CHAPTER 5

TECHNOLOGICAL INNOVATION, THE ENVIRONMENT AND ECONOMIC GROWTH

5.1 INTRODUCTION

Although the notion of obtaining a double dividend seems appealing and could hold significant positive consequences for the South African economy, it is widely recognised that energy efficient innovations not only reduce emissions of greenhouse gases, but also reduce production costs (Blackman, 1999, p1). Therefore, one cannot ignore the need for technological innovation, nor the opportunities that it offers to the country. The need for technological innovation in energy generation in South Africa is apparent from the fact that the South African economy relies almost solely on the use of coal to satisfy its energy needs. The results of the short-run simulations (which will be discussed in later chapters) also indicates that, although some positive welfare effects can be obtained from the use of environmental tax revenue, technological innovation is a necessary condition if South Africa wants to address the pollution problems that arises from the use of coal in the production process.

Apart from the consequences for the environment, technological innovation could also support higher economic growth rates. The aim of this chapter is to provide insight into current economic thought about technological change. This overview is important because it provides the motivation behind the use of tax revenue to fund research and development to reduce South Africa's dependence on coal for energy provision.

Section 5.2 looks at a description of technological change and thoughts about the role it plays in economic growth and sustainable development. Section 5.3 briefly describes the theories about the factors that drive technological change, while section 5.4 describes the opportunities that these theories provide to induce technological change. Section 5.5 discusses the current research and development (R&D) activities of the three South African industries that rely the most on coal in their production processes.

5.2 TECHNOLOGICAL INNOVATION AND SUSTAINABLE ECONOMIC GROWTH

The roots of modern theories of the process of technological change can largely be traced to the ideas of Josef Schumpeter (1942). Schumpeter distinguished between three steps in the process of technological innovation. The first step is invention. Invention constitutes the development of a scientifically/technically new product or process. The second step is innovation. Innovation encompasses the process of commercialising a new product or process. The invention and innovation stages are usually carried out in private firms through a process that is broadly characterised as "research and development" (R&D). According to Schumpeter, successful innovation will prompt firms and individuals to use the invention in relevant applications. The application constitutes the third stage of technological change and is known as diffusion. The cumulative economic impact of new technology results from all three stages, which are commonly referred to as the process of technological change (Jaffe *et al*, 2000, p4).

The importance of technological change is well known and widely recognised in economic growth literature. Solow (1956) was one of the first to show that the "effectiveness of labour" is a very important component that explains differences in growth between countries with roughly the same amount of capital stock, and that countries with more effective labour will attain higher levels of economic growth. What Solow implies with the notion of the "effectiveness of labour" has since been a subject of debate, although many economists reason that it is a catchall for factors other than labour and capital that affect output (technological change). Solow's growth theory spurred interest in research that became known as "new growth theories". These theories explain economic growth by incorporating a variable that represents technological progress. Despite the "new growth theories", the concept of technological progress remains vague.

The mystery that surrounds technological innovation is emphasised by Beltratti (2001) who reviews a number of articles that try to explain sustainable development/economic growth. Beltratti (2001) comes to the conclusion that there is a real need for a better theory of technological innovation. He states that technological innovation is a key parameter, which is often taken as exogenous to the growth theory and, although endogenous growth models try to push the explanation of technological innovation a little further, the economic variables that affect technological innovation need to be cast in more precise terms. He further concludes that there is a need to understand more about the origin of technological progress, and how to effectively increase the productivity of the resources spent on research and development. This conclusion seems to be relevant to both general economic growth theories as well as environmental economics (Beltratti, 2001).

As hinted by Beltratti (2001), technological innovation can also contribute significantly towards the improvement of the environment. This suggestion is well-known among environmental economists. The attractiveness of technological innovation in environmental management is emphasised by Opschoor (2001), who suggests one of four methods that can be used to obtain a sustainable level of economic growth (or a combination of these methods). He suggests that methods should be devised that:

i. raise ecosystems' carrying capacities for economic activity, and/or
ii. reduce the population size, and/or
iii. reduce income or production per capita, and/or
iv. change the environmental impact of production technology.

Not surprisingly, Opschoor (2001) finds the first and the last strategies attractive. He states that both these strategies could be achieved through improved knowledge, technology and management. The achievement of the relevant knowledge and technological change remains a challenge to both policy makers and economists alike (Opschoor, 2001, p32).

5.3 THE DETERMINANTS OF TECHNOLOGICAL INNOVATION

Despite the apparent difficulties, there is a line of research that has attempted to discern the determinants of technological change. Jaffe et al (2000) identifies two major strands of thought regarding the determinants of innovative activity. The first category is called the "investment subject to market failure" approach and the second category the "evolutionary" approach.

The "investment subject to market failure" approach explains the determinants of technological innovation by assuming that firms undertake an investment activity such as R&D with the intention of producing a profitable new product, or to engage in profitable new processes. The investment decision that surrounds R&D has important characteristics that distinguish it from investment in equipment or other tangible assets (Jaffe et al, 2000, p10).

The first characteristic is that the outcome of investment in R&D is much more uncertain than that of average investment undertakings. The second characteristic is that the assets that are produced by the R&D process are specialised and intangible. The costs of the investment are sunk, and R&D can therefore not be used for collateral. These two characteristics of R&D make the financing of research activity through capital market instruments more difficult than would be the case for other investments. This could result in under-investment in research (Jaffe *et al*, 2000, p11).

Apart from the problem of financing investment in R&D, the returns to R&D activities are difficult to keep from other parties that have not invested in the development (the so-called appropriability problem). It seems as if a significant portion of the social return to investment will accrue as "spillovers" to competing firms or to downstream firms that purchase the innovator's products, or to consumers (Jaffe *et al*, 2000, p11).

Both the problems of financing and appropriability raise the cost of R&D activities. Because the "investment subject to market failure approach" assumes that firms undertake R&D activity to maximise profits, these costs could reduce expected profits. It also implies, however, that the rate and direction of R&D activities should respond to changes in the relative prices that affect the profitability of firms. This holds important consequences for the effect that environmental policies could have on technological innovation. Since environmental policies implicitly or explicitly make environmental inputs more expensive, the hypothesis suggests an important pathway for the interaction of environmental policy and technology (Jaffe *et al*, 2000, p12).

The second school of thought explains R&D activities of firms as an investment decision that takes place in reaction to an external event. The so-called "evolutionary" approach assumes that firms are "satisfying" rather than "optimising" and approach their strategy with regard to R&D in a way that is not pre-determinable, but rather event-driven. This approach towards R&D development also holds intriguing opportunities for environmental policies. In as far as a new environmental policy is seen as an "external event" that could provide new profit (or loss) opportunities, it should move firms to re-evaluate their current R&D activities (Jaffe *et al*, 2000, p12).

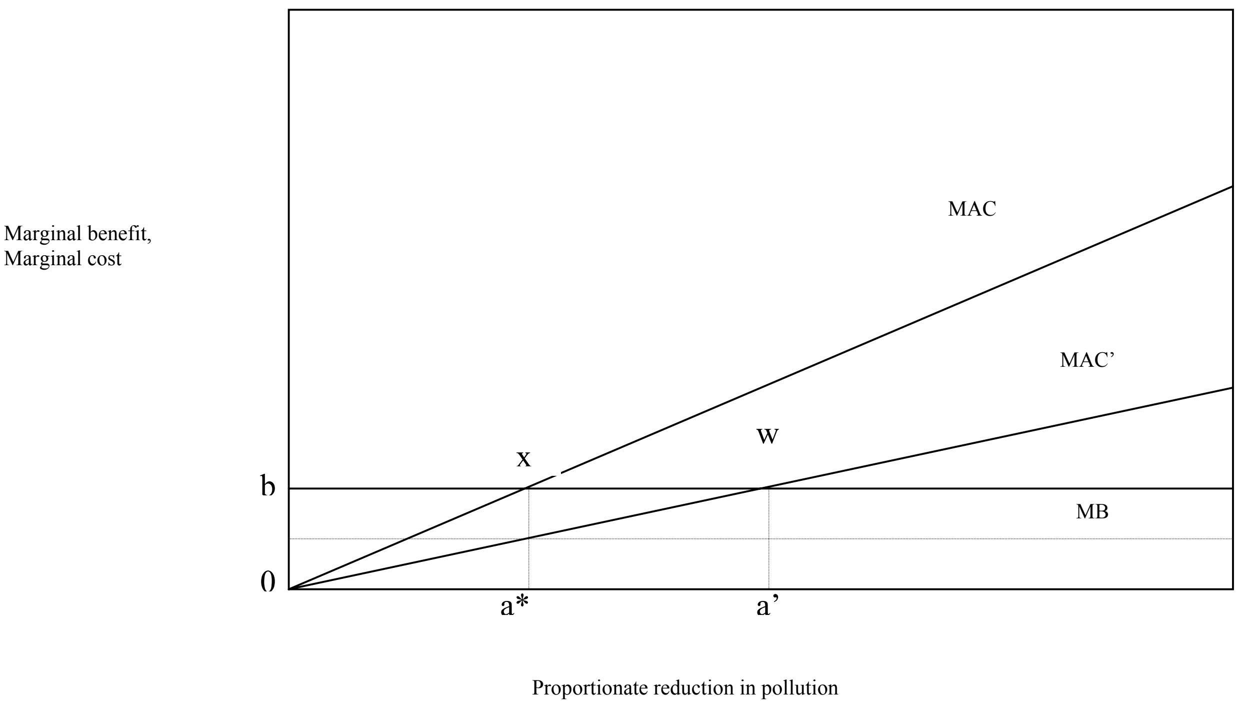
As hinted in the above discussion, the two approaches that are used to explain R&D development also suggest measures that can be implemented to induce technological innovation.

5.4 INDUCING TECHNOLOGICAL INNOVATION

Given the above theories, it is not surprising that environmentalists are among the main proponents of new and more stringent environmental regulations. These groups argue that increasing the stringency of environmental regulations provides an incentive for firms to develop new and less costly ways of reducing pollution. Some proponents argue that it could potentially result in entirely new methods of production which eliminate particular types of emissions and reduce the cost of production (Jaffe *et al*, 1997, p610).

Parry (2001) illustrates the benefits of potential technological innovation with a simple static model. In the traditional Pigovian analysis in which the state of technology for reducing pollution is taken as given, there is usually an upward sloping marginal cost curve for abating economy-wide emissions of a particular pollutant. This is shown by MAC in the figure below. The proportionate emissions reductions is denoted by "a" on the horizontal axes. The MAC curve usually reflects some combination of the extra costs to firms from using cleaner but more expensive inputs in the production process, the costs for operating technologies for treating waste emissions, and the efficiency cost of reduced final production. In addition to the MAC curve, there is a marginal benefit curve (MB). This curve reflects the environmental gains from incremental reductions in pollution, such as the health benefits from clearer air. The optimum amount of pollution abatement is a*, where MB and MAC intersect, and the welfare gain achieving this abatement is triangle 0bx.

Figure 5.1: An analysis of welfare benefits of induced technological innovation



Source: Parry, 1999

As stated, the above analysis assumes that the state of technology for pollution control is exogenous, while in reality it is not and will change over time in response to environmental policies (Parry, 1999, p3). If firms are penalised for polluting, they will have an incentive to come up with improved techniques for pollution control, which will lower the future cost of emission mitigation. Therefore, the MAC curve will move down over time in the presence of environmental policies (e.g. towards MAC'). Optimal abatement would now be at a', where MAC' intersects MB, while the maximum welfare gain from pollution control would now be triangle 0bw. There is thus an increase in welfare of triangle 0xw over and above the situation with no technological change.

Supporters of this school of thought have also suggested that if a country adopts stricter environmental regulations than its competitors, the resulting increase in innovation will enable that country to become a net exporter of the newly developed environmental technologies. This view is known as the Porter hypothesis (Jaffe *et al*, 1997, p610). Three different forms of the Porter hypothesis are distinguished.

i. The "narrow version": this version of the "Porter hypothesis" postulates that certain types of environmental regulations stimulate innovation.

ii. The "weak version": this version states that environmental regulation places constraints on the profit opportunities of firms that were not there before, and that firms maximising profits subject to those constraints will do a variety of things differently from what they would have done without the constraints. A likely outcome of the new regulations is that the activity would result in investments that fund R&D projects which find ways to meet the new constraints at lower costs. However, because the addition of constraints to a maximisation problem cannot improve the outcome, the weak version of the Porter hypothesis implies that the additional innovation must come at an opportunity cost that exceeds its benefits.

iii. The "strong version": this form of the hypothesis rejects the narrow profit-maximising paradigm of production behaviour and postulates that firms under normal operating circumstances do not necessarily find or pursue all profitable opportunities for new products or processes. The shock of a new regulation may therefore induce firms to broaden their thinking and to find new products or processes that both comply with the regulation and increase profits. The strong form of the Porter hypothesis has been construed to imply that environmental regulation is a free lunch, because regulation induces innovation of which the benefits exceed the costs, making regulation socially desirable, even ignoring the environmental problem it was designed to solve (Jaffe *et al*, 1997, p610).

A statement by Opschoor (2001) confirms the intuition that prevails behind the Porter hypothesis. He states: "*the changing of the environmental efficiency of production will come about as a consequence of research and development in industry and scientific institutions; these will emerge in response to price changes and changes in profits, and in response to public programmes and* *funding that stimulate innovation where the market fails to produce signals of adequate strength. Growth may generate the private and public funds necessary for financing innovation but here, again, deliberate policies and specific institutions and mechanisms appear as necessary conditions"* (Opschoor, 2001, p32).

Although the theoretical argument behind the Porter hypothesis seems appealing as an argument for environmental regulation, proponents of these theories emphasise that not all environmental regulations will generate significant innovation offsets. For this reason, policy makers should create new regulations carefully to ensure that they encourage innovation. The latter emphasis follows from a large subset of literature that focuses on the incentives of a firm that faces a decision to undertake R&D in order to reduce environmental compliance costs under different approaches to environmental regulation. This literature finds that R&D incentives tend to be stronger under incentive-based environmental policies than under command and control policies (Jaffe *et al*, 1997, p611).

There is also some research that explores the relationship between the stringency of environmental regulation and incentives for R&D and technology diffusion. Oates *et al* (1993) show that increasing the level of a pollution tax rate increases the firm's incentive to adopt a more efficient abatement technology. Schmalensee (1994) suggests that while R&D devoted to environmental compliance may increase with stricter environmental regulation, this increase will likely come at the expense of other research efforts that could have been more profitable.

Although empirical testing of these theories is difficult, the studies that have attempted empirical tests, confirm in general what is postulated by the above theoretical approaches. Examples of empirical research that prove the relationship between relative factor price changes and technological innovation include Lanjouw and Mody (1996) and Jaffe and Palmer (1997). Lanjouw and Mody (1996) have shown that a strong relationship is found between pollution abatement expenditures and the rate of patenting in related technology fields. Joffe and Palmer (1997) have found that there is a significant correlation within industries over time between the rate of expenditure on pollution abatement and the level of R&D spending. Another interesting study that indicates some relationship between changing factor prices and technological change is that of Popp (2001) in which it is found that patenting in the energy-related fields increases in response to increased energy prices. Jaffe *et al* (2000) summarise the main findings of the empirical research in a comparative table. The table is reflected below.

Table 5.1 Overview of conclusions on induced innovation and the "win-win" hypothesis

AREAS OF AGREEMENT	
Historical evidence indicates that a significant but not predominant fraction of innovation in the energy and environment area is induced.	
Environmental regulation is likely to stimulate innovation and technology adoption that will facilitate environmental compliance.	
Firms are boundedly rational so that external constraints can sometimes stimulate innovation that will leave the firm better off.	
First-mover advantages may result from domestic regulation that correctly anticipates world-wide trends	
AREAS OF DISAGREEMENT	
Win-Win theory	**Neoclassical economics**
Widespread case-study evidence indicates significant "innovation offsets" are common.	Case studies are highly selective.
Innovation in response to regulation is evidence of offsets that significantly reduce or eliminate the cost of regulation.	When cost-reducing innovation occurs, the opportunity cost of R&D and management effort makes a true "win-win" outcome unlikely.
Pollution is evidence of waste, suggesting why cost-reducing innovation in response to regulation might be the norm.	Costs are costs; even if firms are not at the frontier, side effects of pollution reduction could just as easily be bad as good.
Existing productivity or cost studies do not capture innovation offsets.	Existing productivity and cost studies suggest that innovation offsets have been very small.
There is much evidence of innovation offsets, even though existing regulations are badly designed. This suggests that offsets from good regulation would be large.	Since there is agreement that bad regulations stifle innovation, the apparent beneficial effects of existing regulation only show that case studies can be very misleading.

Source: Jaffe *et al*, 2000

5.5 FUNDING TECHNOLOGICAL INOVATION IN SOUTH AFRICA

As indicated above, R&D investment can be induced by well-designed regulatory policies. However, investment in research and development programs will require funding. The funds can originate from either the private sector or from the public regulator. As discussed above, the expected returns from investments in R&D activities is highly uncertain at the best of times. Apart from this uncertainty, it seems as if there are additional factors that inhibit investments in R&D activities in developing countries.

Gilles et al (1992) indicates that developing countries have not yet succeeded in making the development of appropriate technology a dynamic force in their economic development processes. According to the researchers, one of the main reasons for the lack of technological improvement is the absence of competitive pressures. This absence reduces the incentives for firms to invest in technological innovation. Another reason for the lack of technological progress is that most governments of developing countries have not yet fully awakened to the need to promote local research and development. It seems further as if universities of developing countries are usually preoccupied with teaching, and official research institutes in various fields are often slow to be set up or these institutions experience severe staffing difficulties once they open their doors. Given this, it seems as if there is scope for policies that will promote investment in R&D in developing countries (Gilles *et al*, 1992, p213).

Analysis of South Africa's Research and Development Strategy (2002) indicates that the country is no exception to the problem of low R&D that seems to plague the developing world. The R&D strategy of the Government mentions that South Africa currently suffers from an "Innovation Chasm" despite high proportions of private sector participation in some tertiary institutions and research councils. The Government is also acutely aware of the fact that technological innovation is needed for long-term economic growth and it states:

"*In many areas where South Africa is currently competitive, we do not have a capacity for local innovation and are dependent on imported know-how. This is not problematic in the short term. However, countries that make strategic innovation investments will inevitably attract new foreign direct investment and will eventually secure or supplant our current productive capacity*" (Department of Science and Technology, 2002, p38).

The Research and Development Strategy (2002) goes further to state that South Africa has a limited capacity at present to respond to new areas of technology that are regarded as critical in the global economy (such as biotechnology) and that there is a particular need to mobilise sciences to develop far more holistic understandings and interventions to increase the rate of innovation in our society (Department of Science and Technology, 2002, p38).

Although the lack of financial support is not the only factor that contributes towards the low levels of technological innovation, it does seem as if the South African economy suffers from low levels of expenditure on R&D activities. South Africa's total (public and private sector) R&D expenditure amounted to approximately 0.7 percent of gross domestic product (approximately R6 billion in 2002), whereas the average OECD country spent approximately 2.15 percent of GDP on R&D activities (in 2002). According to the Government, the R&D undertaken by large South African companies has shown a significant, measurable decline in the past four years, while global statistics show that the real determinants of technology-driven economic development is a sustained high level of research and innovation by the indigenous private sector firms of all sizes (South African Government, 2002, p21). It is against this background that the South African Government has set itself a target to double investment in R&D over the next three years, with a more gradual increase thereafter (Department of Science and Technology, 2002, p17).

Apart from this, the funding of research and development in South Africa, which could result in appropriate technological innovation, (with specific reference to the problem of energy efficiency) seems to be insufficient at present. There is, however, a common understanding of the importance and urgency of sufficient technological innovation.

Eskom, one of the industries that make intensive use of coal in the production of electricity, states in its 2002 Directors Report that it is committed to strive continually towards sound environmental management and performance. According to the report, Eskom allocated expenditure of R489 million during 2002 for environmental purposes. The Resources and Strategy division accounted for 21 percent (R102.69 million) of this expenditure. This division used the funds mainly for research that was related to the pilot wind energy facility (Eskom, 2002 (a)).

Sasol's expenditure on R&D expenditure has also increased from R268 million for the year ending June, 2001, to R359 million for the year ending June 2002 (Sasol, 2002, p109). A significant part of this expenditure is used on projects that focus on the use of natural gas (rather than coal) to serve Sasol's needs for energy transformation. It seems as if Sasol expects that the Natural Gas project will decrease the use of coal by Sasol Chemical Industrial plant from the current six- to seven-million tonnes to some 1.9- to 2 million tonnes as the primary energy source for the factory's power and steam plants (Engineering News, 2003, p30).

5.6 CONCLUSION

Apart from the positive benefits that technological innovation holds for economic growth and environmental management, it is also evident that environmental policy could, in itself, induce technological innovation in those sectors that are affected by relative price changes. The attainment of technological innovation is, however, not unambiguous, as indicated in the review of the economic literature on this topic.

It is also evident that South Africa currently has an "innovation chasm" despite the benefits that innovation holds for an economy. Although not the only reason, it seems as if a lack of funding of R&D activities in both the government, as well as the private sector, contributes towards the lack of innovative capacity. This is also true for technological innovation in environmentally sensitive industries such as the electricity and synthetic fuel industries.