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The knowledge revolution

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Abstract

We are on the threshold of a truly revolutionary era of discovery – ranging from the origins of the universe to new states of matter and microscopic machines, from a new understanding of the oceans and of the biological connections across the Earth's species to the functioning of the human brain and the origins of consciousness. This 'golden age' of discovery, with frequent breakthroughs occurring virtually in every field, is inducing far-reaching social changes. We are undergoing a social and economic revolution which matches the impact of the agricultural and industrial revolutions. This is a 'knowledge revolution' driven by knowledge and by the technologies for processing and communicating it. Knowledge is an intangible public good. It is privately produced, and it is replacing land and machines as the primary factor of production prevailing in the agricultural and industrial revolutions. This alters the terms of the debate between capitalism and socialism, and leads to a human-centred society with different types of markets, corporate structure and financial structures. Property rights on knowledge are key. Human capital is the engine of development. Markets require more egalitarian distribution of wealth for efficient functioning. The golden age of industrial society, with its voracious and unequal use of the Earth's resources, is reaching its logical limits. A new pattern of economic growth, knowledge-intensive growth, replaces the resource-intensive patterns that prevailed since World War II. This leads to a vision of society that is very innovative in the use of knowledge and very conservative in the use of the earth's resources, a new society centred on diversity and human capital and offering the prospect of substantial economic progress without damaging the ecosystems that support life on earth.

Keywords

Knowledge revolution, information, property rights, market structure, human capital

1. THE KNOWLEDGE REVOLUTION

We are undergoing a social and economic revolution which matches the impact of the agricultural and industrial revolutions. I like to call it the *knowledge revolution*, and below I explain why. Radical advances in information technology are an obvious manifestation of this change. Underlying these are changes in the management of human knowledge: in its

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creation and distribution, and corresponding changes in the organization of society. The dynamics in the world economy today are in computers and software, in telecommunications and biotechnology, in entertainment and financial markets.[1] It is not, as previously thought, a transformation from industrial production to services. We are seeing a transformation from a resource-intensive to a knowledge-intensive economy.

Knowledge has always been the driving force of change in human societies. Tens of thousands of years ago, the shift from a hunter–gatherer society to the agricultural society was driven by the knowledge of how to use seeds to sow and harvest food. In the agricultural society the main 'fuel' is fertile land, but the knowledge about how to use it is what changed the way humans lived, from smaller nomadic societies to more stable, organized and larger settlements.

The next shift, from agricultural to industrial society, occurred in the eighteenth century when we learned how to use machines, particularly the internal combustion engine and the steam engine, to transform fossil fuels into controlled physical power. The 'fuels' of industrial society are fossil: coal and oil. The industrial revolution was driven by knowledge about how to use the new fuels.

Both the agricultural revolution and the industrial revolution had one thing in common: the adoption of new fuels and new knowledge about how to use them. In both cases the standards of economic progress were associated with the increasing use of these specific 'fuels': land in the agricultural society, and fossil fuels in the industrial society. As societies prospered and human settlements expanded, land and fossil fuels have been extensively used, some would say abused, in the pursuit of economic progress.

The current revolution is also driven by knowledge. As with the two previous revolutions, it involves new knowledge about how to use a new and different fuel: information technology. This fuel is fundamentally different because it is not physical, like land and fossil fuels. Therefore, economic progress no longer means using more physical resources. This revolution brings the hope of a society in which economic progress need not mean increasingly extensive use of the earth's resources.

Changes in land-use led to the agricultural society. Changes in the use of fossil fuels led to the industrial society. And changes in the use of information technology are leading to what I call the 'knowledge society'. The knowledge revolution leads inevitably to the advent of the knowledge society, a society which is global in nature, deeply innovative in and dependent on the use of human knowledge and, at the same time, as argued below, conservative in the use of environmental resources.

The most dynamic sectors in the new society are of course those which benefit most from the use of information technology as an inexpensive and abundant fuel, exactly as the most dynamic sectors in the industrial society were those that benefited from the use of fossil fuels as an inexpensive and

abundant input, and those in the agricultural society were the sectors using inexpensive and abundant land products. The new dynamic sectors are therefore those producing goods which use information technology to expand the ability of the human brain to save, process, retrieve and communicate information. Examples are computers and software, telecommunications and biotechnology, entertainment and financial markets, design and animation, and all services based on human knowledge such as medical services and education.[2] These are sectors where the main input to production is the ability to store, organize, process and communicate human knowledge. This is why I call them 'knowledge-intensive' sectors.[3]

The knowledge sectors will expand more quickly than the rest and therefore the resulting society will produce mostly goods which are knowledge-intensive, much as the agricultural society produced mostly agriculture-related goods, and the industrial society produced mostly industry-related goods. This is why I call this new society the 'knowledge society'. The logic for this term is the same as behind our use of the terms 'industrial society' and 'agricultural society'.

None of this means that we will cease to produce food or machines. Indeed, the industrial society did not cease to produce agricultural products. On the contrary: the industrial society used more land and produced more food than the agricultural society did. However, the proportions of economic production were altered in the industrial society: most produced goods involved industrial components. Similarly in the knowledge society we will still produce food and machines. It is all a matter of proportions. An increasing fraction of economic output will be 'knowledge-intensive', and will involve proportionately more use of knowledge than land or machines.

2. WHAT IS KNOWLEDGE?

As human knowledge becomes the main input of economic production, it is important to focus on some of its most striking properties from the point of view of society.

Knowledge is a 'public good'. It is worth explaining why. It is a 'public good' because, at the physical level, one can share it with others without losing it.[4] Knowledge is not 'rival' in consumption, as are apples or oranges for example. One can restrict access to knowledge to gain economic advantage, and this point will be discussed below. Here I focus on a simple physical fact: I can share my knowledge with the reader without losing it myself. This is a difference from other fuels such as land and machines. The latter are 'private goods' because, if I use a piece of land, it is not available to others, and the same is true with a machine.

Things are different with knowledge. The difference leads to a new calculus, a new mathematical framework, for socio-economic thinking. In

the case of knowledge 1+1 is not 2. Rather, 1–1=1.

The knowledge revolution is based on a new type of input. It is non-physical, and it is a public good, while machines and land are private goods. As a consequence, the knowledge revolution introduces a change in social and economic organization. For example, markets with public goods behave fundamentally differently from the classical markets with private goods. More on this below.

Knowledge is different from other public goods. A classic public good is law and order, which is non-rival in consumption. But law and order are provided by governments, as are most public goods.[5] Knowledge is different: it is provided mostly privately. Individuals create knowledge. This does not exclude socially-created knowledge, emerging from educational systems and the cultural heritage of society. But it points out another difference. The knowledge society has one important input of production, which is unusual in being a public good that is privately produced.

All this is new. Sociology, political sciences and economics are still learning to explain a society based on such inputs. The economics of knowledge is in its infancy, and ready for growth. Most developing countries and many advanced countries, such as Japan, have no systems to protect the ownership of knowledge embodied in software. Markets with knowledge are markets with privately produced public goods, and these behave quite differently from classical markets. A newly discovered fact is that, in these markets, efficiency and distribution are very closely interlinked, in a distinctive way.[6] For efficiency, the distribution of property rights must be relatively more egalitarian, assigning more public goods to those who own fewer private goods. This is in contrast with conventional markets where efficiency and distribution are divorced from each other.

In the new society based on knowledge, markets may require a more equal distribution of wealth to function efficiently. The knowledge society could be more egalitarian than the industrial and the agricultural societies, although this is only a well-informed hope.

Another argument in favour of this hope is that knowledge puts humans rather than land or machines at the centre of economic progress. Knowledge is privately produced food and, at the purely physical level, it resides mostly in the human brain. The most interesting and innovative knowledge originates from human brains. Although much knowledge resides in physical and electronic media, such as books and CD-Roms, the ability to create new knowledge and adapt or cross-fertilize across different areas resides in humans.

Human brains, however, cannot be traded due to non-slavery laws.[7] This crucial input of production, knowledge, escapes the rationale of traditional market economics in that future markets for labour, and therefore for knowledge, do not exist by law in most advanced societies.[8] There is therefore a 'market imperfection' built into our laws: non-slavery restricts trade in knowledge. The market for knowledge is quite different from other markets.

3. CAPITALISM AND CORPORATE STRUCTURE

An extraordinary tug of war between capitalism and socialism has dominated world politics and economic thinking for several decades. The basis of capitalism is the private ownership of capital; socialism, on the other hand advocates state ownership or other forms of public control of capital. The distinction is by no means obsolete: privatization is one of the preconditions which the IMF placed on Russia for approving its politically crucial $10 billion loan recently, a loan which was meant to help defeat communism in the polls. The other IMF precondition was to drop export taxes on petroleum, to allow for a cheaper flow of fossil fuels to the world economy, as Russia has very large reserves. The dominant view in international economic institutions for the last 50 years has been that cheap and abundant resources, and extensive resource-intensive exports, are the main components of a successful development policy.

Below, I argue against growth based on cheap resources. Here I wish to point out that the issue of ownership of capital, which is at the core of the distinction between capitalism and of socialism, is becoming less important. Therefore, the traditional debate between these positions is becoming obsolete. Let me explain.

Capital and machines are crucial in the industrial society. But the main scarce factor of production is no longer capital. Knowledge and ideas are more important today and more scarce than capital. Who owns the capital is no longer the main issue. Ownership of ideas is becoming more critical. The ownership of 'intellectual capital' is key. As was pointed out above, this type of capital is different in a number of ways from standard capital, and markets which trade property rights on knowledge, or 'intellectual capital' behave quite differently from our classical markets.

Think of ideas in the technology and entertainment sectors, the most dynamic sectors in the US economy today. If one has a great idea in these areas, capital will come to it. A corporation will realize it. This is the role of the modern financial markets and of the corporate structure. The extraordinarily successful development of these two creatures of capitalism, the corporation and the financial market, is transforming its foundations.

Capitalism is evolving. Physical capital is no longer its most important force. Ideas and knowledge have replaced it. Ideas and knowledge reside in the heads of individuals and groups, so that human capital rules the knowledge economy. A recent study by the World Bank documents this fact. It ranks countries by their wealth, and their human and physical capital. The latter includes natural and manufactured capital. The World Bank data show that for many of the most industrially advanced countries, human capital explains wealth two or three times better than physical capital, see Figure 1.

In the old industrial society the ownership of capital is all important. In the new knowledge society the ownership of knowledge is all important. Property

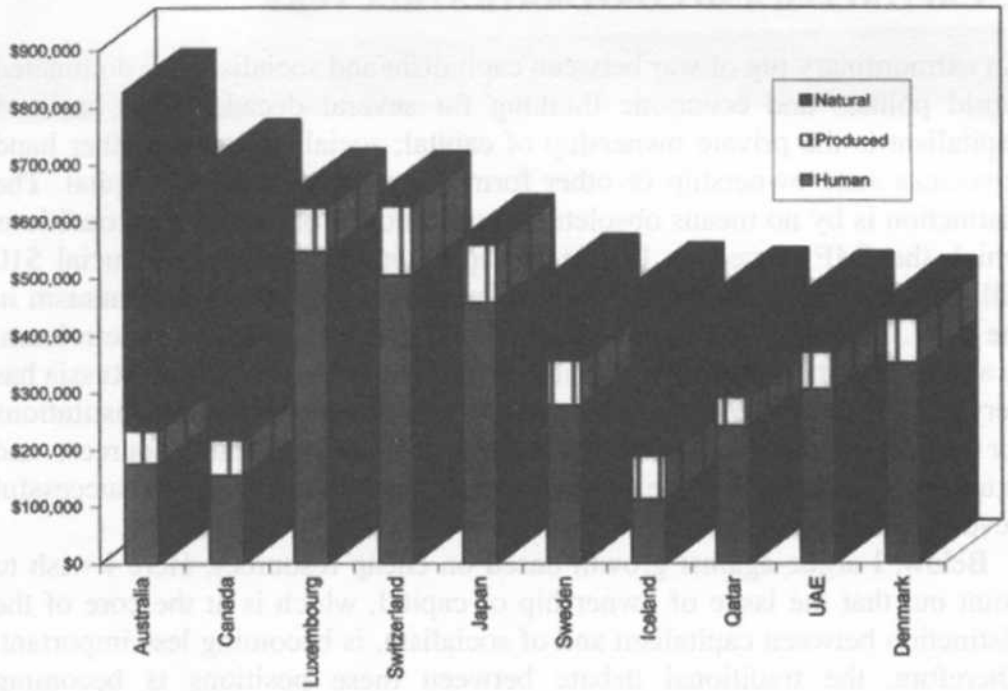

Figure 1 World Bank data on wealth composition, from Serageldin (1995)

rights over knowledge are becoming more important than property rights on capital. One sees this in the increasing emphasis placed on intellectual property rights by the US government in international negotiations. Intellectual capital is quite different from capital.

As already noted, knowledge is an intangible public good that is privately produced. The calculus of knowledge is therefore quite different from anything else. To a certain extent the more one gives, the more one has.

To take advantage of the extraordinary features of knowledge, however, one needs appropriate institutions. As already pointed out, markets function quite differently when knowledge is traded. Property rights play a very important role in inducing market efficiency. The importance of finding appropriate regimes for property rights on knowledge should not be underestimated: these are at the core of the knowledge society.[9] We are moving to a version of capitalism in which markets for knowledge, or for the rights to use it, will be central components.[10]

4. ORGANIZATION OF PRODUCTION

It is well known that knowledge leads to economies of scale associated with 'learning by doing'.[11] The benefits from large-scale production are not new: aircraft production is a classic example. This arises from the need for large

size plants and sizable equipment, and leads to natural monopolies. However, recent research indicates that knowledge leads to a different type of increasing returns to scale.[12] *Larger markets* help achieve more efficiency, but large size plants and equipment may be unnecessary. Firm size may no longer matter. Some of the most productive knowledge-driven firms are small and labour intensive. Software production is an excellent example; another is garment design-and-marketing chains such as Benetton. Here, increased productivity occurs through mobility of labour between firms in the same sector. As the sector expands we learn more and become more productive. Each firm may be small, and still reap these benefits.

This means that we may observe economies of scale with firms small enough to be competitive. The loss of economic efficiency due to monopolistic behaviour is minimized. For example Microsoft and Compac are very large firms. But they are 'disciplined' in terms of prices by threats from small competitors, which do not need large plants or equipment to operate. One can simultaneously have competitive markets and economies of scale which are external to the firm. This could not happen in traditional sectors in which economies of scale require large size and lead to monopolies.

In knowledge-intensive sectors, cooperation between firms drives increases in productivity as much as does competition. Silicon Valley contains examples of this phenomenon, and the most recent management literature already points out such effects in the structure of the new corporations.[13]

5. KNOWLEDGE AND THE ENVIRONMENT

Economic growth in the industrial society has occurred largely by extensive replication of industrial activity, based on intensive use of fossil fuels and generally of the Earth's resources. This involved the use of natural and environmental resources such as the atmosphere, bodies of water, and landscapes. This growth has been fuelled by fossil energy sources, effectively harnessed by the steam engine and the internal combustion engine. Economic growth in the industrial society has meant doing more with more.

Driven by its own success, the industrial economy is coming to its logical end. The last 50 years since the end of World War II were the golden age of the industrial society. The United Nations and the Bretton Wood institutions (e.g. IMF, The World Bank, GATT) measured economic progress by the GDP per capita. They could have equally measured economic progress by the use of energy per capita: in the industrial society both are so closely related as to be one and the same. Today energy comes mostly from fossil fuels, and this has led to global environmental threats. Because of its extraordinary success, the industrial society is now damaging itself. Major international organizations document that, over the past 50 years, runaway consumption of resources, including fossil fuels and atmospheric resources,[14] has led to depletion of the planet's ozone layer, to mass destruction of bioresources, and

potentially to global climate change.[15] For the first time in history human activity has reached levels at which it threatens the atmosphere of the planet, its bodies of water and its biodiversity. The destruction of forest cover is proceeding at a rate which has no precedent. There is growing concern about the impact of energy use on the planet's climate.

We are in the first stage of what could be, if completed, the largest ever anthropogenic environmental transformation of the planet.[16] The impact of this is being seen in many developing countries, where deforestation and the lack of clean water pose serious threats to human survival. This unprecedented environmental transformation is driven by our inability to realize the value of precious resources without destroying them. It arises from our failure to articulate proper connections between environmental assets, economics and markets.[17] In many cases the solution requires new systems of property rights on hitherto open access resources such as water, the atmosphere, and biodiversity. To prevent irreversible losses we need to devise mechanisms which can mediate more effectively between the market and the environment.

At this critical juncture, the knowledge revolution could offer an alternative model of human economic and social progress, one based less on the use of fossil fuel and environmental resources and more on human knowledge and the systems which disseminate and use it.[18] A world where economic progress means achieving more with less, rather than doing more with more.

6. THE DEVELOPING WORLD

North–south relations, namely the economic and political relations between industrial and developing nations, are implicated. Although colonialism ended after World War II, developing nations still specialize in resources and resource-intensive products. These are mostly produced for international markets, and are traded below social costs and are overconsumed in industrial nations.[19] Much of this market dislocation comes from differences in property rights between industrial and developing countries: in the latter, natural resources are more likely to be held as open access or common property resources. Lack of property rights induces an apparent comparative advantage on resource intensive products on the part of developing countries where, in fact, there may be none.[20] In a tragic misunderstanding of the principles of development and trade, international organizations still advocate that developing countries increase the exports of raw materials and agricultural products at undervalued exchange rates, at prices which are often below social costs. The IMF makes this a precondition for loans to Mexico and Russia today. The problem of overuse of environmental resources is global. No policy that ignores this connection can work.

An alternative model of economic development has been followed by the

southeast Asian nations. This was based on technological progress and a rapid shift away from resource-based growth. Their extraordinary success has not been without environmental cost. But the world has taken notice.

The challenge is to develop and implement a model of economic development which, rather than fossil fuels, uses knowledge as a fuel. A model where humans count more than anything else because they produce, contain and distribute the ultimate source of economic value: knowledge. A model where, rather than coal and petroleum, we burn knowledge. Such a model can leapfrog the heavy industrialization period which the now developed countries followed into the knowledge society. Several developing countries, notably Barbados, Phillipines, Singapore and parts of India, are already following this road. India's increasingly confident software industry has now a turnover of US$1.2 billion, established less than a decade ago.[21] East meets West for mutual benefits – and in this crucial sunrise area parts of India leapfrog ahead of many industrial countries. More on this and examples, follow below.

A policy implication that emerges from this conceptualization of the knowledge revolution is the need to shift rapidly to high-tech industries and to provide widespread education for producing the human capital needed for economic progress.[22] For example, in the 1995 World Competitiveness Report, Singapore and Taiwan were rated first and third in terms of the abilities of their educational systems to meet 'the needs of a competitive economy'. One of the most striking characteristics of Singapore, Taiwan and South Korea has been their emphasis on raising the educational standards of the entire population rather than focusing on an elite, as in the cases of Pakistan and India. These countries have consistently exhibited the highest rates of economic growth in the world in the last decade (see figure 2). Widespread scientific and mathematical competence are good predictors of the competitive position and rate of economic progress of a nation.[23] Furthermore, they are important in the implementation of development strategies which are knowledge intensive and are based on financial markets, computers and software, biotechnologies, or any of the emerging environmentally-benign sectors.

By contrast, the two areas which remained most resource-intensive, Latin America and Africa, have remained behind and remind us painfully of their misunderstanding of economic development.

The advent of the knowledge society could not be more timely. The sunset sectors of the industrial economy are resource intensive: heavy industry uses prominently chemicals, minerals and energy. The sunset sectors in the agricultural economy are also resource intensive: they use land, water and chemicals. By contrast, some of the most important sunrise sectors in the knowledge society are environmentally friendly. Human knowledge does not need large-scale deployment of materials. One is reminded of the comment of General Motors's CFO when Microsoft first passed General Motors in

Table 1. Math and Science Scores

2+2=?

13-year-olds average score in TIMSS* (int. average= 500)

	Maths		Sciences	
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	Columbia	354	Colombia	411
41	South Africa	354	South Africa	326

*Third International Maths and Sciences Study

source: TIMSS

**Flanders ***Wallonia

Figure 2 Scientific attainment for selected countries. Source: Educational Testing Services, Princeton N.J. (1992)

market capitalization: 'Microsoft – their assets could fit in our parking lot!'

In sum: economic progress during the industrial society meant doing more with more. Whether we like it or not, times have changed. It must now mean ach-

ieving more with less. Economic progress should be redefined: when progress is measured properly, it could involve less consumption in physical terms.

7. FINANCIAL MARKETS, EMPLOYMENT AND WELFARE

Some of the most interesting financial markets which are evolving today are environmentally driven.[24] Examples are markets for trading sulphur dioxide emissions in Chicago. Catastrophe futures[25] can be traded in Chicago, to shore up the reinsurance of catastrophic risks. Recently Merrill Lynch and Morgan Stanley have floated 'hurricane bonds' that offer similar facilities. Water markets are emerging in California. A proposal by this author for global greenhouse gas emission markets has now been accepted by 166 nations in the Kyoto Protocol of December 1997.[26] Financial markets can mediate between the standard markets and the environment and represent the way advanced societies hedge risks.

Another aspect of financial markets that is often overlooked, is their impact on employment. Most new employment in the US during the last 20 years was generated by small new corporations driven by risk capital. These firms embody the new knowledge, and exploit it faster than the larger corporations. Europe has knowledge, but it has rather inflexible financial markets, dominated by large complacent banks. France and Germany are prominent examples of financial systems that were traditionally driven by large and successful banks, such as Credit Lyonnes and Deutsche Bank. The performance of these two banks is now under close scrutiny, and Chancellor Kohl has recently admitted that financial system reform is one of his main priorities.

The US has a better record of commercial exploitation of innovations because it has more flexible financial markets. This is the main reason why the US has much lower unemployment rates than the EU: less than 5 per cent unemployment today compared with 10–15 per cent in many of Europe's advanced economies. The US has experienced much more job creation in the last two decades than Europe. Many of these new jobs emerged in small start-up skill intensive firms, amongst them many which have eventually become household names. Many of these have been in the media and technology areas, products of the capacity of the venture capital system to raise capital and the ability to establish property rights in ideas. Institutions have been crucial here. Financial markets and property rights over knowledge interact: for the interactions to be most productive, both need to be correctly designed.

8. SOCIAL DIVERSITY

Social diversity is another important factor in the knowledge society. In many cases the more diverse is a society, the more it can innovate by cross-fertilization of ideas from different sources. Innovation is not always welcome

in the agricultural or industrial society because it can disrupt the established order. Order and organization are the foundations of productivity in those societies. But this is not necessarily so in the knowledge society. Change, even chaos, can be productive. The knowledge society can change more rapidly and can absorb innovation with less trauma. Societies can leap directly from agrarian to knowledge societies without going through a period of heavy industrialization. A prominent example in the Midwest of the US is the area in the great lakes surrounding Chicago, an area where agricultural markets have led to financial markets, and another is Tuscany in Italy, a wine and olives economy which is modernizing without going through heavy industrialization. As already pointed out, in the developing world, Barbados, India and the Philippines are following similar roads.

Social diversity is however costly in a world in which work is organized around the old fashioned principles of the industrial society. Recent research has shown that traditional markets can only operate within a limited amount of social diversity.[27] The same is true of voting systems and strategic solutions involving game theory.[28] All these systems of resource allocations, the foundation of modern economics, function within narrow limits of social diversity that can be measured by a topological object, an invariant that gauges social diversity.[29]

Social diversity has an obvious manifestation through unemployment. Much unemployment is caused by lack of educational access, and this access is often connected with differences in the endowments and the preferences of the traders in a market economy, precisely as measured by my definition of social diversity.[30] Today's excess demand for technical services is matched by the excess supply of workers with old-fashioned skills.

Labour mobility distributes knowledge around and, by doing so, generates positive externalities. Society gains, but individuals often lose. The US worker is driven today by fears of losing jobs and the corresponding place in society, perhaps more so than in the past. One reason is that most jobs are in skilled sectors to which an older population of workers may not have ready access. Without proper institutions, individuals are justifiably insecure. Welfare systems are outdated. Everyone agrees that they must change.

9. POVERTY AND HUMAN CAPITAL

It is no secret that for a young American worker the most important determinant of access to gainful employment is appropriate education. After many years of questioning the issue, social scientists have finally accepted the fact that education means higher income, and more education, in the right sectors, means much higher income.[31] It is also no secret that better human capital means better productivity and, therefore, in a market economy, better wages. The value of education used to be regarded with deep suspicion and scepticism. No more. The right education opens the doors to employment and

to social participation. The right education is the golden key to the knowledge society.

The challenge is how to make the knowledge revolution accessible to the underclass in industrial countries and to the large mass of people, about one billion strong, who live today in developing countries below their minimal basic needs.[32] The challenge of using knowledge to fight poverty is, however, enormous. The task may be impossible in the short run, but it is nevertheless of overriding importance. There are no acceptable alternatives.

We know that in today's industrial world unemployment means poverty, and lack of education means unemployment. In the developing world standard resource-intensive development policies have left a legacy of failure, disappointment and often anger. India, the Philippines, and even Barbados are at the forefront of a new wave of economic development which updates the south-east Asian model to the world of the knowledge revolution. India is one of the world's most successful software exporters. Properly harnessed by updated institutions, knowledge may be the key to successful economic development across the entire world.

10. CONCLUSIONS

- The knowledge revolution is changing society.
- Knowledge is an intangible privately produced public good, and is today the key determinant of economic and social progress.
- The primacy of knowledge as an input and as an asset has the potential of altering long-standing debates on the relative advantages of capitalism and socialism, and more generally of free markets and government intervention.
- In a knowledge-based society, markets behave differently and require more egalitarian patterns of distribution of resources in order to achieve efficiency.
- The primacy of human capital can lead to changes in the distribution of income and wealth, in corporate structure and financial markets, and in the environmental impact of economic activity. It can lead to new patterns of development and chart new relationships between industrial and developing countries.
- Since the knowledge society is more innovative, the cross-fertilization of different ideas and ways of thinking may prove valuable. The creation of knowledge may flourish in societies that are more socially diverse than those prevailing under the industrial and the agricultural societies.
- Knowledge-intensive development is the key to economic progress. It replaces resource-intensive growth, which dominated the world economy since World War II and led to a deep and extensive destruction of bioresources, and to substantial alterations to the ecological systems that support life on earth.

- The knowledge society is innovative and diverse, but deeply conservative in the use of the Earth's resources. Humans and human capital are at the centre of economic progress, replacing capital and material property. In this society, economic progress means achieving more with less material inputs, and without destroying the ecosystems to which the human species has adapted optimally throughout the ages.

NOTES

1 Today, more Americans make semiconductors than construction machinery, and the North American telecommunications industry employs more people than the auto and the auto-parts industries combined. See for example Beck (1992).

2 Today the US health and medical industry alone has become 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. See Beck (1992).

3 'Information technology' is different from 'knowledge' in that the former is restricted to storage, organization, processing and communication of the latter. Knowledge is the content, information is the medium that carries and organizes the content.

4 This is a technical definition of 'public goods' as is used in economics.

5 Classic public goods are provided by governments, as for example those public goods studied by Lindahl, Bowen and Samuelson.

6 The issue is new. Mathematical formulations of competitive markets with privately produced public goods have emerged recently, for example: Chichilnisky, *et al.* (1993); Chichilnisky (1997).

7 The issue of child and women slavery has been extensively discussed recently, see for example *The Economist* (1996). There are many societies today where slavery survives, such as Nepal, Pakistan, Sudan and Thailand. Forced employment that is very close to slavery is found today in Brazil and in parts of the US, such as Los Angeles, see also reports in the above cited article.

8 Although an employer cannot contractually obligate an employee to work for him or her in the future, he or she can obligate the employee not to work for a competitor via a 'non-compete' agreement.

9 Lack of property rights on software has handicapped the development of this industry in Japan.

10 New mathematical formulations of markets with privately produced public goods (such as knowledge) can be found in Chichilnisky (1994a, 1995), Chichilnisky and Heal (1994) and Chichilnisky and Milgrom (1996).

11 A concept introduced several years ago by K. Arrow.

12 In additional to empirical literature, there are new mathematical models of competitive markets with external economies of scale, e.g. Chichilnisky (1996a).

13 See for example Moore (1996), Branderburger and Nalebuff (1996), Beck (1992).

14 For example, the use of the atmosphere as a 'sink' for the disposal of CFCs and greenhouse gases, see IPCC (1994), Chichilnisky (1995/96).

15 IPCC (1994). A major study on global warming in the next hundred years and beyond was released last September by the IPCC. A group of 2500 scientists from around the world, first assembled by the UN to study climate change in 1988 – the Intergovernmental Panel on Climate Change (IPCC) – is regarded as the definitive clearinghouse for research on the subject. In a report released in November 1995, the IPCC declared a consensus that, for the first time in history: 'The balance of evidence suggests that there is a discernible human influence on global climate'.

16 See IPCC (1994).
17 See Chichilnisky (1995/96), p. 5–40.
18 See for example Chichilnisky (1986, 1994b).
19 IPCC (1994) and Chichilnisky (1995/96).
20 Chichilnisky (1994b, 1995/96).
21 Among many succesful new ventures is CITIL, a Bombay based software development company owned by Citicorp, a producer of Microsoft software packages which have already been installed in banks in 35 countries. See for example *Financial Times*, (1996).
22 Mohatir Mohammed, Malaysia's prime minister, said last month that with the country short of manpower, firms should stop relying on cheap labour and shift to 'high tech' industries. This prescription also applies to the whole of Asia. See *The Economist*, (1996: 62) and parts of the US.
23 See also 'Those Educated Asians', and 'Asia's Costly Labor Markets', *The Economist* (1996: 33, 62).
24 See for example Bernardez (1996).
25 Introduced in Chichilnisky and Heal (1993), Chichilnisky (1996b), Black (1996).
26 Chichilnisky (1996c). In June 1996 this proposal was supported officially by the USA in the Geneva meetings of the Framework Convention on Climate Change (FCCC), the Kyoto Protocol created this market on emissions right in December 1997.
27 See for example Chichilnisky (1984).
28 A unification of the three main theories of resource allocation in economics – markets, games and social choice – can be found in Chichilnisky (1994c, 1996d).
29 Recently, social diversity has been defined mathematically as a function of what people own (vectors in euclidean space) and what they prefer (utility functions that measure welfare); an algebraic object is constructed from these characteristics (a topological invariant) that provides an exact mathematical measure of diversity, see Chichilnisky (1996e).
30 See Chichilnisky (1996e).
31 The verdict has changed. About 20 years ago it was fashionable for labour economists to question the value of education. Today it is widely accepted that skills determine employment and better skills lead to higher income, although there are quibbles about what these skills should be.
32 The concept of development based on the satisfaction of 'basic needs' is crucial to the current discussion about sustainable development patterns, as seen in the Brundland Report; 'basic needs' were also adopted as the cornerstone of sustainable development by 150 Nations in the Agenda 21 adopted in the Rio Summit of 1992. The concept of development based on the satisfaction of basic needs was created, developed and popularized by Chichilnisky (1977a,b) in the Bariloche Model produced in Argentina in 1972–76, and has been widely used in the United Nations and the World Bank during the last 20 years.

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