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Chapter 6:
Innovation – The Pathway to Threefold Sustainability*

Fundamental and wide ranging innovations are needed if modern economies are to become sustainable in economic, environmental and social terms. New technologies, including information technology, biotechnology, and nanotechnology could facilitate dematerialization and ultimately perhaps environmental sustainability but much depends on the way they are utilised and for what purposes. In the absence of adequate regulation they could equally well contribute to further environmental degradation or greater materialization. New technologies also offer additional economic and employment opportunities if they are used to satisfy the new aspirations of people and develop new markets, rather than to improve and rationalise established production in established markets. New organisational forms, including anthropocentric production systems, virtual factories and e-business offer the same opportunities and risks depending on the extent to which their development is adequately shaped.

Shaping the development of new technologies and organisational forms in a sustainable way represents a tremendous challenge to the capability of a society to make social choices. It also represents a challenge to the capability of the emerging global community to develop the necessary rules for the global game. To meet this challenge significant far-reaching social innovation will be necessary. New cultural habits may constitute the environment in which new technology and new organisational forms can be developed and guided in a sustainable direction. New political structures will be needed to increase the capability of societies and the emerging global community to enact and facilitate social choices and political goals.

Although innovation is an indispensable element of efforts to achieve threefold sustainability, not all innovation advances all of the dimensions of sustainability - or advances them sufficiently. In the past, it was often the case that innovations that enhanced the competitiveness or long-term efficiency of the economy had negative impacts on the environment and employment or real wages. There is no guarantee, of course, that innovations which advance one dimension of sustainability are equally beneficial for the other two. The attainment of threefold sustainability constitutes a challenge to public policy. "Getting the prices right" which is often hailed as the only economic way to achieve sustainability is not sufficient. The attempt to target the right innovations with subsidies is also misguided. What is of paramount importance is the creation of appropriate incentives through law and taxation that can transform industrial societies into sustainable societies– that is the development of an adequate institutional framework for the market

At the beginning of the 21st century, the management and political control of innovation has become an extremely difficult and complex process. For many years now, the world production of knowledge has been growing rapidly. The result is, what the OECD amongst others

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somewhat misleadingly terms - 'the knowledge-based economy'. In the knowledge-based economy, the innovation process is no longer technology-driven although technology plays a crucial role. Technological development is increasingly associated with a variety of different trajectories that coincide with an even wider variety of economic opportunities. Innovation is no longer driven by one key technology, but by several that all deserve to be called key-technologies. Organisational knowledge in conjunction with information technology, is developing in a similar way opening up a variety of different organisational opportunities.

The rapid and multifarious development of new technological and organisational opportunities is associated with considerable risk not only for the economy, but also for society and nature and the ability to cope with this risk has become an important determinant of successful innovation. A gap has thus appeared between the rapid growth of scientific and technological knowledge and the ability to generate the social and economic innovation that is necessary for an economically, socially and environmentally sustainable mode of development.

Types of Innovation

In this work, we distinguish technological, organisational, and social innovation, although these distinctions may not always be very sharp. They are, in any event, related to one another and are necessary for the transformation of the industrial state towards sustainability.

Technological change is a general - and imprecise - term that encompasses invention, innovation, diffusion, and technology transfer. Technological innovation is the first commercially successful application of a new technical idea. It should be distinguished from invention, which is the development of a new technical idea, and from diffusion, which is the subsequent widespread adoption of an innovation beyond those who developed it. The distinction between innovation and diffusion is sometimes hard to draw, however, because innovations can rarely be adopted by new users without some modification. When modifications are extensive, i.e., when adoption requires significant *adaptation*, the result may be a new innovation. Sometimes the innovation is embodied in hardware, devices, inputs/materials and process technology. Sometimes it is embodied in the skills of labour and/or the organisation of production and work and sometimes in all these factors.

Innovation can be driven by scientific discovery (an invention) searching for application (technology push innovation) or by a market need or opportunity (market pull innovation). Both are important. However, the evolution from discovery (invention) to innovation to diffusion is not a linear process, but is a complex, dynamic, interactive, iterative one involving many factors and actors[1]. The process of technological innovation has to be conceived of as an ongoing search activity that is shaped and structured not only by economic forces that reflect cost considerations and resource endowments but also by organisational conditions, the present state of technological knowledge, and by consumer demand for different categories of products and services. As we will explain later in this chapter, in the so-called information age, the complexity of the process of innovation has drastically increased as knowledge generation and technological development have become multifarious making the dynamism almost unpredictable. Market pull has become much more important. This has important implications for public policy concerning innovation.

Like the term technological change, the term technology transfer is also somewhat imprecise, sometimes referring to the diffusion of technology from government to industry, or from one industry or country to another. Sometimes government transfers a technology (from national laboratories or research centres, for example) that is not much more developed than the invention stage, in which case the transfer to industry can actually result in innovation.

A technological innovation can be characterised by its type, by its significance, or by its motivating force. Distinguishing between different kinds of technological change is essential for policy design, since the determinants and consequences of each - and the incentives for, and barriers to - the success of each are different. Technological innovation that is process-oriented, for example, affects employment and the environment in different ways than innovations that are product-oriented. Also, certain conditions contain strong incentives for process-innovation, but may hinder product-innovation.

Innovation can be incremental or radical in nature. Incremental innovation is the improvement of an existing product or line of products for established markets. The improvement may be modest or very far-reaching. The important point is that even if the innovation implies far-reaching change of the product, the properties of demand, of the market more generally, of the product and of the relevant production process are known. In contrast to this, a radical innovation is the introduction of a new product for a new market. Here, the innovator has little real knowledge of the new market, of the properties of emerging demand, of the required properties of the product or of the working of the planned production process – the innovation takes place in an environment of uncertainty.[2]

The distinction between incremental and radical innovation is not simply one between two points on a continuum. Incremental innovation generally involves continuous improvements – characterised by some as 'technological regime shifts' brought about by 'strategic niche management' – while radical innovations are discontinuous, possibly involving displacement of dominant firms and institutions, rather than evolutionary transformations. It is argued here that more radical, rather than incremental innovation, is needed to achieve improvements in both resource productivity and pollution reduction of at least a factor of 10.

From another perspective, product innovations can also be classified as 'sustaining' [not to be confused with sustainable] or 'disrupting'. This dichotomy is based on 'value networks' (networks of customers with well-defined demands) and reflects whether or not changes in product attributes that require innovation are demanded by current customers. Sustaining innovations fit into existing patterns of demand and customer relations while disrupting innovations do not. A "value network" is "the context within which a firm identifies and responds to customers' needs, solves problems, procures input, reacts to competitors and strives for profit".[3] In the case of sustaining innovations, companies act within their established "value network", whereas disrupting innovations mean that firms have to form a new value network.

Sustaining innovations occur when established firms seek to improve customer satisfaction with improved products. Those improvements are incremental because they come in successive waves from established firms in that product market. Disrupting innovations cater to different, not always clearly defined, customers with product attributes different from those in the established producer-consumer networks. The creation of new products in this case does not take the form of a wave built upon prior waves, but occurs in an entirely new market. Disrupting innovations may be incremental or radical. Radical innovations are always disruptive, incremental innovations are usually sustaining, but may occasionally be disrupting – for example if a product innovation is introduced in a market segment in which the company was not hitherto active.

Product attributes are valued differently by different value networks. Existing mainstream customers may demand different things than 'special customers' who may be small in number, but who could eventually reflect future mainstream demand. Sometimes networks emerge that reject a product that was previously accepted. For example, producers of genetically-engineered foods, reinforced by their traditional consumer network, believed that these foods would be acceptable, and they therefore ignored a small, but vocal and different group of consumers who ultimately became a serious force to contend with. The industry was lulled into complacency because producers listened to their main customers and did not entertain the possibility that things would change.

In principle, new products and services related to triple sustainability could be developed and brought to the market as sustaining or disrupting innovations. The relevant features, for example, resource intensiveness could be important to the existing customers of a company and, thus, be developed as sustaining innovations. An emerging case in point is environmentally friendly packaging that appeals to a defined customer base. Often, however, the far-reaching innovations that are needed to achieve triple sustainability, and the opportunities which the new key technologies offer, are likely to involve innovation which is radical and disrupting. Managing radical and disrupting innovation is clearly a complex task for companies. Sustainability is unlikely to be achieved without strong consumer demand or as a result of regulation. Radical and disrupting innovations, therefore, require the focused attention of policy-makers to promote triple sustainability.

Innovation is often narrowly conceived as technical innovation. But in recent years in particular, organisational innovation has become an important element of regional development and of industrial competitiveness in many sectors. This is well illustrated by the case of lean production in the automobile industry or the development of powerful innovation networks in Silicon Valley. Often, the term organisational innovation is used to refer to larger organisational features of the firm, beyond the organisational features of a specific product line, and is concerned with changes in and among various functions such as R&D/product development, marketing, environmental and governmental affairs, industrial relations, worker health and safety and customer and community relations. We adopt a broader concept which also includes the specific organisational features of a specific product line. Discussions of innovation networks focus on the importance of mutual learning among the members of the production chain and have spawned a whole new area of interest in product change management.

A preoccupation with product and process innovation, to the neglect of organisational and social innovation, may undermine the potential to achieve triple sustainability. The benefits of organisational innovation seem to be underestimated and organisational changes that ignore the potential benefits of anthropocentric or human-centred production may not achieve their intended results. For example, a focus on limited organisational change as in the concept of 'lean production'. emphasises the organisation and selective automation of tasks, maximising the technological and minimising the human aspects of production, especially the extent to which problem-solving is actually a significant part of the worker's involvement [4].

It has recently been increasingly argued that organisational innovation within the firm, rather than technological innovation per se, is the area most in need of exploitation, especially in Europe.[5] During the last two decades, productivity in many industries, was driven by new organisational concepts and re-organisation rather than by the technical concepts of an automated factory which were fashionable in the 1970s and 1980s. However, many companies continue to resort to traditional technical rationalisation concepts and appear to be largely incapable of undertaking a programme of systematic re-organisation. The much more far reaching organisational innovations which are necessary to exploit the enormous potential of information technology will exceed the existing organisational capabilities of many firms. Certainly, changes in management attitudes, capabilities, and incentives are important determinants of the ability of a firm to change. The idea of networks - involving actors inside and outside of the company - is also important. The firm participates in perhaps several networks in which mutual learning occurs involving suppliers, consultants, trade associations, industries with a geographical proximity, consumers, workers, government and others.

This situation illustrates the importance of social innovation and cultural change. In this book, the definition of social innovation includes both purposive changes in the preferences of consumers, citizens, and workers for the types of products, services, environmental quality, leisure activities, and work they want – and purposive changes in the processes by which they influence those changes. Social innovation is the product of social engineering in companies or at a societal level. In contrast to that, cultural change is a spontaneous process emanating from information, education, communication, and enlightened self-interest. Social innovation and cultural change can alter both the demand for, and the supply of, what the industrial state might offer.

In this context, we treat the acquisition of employment skills as a supply-side concern, and arguably within the ambit of technological innovation, since physical capital, labour, and knowledge are currently considered the most important factors in production and service. Labour skills and know-how can have a profound impact on the innovativeness of the firm and a particular industrial sector [6]. However, whilst the so-called "knowledge-based economy" holds great promise and there are certain sectors and firms for which high returns might be expected for investment in worker education and training, the competitiveness strategies of many firms may still rely on cost-cutting, particularly the cutting of labour costs with little investment in human capital. On the other hand, a simplistic call for more worker training to upgrade skills, without corresponding changes in both technological and organisation innovation, may not be particularly helpful. Not all firms and sectors are in a position to utilise these skills. Similarly, the large, unfocused government programmes to increase the skills and qualifications of the labour force will be no more successful than are the large subsidies distributed across the board. More targeted policies may be needed.

From a macroeconomic perspective, it should be noted that changing the capabilities and skills of workers will also alter the demands they make upon the market both because it changes what workers may want and because it may augment their purchasing power. Enhancing the capabilities and skills of workers in a reasonable way is, hence, a promising midterm strategy to increase the quality of domestic demand.

It should be apparent that all three types of innovation need to receive attention in a coordinated fashion in the design of policies to promote triple sustainability. Moreover, there is an increasing belief that "new growth theory", asserting that the combination of technological, organisational and social factors, more adequately explains growth (and the Solow residual), rather than R&D, capital, or human investment alone, because greater investment in both physical and human capital may create positive externalities and aggregate economies-of-scale effects, rather than simply augment the productivity of labour. Further, it is alleged to lead to more rapid diffusion and adoption of new production methods and techniques. [7]

In 1992, the OECD was cautious about the conclusiveness of the evidence for new growth theory. By 1996, the OECD was enthusiastic about the importance and revolutionary promise of the "knowledge-based economy", arguing that, unlike capital investment, the rates of return on investment in education and training seem to increase over time and further, that industrial networks facilitate the ability of firms to share and combine elements of know-how to even greater advantage. [8] Thus, through the lens of "knowledge-based" work, the importance of 'networks' took on new significance and seemed to provide support for new growth theory. These networks promote inter-firm interactive learning and are regarded as important components of 'national innovation systems' (see the discussion below). Whether 'knowledge networks' are important across the board, or are only useful in a narrower context is an important question to be answered.

The Importance of Technology for Sustainability

Technological innovation creating "winds of creative destruction"[9] is widely accepted as the driving force of economic growth in industrialised societies, historically leading to impressive increases in the standard of living for their citizens. It is credited as the factor that moves nations from static economic efficiency to dynamic efficiency - and is necessary in order for nations to continue to change. It helps explain the transformation of societies from agrarian to early manufacturing, to chemicals and materials processing, and on to post-industrial or service economies through a variety of 'technology clusters'. Technological innovation is also alleged to explain the differing degrees of economic growth among the industrialised countries.[10]

Historically, advances in technology were often concentrated in specific sectors, for example the use of fertilizers and pesticides in agriculture, or mass production in manufacturing, and were sometimes deployed in many sectors, such as the harnessing of steam power, or the development of new materials such as plastics and ceramics. In the post-war years, there seemed no end to technological advancements, along with the jobs they created. However in the 1970s, the overall rate of growth began to slow and continued to do so in the subsequent two decades. During the 1990s, industries associated with the so-called knowledge-based economy began to grow and were responsible for an increasingly large share of employment growth. This must be viewed in proper perspective. Employment growth associated with gearing up to the "information age" is a *transitional* phenomenon. It says little about the expected level of employment at equilibrium, when things level off – if they do. Relatedly, the exuberance of the U.S. stock market performance is now being viewed more cautiously in light of the realisation that most stocks have decreased in value, with the market buoyed up by high technology, computer-related investments.

It is argued that knowledge-based, information and communication technologies (ICT) have the potential to transform virtually every aspect of production and consumption . The microchip has doubled its information-processing capacity every 18 months and other dramatic changes occur with unprecedented speed. Beyond ICT technologies *per se*, it is argued that a knowledge-based economy allows smarter production, products, and ways of working and further, facilitates new ways of integrating heretofore segregated human activities. According to this view, knowledge-driven innovation will be the next engine of economic growth.[11]

A somewhat contrary view has recently been expressed by Drucker who argues that new technologies will indeed emerge, but they will have little to do with the knowledge-based economy. He muses that e-commerce (electronic commerce), which will change the *mental* geography of commerce, will have the more profound effect by eliminating distance; there will be "only one economy and only one market." Competition will know no boundaries, but the products and sectors that are affected will be eclectic and unexpected. "New distribution channels [will] change not only how customers behave, but also what they buy." And more to the point: "The one thing…that is highly probable, if not nearly certain, is that the next twenty years will see the emergence of a number of new industries. At the same time, it is almost certain that few of them will come out of information technology, the computer, data processing, or the Internet." [12]

Drucker draws on both historical precedent for his predictions and on the observation that biotechnology and fish farming are already here. He opines that probably about a dozen technologies are now at the stage that biotechnology was 25 years ago. He reminds us that "the new industries that emerged after the railway owed little technologically to the steam engine or to the Industrial Revolution in general," and that they were the product of a mindset that eagerly welcomed invention and innovation. Finally, he observes that "software is the reorganization of traditional work, based on centuries of experience, through the application of knowledge and especially of systematic, logical analysis. The key is not electronics; it is cognitive science. This means that the key to maintaining leadership in the economy and the technologies that are about to emerge is likely to be the social position of knowledge professionals and social acceptance of their values."[13]

Like information technology, biotechnology - which, of course, is not a single technology - has the potential to transform agriculture, chemicals, pharmaceuticals, health care, environmental clean-up, energy production, and even human reproduction itself. New production methods and sources of food, chemicals, pharmaceuticals, and health care products are being developed. The repair of undesirable genetic characteristics related to disease, the slowing of the ageing process, the restoration of sight and hearing and human reproduction are already the focus of research activity. The transformation of unwanted by-products of industrial production and waste, and the creation of new sources of energy are also being developed. Although many developments in biotechnologies have not advanced to the same extent as information technology, a revolution is in the making.

In a sense, biotechnology is a typical illustration of the changing role of knowledge in the knowledge-based economy. Biotechnology as the economic utilisation of biology is not new. For example, the use of rennet, an enzyme from the gastric liquids of a calf – used in the production of cheese dates back a thousand years. In the last thirty years, biotechnology has gained a strong momentum – genetically produced medicaments already account for approximately 5 % of the world market and their share is increasing rapidly. What is changing however, is that in biotechnology, knowledge is becoming the major production factor. With biotechnology, medicaments and other substances and materials may be produced entirely artificially and with little or no use of natural resources. With the help of information technology, the production of medicaments as well as of other substances and materials may be fully customised. All this amounts to an industrial production which has little in common with industrial production in the industrial age.

While its impacts are often difficult to assess, innovation, radical innovation in particular, contains the promise of achieving triple sustainability via new materials, products and processes. Innovation is the key to those radical changes which are needed in order to develop a sustainable economy but this is far from a simple 'technological fix'.

Along with increases in the standards of living in developed countries, the unprecedented use of natural resources and energy, the transformation of raw materials into products and new agricultural, manufacturing and production technologies are now known to both increasingly deplete the stock of resources and energy sources and degrade the environment to the point that current industrial, agricultural, and transport systems are becoming unsustainable. The traditional ways of addressing environmental problems in terms of pollution control or so-called end-of-pipe approaches, *after* technological systems are designed and implemented, are no longer seen as adequate. Similarly, small advances in the efficiency of energy and resource use can no longer compensate for increased world demand and consumption of resource and energy-intensive technology. This was discussed in chapter 3. We also argued there, that radical and significant new approaches require that inputs and materials, final products, and processes be changed, but even more is needed. A shift to product-services with net significant dematerialisation is also necessary, for example, through the leasing of carpets, washing machines, or automobiles with guaranteed maintenance or remanufacturing. Beyond product-services, entire systems may need to be changed, for example the substitution of transportation systems for individually operated automobiles or changing agricultural methods and distribution systems.

The knowledge-based economy and the key technologies which drive its development offer the potential for radical dematerialization and a radical improvement of the relationship between material input and service output – the MIPS-relation which we described in 34. Information technology and biotechnology not only allow for a significant reduction in material inputs, but also the substitution of natural resources either by artificial resources (biotechnology) or by virtual reality (information technology). Moreover, they constitute the basis from which to construct and efficiently manage in reality and in virtuality systems of production and distribution which so far have not been possible. These would include integrated and highly customised systems of private-public transportation which combine high mobility of people and goods with low material input, or systems of cascade utilisation and subsequent re-cycling of materials which may increase the service output of a given material input dramatically.

Yet, it would be more than naive to neglect the fact that the same technologies also bring new and unprecedented dangers for nature. Information technology is currently associated with very high rucksacks and often adds as much if not more to material input than its application may help to save. Much more dramatic is the impact of biotechnology - whilst it helps the substitution of natural resources by artificial ones, it also allows for a level of human intervention in nature far in excess of anything previously possible. This intervention may not be associated with an excessive use of nature, but may dramatically alter the process of evolution – it creates the opportunity to change rapidly and in the short-term, relationships between people and nature which have evolved gradually over a long period. The impacts of such intervention are even less calculable than the impacts of the exploitation of natural resources. The MIPS-principle therefore, also needs to be applied here - economic utility should be produced with the minimum intervention into evolution as possible. The authors of this report do not feel competent to say what this could and should mean practically. This has to be discussed by and with biologists.

A cleaner and less resource intensive environment is only one of the constituents of a sustainable society. Secure and meaningful employment that provides workers with adequate purchasing power is (as explained in chapter 4) an essential ingredient of a sustainable and socially cohesive economy. A growing economic system, one that increasingly satisfies human aspirations (i.e., increases wealth), needs an adequate supply and quality of human capital. ICT and biotechnology are two technological newcomers that both challenge our conventional views of labour, production, and products and provide unanticipated opportunities for change. Whether the development of these technologies will result in changes in the right direction remains to be seen.

The assertion that possible decreases in employment and/or wages brought about by labour-saving, productivity-enhancing technological change would be adequately compensated by lower prices, subsequent increased demand, and increased production volume is seriously being called into question.[14] Incremental, labour-saving innovation which dominates the majority of changes occurring in mature industrial economies is said to lie at the root of creeping unemployment and underemployment involving the deskilling of at least some labour. Whilst new challenging and rewarding skilled work is being created in some firms or sectors, employment is being destroyed in others. It cannot be said that the winners can compensate the losers in either the nature or the amount of employment.

Relevant research shows that enterprises which engage in product innovation, usually outperform those that are not innovative in terms of creating new jobs. On a sectoral level too, relevant research indicates better performance in terms of employment for innovative enterprises.[15] This does not imply however, that on a macro-economic level, product innovation always leads to more employment. The reason is that there are indirect employment effects which may counteract the increasing employment in innovating firms. An innovation which may increase employment in one firm may create a considerable competitive disadvantage for that firm's competitors who may lose more jobs than those created by the innovating firm.

With respect to process innovation, the case is similarly ambivalent. Process innovations initially serve to increase productivity in the innovating firms which creates potential job losses. However, productivity gains may increase the competitiveness of the innovating firm so that it can increase its turnover and this may more than compensate potential job losses from increasing productivity. At the macro-level, there are again indirect effects. The productivity gains of an innovating firm and the resulting competitive advantage may result in job losses in competing firms who find themselves at a corresponding competitive disadvantage. On the other hand, job losses in firms and whole sectors which increase their productivity by process innovation may be compensated or exceeded by job gains in those companies producing the technology and consulting services required for process innovations.

As far as employment is concerned, significant opportunities for net employment gains can only be anticipated with respect to radical innovation. The development of new markets is associated with new employment opportunities and there are no necessary trade-offs of employment between the new and the established markets. In this context it should be noted however, that empirical evidence offers a warning. As figure 6.1.illustrates, high-technology sectors enjoyed a much better employment performance over a long period, but recently employment in these sectors has developed along lines similar to that in the medium and low-technology sectors.

Fig. 6.1.: Employment in high-technology and low-technology sectors in OECD countries

In this context, it is important to note an argument of Richard Gordon concerning the impact of technological innovation (information technology in particular) on the quality of employment. Gordon argued that both deskilling and reskilling can occur with similar technologies, task structures and occupations, and that far from determining a unique outcome, information technologies simply expand the work organisation options.[16]

The nature and rewards of work, both monetary and non-monetary, are undergoing structural change and revolution. But these changes are being brought about by new production, transportation, energy, and agricultural technologies that are undergoing innovation *without concern or planning for their impact on the nature and level of employment*. Whilst compensatory policies, related to education, retraining, and the re-organisation of work exist or are being planned, they are *reactive* to technological changes. Here we need to take a lesson from the environmental problems created by rapid and extensive technological change. It is not sufficient to consider the effects on the environment as an *afterthought*. Environmental quality needs to be *built in*. Similarly, it is suggested that thinking about work *after* technologies are designed and implemented may be far too late to address their possible adverse consequences effectively or to realise the full potential of the technology.

We argue that production, consumption, environment, and employment ought to be *co-optimized* and considered simultaneously. This means technological, organisational, and social innovations need to be *proactive and anticipatory*, rather than reactive. A knowledge-based economy potentially allows for more flexibility and new definitions of work, leisure, production, and consumption. The context established for innovations in all dimensions needs to reflect the realisation that the real wealth of people lies in economic, environmental, and social sustainability.

Innovation in the 21st century: A new model of change

With the transformation from the industrial age and its throughput economy to the information age and the knowledge-based economy, the nature of innovation is changing fundamentally. In the industrial age, there were significant changes in the nature of innovation, but what we can expect now may go far beyond these changes. Much of what we have learnt about innovation even in recent years may have to be revised in the near future.

As industrial societies mature, the pattern of innovation changes. New technologies become old technologies. Many product lines (e.g., washing machines or lead batteries) become increasingly rigid, and innovation, if there is any, becomes more difficult and incremental rather than radical. In these product lines/sectors, changes are focused on cost-reducing production methods - including increasing the scale of production and displacing labour with technology - rather than on significant changes in products. Gradually, process innovation also declines. Sometimes, the dominant technologies (such as the vacuum tube and mechanical calculator) are challenged and rather abruptly displaced by significant radical innovations (such as the transistor and electronic calculator), but this is relatively rare. As industrial economies mature, innovation in many sectors may become more and more difficult and incremental. Regulatory and government policies are increasingly influenced, if not captured, by the purveyors of the dominant technology [regime] which becomes more resistant to change. However, occasionally, traditional sectors can revitalise themselves, as in the case of cotton textiles. Other sectors, notably those based on emerging technologies, may experience increased innovation. The overall economic health and employment potential of a nation as a whole is the sum of these diverging trends, and is increasingly a function of international trade.

In the industrial age, innovation could be described as a linear process. Knowledge was created by scientific research far from its application, later it was transformed into technology which, after a time lag, resulted in new products. In the market, new products first sold in fairly small quantities. After a further time lag volumes increased rapidly and additional competitors entered the market with the same or a similar product. In this phase of sustained growth, the product was continuously improved in order to gain a competitive edge. Finally, the product matured and was mass-produced in a competitive environment. In this final stage, price replaced innovation as the momentum of competitiveness. After some time, the product was replaced by a new one that developed in the same way. Scholars have described this linear process as a series of 's-curves'.

Fig. 6.2. The linear model of innovation

This linear process of innovation has accelerated in recent decades. For example, as previously mentioned, the capacity of computer chips has doubled approximately every 18 months. This means not only that the speed of computers increases, but that new types of applications and higher performances are enabled. As a result, the speed with which computers have to be replaced in order to keep pace with the development of information technology applications has increased accordingly. With increasing speed, the economic risks of innovation for firms have also increased. Firms run the risk that new products which they bring to the market will be replaced by new ones before their own product has matured and reaped the rewards of investment. In order to reduce this risk, the more innovative companies try to bring new products to the market as early as possible. They apply new knowledge and technology to new products long before the knowledge and the resulting technology have been tested. Knowledge and technology frequently develop in response to their early application in the market in the form of new products/services. Response from the market feeds back into R&D where knowledge and technology is again further developed. The different stages of the innovation process in the linear model increasingly coincide and interact with each other. What began some decades ago as an acceleration of the linear model, is now in effect the end of this model – the linear model has been replaced by an interactive one.

This change has been strongly reinforced by globalisation. Gordon, building on the optimism of Castells, argued that globalisation enhanced by ICT "provides a basis for new forms of world-wide interaction and control and liberates organizational structure from spatial constraints." His view of modern innovation was that it "tends to be neither radical exogenous invention (as in the linear model) nor narrowly path-dependent incremental change (as in the evolutionary model). Far more frequently, innovation tends to occur in the un-illuminated space between these options: that is, while proceeding substantially within existing frameworks of knowledge and practice rather than initiating or requiring breakthroughs in science and technology, innovation nonetheless commonly tends to push at the margins of established organizational, technical, and economic practice as opposed to cooperating within a more restricted field of "normal problem-solving routines." [17]

Innovation in the industrial age could be well described not only by a linear model, but also by the concept of 'technological regimes', which are defined by certain boundaries for technological progress and by directions or trajectories in which progress is possible and worth undertaking. The concept is applicable for two reasons. Firstly, in the industrial age technological development was fairly predictable - at least with regard to major directions and principle time horizons. There was a reasonable knowledge of technological progress and there was an understanding of what level of progress could be expected within a given time. Secondly, the innovation process was strongly determined by technological development. Even organisational innovations were often induced more by technological development than by social developments. Although markets and demand were also important, innovation was primarily pushed by technology. Companies and policy-makers could reasonably act on the assumption that useful technology would "find" a market at some point. As a result, both business leaders and policy-makers have been primarily concerned with technology to drive innovation.

In the knowledge-based economy, this is fundamentally different for one simple, but far-reaching reason: in the knowledge-based economy, knowledge is the key factor of production, but it is not scarce. In the industrial age, a huge machinery for the production of knowledge was established. The machinery consists of various private and public research facilities and laboratories, industrial R&D departments, think-tanks, colleges and universities, and with the development of information technology, these institutions and organisations are linked in a global network. To illustrate the size of this machinery, it is interesting to note that well in excess of 50% of scientists who have ever worked in the long history of humankind are working today. .For some time now, knowledge (measured by the number of publications) has doubled every seven to ten years. With the use of computers, complex experiments which previously required years to undertake can nowadays be completed in a matter of weeks. With the internet, all of this knowledge can be used, combined and further developed at most points of the world. This machinery produces much more economically useful knowledge than is actually used. Many companies, for example, hold patents which they do not use because entry costs into the market are too high or because the investment opportunities resulting from these patents knowledge exceeds their financial means. Even more importantly, the machinery also produces knowledge simultaneously in a large variety of different directions. It no longer produces a few technologies developing in rather clear trajectories, but a large variety of different developments which can be combined in a variety of different ways in complex bundles of technology. Rather than a few clearly demarcated technological trajectories, there is an almost unlimited space of technological development.

Modern information technology, for example, is no longer a single technology - semiconductors - but a fusion of a variety of different technologies including : new materials, opto-electronics, neuro-informatics, nanotechnology and biotechnology. In various combinations, these technologies have already changed information processing significantly, and will do so even more in the near future. In the not too distant future, quantum physics may join this range of technologies and create yet another revolution in information technology. In order to cope with these developments and to take advantage of the opportunities which they offer, companies have to invest heavily in different developments, but cannot adequately assess which of the many developments may be economically successful.

Genetic technology and information technology, to take two further examples, are about to create a new pharmacology. They enable medicaments to be customised, that is designed to treat an individual customer's specific illness and physical and mental condition. Robotics speed up the necessary R&D process dramatically and advanced production technology enables a profitable 'mass customization' in the pharmaceutical industry. Within a short space of time, a new pharmacology may emerge which provides new opportunities; however, it may also involve high levels of investment and risk.

Technological development which involves a variety of different technologies in different combinations clearly contains little guidance for industry. It is associated with extremely high levels of uncertainty with regard to two important questions: which of the many possible technological developments will be developed earlier, faster and more successfully than others? and, which of the many alternative combinations of these technologies will be implemented and brought to economic success? These are the questions which innovating companies as well as policy-makers have to ask when they want to invest in or advance certain technological developments.

The answers to these questions can no longer be found by understanding technological trajectories. Rather, they will eventually emerge from a variety of decisions made by a variety of actors in a barely coordinated setting. Relevant actors include laboratories or R&D departments which invest in some technologies rather than others, companies which exploit one rather than another of their many patents, or politicians creating conditions which facilitate one rather than another development. To summarise : technological developments no longer follow their own inherent logic and are no longer embedded in distinct trajectories, but are determined in complex social situations which are virtually unpredictable. Moreover, technological developments are increasingly dependent upon social innovation.

A crucial implication of this situation is that innovation is no longer technology-driven in the sense of guidance. This does not mean that technology is losing its importance, but only that technological developments no longer determine the direction of innovation. In order to gain reasonable guidance for the innovation process, both innovating companies and public policymakers have to place much more emphasis on market development. Market pull will have to replace technology push in the steering of innovation. This not only helps to speed up the commercialisation of new technologies and avoid investment in technological developments which in the end are not successful in the market, but also advances the acceptance of new technology. Moreover, it advances the inclusion of human aspirations in the market, and the development of a much more service-oriented economy in terms of the MIPS-concept explained in 3.

In order to increase the chances of successful innovation companies need to develop markets and technology simultaneously. This is not really a new development. In the aircraft industry this already has a long tradition – new aircraft are developed in close relation with lead clients. In Japan, megatronics, the famous fusion of electronics and mechanical engineering, was also developed simultaneously from both the technological and the market end and it became a great success. In Germany, the environmental industry was economically very successful in the 1970s and 1980s again because regulation called for new technological solutions and created a market for these new solutions. There are certainly more examples of this case which was the exception in the past but is likely to become the rule in the near future.

In this context, it should be noted that this is not a plea to switch from a one-sided technology-push mode of innovation to an equally one-sided market-pull mode. The technology-driven mode of innovation certainly has considerable economic disadvantages. Over-engineering imposes considerable costs on companies and progressive strategies of technology development often turn out to be economic failures. On the other hand, a one-sided market-pull mode of innovation may have as many economic disadvantages since it may serve to hinder long-term profitable innovation strategies on the grounds of short-term market considerations. It also hinders the economic exploitation of the inherent dynamics of science.

For policy makers, market development is becoming even more important – as technology development no longer provides the key to the innovation process. Market development, together with regulation is becoming the major tool to boost innovation in desired directions and to advance employment and competitiveness. It is also a major tool with which to reduce the risks of an increasingly radical innovation process.

The huge production of knowledge and the rapid pace at which new technological developments are pushed creates the potential for the development of new products and new markets. In the knowledge economy, innovation is likely to become more radical. This does not mean, of course, that most innovation will be of the radical type. Nevertheless, in the industrial age, radical innovation was not a regular feature of innovation whereas in the knowledge economy it is. The majority of companies in a given economy may still confine themselves to an incremental pattern of innovation, but the leading-edge companies as well as many newcomers will engage in radical innovation.

The argument presented in this section can be summarised as follows : in the information age and its knowledge-based economy, innovation tends to be much less bounded by technological trajectories, much more open, more rapid and more radical than in the industrial age and its throughput economy. This increases opportunities as well as risks and creates a strong dependence of the whole innovation process (and its economic, social and environmental impacts) upon social innovation.

Information technology and biotechnology: An ungovernable world?

With good reason, the period following the industrial age is called the information age but information technology is not the only key technology of this age – and probably not even the one that changes the world more than others. Biotechnology will probably be responsible for more changes in the economy, society and nature than information technology - as noted above.

As is well known, chemicals and pharmaceuticals hitherto have been typical industries of the industrial age. They are characterised by a highly developed form of mass or process production which has been organised on a global scale for many years. They are resource intensive industries which have also been major polluters resulting in risks to health and other environmental damage. Modern biotechnology is about to reverse this situation. Chemicals and pharmaceuticals will become highly customised and at the same time almost dematerialised. Using extremely low material inputs, they will produce high service outputs. They are likely to develop new organisational structures of the type which William Davidow and Michael Malone describe in their book "The Virtual Corporation".[18] Davidow and Malone argue that in contrast to many companies involved in mass production, the structures of innovative companies with high customisation are based on teams which are flexibly integrated into task-oriented production networks. This flexible integration works well because it is based on a powerful information and communications system and on workers who have interpersonal as well as technical skills. This development is likely to be associated with fundamental changes in work organisation, not only inside companies but also in their external networks. In the case of customised medicaments, for example, the virtual factory will include doctors (or medical centres) where diagnoses are made and the relevant genetic and other data are collected in order to produce the medicament.

The case of the chemical and pharmaceutical industries illustrates the far-reaching changes which we may expect from information technology and biotechnology. It suggests that within a few years from now, we may expect much more dramatic changes than we have experienced in recent years. So far, most companies and even sectors have only been marginally affected by the progress of information technology, biotechnology and other technologies (and the knowledge of organisation and networking). What already appears to be a massive change is just the beginning of a much greater change. It is difficult if not impossible to assess what these changes will bring for companies and their workers. It is even more difficult, if not impossible, to assess the implications and impacts at the macro level –on social structure and the environment in particular.

Jürgen Mittelstraß, a German philosopher, calls the modern world a "Leonardo World".[19] He names it after Leonardo da Vinci a researcher, inventor and artist who represents the spirit of innovation and creation. The concept is relevant as it underlines the fact that innovation and technical progress do not simply happen, they can be shaped by people, organisations and government. The 'Leonardo-world' is a world that depends heavily upon the ability of people to participate in the development and shaping of change. It depends heavily therefore, on the ability of people, companies and governments to integrate organization, technology and culture in work and social life in a way that makes sense to people. If this integration works, even rapid change may be shaped in a reasonable manner through social choices.

The Leonardo world which we enter at the beginning of the 21st century is an extreme Leonardo world. The opportunity to intervene and shape social development and nature are much greater than ever before. Information technology has the potential to completely change the social sphere, and biotechnology has an even greater potential to change nature and evolution. Information technology is likely to create a new stratification in advanced and developing countries where those who have access to information technology and are able to use it may accumulate wealth whereas the have-nots concerning information technology will be excluded from wealth with little opportunity to change the situation. The internet creates not only a platform for business and cultural exchange, but also facilitates a global criminal network and enables the free communication of racism. These are just a few of the "black holes of informational capitalism" as Castells calls it.[20] Biotechnology is about to gain the ability to intervene deeply and extensively in evolution. Human intervention may bring about changes within a few years which would have taken hundreds of years to occur naturally. The direction of evolution may be changed in unforseen ways.

The potential to effect a widespread and rapid process of change gives rise to a new world of risk and uncertainty because social and environmental disasters may occur which are only preceded by weak signals and for which there is little lead time to respond. Time to prepare for and to cope with disasters is compressed. The established repertoire of strategies and activities to cope with risk and uncertainty are likely to be inadequate in dealing with this situation. Even worse: they may exacerbate existing risks in an uncertain world. New strategies and adequate responses to undesirable developments and disasters may have to be decided and implemented quickly. This places a heavy burden on the ability of people and institutions to understand and shape innovation and change.

This illustrates the most fundamental problem of innovation at the beginning of the 21st century. In recent decades, institutions, rules and norms, even in the advanced economies, have failed to keep pace with rapid technical, social and economic change. As discussed in the second chapter of this book, this was and is the major reason for the important economic, social and environmental problems which we have carried from the industrial into the information age and with which we may burden future generations. As the speed and scope of innovation and change is now increasing dramatically, these institutions, rules and norms will fail even more and create new or aggravated problems - unless we are capable of changing institutions, rules and norms in a great project of social innovation. This will be further discussed in the final chapter of this book.

The need to change institutions, rules and norms in order to cope more adequately with the high speed and scope of the innovation process at the beginning of the 21st century draws our attention to innovation systems. Nelson and Rosenberg define (national) innovation systems as the institutions whose interactions determine the innovative performance of firms in a national economy. [21] In this book, we use a broader concept and define an innovation system as the institutions, infrastructures, organisational structures, rules and norms on which the innovative performance of firms and whole economies depend. This also includes those less tangible factors which comprise what Camagni calls an “innovative milieu”.[22]

Innovation systems are not only important for the performance of firms and whole economies, but also for the capacity of society to shape innovation and change. This is particularly true with respect to the rapid and far-reaching innovation and change associated with information technology and biotechnology and the high uncertainty and risks that this process involves. With formal institutions and rules, this rapid process cannot be adequately guided because the rules and institutions cannot be adjusted to change at the speed which is required. Formal rules and institutions need to be complemented or replaced by more informal mechanisms of cultural acceptance and legitimacy. For governments whose abilities to guide markets via rules and institutions are increasingly in a global and information economy, innovation systems may constitute a good entry point to influence economic development in the public interest.

Governing innovation: Alternatives for sustainable development

In an age of information and globalisation, governments face a complex challenge to shape innovation in the direction of sustainability. As innovation is no longer driven or guided by technology, the kind of technology policy previously adopted by most OECD countries becomes redundant. The attempt to target the “right” technology and provide subsidies for development has not proven to be an effective way to spend public money. Frequently, companies used grants to invest in innovation in which they would have invested anyway. Worse, some companies were encouraged by subsidies to engage in innovation which they could not have justified on purely economic grounds. Therefore, subsidies even served to misdirect companies. Now, with a new model of innovation the strategy rarely makes any sense at all because it is only by chance that governments manage to target the “right” technological development and they run the risk of grossly misdirecting the economy, at the expense of competitiveness and employment.

However, the conclusion from this line of reasoning does not support a laissez-faire doctrine of technological development. Technological change continues to bring about adverse effects on the environment in terms of resource depletion, energy use, and pollution and adverse effects on employment in terms of unemployment, skill content, rewards, and dislocation. Consequently, it is beyond question (in our view) that the process of technical (and organisational) innovation needs to be guided by the public interest. The question is, how this guidance can be implemented politically in a way that reflects the appropriate role of government – which is not “laissez-faire”, but an approach which incorporates social choices and the public interest in the definition of the institutional framework of the market and the development of new markets.

The ideology of laissez faire suggests that government regulation is mostly unhelpful or inefficient, but there is increasingly persuasive evidence that regulation – properly designed – is not only necessary to achieve sustainable economies – but that it can actually stimulate innovation leading to improved competitiveness, employment and to an improved environment.

Early MIT research stimulated more focused research into the effects of government regulation in the United States. It was found in a number of MIT studies beginning in 1979 that regulation could stimulate significant fundamental changes in product and process technology which benefited the industrial innovator, as well as improving health, safety and the environment, provided the regulations were stringent, focused, and properly structured.[23] This empirical work was conducted fifteen years earlier than the emergence of the so-called Porter Hypothesis which argued that firms at the cutting edge of developing and implementing technology to reduce pollution would benefit economically by being first-movers to comply with regulation.[24]

One could describe the Porter Hypothesis as having both a weak and a strong form. Porter himself actually discusses only the weak form. The weak form is essentially that regulation, properly designed, can cause the [regulated] firm to undertake innovations that not only reduce pollution -- which is a hallmark of production inefficiency -- but also save on materials, water, and energy costs, conferring what Porter calls 'innovation offsets' to the innovating firm. This can occur because the firm, at any point in time, is sub-optimal. If the firm is the first to move by complying in an intelligent way, other firms will later have to rush to comply and do so in a less thoughtful and more expensive way. Thus, there are "learning curve" advantages to being first and early. Porter argues that in the international context, first-mover firms benefit by being subjected to a national regulatory system slightly ahead of that found in other countries. The strong form of the Porter Hypothesis was not put forth by Porter at all and would have to be that stringent regulation could cause dramatic changes in technology, often by new firms or entrants *displacing* the dominant technologies. The replacement of dominant technologies by new entrants, rather than incremental change by existing technology providers, has been the source of the most important radical innovations this century.

MIT research found paradoxically that the only government policy that affected innovation was in fact health, safety and environmental regulation, not strategies devised by government as a part of its industrial policy. Moreover, the effects of regulation on innovation turned out to be positive, not negative as expected by the conventional wisdom at that time. Stringent regulation could stimulate *entirely new products and processes* into the market by new entrants with the displacement of dominant technologies rather than the transformation of technologies by existing firms. One of several vivid examples is the displacement of Monsanto's PCBs in transformers and capacitors by an entirely different dielectric material pioneered by Dow Silicone. Regulation can thus encourage disrupting innovations by giving more influence to new 'value networks' in which demands for improvements in both environmental quality and social cohesion are more sharply defined and articulated. Of course, industries that would fear disrupting new entrants would not be expected to welcome this regulation. This explains in part their resistance to regulation and their propensity to try to capture regulatory regimes, surreptitiously or through direct negotiation.[25]

In principle, regulation is an effective and proper instrument for government to guide the innovation process. Well designed, it is likely to be more effective than financial subsidies which in view of the changes of the innovation process described in this chapter cannot be applied as a tool to guide the innovation process. In contrast, regulation which sets new rules changes the institutional framework of the market and may be an important element in creating favourable conditions for innovation which could enhance triple sustainability. A new framework could also help to develop powerful lead-markets which pull innovation towards triple sustainability.

In industrial economies, the firm is the most important locus of technological innovation, although, as mentioned above, the formation of innovation networks involving suppliers, consumers, workers, trade associations, others firms, and government more accurately captures the dynamics of the innovation process. In addition, government itself has also had a major role to play as a direct source of basic research and innovation; for example, the cases of the early development of computers, air transport, and cancer therapies. As discussed earlier, a better description of the innovation process might be an iterative process where new knowledge and applications create reciprocal feedback which gives rise to new synergies and further development.

In order for innovation to occur, the firm (or government itself) must have the willingness, opportunity, and capability or capacity to innovate.[26] These three factors affect each other, of course, but each is determined by more fundamental factors. Willingness is determined by both : (1) attitudes towards changes in production in general and by (2) knowledge about what changes are possible. Improving the latter involves aspects of capacity building, while changing the former may be more idiosyncratic to a particular manager or alternatively a function of organizational structures and reward systems. In the context of disrupting innovation by firms representing the dominant technology, willingness is also shaped by the [rare] commitment of management to nurture new approaches that are at odds with its traditional value network.

Opportunity involves both supply-side and demand-side factors. On the supply side, technological gaps can exist (1) between the technology used in a particular firm and the already-available technology that could be adopted or adapted (known as diffusion or incremental innovation, respectively), and (2) the technology used in a particular firm and technology that could be developed (i.e., major or radical innovation). On the demand side, four factors could push firms towards technological change -- whether diffusion, incremental innovation, or major innovation -- (1) regulatory requirements, (2) possible cost savings or expansion of profits, (3) public demand for more environmentally-sound, eco-efficient, and safer industry, and (4) worker demands and pressures arising from industrial relations concerns. The latter two factors could bring about changes in the value networks, and could stimulate change too late in the dominant technology firms, if new entrants have already seized the opportunity to engage in developing disrupting innovations.

Capacity or capability can be enhanced by : (1) increases in knowledge or information about more sustainable opportunities, partly through deliberately undertaken Technology Options/Opportunity Analyses, and partly through deliberate or serendipitous transfer of knowledge from suppliers, customers, trade associations, unions, workers, and other firms, as well as from available literature; (2) improving the skill base of the firm through educating and training its operators, workers, and managers, on both a formal and informal basis; and (3) by deliberate creation of networks and strategic alliances not necessarily confined to a geographical area or nation or technological regime. Capacity to change may also be influenced by the inherent innovativeness (or lack thereof) of the firm as determined by the maturity and technological rigidity of a particular product or production lines.

The different dimensions or factors of willingness, opportunity, and capability offer a variety of different starting points for government policies for stimulating technological and organisational innovation. This represents an opportunity as well as a problem. The opportunity is that government does not depend on a few specific instruments, but may have command of a whole variety of instruments. These include removing regulatory barriers to innovation, stimulating innovation by getting the prices for natural resources right, using government regulation to stimulate innovation, procurement and investment to develop *new* markets, advancing knowledge-transfer from universities to small and medium enterprises, implementing pro-active programmes for the education and training of labour for a knowledge-based economy, and encouraging management and labour to bargain before technological changes are planned and implemented, and last but not least, cultural activities to enhance openness and willingness to engage in change.[27]

The problem is that these instruments must be integrated in a systematic approach or they will create various contradictory and conflicting effects – as is often the case with uncoordinated public policy. The co-ordination of a variety of different policy instruments is often a complex task which exceeds governments' capacities. The real challenge, thus, is to find effective approaches and methods to coordinate a complex variety of instruments with complex impacts in a systematic way. We will further discuss this problem and its solution in chapter 9.

The argument in this chapter is that more than technological and organisational innovations are needed. The really great opportunities and enormous risks of the key technologies at the beginning of the 21st century cannot be managed successfully with institutional structures and strategies rooted in the industrial age or even earlier which fail to make use of the technical and organisational potentials of the knowledge-based economy. Social innovation is needed with respect to education and the provision of information and most importantly, to participation in both private-sector decisions and markets, and in governmental decisions. Two examples may illustrate our case.

Whilst the application and performance of computers is increasing at a rapid pace, schools even in the rich societies still use computers only marginally. Education even in many of the rich societies does not take account of the fact that the ability to cope with modern information technology in a very practical way has become a skill almost as fundamental as reading and writing. Neither does it take account of the fact that with the help of information technology teaching and learning processes can be radically changed towards a much more individual or "customised" pattern which helps pupils to develop their individual talents, skills and qualifications more effectively than the current system of education, which in many ways represents a form of industrial mass production.[28] The lack of social innovation in education creates a notorious deficit concerning the availability of skilled workers, technicians and researchers which hinders innovation in industry. Even worse, it impedes the equal access of children and young people to information technology which constitutes a significant threat to social cohesion in the information age.

As discussed here and illustrated in the relevant literature, radical innovation cannot take place in companies if they continue to be managed in the traditional hierarchical top-down way. This style of management has proved to be obsolete even in much less innovative companies. Management and labour have an intricate relationship involving an explicit or implied employment contract, job health and safety, other worker safeguards and frequent, if not daily contact. Their relationship is influenced by both a complex web of laws and by industrial custom. [29] In practice, management usually holds quite tenaciously to its prerogatives to make unilateral decisions concerning changes in the technology or technical trajectory of the firm. Labour and industrial relations laws protect this management prerogative to various degrees, depending on the country. In a knowledge-based economy with rapid and radical innovation, however, the hierarchy often fails and has to be replaced by decentralised structures. Formal instruments of guidance and control often do not operate adequately and guidance and control has to operate through informal and cultural means. Social innovation involving legal, institutional and cultural change is overdue.

Probably the most far-reaching social innovation is needed in order to develop forms of governance that are sensitive and accountable to people's values and preferences concerning the exploitation and control of information technology and biotechnology. Current systems of social choice, particularly current systems of political decision-making and international organisation are likely to fall far short of what is required. This will be further discussed in chapters 9 and 10.

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[1] For an extensive discussion of the dynamics of the innovation process, see "Chapter 1: Technological Innovation: Some Definitions and Building Blocks" in OECD, Technology and Economy: The Key Relationship. Paris: Organisation for Economic Cooperation and Development, 1992, pp. 24-29. Also see Mowery, David C. and Rosenberg, Nathan, Technology and the Pursuit of Economic Growth Cambridge: Cambridge University Press, 1989.

[2] The distinction of incremental and radical innovation is well discussed in Martin Baethge and Volker Baethge-Kinsky, Der implizite Innovationsmodus: Zum Zusammenhang von betrieblicher Arbeitsorganisation, human resources development und Innovation, in F. Lehner, M. Baethge, J. Kühl, F. Stille (Hg.) *Beschäftigung durch Innovation.* München-Mering: Hampp, 1998.

[3] The concepts of a value network, and of sustaining and disrupting innovation are described in Christensen, Clayton, The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail, Harvard Business School Press, 1997

[4] See Charles, Tony and Lehner, Franz, "Competitiveness and Employment: A Strategic Dilemma for Economic Policy", Competitiveness and Change 1998, 3:207-236, for a discussion of lean production and why it imposes considerable limitations on a company's propensity to innovate.

[5] Cf. Coriat, Benjamin"Organisational Innovations: The Missing Link in European Competitiveness." Europe's Next Step: Organisational Innovation, Competition and Employment, Lars Erik Andreasen, et al. (eds.) London: Frank Cass & Co., 1995, pp 3-32.

[6] See "Chapter 7: Human Resources and New Technologies in the Production System" in OECD, Technology and Economy: The Key Relationship. Paris: Organisation for Economic Cooperation and Development, 1992, pp. 149-166. See also OECD, The Knowledge-based Economy, Organisation for Economic Cooperation and Development, Paris, 1996.

[7] See the discussion of new growth theory in "Chapter 8: Technology and Economic Growth" in OECD 1992, pp. 167-174. – Also see (among others) Grossman, G. M. and Helpman, E. (1994) "Endogenous Innovation in the Theory of Growth" *Journal of Economic Perspectives* 8(1); Romer, P. (1994) "The Origins of Endogenous Growth" *Journal of Economic Perspectives* Volume 8.

[8] See OECD, 1992, chapter 8, and OECD, 1996 as cited above.

[9] Schumpeter, Joseph A., Business Cycles: A Theoretical, Historical and Statistical Analysis of the Capitalist Process New York, McGraw-Hill,1939 as discussed in Niehans, Jurg. Joseph Schumpeter. A History of Economic Theory: Classic Contributions 1720-1980. Baltimore: Johns Hopkins University Press, 1990, page 448.

[10] Cf. Grubler, Arnulf, "Industrialization as a Historical Phenomenon" in Industrial Ecology and Global Change R Socolow, et al. (eds.) Cambridge, UK: Cambridge University Press, 1994; and

OECD 1992, Chapter 8.

[11] See Castells, M.: The Rise of the Network Society. The Information Age: Economy, Society and Culture, Volume 1. Malden-Oxford, Blackwell, ; OECD 1996.

[12] See Drucker, Peter, "Beyond the Information Revolution," *The Atlantic Monthly* October 1999, pp. 47-57; quotation from page 54.

[13] Drucker, 1999, page 57. - Drucker is not focused on innovation in ICT, but rather those innovations necessary for other new technologies to emerge. Since, according to his thesis, it is not generally known what these technologies will be, it is a reminder that investment in deliberate, applied areas for development could short-change the future.

[14] Cf. European Commission, Growth, Competitiveness, and Employment: The challenges and ways forward into the 21st century. Brussels: European Commission, 1994.Freeman, C. and Soete, L., Work for All of Mass Unemployment? Pinter: London, 1994; OECD (1998) Technology, Productivity, and Jobs Creation: Best Policy Practices, OECD (92 98 05 1P) ISBN 92-64-16096-5, Organisation for Economic Cooperation and Development, Paris.

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[26] See Ashford, N. A., "An Innovation-Based Strategy for the Environment," in Worst Things First? The Debate Over Risk-based National Environmental Priorities, A. M. Finical and D. Golfing (eds.), Resources for the Future, Washington, DC, 1994, pp. 275-314.

[27] Ashford, N. A., "An Innovation-Based Strategy for the Environment," in Worst Things First? The Debate Over Risk-based National Environmental Priorities, A. M. Finical and D. Golfing (eds.), Resources for the Future, Washington, DC, 1994, pp. 275-314. Ashford, N. A. "An Innovation-Based

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[29] Cf. Ashford and Caldart 1996 as cited above.