above, knowledge is a privately produced public good. In this sense the model presented below is a model of a market that trades private goods as well as a privately produced public good, in this case, knowledge.

16.2 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

[15]The OECD model is called GREEN.

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 own licences that allow them to use knowledge, $\overline{a_i} \in R$. 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.

16.3 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 $\overline{a_1}$, $\overline{a_2}$,
- For each trader i, a level of consumption of private goods x,
- For each trader i, the amount of knowledge produced a_i^*,

so that:

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

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

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

- Markets clear

$$\overline{a_1} + \overline{a_2} = a_1^* + a_2^*.$$

A competitive equilibrium determines endogenously a number of prices and quantities:

- 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 knowledge: it is the monetary value that must be paid for using knowledge over and above the level allowed by the initial allocation of property rights.

16.4 Equity and efficiency in markets for knowledge

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 formalized in the neoclassical theory of competitive markets that has prevailed in the Anglo-Saxon world since the 1950's. The efficiency of markets is summarized 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. The first welfare theorem has practical importance. It had a major impact in the functioning of economies such as the US, which are market oriented. 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 are a "public service." Economic actions that undermine the ability of the market to act competitively therefore detract from the public good.

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 traders public goods, such as the rights to use the planet's atmosphere, or 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.

Theorem 1 *(Chichilnisky, Heal and Starrett). Given a total global level of emissions $\bar{a}$, 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) $\bar{a}_1, \bar{a}_2$, with $\sum_{i=1}^{2} \bar{a}_i = \bar{a}$, 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, then the trader with more private goods should be given fewer property rights on the public good.*[16]

This theorem is illustrated in figure 9, provided below. 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 favor 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 means that the first distribution was not Pareto efficient, and illustrates the potential efficiency gains obtained by redistributing permits in favor of the poorer countries.

Theorem 2 *By allowing world emissions $\bar{a}$ 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 to the model presented above, which is different from the model of environmental markets in that the privately produced public good is *knowledge*. The mode 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 (as 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.*

[16]For environmental markets rather than markets with knowledge see also Chichilnisky 1993a, Chichilnisky and Heal 1994 and Chichilnisky, Heal and Starrett 1993.

Proof. See Chichilnisky (Chichilnisky 1996f) and (Chichilnisky 1997c). ■

Theorems 2 and 3 identify the set of all "efficient" allocations of property rights on the 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. It turns out that the allocations that yield efficient solutions provide more property rights to those traders who have fewer property of private goods. As an example, this would involve providing people of lower income free free access to a number of courses or software programs, a number that is larger that 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. In addition it can be shown that they are not "second best" efficient as well, 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.

17 Appendix II

17.1 Data description, data sources and regression results by Julien Hanoteau and Yun Lin

Table 1 is taken from "World Education Leagure", The *Economist*, p. 21, March 29, 1997. Figures 1 and 2 are based on data from World Resources: 1994-5, by World Resources Institute.

Data for figures 3-9 are based on the following sources: Communication, Finance and Entertainment data are from the Bureau of Census database. AEROSPACE, PHARMACEUTICALS and ELECTRONICS data are from the European scientific report which uses based on the OECD STAN-database. SOFTWARE is taken from "The Computer Revolution". The data are taken from the Phisters database and from the Bureau of Census. Because this series was not complete, we figure the values 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 subtances, medicinals and botanicals, because we had not the data for 1981 to 1984, we have completed the series by extrapolation. All those variables are given in constant 1987 $US. The Total Material Requirement (TMR), measured in tons, is taken from the World Resources Institute database, and expressed in tons.

Table 1. Math and Science Scores

2+2=?

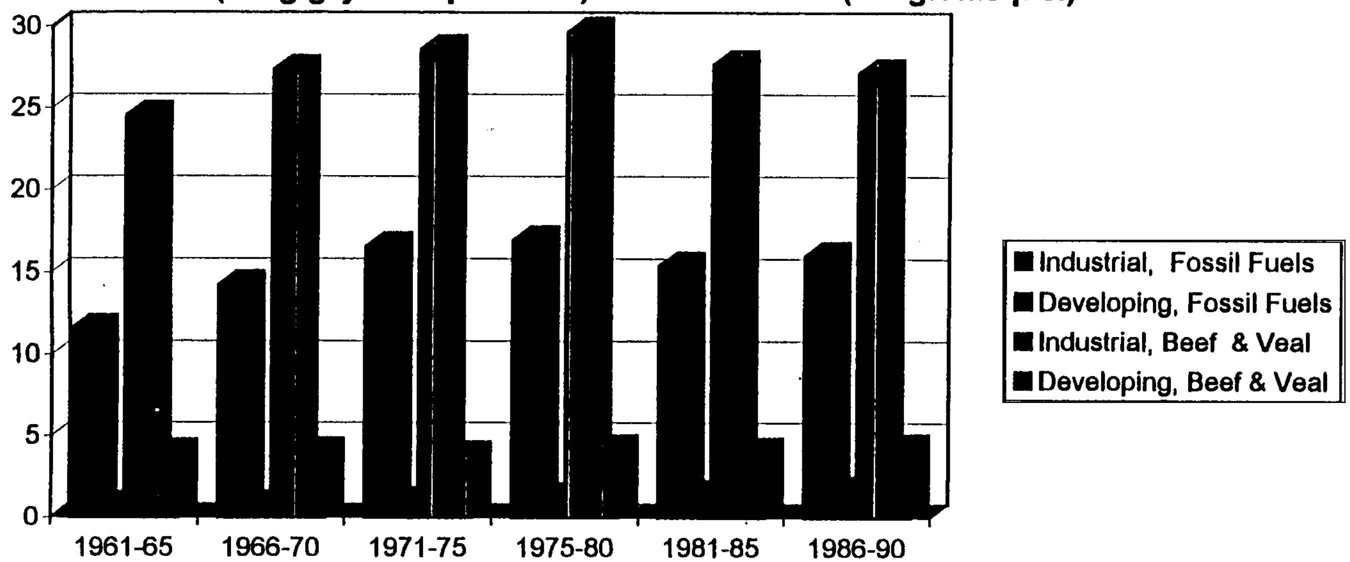
13-year-olds' average score in TIMSS* (Int average =500)

	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
	Australia	530	Sweden	535
	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 †Flanders ‡Wallonia

Source: TIMSS

Industrial & Developing contry consumptions of fossil fuels (10xgigajoules per head) and beef & veal (kilograms p.c.)



World Trade Matrix, Mineral Fuels, 1990

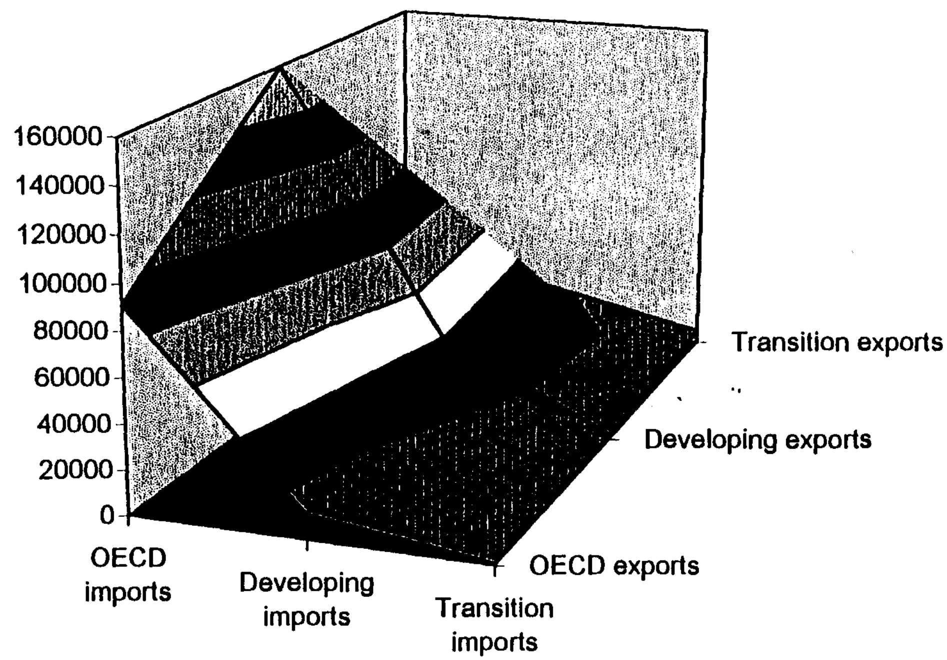


Figure 3. Cross Section GDP/capita vs Math/Science Scores (27 Countries)

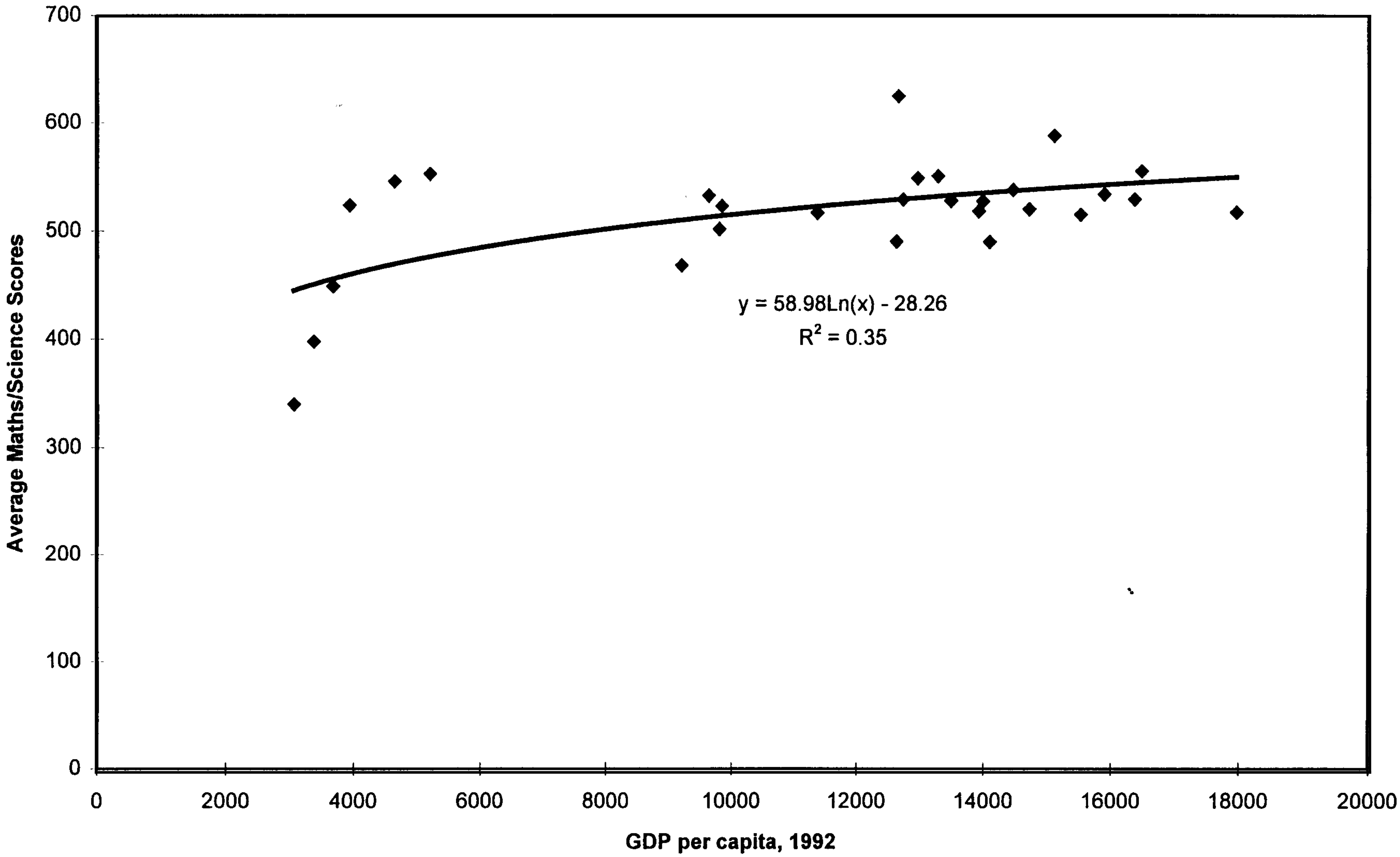
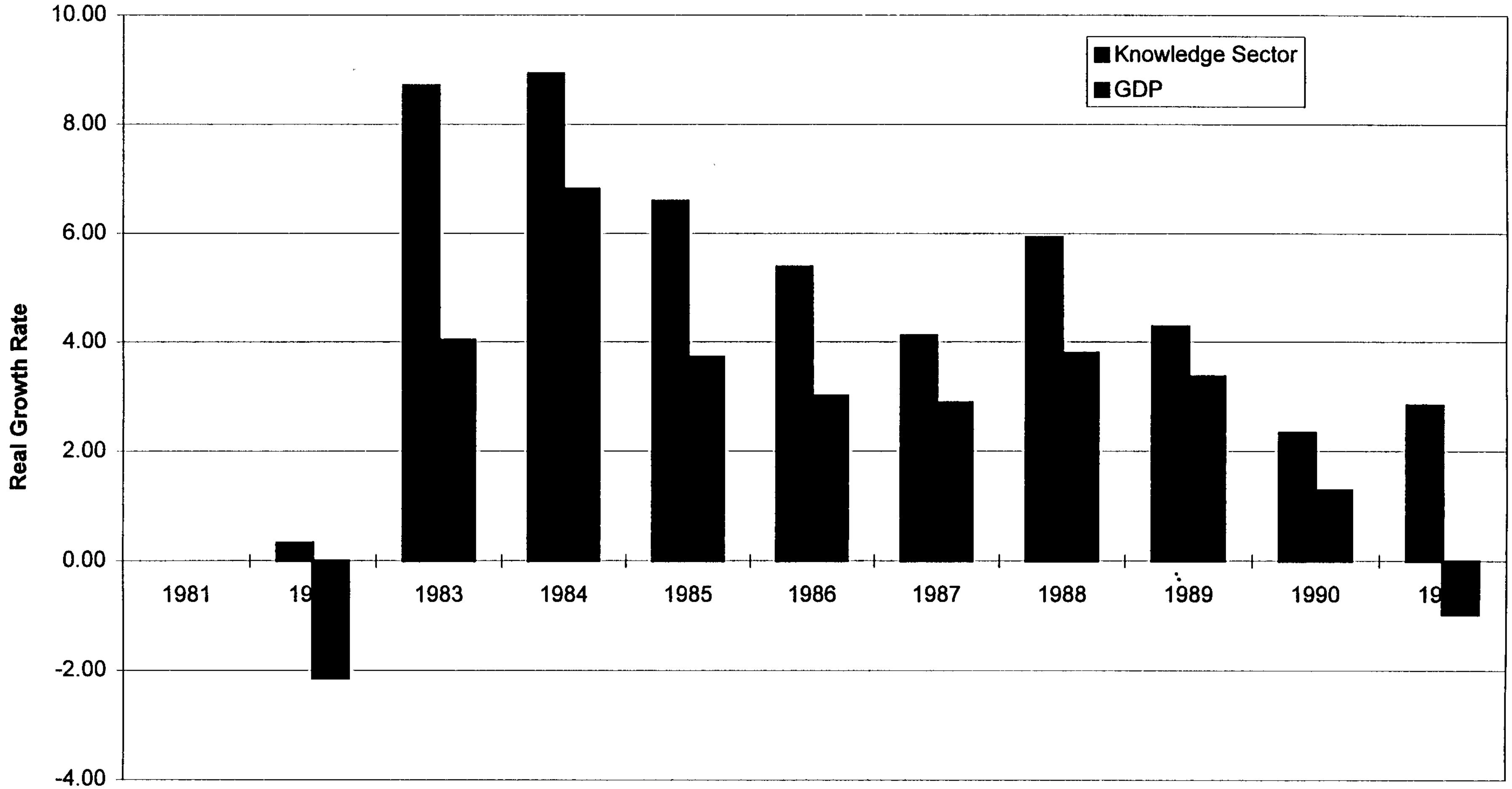


Figure 4. Growth rate of US GDP and of its Knowledge Sector, 1982 - 1991
(including Communication, Finance, Entertainment, Electronics, Computers and Scientific instruments, Pharmaceuticals, Aerospace and Biotechnology)



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 wich had been at 2.5%.

Figure 5. Knowledge Sectors (as % of GDP) vs GDP
USA, 1981 - 1991

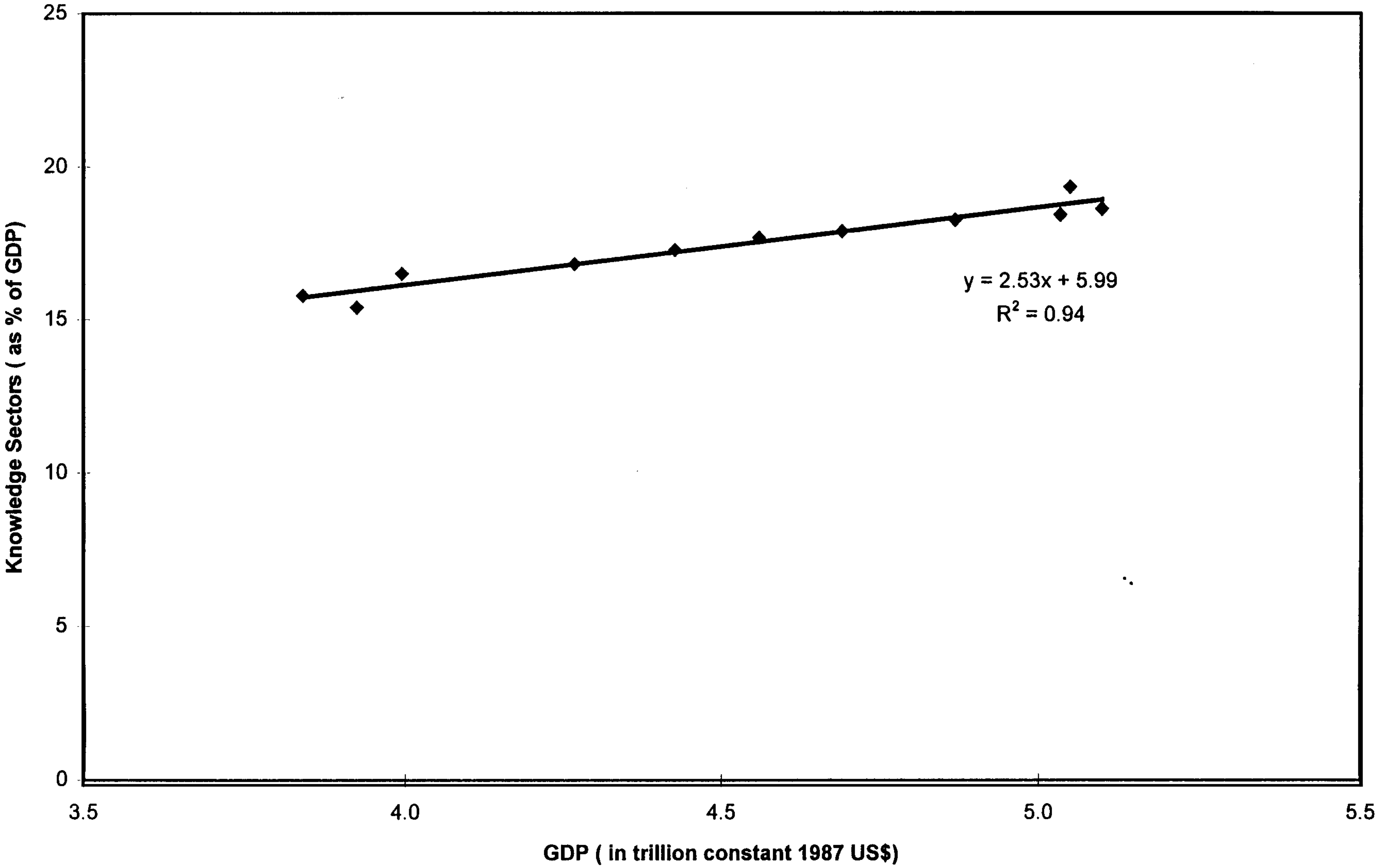


Figure 6. Knowledge Sectors (as % of GDP) vs Total Material Requirement USA, 1981 - 1991

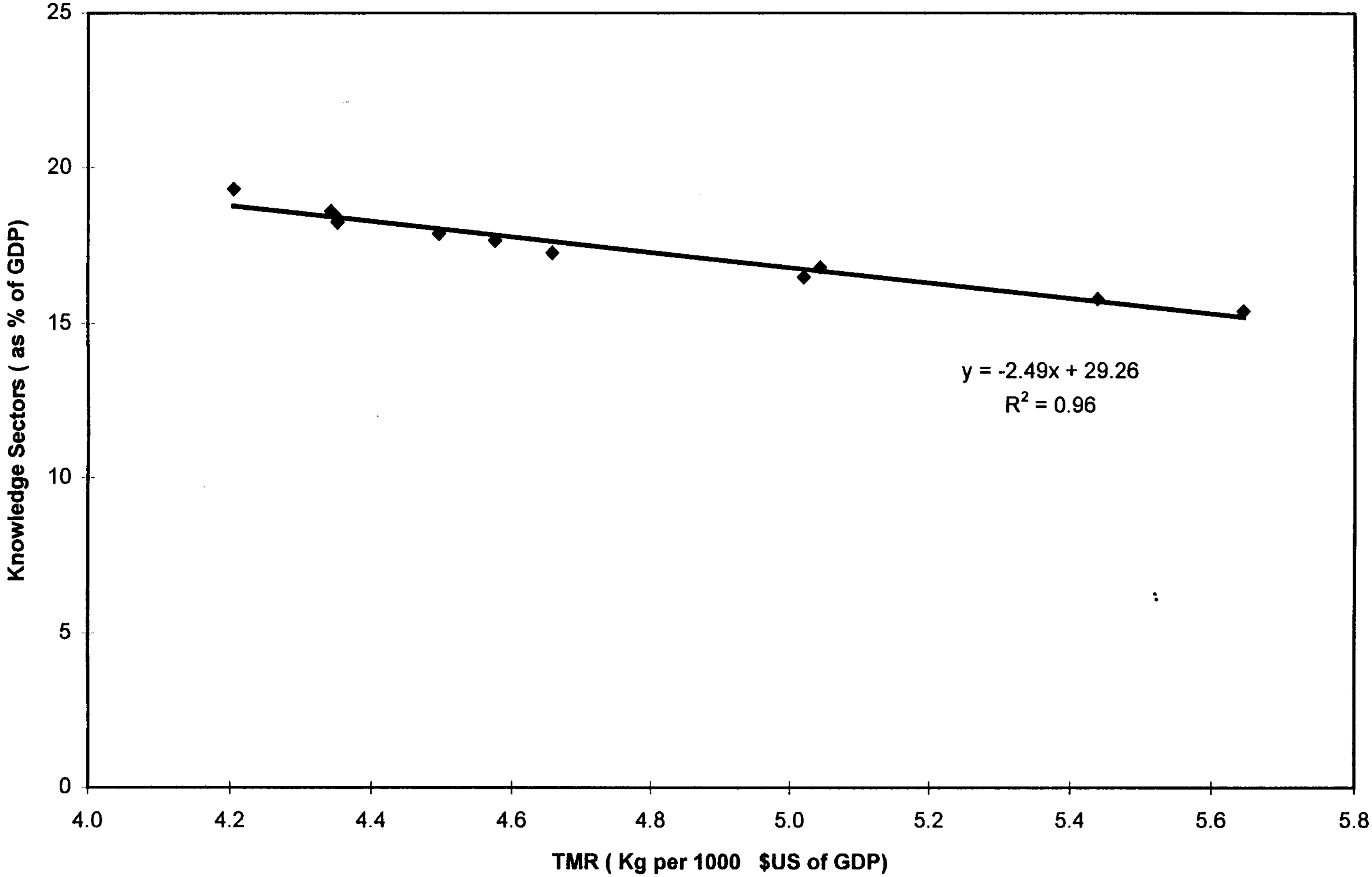


Figure 7. Total Material Requirement vs GDP
USA, 1975 - 1993

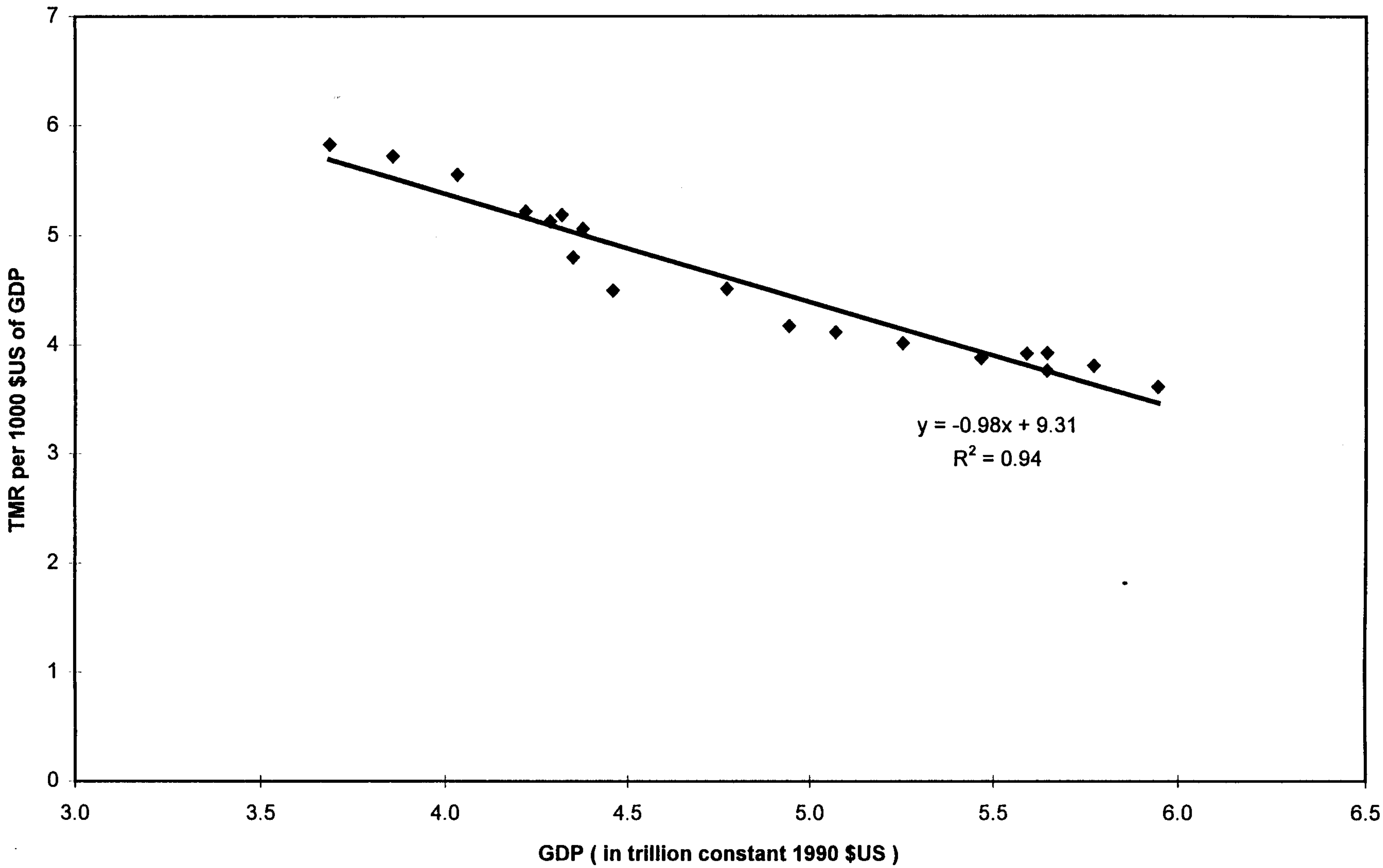


Figure 8. Knowledge Sectors (as % of GDP) vs CO2 Emissions USA, 1981 - 1991

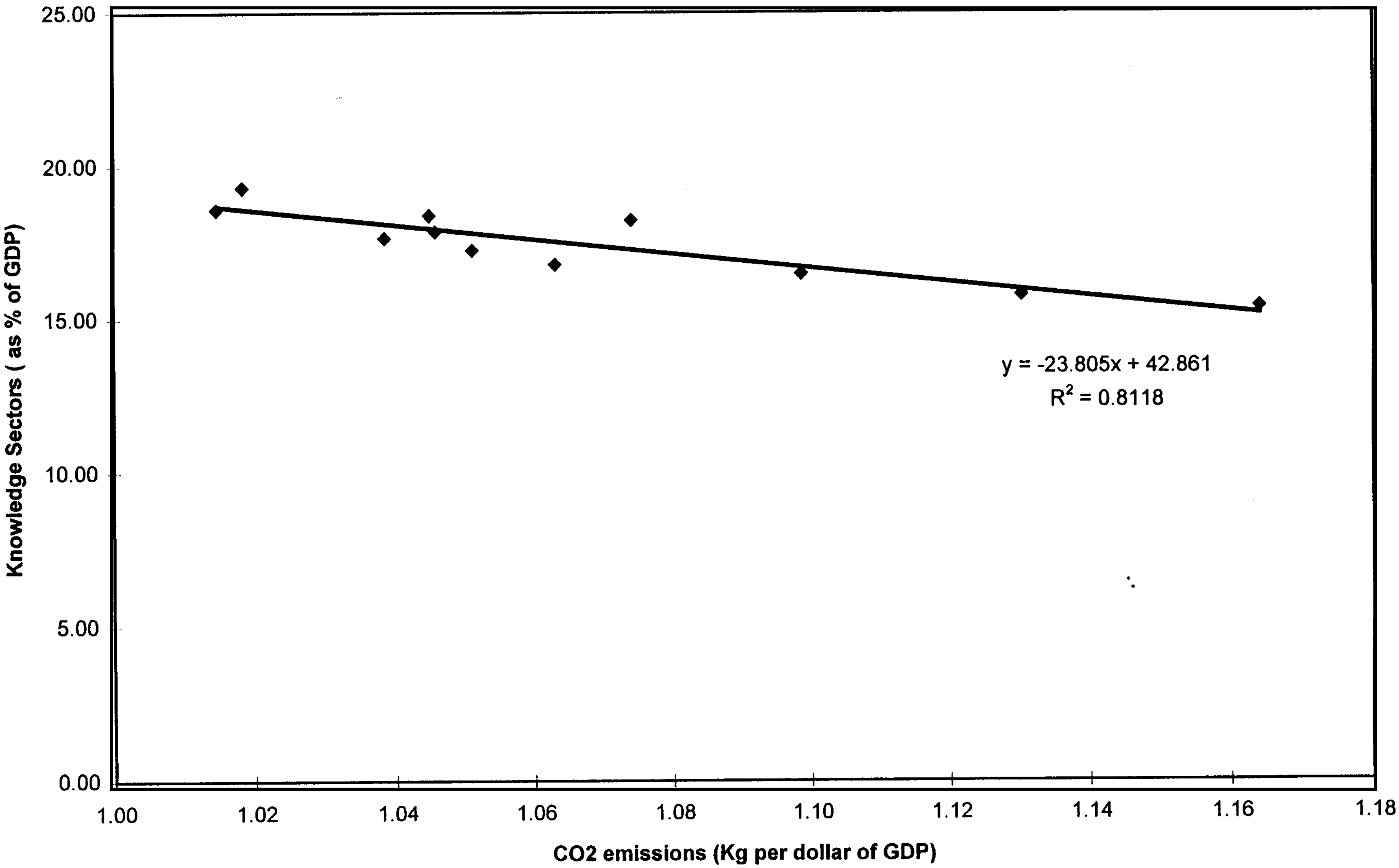
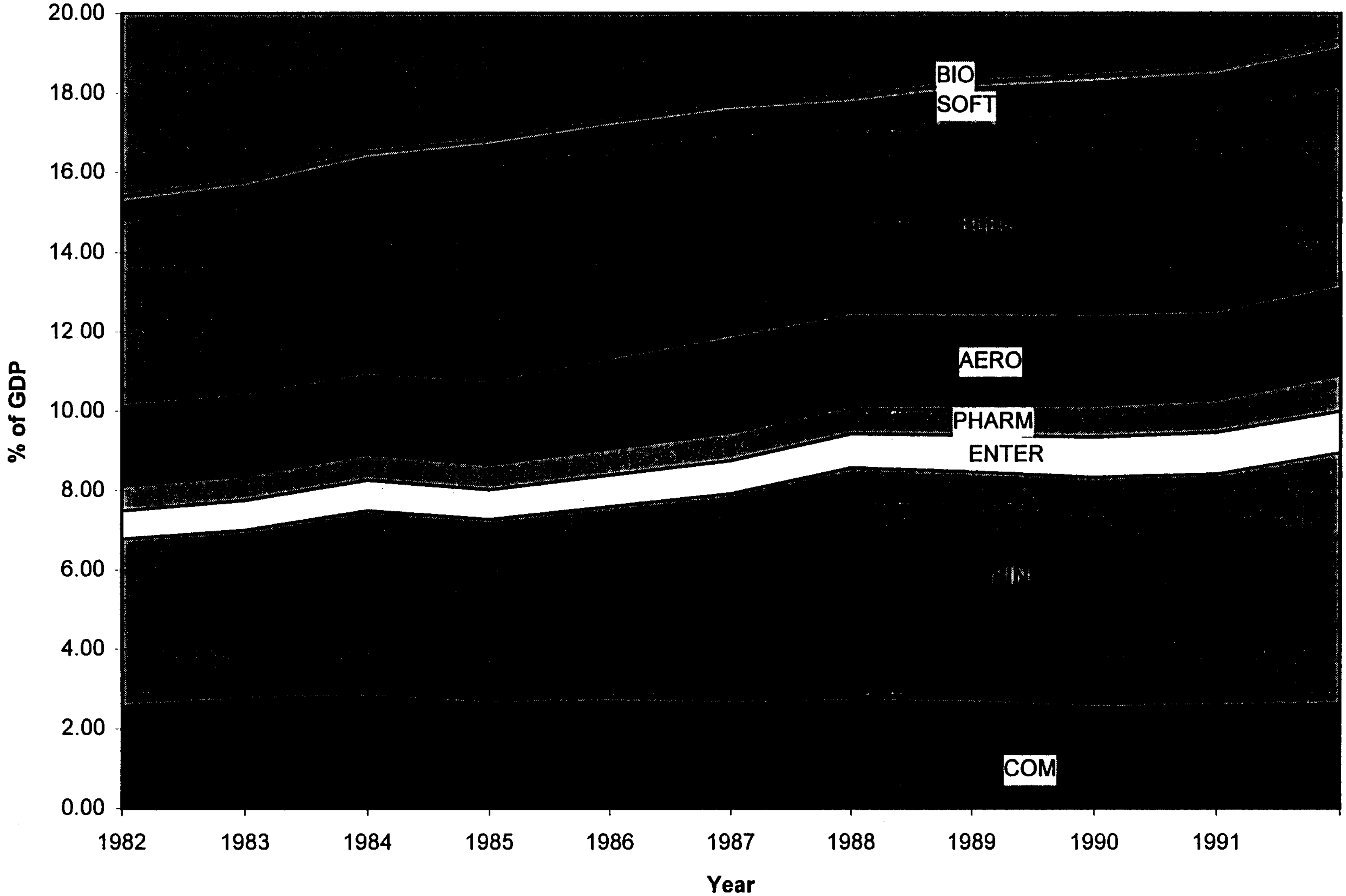


Figure 9. Knowledge Sectors of the US Economy
1981 - 1991



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