JYVÄSKYLÄ STUDIES IN BUSINESS AND ECONOMICS 6

Minna-Maari Karvonen

An Industry in Transition

Environmental Significance of Strategic Reaction and Proaction Mechanisms of the Finnish Pulp and Paper Industry

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JYVÄSKYLÄN YLIOPISTO

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ABSTRACT

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The pulp and paper industry has traditionally had a strong significance in the Finnish economy. In the past years, the industry has had to cope with new, mainly environmental, demands from various stakeholders. New tools and techniques need to be developed that could aid decision making. This research aims to identify, explain and partly to predict, the reaction and pro-action mechanisms in the Finnish pulp and paper industry, to changes in the external operating environment. The focus is on water emissions by a single industry, allowing an in-depth exploration and illustration of the concepts developed in environmental and ecological economics as well as in corporate environmental philosophies and management. This thesis is descriptive research using literature review, logical argumentation and quantitative modeling. This thesis demonstrates the possibility for simultaneous environmental and economic modelling in the neo-classical framework. The study also shows that mutually beneficial situations for the economy of the firm and the environment are possible. These situations coincide with the complementarity of natural and human-made capital. The thesis also looks into the life cycle assessment field demonstrating the need to account for industry dynamics in LCA studies. The findings include suggestions for the planning and design of national environmental policy to encourage sustainability and bring benefits for the environment and the economy. The policy conclusions drawn here differ from the more general literature, offering good ground for further research. The study provides insight into an area that can no longer be ignored in business, political or societal decisions.

Keywords: pulp and paper industry, economic-environmental modeling, environmental policy

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FOREWORD

This thesis in many ways demonstrates the end of four years of juggling between decisions to stay in "school" or to work. A dissertation was not included in my plans for the foreseeable future three years ago, now it seems almost natural. I have learned far more in the process than can be captured in the thesis itself; most of those lessons reach well beyond the narrowly defined subject area here. All in all, it has been a process that has shown to me at least, that determination will take me even through solid rock, even if sometimes alternative routes would be easier.

I have had a personal interest and certain affection for the environment all through life. I was intrigued by the possibility to study environmental management and immediately felt this to be what I wanted to do. Corporate environmental management is one way of incorporating a certain amount of idealism into too much realism. I feel now, that environmental issues are undervalued in corporate decision making, a fact that does not reflect their economic significance or the inherent business opportunity of sound corporate environmental management. The opportunity to work in this research group in finding ways to incorporate economic and environmental information in a meaningful way has been very rewarding, on both a personal level and on a professional level.

First and foremost my gratitude goes to Professor Tapio Pento for providing me with the opportunity to work in his research group. His professional guidance and support have helped me along greatly and provided belief in times when I had little myself. I am glad to see this endeavour has not left us battling for fortresses but rather has evolved into a mutual friendship.

The quality of this thesis and its argumentation, as well as that of the preceeding licentiate, have been improved significantly by the constructive comments and guidance of Professor Matthias Ruth from the Universiy of Maryland, one of my examiners. His insightful critique pointed out areas that I had overlooked and also provided motivation to continue working on the thesis. I applaud his patience in reading several versions of both theses and reviewing several versions of submitted articles; this was a daunting task even to me.

I owe my gratitude also to Professor Dr. Dietfried Günter Liesegang from the Ruprecht-Karls Universität Heidelberg for agreeing to share his experience and knowledge in serving as the opponent for my thesis defense. No doubt this event will be memorable, educational and rewarding in its own right, although at the time I am writing this, it still only looms ahead. The knowledge that the thesis will be examined by someone with the highest qualifications and a wealth of experience is a source of comfort, and a little agitation.

Financial support has come from the Ministry of the Environment, The Academy of Finland and the Foundation for Economic Development. The financial support has been crucial and has been well spent. Professional and personal support, guidance, advice and friendship has come in many shapes and sizes from very different people in very different places. I shall not list you all here, you surely each one know who you are. I have been blessed to have such a wonderful group of family, relatives, friends, companions and colleagues to share my life, love and thoughts with; I only wish I can give to all of you as generously as you have given to me.

Happy, glad and eager to see what challenges now greet me,

Minna-Maari Karvonen
Jyväskylä 25.10.2000

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1 INTRODUCTION

" We abuse the land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect."

- A. Leopold

Environmental issues are among the fastest growing problem areas in contemporary business studies. Corporate environmental management research is geared towards the inclusion of environmental variables and a holistic environmental perspective as an equal component into the decision-making processes of companies. Evidently the discussion of the relationship between human economic systems and the natural ecosystem is gaining momentum in economics as demonstrated by the currently established fields of economic thought although the introduction of environmental issues to economics can be traced back to the birth of the economics discipline itself. Recently new directions have risen to challenge neo-classical assumptions on natural resources, ecosystem services and sustainable growth.

Environmental phenomena, of which environmental pollution and degradation is one unfortunate example, know no boundaries. Their nature is global and their threats are also global in nature. Therefore any solutions can not be purely local but must also be unrespective of national boundaries and national as well as international geopolitics. Actions will always remain local in nature but they must fit into the bigger global picture and thus in essence not be restricted to the locality.

Finland has traditionally built its success on natural resource factors; the driving forces behind the economy's growth have long been derived from natural, mostly renewable resources. Finland has actively developed its own national environmental policy. In addition the development of pollution prevention as well as clean technology has been rapid. After joining the European Union, Finland has become an active member in the development of the Union's environmental policies and guidelines. Especially in the pulp and paper sector, the Finnish involvement in the Union's environmental policy playing field is strong. The study uses the Finnish pulp and paper industry as its empirical case. The industry has been involved in environmental protection for a long time; after all protecting the environment has also meant in the long run protecting the raw material basis of the industry.

In planning appropriate policy measures historical trends need to be taken into account and respected. Also in the planning of concrete actions, the lessons learned from history should play some role and be respected. Mostly historical trends have been used in the projection of probable future behaviour. Through looking at past development it is possible to identify those factors affecting the development in any one direction. History also sets some limits to the possible achievable targets given the current economical, social and political as well as psychological structures.

The traditions of classical and neo-classical economic disciplines are long and wealthily documented. Also the field of environmental and natural resource economics, although not as long, is well established and practised since the last turn of the century. A more recent spin-off is the ecological economics tradition, which is only now stepping up, taking form and actively shaping and justifying its position. A closer look however, reveals an academic vacuum separating the taxation-oriented neo-classics from the ecological economists motivated by the ideal of a steady-state. Also the position of the state has divided opinions; from the state being in the role to correct market failures to state being the failure in itself.

This thesis attempts to indicate some similarities between different schools of thought often regarded as distinct from each other. The thesis is motivated by the realisation that environmental constraints in production functions and in industrial activity can no longer be overlooked. However, traditional neo-classical economists and ecological economists tend to view the same issue with their own distinct viewpoints. Some middleground between these approaches is attempted in this thesis. This task is no doubt challenging and can not be done in one post-graduate thesis alone. Rather the focus here is on providing a new lens through which to see the situation that combines old with new and conventional with, at times, radical. The objective is to identify and apply a typically microeconomic concept on an industry level and also to develop that concept to be in a position to better answer those needs and requirements set about by the demands of modern society. The development of an industry is documented with econometric analyses. This econometric analysis then provides the basis on which further analysis with different objectives is performed.

The main aim of this thesis is to empirically explore, find and test an economic-environmental production function (EEP) for the Finnish pulp and paper industry demonstrating the relationships between effluents, production volumes and investments. This tested model is then reflected on with concepts of material flow models (MFM), especially life cycle analysis (LCA). An empirically tested production function will provide valuable input to both models in terms of their basic assumptions. The research aims to examine whether the EEP can be estimated in practice and what it implies. Further it is assessed how the EEP can be used in analysing the industry and what kind of further application options exist.

This study uses a retrospective approach to look at possible future development paths or alternatives. Such an analysis can easily be criticised since the past may not be an adequate predictor of the future. This is especially true in a dynamic and rapidly changing setting such as the interaction of economics and the environment. Unpredictable changes with dire consequences on both natural and human activity are not uncommon and can quickly invalidate predictions about future based on the past. However, if this premise is adequately recognised, such historically based analysis can be extremely useful. In this study, the limitations of retrospective analysis are admitted and the results can be viewed with the appropriate caution.

Exogenous drivers are perhaps among the first motivations for shifting more emphasis on environmental issues in business decisions and in public policy. Exogenous drivers include increasing environmentalism, increasing consumer pressure and in general increasing awareness of environmental degradation. These pressures are then expressed either directly, through pressure groups or through legislation creating situations for companies or policy makers in which they must react. Endogenous drivers on the other hand, stem from within the corporation. A proactive company may seek to increase profitability through decreased costs or increased efficiency, or to improve corporate image through environmental management. In reality, the distinction between endogenous and exogenous drivers may not be so clear.

1.1 Benefits from this research

This research is useful in widening the information basis concerning Finnish pulp and paper studies. It produces new knowledge and provides expertise concerning the pulp and paper industry as well as promotes co-operation between industry practitioners and policy makers. It also aims to promote, or at least consider the role of, international relationships in terms of policy design and implementation. Its main application will be to serve as a tool and basis for decision-making concerning the planning and development of policies for the pulp and paper industry as well as provide support for the micro-level business decisions. Thus potential beneficiaries of the research are both in the public and private sector; and almost needless to mention, the author herself.

Currently there is an ongoing Environmental Cluster Research Programme in Finland. The purpose of the program is "*to produce knowledge, innovations, expertise and co-operation in the environmental sector and to promote sustainable development, entrepreneurship, economy and employment. A further goal of the collaborative project is to enhance contacts between researchers, research groups and the utilisers of research findings and* *to encourage co-operation between the agencies funding environmental research*" (www.vyh.fi/eng/research/cluster/objectiv/objectiv.htm). Thus this research fits well into the objectives of the environmental cluster research program and has in fact enjoyed funding from it.

1.2 Is there a demand for this research?

Doing research only makes sense, for the researcher and in a larger sense society or the financiers, if it fills or meets some demand. As the research relies to an extent on economics, the author feels obliged to defend the very existence of her work by the familiar arguments of supply and demand. A large body of current and historical research until today has mainly focused on analysing the impact of exogenous drivers such as environmental regulation and pollution control on the firm and on the environment. Several journals are published around this theme and new associations and societies have sprung up as a result. This type of traditional economic research is perhaps in oversupply. No doubt demand is great, but the author feels that the trend represented by the majority of current research does not quite meet the demand side in essence, although in amounts the case may be so.

The focus of this research is rather than exogenous, looking at endogenous drivers such as investments in shaping pollution. This makes more sense for the policy maker as well as for the practitioner, as will be demonstrated here. Most importantly it transforms the role of the practitioner from the reactive bystander or follower into a proactive shaper or trendsetter. Moreover, the models that the research questions are answered with are simplified when compared to many others in the literature today. This makes them more applicable. The author senses an undirected demand for this type of research and hopes to make a contribution by answering and pre-empting this unvoiced demand.

Yes, there is a demand. Firstly for scientifically verified information and analysis as well as analysis tools as potential inputs into decision making processes. Secondly for an academic contribution in a polarised arena.

2 RESEARCH DESIGN & PROBLEMS

2.1 Research questions

Research problems are characterised as the initiating force or basis of scientific research. These problems may be articulated to varying degrees but mainly they are characterised as being unanswered or only partly or insufficiently answered. Answering the research problems ties the research to societal demand. This current research has also been borne out of a societal need for understanding environmental related phenomena better to facilitate planning and implementation of appropriate policy measures.

The aim of this research is to broaden the understanding concerning the different variables and mechanisms that have and continue to shape the environmental effects of the Finnish pulp and paper industry. The main research question is

"How to describe, explain and potentially predict, the reaction and pro-action mechanisms of the Finnish pulp and paper industry to recent changes in the external and internal operating climate, especially with respect to environmental issues?"

and more specifically

"Can the recent developments be presented in the production function framework?"

The study recognises as its starting point that the Nordic pulp and paper industries have a very different environmental or eco-efficiency profile from that of similar industries in North America or Central Europe, not to mention Asia and Latin America (see for example research carried out by Ekono 1996, 1997, 1998). Thus it is assumed that there must be something profoundly different about the behavioral and/ or decision making mechanisms that generate this difference and result in the current observable situation.

This study follows a rather theoretical approach. Despite the framing of the research hypothesis, this is not an econometrics study. Rather the study borrows and uses some concepts from such a theoretical field to hopefully arrive at a solution that may find application in public policy and in the private practices of firms. Its basic aim and function is to analyse a situation through a chosen lens. As a result, the research, rather than providing a concrete toolbox, gives inputs for discussion. The production function and its enlargement suggested by the research hypothesis can be considered as one possible way of approaching the discussed issues, or in some sense, a tool. The effectiveness or "goodness" of any tool can only be assessed by exploring the possibilities for the tool's application in different settings. The additional research questions or hypotheses bring refinements to the original broader hypothesis. These detailed research questions are argued to provide a sufficient justification for answers to the main research hypothesis. The additional questions to be answered within this research are:

- Do so-called win-win situations really exist and what could the nature of the relationship between economy and the environment be?
- How should the dynamic nature of industry development be accounted for in LCA studies?
- How should environmental policy be planned to encourage eco-efficiency?
- Are there application possibilities for the emissions production function in
  - → the public sector and
  - → the private sector?
- Is the Finnish pulp & paper industry sustainable? Can its growth be characterised as such ?

2.2 Philosophy and methodology of research

Philosophies of science are often divided into three: positivism, marxism and hermeneutic philosophy (Eskola 1966, Töttö 1983, Riggs 1992, Järvinen and Järvinen 1995). Here the positivist scientific tradition is followed. This research relies on a theoretical basis explicitly stated in the research hypothesis. Thus the research is undertaken not from *tabula rasa* but based on the hypothesis that will be either corroborated or refuted in the thesis. This definition of research is in line with Karl Popper's critical rationalism (Popper 1959), itself an evolution of positivism and logical empiricism (Pietilä 1983, Riggs 1992). In a sense this research can be seen as basic research; its aim is to find out whether and under which conditions the production function can be widened to incorporate environmental issues, or in a sense to find out natural laws and causalities defining and characterising the system (Pirttilä & Raiski 1977).

The objective of research is to fulfill the desire to know more. Here the research is the author's voyage to the partly unknown. More specifically the thirst for knowledge can be to describe, to explain, to predict or to control (Huczynski & Buchanan 1985). The objective determines to an extent the choice of methodology (Eskola 1966). A rather strong distinction is often made between quantitative and qualitative research designs and the two are unnecessarily regarded as mutually exclusive[1]. Just as any research will have theoretical elements, quantitative research is accompanied by qualitative reasoning. Figure 2.1 presents some of the most commonly stated research methodologies (Uusitalo 1991, Churchill 1991, Tamminen 1993, Järvinen and Järvinen 1995, Soininen 1995). The figure is not exhaustive as there is an abundance of methodologies. The presented methodologies are equally applicable to qualitative and quantitative research designs. The suitability of methodology really stems from the research traditions, or the scientific norms and principles, paradigms (Kuhn 1962), as well as from the research questions to be answered.

In its quest to understand reality and to find out the underlying natural laws that govern the development, the research can be seen as positivist in nature (Uusitalo 1991, Riggs 1992). The goal and end result of scientific research can be seen as the creation of theory through the testing of hypotheses (Pirttilä and Raiski 1977); this research is no exception, but here research questions substitute explicit hypothesis.

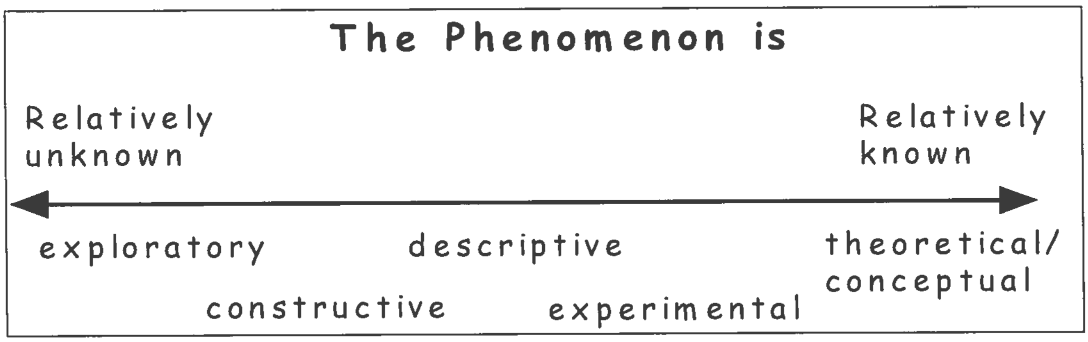

FIGURE 2.1 Methodological approaches with respect to novelty of studied phenomenon.

[1] This opinion was voiced at a panel discussion on quantitative and qualitative approaches during a post-graduate tutorial at Lappeenranta University of Technology, November 1999.

The nature of the basic research question requires a quantitative approach, but it will be supplemented with qualitative evaluation, reasoning and testing of applications.The research aims to describe a phenomenon through quantitative, econometric modelling. Descriptive research designs aim to describe the nature, commonness, historical development or other characteristics of a phenomena or situation (Huczynski & Buchanan 1985, Soininen 1995).

Case studies are generally applied to purely qualitative research (Soininen 1995). However, there is no real contradiction in calling quantitative research a case study given that the statistical data and methods refer to a certain case. In this research one industry forms a case that is studied. However, this research cannot be understood as pure case research as defined for example by Pettigrew (1997), Eisenhardt (1989) and Stake (1995). In this research, the application of case study methodology would likely not add value or make answering the research questions any easier.

The background of this study lies in well established fields of economic literature. However, a small excursion into explorative research is taken in the construction of the model, which, as will be demonstrated, deviates from mainstream economics practices.

2.3 Outline of the thesis

Chapter 1 provides an introduction to the topic and presents the background against which this research has been undertaken. It also points out the need for such research to be done and the main beneficiaries and application areas from the study.

Chapter 2 explores the research questions, design and methodology. It articulates the topics raised in the first chapter into a clearly defined main research hypothesis and elaborates additional questions to be answered by the research. The chapter also provides the philosophical tradition that the study follows and finally, the outline of the study. The validity, reliability and objectivity of the study is briefly brought up.

Chapter 3 presents the historical development of those fields of economics relevant for this research. The literature review includes a review of the relevant economic theories as well as an overview of the strategic management field. Especially the early studies of externalities, the development of environmental and resource economics and the more recent emergence of the thermodynamic school and ecological economics are presented. A brief introduction is also made of life-cycle assessment as it is also relevant for this research. The literature review aims to help the reader focus on the appropriate background that has led to the formation of this thesis. Some of the presented ideas are less directly related to the issue here but serve to demonstrate the development of thought.

Chapter 4 introduces the industry and provides a characterisation of the Finnish pulp and paper "playing field". The main characteristics of national environmental policy are presented as well as the background, collection and sources of data used in this study. As this thesis is a case study of the industry, it is justified to characterise the industry and its main processes as well as associated environmental problems. This will help the reader to follow the argumentation, discussion and analysis that follows.

Chapters 5, 6, 7 and 8 are formed by a collection of research articles by the author presented at international conferences or under review for publishing in international scientific journals[2]. Each paper is included in the thesis in the format in which it has been submitted. Only the references and acknowledgements have been removed to avoid repetition and are included in the references at the end of the thesis and all acknowledgements are made in the foreword by the author. The publication details are included with each article. The articles mainly serve to present some ideas that are brought up in the preceding and concluding chapters more in depth and to clarify the development of tools, concepts and ideas.

Chapter 5 presents the econometric model used in the study and shows how the author has arrived at the chosen model. The empirical environmental-economic production function is then used to show the general macro-level development of the past 20 years and also to predict possible trends in the future.

Chapter 6 expands the modelling aspect to the field of life cycle analysis and provides a natural link between the econometric study utilised here and prevalent LCA modelling approaches. The main drawback of current LCA practices are presented and some improvements are suggested that could increase the credibility of LCA studies and their results.

Chapter 7 expands the thinking to a micro-level and looks at the popular win-win rhetoric and its possibilities in reality. In essence, chapter 7 explores in greater, or micro-level, detail the general tendencies presented in the previous chapter. The chapter tries to identify some of the drivers behind the observed development in chapter 5.

Chapter 8 uses the model to arrive at a definition and characterisation of sustainability and sustainable development for the industry. Although the definition of sustainability is still vague and manyfold, the chapter attempts to present some ideas of how sustainability, or lack thereof, could be measured in concrete terms.

Chapter 9 discusses the presented ideas and the main findings of the study and explores the applicability of econometric modelling for emissions. The discussion is not stand-alone readable without the research articles presented in chapter 5-8 although each article forms its own entity. The general discussion relies on the articles as they go more in-depth into the relevant

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[2] Chapters 5 and 7 have been accepted for publication, while due to the time lags in publishing, at the time of printing chapters 6 and 8 are still under review.

issues. To avoid repetition, the coverage of some issues in this chapter of the research is necessarily left to less attention.

Chapter 10 concludes the study, re-stating the answers to the main research questions and also suggesting fruitful areas for further research.

3 BACKGROUND TO THE THESIS

Since this thesis is an attempt at understanding and describing the chosen strategies in an industry, the relevant fields of study could be numerous. Here, the decision is made to concentrate on two separate viewpoints; the corporate strategic decision making, i.e. firm-level issues and on the more rigid economy-wide level of political decision-making. Hopefully by looking at them both in an integrated manner, the mentioned two points of view can be combined. Crucial to explaining the reaction mechanisms is an understanding on how the same issues are dealt with on a more aggregate level. This is especially true in the case of environmental management decision making, since it is often very strongly driven by company external demands. The company's own, internal strategy is then an attempt at answering external conditions. The distinction between exogenous and endogenous drivers was already discussed on page 7.

The first part of the literature review examines the development of the economics discipline towards a greener perspective. This introduction is relevant to the research here, since the strategic choices made in the industry are modeled with traditional economic tools. The main focus of this thesis is not purely economic but to try, as precisely as possible, to look at the reaction and pro-action mechanisms in the Finnish pulp and paper industry, explain them and come up with some suggestions for a political and also for a corporate justification for the observed behavior. The second part of the introduction deals with the strategic level of corporate management and then more precisely, the way in which corporate business strategy and the environment are intertwined. The merits of choosing an environmentally proactive strategy is discussed as it pertains to the main findings in this thesis.

Different economic models are aimed to help decision making and to help differentiate between alternative courses of action. Some economic models are more suitable for corporate settings whereas others take a more holistic view of the institutional setting and thus are applicaple in policy formation, an example of one such model is the cost-benefit analysis, CBA. Some models are presented here as they can be used as the basis for decisions both on strategy and on policy. Models are necessarily based on assumptions and simplifications and thus include bias; or as argued by Kenneth Chilton in his speech at the Chicago Resourceful Earth Day Conference in 1999[3]: "not even economists believe that its (*neoclassical economic theory*) assumptions are realistic".

Strategy is essentially a firm's own recipe for dealing with change and long-term objectives. An environmental or environmentally-oriented strategy will examine ways in which to incorporate those issues to bring about competitive advantage. Environmental economics, on the other hand, tries to identify ways in which environmental concerns could be incorporated into formal, rigid, economic modeling. Standard economic models, such as the cost-benefit analysis are frequently used as a tool in the public decision-making process, in order to reduce complexity and ambiguity. This thesis presents a situation that is brought about by the interaction of these two levels of decision making, the corporate and the public. Thus it is justified that in introducing the ballgame, both levels are briefly described.

3.1 Economic Models for Decision-Making

The literature review undertaken here provides a background for this thesis. It is not an exhaustive list of all relevant literature as the field is broad. The main historical development paths leading to the present day situation are presented. The situation is depicted in figure 3.1. Marxist ideas and institutional economics are not discussed here. The review also helps to place this thesis in the appropriate nichè of economic thought. The literature review intentionally combines macroeconomic literature with microeconomic. This combination is a trait that follows throughout the thesis. Micro-level decisions concerning the use and production of environmental variables is inevitably also a macroeconomic issue as explained later by the theory of externalities. Thus business decision making is inseparable from macroeconomic decision making and in order to achieve development that is sustainable, macro and microeconomic values need to be combined (Paloviita 1999).

The literature review first presents the way in which environmental arguments were treated in classical economics and how they subsequently disappeared with the advent of neo-classical economics. The theory of externalities is then presented as this is the cornerstone of the environment-economy discussion. Two extremes on the treatment of externalities are introduced. The current economics field with its different conceptions of environmental demands is also portrayed. The section concludes with an analysis of the microeconomics of pollution and the different tools that have been suggested for use with it.

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[3] A copy of the speech is available in *Vital Speeches of the Day*, Vol. 65, Issue 16, p. 501-505.

Figure 3.1 presents different "avenues" of economic thought evolving from the very early economists to present day environmental and ecological economists. The niché where this thesis can be placed is indicated by the star. The justification for this positioning will become apparent as the thesis develops.

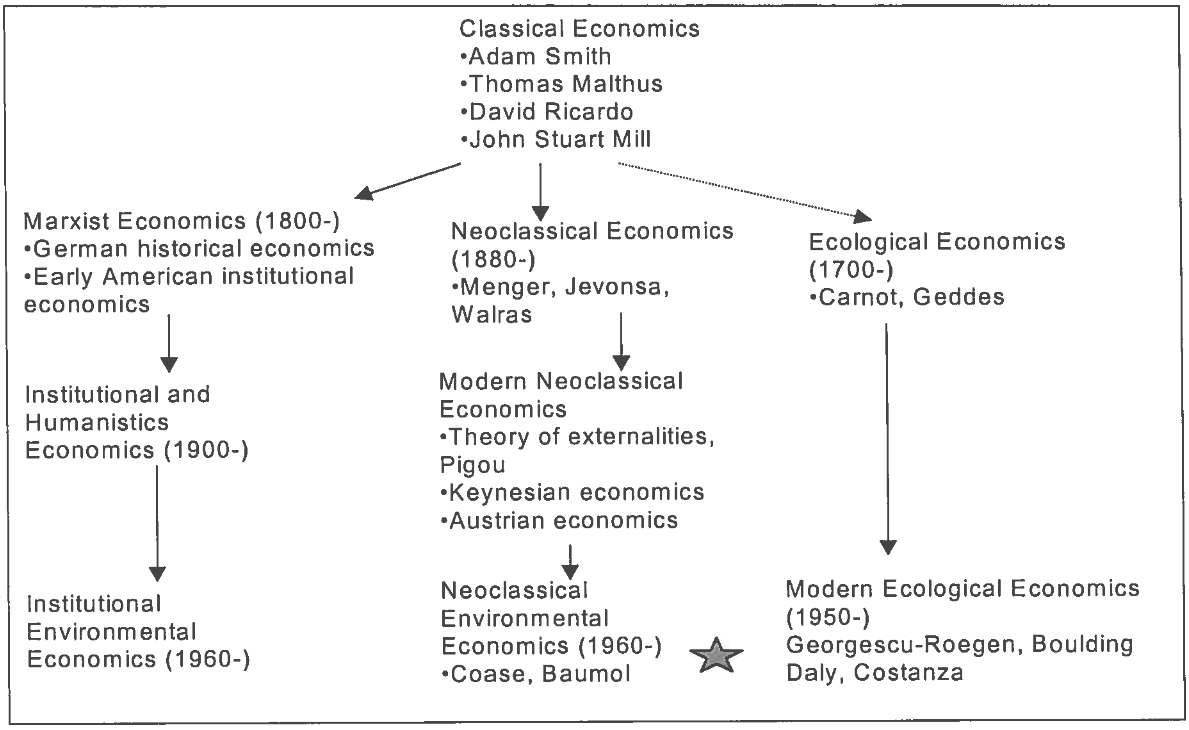

FIGURE 3.1 The development of environmental economics[4] (adapted from Massa 1995 and Kyrö 1999)

3.1.1 Early economic paradigms with environmental consideration

The history of environmental considerations in economics goes as far back as the first established economists. This is clearly understandable since in agrarian dominated societies the availability of quality resources played an important role. The first economists to doubt the possibility of long-term economic growth based on environmental arguments were Thomas Malthus (1766-1834) and David Ricardo (1772-1823). Malthus's rather simple model assumed an absolute fixed upper limit on the amount of available resources and diminishing returns. Thus, with population growth, relative food supplies per head would decline. Ricardo's model relied not solely on absolute scarcity but rather on the varying quality of agricultural land. With increasing demand agriculture would be

[4] Coase could equally well be classified under institutional environmental economists as he advocated property ownership and explored corporate structures and their linkages. Here, figure 3.1 is adapted from the mentioned sources and their classifications are followed.

forced to shift to cultivation of land of declining quality. Ricardo's model left little room for consideration of technological progress that would enhance the quality of otherwise unarable land. The classical economists, including also Adam Smith (1723-1790) and John Stuart Mill (1806-1873) saw, however, economic growth not as a continuing persistent phenomenon but rather a move between two equilibria, or steady-states. The ideas of both Malthus and Ricardo are still highly relevant today and have been re-introduced into present day economic discussion (for example by Meadows et al. 1972).

During the time of the classical economists, land was an important factor of production and hence it seems only natural that economic discussions of the time included this important natural resource. Soon however, many of the assumptions were proven not to hold, resources did not deplete, and as a result natural resource scarcity lost its dominating role in economic discussion. The classicals were soon followed, or replaced, by the neo-classical economists of the late 1800's. The neo-classics became best known for the "marginalist revolution". Scarcity became the determining factor of commodity prices and the interactions of supply and demand were studied. Now scarcity increasingly referred to factors of production other than land. The assumption of the rational individual was made, who would make consumption choices based on the marginal personal utility gained from the available options. The markets would define competitive equilibria, of which each would represent a Pareto-optimum.

Mainstream economists during the neo-classical 'era' are often criticised for failing to include environmental considerations and trusting in economic growth being sustainable for indefinite periods of time (Söderbaum 1992, Daly 1997). The neo-classical "world-view" is pictured in figure 3.2. It is the author's opinion that this tendency merely reflects the time in which it is situated. Those factors considered in production functions represent scarce or limiting factors, which during the neo-classical era were mainly labour and capital and not natural resources. In the early days of economics, the emphasis was on achieving the greatest return on scarce labour assets; natural resources were in most cases abundant. As Daly (1996) has argued, the limiting factor today are natural resources, more specifically their scarcity, or rather the perception or threat thereof. The productivity of capital and labour has increased rapidly especially in the post-war era: so much in fact that they no longer pose constraints on production. An exception may be the explosive growth of the information technology sector where currently there exists a labour shortage of some magnitude.

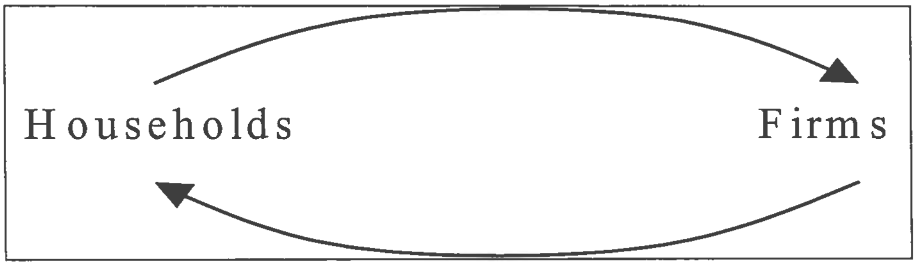

FIGURE 3.2 The circular neo-classical economic model (see for example Estola 1996 or Begg et al. 1997)

Some of the assumptions of the neo-classists, for example the underlying rationale of full employment, came under attack in the inter-war years of the early 1900's. Keynesian economics emerged shifting the focus away from markets and placing a more important role on governments. After the second World War environmental issues and environmental awareness gained wide acceptance and several different economic schools of thought adopted ideas of natural resources into their agendas. The neo-classical tradition saw the birth of environmental and natural resource economics and ecological economics was born with the thermodynamic school.

3.1.2 The theory of externalities

3.1.2.1 Pigouvian taxes

The nature, existence and implications of externalities have a firm role in the economic agenda and have been relatively extensively studied for almost a century (see for example the works of Pigou 1932/1962, Ellis and Fellner 1943, Ayres and Kneese 1969, Baumol 1972)[5]. Basically externalities refer to an uncompensated change in one's utility that can be either positive or negative. In the environmental economics literature externalities are often defined as negative changes that are a cost to society and individuals and a type of subsidy to those causing the externality, mainly polluting firms. An example of an externality in the context relevant for this thesis is for example water pollution. A pulp mill produces a wastewater discharge rich in organic pollutants which causes excessive vegetation in the receiving waters. This in turn depletes oxygen resources in the water and causes harm to the water's biota. These effects decline the utility, or personal satisfaction, previously enjoyed by the residents or recreational users of the lake. This loss of utility has often gone uncompensated. Pigou himself defines an externality

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[5] A good and comprehensive survey of the work on externalities in economic literature is provided by Papandreou 1994.

> *"one person A, in the course of rendering some service, for which payment is made, to a second person B, incidentally also renders services or disservices to other persons (not producers of like services), of such sort that payment cannot be exacted from the benefited parties or compensation enforced on behalf of the injured parties."* (Pigou 1962, p. 183)

Pigou's definition of externalities concentrates on the premise that production output is not at the optimum since firms make economic decisions based on marginal cost and revenue functions. These functions however, do not include the full social cost, or benefit, of production and thus the resulting optimum can not be an optimum in social terms. The efficiency of industries could be increased, or the optimums could be moved closer to a real social optimum by a system of taxes and subsidies levied on the industries. Hence the familiar term, Pigovian tax (Pigou 1962). The optimal Pigovian tax equals the marginal external cost and thus equates the costs borne by society and by polluter arriving at the socially optimal level of pollution. One problem in the framework is the derivation of damage functions, or expression of individuals damage in monetary terms. This problem is also referred to in 3.1.6.

The Pigovian tax scheme aims to arrive at an *optimal* level of pollution. This term has perhaps derived from the firm belief in the markets expressed by the classical and neo-classical economists of the time. However, nowadays it is more often replaced by the term *acceptable* pollution. The latter is also easier to define and determine than the first. Currently instruments closely resembling Pigovian taxes, for example pollution charges, are in use in many countries (Määttä 1999)

3.1.2.2 The theory of assigned property rights

R. H. Coase opposed the economic tradition initiated by Pigou by saying that the *"courses of action are inappropriate, in that they lead to results which are not necessarily, or even usually, desirable"* (Coase 1960, p. 2). In his view, the concentration should not be merely centered around how to restrain the polluter but instead on questioning whether the polluter has the right to cause the externality in the first place. In Coase's view the shift in a situation of negative externalities to the optimum does not require extensive policy action from the government in terms of tax schemes and subsidies. Instead he argues that the problem of social costs can be best answered by assigning property rights, property being any good or resource, also the environment. The sufferer and the polluter could then enter into negotiations and would reach the optimum in terms of the cost and benefit functions of each. The Coase theorem as it has become known states that *"irregardless of who holds the property rights, there is an automatic tendency to approach the social optimum."* If it is correct, there is no need for government regulation of externality, as the market will take care of itself.

The Coase theorem has received much praise but also scepticism. Like much neoclassical economics literature it relies on markets, or more precisely perfectly competitive markets that have often been proven not to exist. In addition the theorem entails bargaining between a restricted number of parties. In reality though, environmental negative externalities usually affect a larger public. In addition the initial assigning of property rights can not be regarded as straightforward. Especially in the case of such common pool, intangible resources as clean air, scenery or clean water, ownership is almost impossible to define. Thus the practical implementation of the Coase theorem is problematic as ownership remains undefined.

3.1.2.3 Overview on externalities

The two points of view presented above, Pigouvian taxation and the Coase theorem, represent two extremes with respect to the treatment of negative externalities. The first relies completely on price adjustments brought about by government legislation whereas the latter relies totally on efficient markets given that resource ownership is defined. Increasing environmentalism of the post-war era has led to legislative and consumer pressure towards the internalisation of externalities for the polluter. The environmental regulation schemes currently adopted in (mostly western) nations reflect to an extent the ideas presented by Pigou. However, there is an ongoing and heated debate concerning the appropriate role of the government in ensuring a decrease in the aggregate amount of externalities and thus there are various positions in-between the presented two extremes. Nehrt (1998) provides a good overview of different regulatory regimes and their effects on a firm's competitiveness.

According to the precautionary principle uncertain negative consequences should be avoided in decision-making. If some decision could lead to a negative outcome, it should be avoided and a safer alternative course of action with known consequences should be preferred. This principle has been the basis or underlying theme of a lot of public policy making, for example in recent European environmental legislation, such as the EC Directive on Packaging and Packaging Waste (94/62 EC) or the German packaging ordinance, Kreislaufwirtschafts-gesetz. The EC Directive on Packaging and Packaging Waste aims to reduce the amount of packaging waste going to landfill sites by setting targets for recycling and recovery. Packaging waste must therefore be re-utilised through recycling and other recovery methods by the year 2001. The aim of the regulations is to ensure that the real environmental costs of producing, using and disposing of packaging fall directly on those who produce or use it. Figure 3.3 demonstrates the rapid growth in new environmental legislation in the EU area.

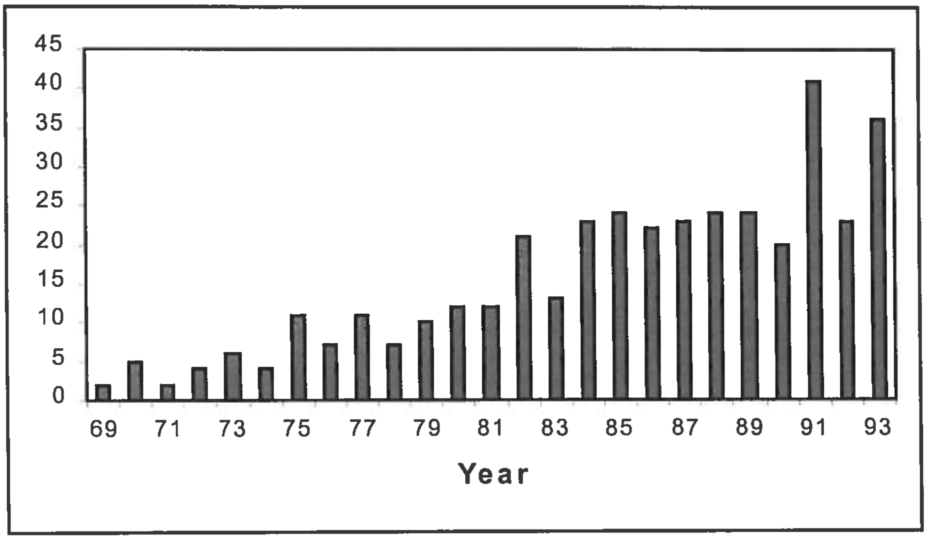

FIGURE 3.3 Number of new EU environmental legislation adopted each year (Source: Lévêque 1996)

The precautionary principle has been relatively widely adopted into policy and business philosophy and has lead governments and firms alike to pre-emptively approach the internalisation issue. Firms increasingly need to make business decisions based not solely on economic criteria but on environmental criteria, values and ethics. Therefore environmental considerations need to be incorporated into the tools that are traditionally used for economic decision making. This thesis is an attempt to provide one such incorporation and show its application areas.

3.1.3 Modern Environmental Economics

Environmental and natural resource economics generally uses traditional economic instruments and frameworks to analyse the economic basis of environmental problems and the optimal handling of public goods (Baumol and Oates 1988, Oates 1992, Hackett 1998). The theory of externalities as well as the notion of dynamic efficiency are recurring concepts in the literature. The field of environmental economics focuses on the polluting firm and its production processes as well as on the optimal control instruments for pollution (Folmer et al. 1995, Pearce and Turner 1990, Tietenberg 1992). It aims to arrive at policy solutions that would remedy the unjust creation of externalities by economic agents. Environmental economics as a field in its own right has been initiated by the early works on externalities presented above. However, environmental economics has for the most part been looking for instruments that would control the quantity of the externality directly rather than through price adjustments as suggested by Pigou (Baumol and Oates 1988). In this sense, Coase can be regarded as an early environmental economist (Massa 1995, Kyrö 1999).

The original idea was that correct economic policies could enhance the quality of life. Attention has been focused on designing optimal regulatory measures to deal with the polluting firm (Baumol and Oates 1988, Tietenberg 1992, Pearce and Turner 1990). Suggested regulatory measures include both economic incentives, or price adjustments through taxes, as well as legal-administrative measures such as permits. One development of the environmental economics school is the recently popularised and implemented idea of tradable pollution permits first suggested in a seminal paper by Weitzman in 1974 (Weitzman 1974).

The "Gestalt" shift from the neo-classical world view to the one held by environmental and resource economists can be seen by comparing figure 3.2 with figure 3.4. The latter has seen the introduction of nature as part of the model. Nature is in direct interaction with both households and firms in providing services, of raw materials and also of waste disposal.

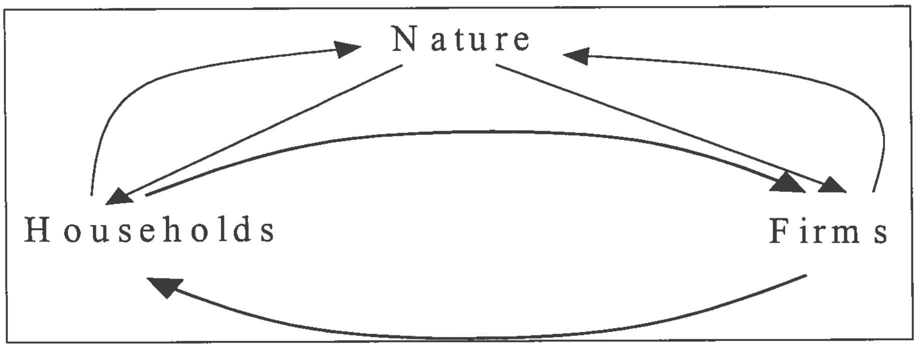

FIGURE 3.4 The economic model of environmental and resource economists (adapted from Callan and Thomas 1996)

3.1.4 Ecological Economics

In its modern form ecological economics aims to take a broader and longer view of the environment-economy interactions especially in terms of space, time and the parts of the system under study (Costanza 1991). The proponents of ecological economics point out that traditional economic models fail to deal with global, long-term ecological problems. Ecological economists argue that a preanalytic vision of a full world is a necessity and that this shared preanalytic vision separates the ecological economists from the conventional or neo-classical economists (Norgaard 2000). The strong coherence around the preanalytic vision has also been named "passion"; another factor setting the ecological economists apart from the mainstream (Norgaard 2000, Max-Neef

2000). Central to the ecological economics school is the thought that in a full world, efficient is not sufficient (Max-Neef 2000).

The ecological economics tradition was initiated by Kenneth Boulding's metaphor of the modern society moving from cowboy economies to spaceship economies presented in his paper *The Economics of the Coming Spaceship Earth* (Boulding 1966). In the paper, Boulding argued that humans had for too long regarded the planet as limitless; a trend which was fast eroding the very systems human existence relies on. He called for a move towards regarding the earth as a closed system. Much in the same tradition were the thoughts of the physicist Nicholas Georgescu-Roegen who introduced the concepts of entropy and also of closed systems to human economic systems (Georgescu-Roegen 1971). Recent advances in ecological economics rely on the same basis, i.e. partially closed systems (with only solar energy coming from outside the system) of increasing entropy, coming up with new metaphors such as the notions of the full and empty worlds (Daly 1996). In his argumentation, Daly states (p. 46) that given that the size of the ecosystem remains constant as the economy grows, inevitably over time the economy becomes larger relative to the containing ecosystem. This he calls the transition from an empty to a full world.

The ultimate goal of ecological economics is to redefine economic growth and chart the way to a sustainable future and also to tackle such issues as appropriate scale and not only dynamic efficiency, but of allocative and distributive efficiency (Daly 1992). The ecological economics field has raised plenty of discussion and brought important topics to general economics discussions. However, it has produced relatively little practical suggestions or constructs either for practitioners or policy makers. This is also partly to the novelty of the field and the immense challenges of incorporating inter-disciplinary ideas into concrete models. Perhaps accountable to that, it is regarded as a marginal group by mainstream economists[6].

3.1.5 Theory of production and the microeconomics of pollution

In the production process, firms turn inputs or factors of production into outputs or products (Cohen & Cyert 1965, Mansfield 1991). Traditionally inputs have been regarded as raw materials, labour and capital investment in equipment and machinery. Outputs have only included products that have positive market value, i.e. those with negative market value have been regarded as costs rather than products. The relationship between the inputs to the production process and the resulting output is described by a production

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[6] The latter comment is further confirmed by discussions of the ecological economics notions and ideas with representatives of mainstream economists at the 49th annual IAES meeting in Munich in 2000.

function. Traditional production functions in economics have been expressed as the relationship between output Q and inputs of capital K and labour L:

(3.1) $$Q = f(K, L)$$

The Cobb-Douglas production function is one specific type of the general function (3.1), written in its common form as:

(3.2) $$Q = \alpha * K^{\beta_1} * L^{\beta_2}$$

,where the βs represent factor shares of income when applied to the economy as a whole. The Cobb-Douglas production function is an explicit representation of a 'law of production' and arguably the closest that economics has resembling laws in natural sciences (McCombie 1998). The Cobb-Douglas function represents clearly the technological relationship between the maximum value of output and the factor inputs, where the factor inputs very closely predict real values. It is a mathematically convenient function form as the exponents, β_1 and β_2, of the factors convey their relative importance and when added up indicate the marginal rates of return of the function. The Cobb-Douglas function is originally a microeconomic concept but aggregations have often been made to reflect a macroeconomic aggregate production function. Empirical estimations of both micro- and macroeconomic production functions have been made (for recent examples see Woolway 1997, Michl 1999).

As natural resources continue to grow scarce and sinks continue to lose their assimilative capacity, there is pressure to price elements of the environment as far as possible. In fact, the idea of adding undesirable output variables into production functions was first stressed in the 1970s by Shephard who stated "*Since the production function is a technological statement, all outputs, whether economic goods are wanted or not, should be spanned by the output vector y.*" (Shephard 1974, p. 205). The addition of environmental variables into microeconomic production functions is a direct consequence of the vivid discussion on externalities demonstrated earlier. Such notions as polluter pays, extended producer responsibility and integrated pollution prevention create new costs for companies that were previously externalised. The changes have also changed the productivity of both capital and labour as the amount of non-zero valued products increases. As the amount of emissions and waste has to be minimised, a situation that only produces the maximum achievable output of wanted products is no longer efficient.

Excluding environmental issues in the production function is also in stark contradiction with the first and second laws of thermodynamics popularised into economic literature by Georgescu-Roegen (1971). Thermodynamic constraints effectively limit natural and economic transformation processes, of isolated or closed systems. The first law refers to the conservation of energy and the second to increasing entropy, or disorder. Energy can neither be created nor destroyed, it can only be transformed by any system. Thus, no economic activity can create energy, it can only transform the energy inherently available in resources into a more economically useful form. The amount of available energy then sets upper limits on the activity. Increasing entropy means that as time goes by, energy will be available in less and less useful forms, meaning that its transformation will become increasingly more difficult.

Theoretically thermodynamic constraints refer to closed or isolated systems. However, as they have been adopted into economic thinking, the assumption of closed systems has been dropped. Economic systems are processes that turn inputs into outputs through some process of transformation. In this sense they can be seen as processes that are governed by thermodynamic constraints. The relevance of thermodynamics to economics has become visibly more apparent with realisation of finiteness of natural resources.

Several authors have proposed models of production that comply with thermodynamic constraints (for examples see Eriksson et al. 1984, Perrings 1986, Ruth 1993). These approaches have often either utilised exergy, or energy-exergy blances or the mass balance conditions as a starting point of analysis. The thermodynamically compliant models are able to decsribe the qualitative transformation of a process and thus indicate gross efficiency of a system. This can be used for comparison of different systems.

The Cobb-Douglas or CES production functions do not set limits on the productivity of the inputs or, theoretically, on the subsitution possibilities of the inputs. This implies that growth is possible. If then the planet Earth is regarded as a closed system with the only input being solar radiation, then any growth rate greater than zero of any one subsystem must happen at the expense of some other subsystem experiencing negative growth (Daly 1996, Perrings 1986). More and more, this has meant that human systems are growing at the expense of natural sustaining systems.

3.1.5.1 Production functions with the cost of polluting

More recent studies have aimed to quantify the cost of polluting or the cost of not polluting to firms in the form of production and cost functions (Pittman 1983, Barbera and McConnell 1990, Färe et al. 1993, Barde 1995, Hetemäki 1996). It has been hypothesised that pollution prevention brings financial benefits for the firm (Porter and van der Linde 1995, Esty and Porter 1998) although the contrary has also been supposed (Jaffe and Peterson 1995, Walley and Whitehead 1996).

Environmental considerations are poorly reflected in traditional production functions; mainly the cost function has been extended to introduce the cost of polluting or the cost of abatement and this is often treated as a fixed input (Barbera and McConnell 1990, Färe et al. 1993, Barde 1995, Hetemäki 1996). It is argued that the mere introduction of those variables in the traditional framework adds essentially nothing new to the theory (Uimonen 1992) in the case that the effluent is priced at its tax. In fact the first additions of environmental variables were introduced in the late 70's. The cost function, however, helps the firm to concretely realise those costs arising from pollution or abatement thereof.

The cost functions have been further worked on as distance functions that reflect the shadow prices of pollution (Hetemäki 1996, Chung et al. 1997). Distance functions give a more realistic picture of the actual cost of pollution in that the effluent is not priced at its tax but rather the price is derived through other variables thus giving the implicit true price of pollution. However, the problem of monetary valuation, referred to in 3.6. remains. Moreover, distance functions are relatively difficult to apply or run decreasing the usefulness of the tool.

3.1.5.2 Fixed coefficients of pollution

3.1.5.2.1 The LCA approach

Environmental life cycle analysis, or LCA as it has become known, studies all inputs and outputs associated with a product system from cradle to grave. Thus the study includes all steps from raw material acquisition and design through manufacturing to end disposal and also recycling and reuse (SETAC 1992, Consoli et al. 1993, Weidema 1997). A simplified version of the product's life cycle is presented in figure 3.5. The LCA has a strong product orientation in that it studies the life cycle impacts of a chosen product. In this sense it can not be regarded as a strictly micro-economic, firm-specific instrument. In fact to succeed, an LCA must be supported by all actors along the life cycle (Schaltegger 1997, Nierynck 1998).

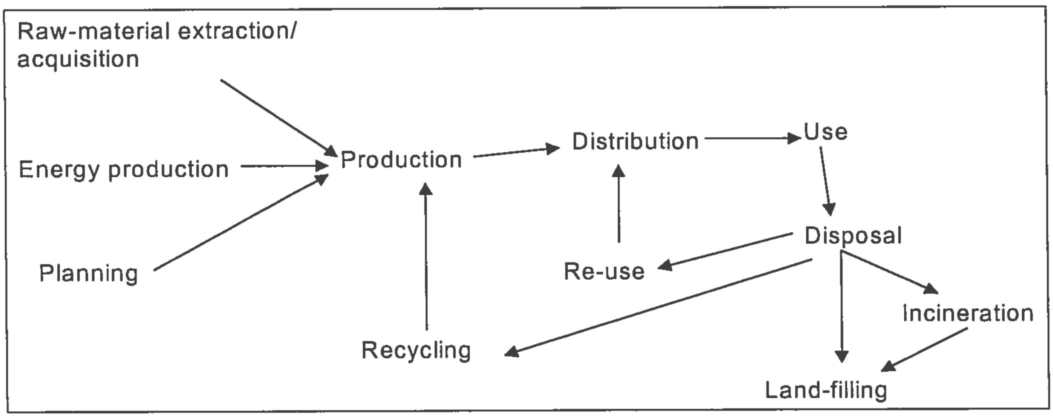

FIGURE 3.5 The product's life cycle

The life cycle analysis (LCA) is based on a collection of equations derived from gathered data, which together form a flowsheet or a mathematical calculation sheet. Basically each process that is included in the life cycle of the product gets assigned emissions based on an emissions coefficient that is multiplied by the production output. The production output is determined by the objective, or functional, unit of the flowsheet. Life cycle analysis assigns fixed coefficients to describe the formation of pollution. In a sense, the coefficients can be regarded as microeconomic production functions, or recipes, as they depict the production of emissions in kilograms as a function of total production output. Each process or black box is thus described with a recipe.

The flowsheet, once successfully calculated, shows an inventory of the inputs and outputs of the studied system. It is not yet an assessment of the system's environmental impacts. The disadvantage of the LCA approach, although intrinsically attractive, is that pollution is only dependent on production output while other variables of the production process are excluded. Thus any improvement in an environmental sense can only be achieved through contractions in the aggregate output of the product system. Another disadvantage is that the LCA does not allow dynamic modelling of change in the real coefficients over time.

3.1.5.2.2 Input-output theory and the environment

Input-output models were originally developed by Leontief to study the production structure of economies (Leontief 1986). Most applications were on a sectoral level showing, in essence, a sectoral production function and production boundaries. The input-output model assumes mathematically quantifiable relationships, more specifically a set of linear, deterministic equations, between the variables and is neo-classical in its approach. Leontief's original focus was on applying the input-output table to study technological change.

The input-output tables treat variables in their physical units. This may have been the models greatest strength but also the reason it came under the critique of mainstream, money-oriented neo-classical economists (Duchin 1998). Originally emissions or other non-marketed environmental considerations were not included in the model. Recent developments have added an emissions matrix to the tables resembling to a large extent the life-cycle modelling approach, where coefficients are fixed (Duchin et al. 1994, Duchin 1998, Holmijoki and Paloviita 2000). The input-output framework has also been adopted to the study of ecological systems incorporating the various flows and interdependencies of the system in the model (Hannon 1991). Some developments have included monetary matrices (Lave et al. 1995, Konijn et al. 1997) almost apologetically to satisfy neo-classical interests.

3.1.5.3 The economic-environmental production function, EEP

Environmental taxes or charges result from actual pollution; a CO_2-tax is a result of CO_2 emissions (calculated on the basis of the carbon contents of fuels) and waste charges are a result of waste transported to landfills. Hence consideration of environmental variables without monetary evaluation would seem sensible. Recently an economic-environmental production, EEP, function (Pento 1998a) has been developed which take into account also environmental variables of the production process in their physical quantities. It studies all inputs and outputs of a production process in the form

$$(3.3) \qquad G(O_1...O_p; O_{p+1}...O_n) = F(I_1..I_k; I_{k+1}...I_m),$$

where the outputs $O_1...O_p$ are products with positive economic value, and $O_{p+1}..O_n$ are emissions and waste. The inputs $I_1...I_k$ are human-made inputs, such as capital and labour, and $I_{k+1}...I_m$ are inputs from the natural environment. Some emissions and waste have either positive or negative value (Hetemäki 1996) while others are still valued at zero, such as for example waste heat. The EEP function is more objective in its treatment of environmental variables as it does not abstract them into money terms. In addition, treatment of the variables in their physical units enables the design of appropriate actions to deal with them.

Uimonen (1992) argues that a joint multi-output modelling, or distance function approach provides various indisputable advantages compared to the approach suggested by the EEP. However, for purposes of simplicity and ease of interpretation it is not necessary to include in models multiple unwanted outputs or effluents. In the case put forward here, one emission at any one time is described as a function of traditional factors of production using a conventional production function approach.

The basic position of complementarity as suggested by Daly (1996) looks at natural and human-made capital essentially as complements instead of substitutes. This means that one factor can not be indefinitely replaced with another and as such there exist limits to substitution and some feasible range of combinations between factors of production, i.e. none of the factors are of any use in isolation. Traditional production functions have failed to take this view whereas the EEP and in theory also the Leontief input-output matrix treat all factors of production as complements. Therefore, the EEP provides a worthy basis for further study of complementarity in economic production theory. This EEP has been further worked on in the form of a Leontief type input output matrix for one or more products (Pento 1998a). This has a direct linkage to current LCA theory as the matrix can be used to arrive at a process material balance.

The EEP is an abstraction of a production system. Theoretically it complies with thermodynamic constraints. The practical application of the EEP, as will be shown later in this study, does not incorporate first or second law constraints. This detachment is justified by the focus of this study, which is not on analysing the qualitative changes in the production system itself but rather on analysing the dynamics of emission creation. The focus is not on the generation or destruction of energy or exergy within the system; for such an analysis first and second law constraints would be crucial. The same model could theoretically be expanded to that but here it is used only to portray the dynamics of emissions creation.

3.1.6 Economic valuation of the environment

All the mentioned regulation instruments and approaches as well as most micro-level decisions of the firm are based on the implicit assumption that the negative or positive externality can be measured using monetary values in order to be able to make cost-benefit trade-offs. After all, the determination of costs and benefits requires a monetary estimation. An exception is the use of LCA, or the inventory part of it, where the different environmental interventions are measured in physical units and compared either in absolute terms or with some assigned weights.

There have been several direct and indirect methods of economic valuation of environmental assets suggested for those assets that are not sold on the free markets. These are the common-pool resources or pure public goods, characterised by non-excludability and non-rivalry (Stiglitz 1998), such as clean air or water, the consumption of which does not exclude another individual from consuming the same resource.

Widely used and accepted valuation methods are for example contingent valuation, hedonistic pricing approach, travel cost approach, willingness to pay and willingness to accept or damage oriented approaches (for discussion and introductions see for example Tamminen 1996, Hackett 1998). Although all methods have been argued to be more or less arbitrary and subjective, several studies continue to be made with the help of these methodologies. Recently valuation methods have been suggested from environmental accounting that use the cost of remediation or the cost of attaining a desired state as the valuation basis (Kloock 1993, Kurki 1998).

Much of the environmental economics literature has focused on providing monetary estimations, often neglecting the physical dimensions of pollution. The application of monetary values makes the study susceptible to substantial price variations resulting in interpretation difficulties (Böning 1994, Vatn and Bromley 1994, Pento 1998b). A prime example of the controversy of monetary measurement is the vivid discussion sparked by the Costanza et al. (1997) paper where the value of the world's ecosystem services was calculated at US$16-54 trillion ($10^{12}$) annually. The use of monetary values suffers from instabilities caused by world commodity prices, inflation and flexible exchange rates.

Monetary valuation suffers not only from variations but also the information value of monetary data can be doubted. Individuals place highly different values on money and as a result, its use to convey meaning and to provide a common ground can be doubted. The ideal solution would allow modelling of environmental issues alongside the economic, in units that are sensible and objective. The latter is a subjective notion, and the suitability depends on the person and the task.

3.1.7 The economic niché of this thesis

The ideas presented in this thesis follow very closely from the neo-classical traditions of environmental economics although some parts have benefited greatly from the ongoing discussions of ecological economics. In a sense it can be seen as a deviation from the mainstream economics tradition since it speaks not of money but of tonnes. In a sense the tools are derived from environmental economics and the philosophies from LCA studies and ecological economics.

It differs also from the mainstram economic traditions in its empirical approach and lack of extensive theoretical model building. The author feels that the simplifications that have been made in terms of the theoretical formulations are more than made up for in the subsequent ease of analysis and application that the model enjoys. Hopefully the reader will also come to share this opinion.

3.2 Strategic thinking

3.2.1 The essence of corporate strategy

Any successful corporation has a set of long-term goals that are a result of the corporation's missions and original business idea. To suit these and to help in their achievement, the corporation develops and follows large-scale, general action plans, or strategies, which indicate how the firm will interact with its environment and what kind of strategic position it wishes to occupy in the competitive market (Bartol and Martin 1994). Strategic management in turn is a managerial process through which corporate leaders formulate and implement strategies aimed at optimising and securing strategic goal achievement, subject to external environmental and company internal conditions. In other words, strategic management is a way of aligning the corporation with its operating environment (Schendel and Hofer 1979).

Strategy can be described in a multitude of ways. For example Mintzberg provides five different viewpoints or definitions for strategy; as plan, ploy, pattern, position, and perspective (Mintzberg 1987). Common to all definitions is the idea that strategy is a conscious choice, purposeful and reflects in consistent patterns of action believed to lead or help in obtaining certain specified goals or results. A good and adequately expressed strategy will help the corporation set direction, focus efforts, define its existence as well as provide consistency in operations. In a sense, the strategy provides a rough roadmap and compass in the competitive terrain.

Strategy formulation is always dependent and embedded in the operating environment of the corporation; it is not shaped in isolation. Therefore, the strategy can also be seen as an answer to the demands in the competitive market. Both radical and incremental changes in the operating environment can and will be reflected in corporate strategy as they, by definition, change the very operating environment of the firm.

3.2.2 The call to re-think strategy

Clearly the postmodern pluralist society has brought issues into corporate agendas that conflict and compete against existing objectives. Environmental concerns are increasingly geared towards firms, which are compelled to project themselves rather as the solution than the cause of the environmental "problem". Very few industries can ignore the oscillation of consumer environmentalism and as a result, corporate environmental management and corporate environmental strategy have gained a foothold amongst other objectives on the management agenda.

Two of the main factors in the firm external environment that have prompted more environmentally sound operations and products are changes in the legislative requirements and changes or greening of consumer attitudes. Most western governments have been active in developing an extensive regulatory system to ensure environmental quality and to define property rights and the rights and obligations of corporations with respect to their activities, neighbours, community and employees. Consumers on the other hand have become increasingly green in their attitudes and require corporations to demonstrate changing values and corporate ethics. Consumer attitudes, are however, rather rarely matched by their actual behavior (Cornwell and Schwepker 1995, Peattie 1995, Ottman 1998). Nonetheless, both changes have had dramatic impacts in the shift of corporations from primarily profit maximising-oriented businesses to businesses that while maximising return also try to minimise environmental harm. Society is a *de facto* stakeholder in environmental business decisions since the firms activities consume public goods and deplete them either directly or though externalities.

An environmental strategy addresses all core elements of the business strategy; from redefining who is the customer, to green product design and appropriate communication and marketing activities. An environmental strategy also focuses on the core objectives of the company and how it defines its existence. The issue is thus no longer merely one of environmental strategy. Managers must recognise that environmental issues require a holistic new total business strategy (Hirschhorn 1994). To be credible and successful in the dynamic and multi-stakeholder market-place, the strategy must be proactive and honest (Welford 1995).

Michael Porter argued in 1980 that the "*essence of strategy formulation is coping with competition*". He identified five competitive forces as these elements of industry structure, intensity of rivalry among existing firms, threat of entrants and substitutes as well as bargaining power of both suppliers and customers. Later on, with increasing environmentalism, Porter claimed the conflict between environmental protection and economic performance as a false dichotomy (Porter 1991), resulting amongst other things from a narrow and static view of competition. In essence, industry competition and thus the shaping of strategy is increasingly defined by forces previously regarded as sufficiently external to not affect corporate decision making in any manner. As Welford (1995) argues, successful environmental management and strategy implementation requires a partnership approach and acknowledgement of all the relevant stakeholders.

A strategic shift towards the increased environmental awareness demands a culture change within the organisation. Changing corporate culture, behavior and even identity is extremely difficult. This is especially true in situations where there is no real resentment or discontent with the current status; as is often the case when speaking of environmental demands affecting strategy and structure. The difficulties are expressed in the words of one of the great early strategists, Machiavelli:

> "*And one should bear in mind that there is nothing more difficult to execute, nor more dubious of success, nor more dangerous to administer than to introduce a new order of things; for he who introduces it has all those who profit from the old order as his enemies, and he has only lukewarm allies in all those who might profit from the new. The lukewarmenss partly stems from fear of their adversaries who have the law on their side, and partly from scepticism of men, who do not truly believe in new things unless they have actually had personal experience of them.*" (The Prince 1513)

3.2.3 The importance of technology

One important component of strategy that has a potential to profoundly change the environmental profile, risks and costs of a company, is its choice of technology and investment strategies (Kotha and Orne 1989). The choice of technology defines to a very large extent whether the company is a trend-setter or first-mover rather than a follower. Process technologies basically set the boundaries and define the production possibilities frontier, PPF, also in an environmental sense and affect all strategic and operating variables in the firm. Environmental, whether clean-up or cleaner production, technologies change the competitive landscape in at least three ways; by creating and expanding market demand, by changing the cost structure of industries, enhancing firms' strategic flexibility and also by making firms more attractive to communities (Shrivastava 1995a). An innovative and environmentally oriented technology strategy then, is one way of answering the changes in the operating environment and, as mentioned, the answer the Finnish pulp and paper industry has chosen.

The resource-based view of the corporation views the firm's resources as the way to achieve competitive advantage (Conner 1991, Barney 1991, Mahoney and Pandian 1992, Prahalad and Hamel 1990, Bartlett and Ghoshal 1990, Nobel and Birkinshaw 1998). Technologies that alter the environmental profile of the corporation can become a key strategic resource factor. The benefits of using such technologies can provide permanent, unique and inimitable competitive advantage for the corporation, its products and its corporate image (Schmidheiny 1992, Shrivastava 1995a, Nehrt 1998).

As will become clear in this thesis, the Finnish pulp and paper industry has embarked on a technology strategy very reliant on frequent technological innovations both in the traditional productive sense as well as in the environmental technology and protection field. The Finnish pulp and paper industry has in general invested very heavily and been very active in new product development to bring about efficiency increases in production as well as decreases in all major types of pollutants (for example Artto 1991, 1997).

Strategy often needs to build on the core competence, the *raison d'être*, of the company. In Finland the core strength to promote innovation has come from the forest cluster which has offered a strong and sufficiently wide cooperation network to carry out extensive product and technology development projects. The cluster has created a national competitive advantage for the industry (Porter 1990). The Finnish core competence can be identified as technological leadership and vast innovative capacity. The American competence for example, on the other hand, lies in serving the large domestic market and creating economics of scale.

3.2.4 The merits of an environmentally oriented strategy

The importance of addressing the interests of different stakeholders has been noticed by the "enlightened" companies (McDonagh and Clark 1995). They have been able to capitalise on environmentalism by reacting to the awareness fast and creating competitive advantage from corporate responsiveness; in essence they have reacted to endogenous drivers. Companies have had to make a crucial decision between staying reactive, defensive and passive or changing the mindset and purposefully capitalising on the seeminglessly unlimited global demand for increased environmental quality. Successful companies are those that have chosen to be proactive whereas those choosing to continue with existing products and existing technologies have become failures and the latter have in time had to react to exogenous drivers.

A proactive strategy on part of the corporation is, by definition, a pioneering strategy. Such pioneering companies and their managers have taken the decision to cease to wait for full scientific understanding or proof of some phenomena but rather to take steps in advance without knowing the exact effects of their actions. A proactive environmental strategy and orientation is undoubtedly good for the firm's image, i.e. brings clear added value to the image, and can be used as a tool for achieving social legitimacy (Shrivastava 1995b, Grolin 1998).

Being responsive to consumer pressures and environmental changes will benefit the corporation as the creation of competitive advantage. The "smart" corporations have also realised that reacting to internal and external environmental demands by increasing the environmental performance or efficiency of the firm is not a goal conflicting with profit maximisation; most increases in environmental performance are a result of traditional efficiency improvements that clearly translate into cost savings.

Nehrt (1998) recognises three factors determining the maintanability of first-mover advantages, in order of decreasing imitability, as the learning curve, the firm's choice of environmental technologies and the firms collection of human and organisational assets that allow cost-reductions, sales-enhancement and pollution-reduction. As with maintaining any competitive advantage, the more unique a position the firm can occupy, the more successful it is.

3.2.5 The regulatory reality

Since the tightening regulatory climate is often raised in the discussions of environmental strategy, it is also mentioned here. Regulation and government power is one important stakeholder in the firms external environment but at the same time it is not the single most significant source of pressure. This has also mentioned previously and pointed out for example by Henriques and Sadorsky (1996). Still perhaps the most well-known argument in the strategic management literature with respect to the effect of environmental regulation is the so-called Porter Hypothesis (Porter 1991, Porter and van der Linde 1995, Esty and Porter 1998). Porter argues that environmental protection can enhance competitiveness of industries and that environmental regulation will boost innovation in technologies and operating practices that translate into increased financial performance.

There is no concensus on the debate whether stricter environmental regulations and consumer demands in fact benefit or hinder the economic performance of the firm (Hart and Ahuja 1996). Both cases have been argued for and against. Regardless of the real nature of the relationship, if there ever can be one, it is certain that these factors influence the competitive climate and the necessary competitive strategies of firms. They do this by introducing new costs and investment demands (for technologies that may or may not be productive) but also by creating new innovation opportunities for cost reduction and efficiency improvements. Increasingly it is seen that reducing wasteful resource flows is in fact a major business opportunity (Lovins et al. 1999) and that wastes and emissions are a sign of poor efficiency and thus an environmental problem but also an opportunity. This is evident from studies that have shown that emissions reduction is most beneficial in financial terms for firms with high emissions levels to start with (Hart and Ahuja 1996). Environmental regulations and consumer pressure have already changed the strategic choices firms can make concerning for example raw material procurement and product design (Smart 1992).

In their thorough review of the win-win and win-lose literature Rugman and Verbeke (1998) found unambigous support for neither position. Instead they developed a framework for analysing the impact of environmental regulation on the multi-national corporation. They found that the real impacts are dependent on an interrelated set of both country-specific advantages and firm-specific advantages but that no universal answer can be given. The effects of environmental regulations on international trade is a field of study in its own right (for a summary see for example Ulph 1999). The trade issue involves such things as optimal timing of innovation, the choice to imitate or innovate as well as purely game theoretic questions (Hanley and Folmer 1998, McGee 1998, Lieberman and Montgomery 1998).

The strategic management literature is distinctly different in its analysis of the economic impact of pollution prevention from the viewpoint of the majority of economics literature. As Nehrt (1998) points out, the main emphasis in the environmental economics literature has been on the domestic US market that has dealt with a command-and-control approach to environmental policy. Not surprisingly, the results confirm that pollution prevention is a financial burden on the firm.

3.3 A note on the role of science in (political) decision making

Existing economic systems fail to incorporate the true, full ecological cost of public goods into product prices and as a result portray many polluting and wasteful goods and services as inexpensive and attractive. Also the tax system, as part of the economic system, has been criticised for subsidising resource depletion and pollution at the expense of penalising jobs and income (see for example Lovins et al. 1999 or Jackson and Clift 1998). These conflicts and demands for changing patterns of behavior have been brought up into the public debate in the past few decades and have created demand for changes in public policy design .

Political decision making and public policy design is a diverse and difficult process with multiple actors and also a multitude of decision making criteria and tools. Basic and applied scientific research is aimed at providing decision support tools and instruments to increase the transparency of the process and to decrease its inherent complexity. Sometimes it is argued, however, that modern science "rarely offers the practical advice that practical men need" (Böhmer-Christiansen 1994). There is still a heavy reliance on "hard" science and facts in the development of environmental policy (Funtowicz and Ravetz 1990) and thus rigid modeling continues to be popular. Hammond and colleagues (1983) identify three classes of obstacles for the use of scientific information on public policy making as situational, cognitive and scientific obstacles and consequently draw a rather grim picture of the potential of science in the formation of public policy.

Since science has become highly specialiced, policies based on so-called scientific evidence often neglect dimensions not covered by that scientific information or knowledge base. The choice of knowledge is often also dependant on the personal scientific background of the policy-maker. A biologist in public or private decision making tends naturally to apply biological knowledge, an economist will tend to favour economic approaches, and so on. Even when the decision making is left to a group of people, there is tendency to converge on some viewpoint as the integration of scientific tools and models is not straightforward. This creates an obvious conflict in the real-world situation where any public decision making situation has become rather more complex than more specialised.

Problem displacement, or the mere shifting, instead of solving, of problems, can be seen as a consequence of specialiced approaches (Jänicke and Weidner 1995). The consequences of problem displacement become more and more visible, above all in environmental issues. The broad public either feels these consequences directly or the message is transmitted through powerful mass media. "Bad" policies are recognised as the driving forces behind the visible environmental problems, which eventually has led to a mistrust in policy-making institutions and to a loss of their legitimacy (Beck 1992). For the institutions to overcome this problem and gain back trust and legitimacy, the decision-making processes need to be improved. This is best achieved by designing integrated policies that do not shift problems from one area to another and that take a holistic approach.

3.4 Economics, strategy and decision-making

This thesis examines the use of an economic model in a strategic decision making situation, hence the introduction of both fields. The Finnish pulp and paper industry has seen a dramatic change in the operating environment and as a result has chosen certain strategic reactions to these changes. The actors in the industry have also demonstrated very proactive strategies, i.e. responses to endogeous stimuli. The attempt is made here to analyse these strategic choices through the developed economic framework.

4 THE FINNISH PULP AND PAPER INDUSTRY

The pulp and paper industry has been the subject of much controversy globally over the past two decades and the Finnish industry has been no exception. Recent developments in society have resulted in increased concern for the "global commons" and the fate of natural habitats. This has put pressure on industries that rely on nature's services. The growing concerns have in part also been captured by legislation in the form of environmental policies and laws governing the use of nature both as a resource and as a sink. The forest sector has had to deal with environmental pressures early on and thus the development of environmental thinking as well as of tools and technology are relatively easy to observe.

The improvements in the environmental performance of the industry are much a consequence of demand pressure from the main markets. The environmental movement in Central Europe and especially in Germany, Finland's largest single export destination, has been strong at times and ensuring a foothold on the markets has meant alteration of the product to meet customer wants.

Some economic research with an environmental focus has been conducted previously with the Finnish or Scandinavian pulp and paper industry as its object. Artto (1991, 1997) has compared differences and changes in competitiveness during the years 1983-1996 across countries, mainly between Finland, Sweden, Canada and the USA. Artto et al. (1979) also studied the environmental costs of the pulp and paper industry among other industries. Palo and Nissilä (1975) studied the economic impacts of paper recycling in Finland. Hakuni (1994) and Helminen (1998) have both looked at efficiency and eco-efficiency. Hetemäki (1996) approached the impact of pollution control with a theoretical distance function approach. Other environment studies, mostly concerned with paper recycling rates and LCA modeling are more common (Huhtala and Saloheimo 1990, Virtanen and Nilsson 1993, Pento 1994, Gronow and Pento 1995, Weaver et al. 1997). The pulp and paper industry presents a large portion of the Finnish industrial structure and is also the main environmental investor in the country. Effective environmental policies require reliable information on policy outcomes. The proposed research widens the current information basis by providing precise, mathematically and empirically, modelled data on emissions. This information will help both policy planning and forecasting.

4.1 Industry characterisation

For most of the last century Finland's economy has traditionally built on forestry related industries, mainly the pulp and paper industry. Only lately the role of this sector in the national economy has become challenged by emerging industries, such as information technology and communications. Currently forestry and forest industries only account for a modest 7% of the gross national product (Sevola 1998). The role of the sector becomes more significant when looking at exports: the share of the forest industries of total exports was almost 30% in 1998. In the 1970's this share was over 50% (Diesen 1998, Kaukiainen et al. 1998). In 1998 the exports amounted to FIM 66,2 billion of which the export of paper was roughly half. The importance of the exports from the forest industry sector are important also for another reason; it requires relatively far less imported raw and auxiliary materials than other exporting sectors of the economy. For the majority the raw material base is domestic, energy is produced domestically or even locally at the plants. The average share of imported goods and resources in the forest industry sector is 15% (Diesen 1998). Due to the lower dependence on imported goods the sector has a significant role in the net currency flows. The most important export markets are Germany (18%), United Kingdom (17%) and France (6%) (FFIF 1998).

Much less recycled fibre is used in the production of paper in Finland relative to that in central Europe. This is directly related to supply factors; the Finnish supply of collected papers is limited whereas the supply of virgin fibres is ample. As a result, Finland is a major producer and supplier of virgin fibres into European markets, creating the important influx of virgin fibers into the waste paper based European paper manufacturing. Without this influx, the quality of the raw material would eventually decline to a level at which it could no longer be used for paper production.

The forest sector has also created a support network sometimes referred to as the forest cluster. Finland has rather long traditions in felling & forestry machinery as exemplified by well-known firms such as Ponsse and Timberjack as well as traditions in paper machinery through the internationally recognised producer Valmet. Tampella and Ahsltrom were previously main players in pulp mill technology and machinery. Jaakko Pöyry Group on the other hand is internationally very well recognised in pulp and paper industry related engineering services. Almost a fifth of the metal sector's output is related to the forest industry sector. The high domesticity of the forest industries sector combined with the domestic complementary or supporting industries creates a strong national and competitive advantage for the sector. The advantages are further accentuated by advanced energy and power technologies.

The pulp and paper industry has shifted to production of higher value added products since the 1960's when market pulp was still exported more than paper and board (Kaukiala et al 1998). In 1999 pulp and paper are exported in roughly the same tonne amounts (Sevola 1998, www.forestindustries.fi 2000). The growth of the production volumes has been dramatic; in 1960 only 2 million tonnes of paper and board were produced whereas in 1999 the figure was almost 13 million tonnes. The recent production increases in Finland are mainly in printing papers at the expense of newsprint. The production of newsprint has largely moved closer to source, to central Europe where collected recycled fibre is available in ample supply.

The Finnish forest sector is dominated by two large companies, in 1999 StoraEnso held 40% and UPM-Kymmene 31% of the industry when measured by turnover. Together with Metsäliitto Group the three largest corporations control roughly 92% of the market. Both largest companies have since then merged with major American firms forming some of the world's largest pulp and paper companies[7].

4.2 Production methods and main sources of emissions[8]

Pulping can be either mechanical or chemical. The majority of Finnish pulp is manufactured with the chemical process (7 million tonnes in 1999 or 60%) and the remaining 40% or 4.6 million tonnes with mechanical processes. Chemical pulping uses de-barked and chipped birch and pine that are cooked in a cooking liquor to separate lignin from wood fibres. The main cooking chemicals are sodium hydroxide and sodium sulphide. In Finland, only the sulphate process has been used since 1992. The resulting pulp is bleached with oxygen, hydrogen peroxide and chlorine dioxide. No elemental chlorine is used in bleaching and many mills today opt for TCF (totally chorine free) bleaching. The chemical pulping process produces a black liquor which is collected, the chemicals are separated for re-use and the dissolved organics, i.e. unused parts of the wood, such as bark and chips, are used for energy recovery. As a result, chemical pulp mills are more than energy self-sufficient and in most cases produce district heating and electricity for the locality. Other side products of

[7] Press releases of the mergers are available at www.storaenso.com and at www.upm-kymmene.com. The UPM-Kymmene-Champion merger was, however, later cancelled after disagreements over appropriate acquisition price.

[8] The main sources relevant for this section are Ryti 1989, Krogerus and Hynninen 1992, Biermann 1993, Vehmas 1994, Seppälä and Jouttijärvi 1997. EIPPCB 1999, and www.forestindustries.fi. These sources will not be repeated throughout this section.

the chemical process are tall oil, turpentine, resin and certain sitostanols, which all have positive economic value.

Mechanical processes mechanically grind the wood with the help of steam to make pulp. Sometimes the process is enhanced by the use of pressure (PGW), pre-cooking or steaming (TMP) or pre-cooking with chemicals (CTMP). The raw material yield of the mechanical process is higher than that of the chemical process, producing twice the amount of pulp from the same raw material, but requiring substantial amounts of external energy. The main wood for mechanical pulping in Finland is spruce.

Felling and transportations aside, the main emissions from pulping processes have to do with oxygen depleting pollutants to water and sulphur compounds to air and nitrogen emissions from energy production. The oxygen depleting substances are mainly dissolved during the pulping stages and consist to a large degree of carbohydrates and are measured by BOD and COD. Solids emissions to water are a result of bark, fibre (and fillers in papermaking) released into water and consist mainly of nitrogen and phosphorus and cause excessive vegetation. Since the early 1990's there are practically no elemental chlorine emissions (AOx) from bleaching. Negligible amounts of chlorine are released from the raw material itself and some are formed in the process. Most of the sulphur derives from the sulphur containing chemicals during cooking. Even small amounts of reduced sulphur compounds (malodorous gases mainly mercaptans) released into the air can be sensed by the human nose. These compounds, once in the air, quickly oxidise and become sulphur dioxide, which is far less detectable by nose. Sulphur oxides are also formed during energy production from sulphur containing fuels and from the incineration of malodorous gases. Nitrogen oxides are formed during energy production.

Water emissions have been dramatically reduced with active sludge treatment of wastewaters. Modern activated sludge treatments can remove 95% of BOD_7, 40-70% of phosphorus and 30-50% of nitrogen (EIPPCB 1999). Sulphur dioxides can be removed with for example electrostatic precipitators. The removal of nitrogen from air emissions is not possible with the same methods as for sulphur. These are examples of end-of-pipe treatments for pollutants. However, there are increasing efforts to search for integrated clean production techniques that eliminate waste formation during processes removing the need for EOP treatments.

4.3 Finnish environmental legislation

Finnish industrial environmental legislation uses both economic and legal-administrative regulation to deal with environmental problems (Rautio 1997, Määttä 1999). The pulp and paper industry is subject to the carbon tax calculated on the basis of the carbon content of fuels. More importantly, the industry is subject to pollution permits, or rather permit levels for major controllable water and air emissions. The permit levels are set separately for each mill taking into consideration plant specific attributes and possibilities for emissions reductions. Permit levels are set for three-year periods after which the emission levels are re-evaluated. Permit levels may not be exceeded, even temporarily, however pressing the reason (Rautio 1997). If limits are exceeded, the actor must immediately inform the relevant authorities and undertake action to remedy the situation.

Mills employ mainly self-monitoring according to guidelines stipulated in the permit by the relevant authorities, the Ministry of the Environment and the Finnish Environment Institute. The authorities have been successful in standardising the methods and practices used for monitoring and thus the data is comparable within the country. The mills are then required to report their monitoring results to the authorities and all data will subsequently be places in public databases and is available to all. The public databases are maintained by the monitoring authorities and the national statistics centre, Statistics Finland.

So far there is no continuos measurement of emissions as it would be very costly. Water emissions have been regulated and monitored for the longest time period and also the measurement instruments are relatively reliable and well developed. Measuring air emissions from smokestack samples is still today subjective to large variations and thus the data can not be regarded as reliable as the data for water emissions. Measurement of air emissions is also more costly than that of water emissions.

Another area of environmental legislation affecting the pulp and paper industry is those laws governing the harvesting of virgin wood. Already in 1928 legislation was passed that obliges forest owners to ensure that harvested forests are regenerated (PI-Consulting 1997). The law, although primarily affecting local forest conditions also prohibits excessive clear felling on a national level. In addition, roughly 10% of Finland's forest area is under protection from all types of commercial use.

In addition to official, compulsory regulation, plenty of voluntary certification and management system schemes have been adopted in the Finnish pulp and paper industry. Most mills have adopted environmental management systems according to either ISO or EMAS requirements. Also most products are eco-labelled by governmental, objective, criteria and institutions. There are also various certification schemes with respect to forestry practices. Currently 180 000 forest owners have taken part in the Finnish Forest Certification System, FFCS (www.smy.fi/certification/suo/ 2.4.2000). The certificate ensures that the forests are managed and used in a sustainable manner.

Sustainable forest management, or harvesting below yields, means that the stock of natural capital, or the resource grows. This in turn means that the forests are able to bind more CO^2 from the atmosphere. Forests, and especially since the resource base is growing, are an important sink in the country's carbon balance.

5 BOD_7 PRODUCTION FUNCTION OF THE FINNISH PULP AND PAPER INDUSTRY

Karvonen, M-M[9].

Abstract

Traditional neo-classical production theory analyses the relationship in a production process between inputs and outputs, which have a positive market value for the producer. The externalities of production, which have non-positive market values, are discarded, or are included as a cost in a cost function. This paper studies the relationship between BOD_7 emissions, i.e. an output of non-positive value, and the more traditional factors of production, i.e. investments, labour, output and raw materials. An emissions production function is theoretically presented and empirically estimated with data from the Finnish pulp and paper industry. The approach is based on the observation that it is the minimisation of effluents rather than, or together with, the maximisation of yields, which increasingly defines the technological frontier of production processes and of production functions. As such, these variables should be an explicit argument of the production function. The empirical function estimation demonstrates the validity of the proposed novel modeling aproach. Results show that during 1972 and 1998, technological development enhanced environmental performance at a pace greater than the increased environmental burden caused by increased production allowing growth with minimal increases in pollution.

JEL: O40/Q20

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[9] An earlier version of this paper was presented at the 49th IAES (International Atlantic Economic Society) Conference, Munich March 14-21, 2000. This paper will be published in *International Advances in Economic Research,* Vol. 7 No 2, May 2001.

5.1 Introduction

Technological development has in many industries and in many countries accelerated in the past decades. In some countries, as in the case of Finland, the growth of industrial output and technological development as its by-product has been especially pronounced in the post-war years. At the same time increasing environmentalism has urged industrial designers and planners of new technology to incorporate aspects of environmental management and protection into new technologies that are introduced to the market.

Emissions are an unwanted product of the production process of goods. They can be eliminated either by improving the process to produce less waste and emissions or by installing equipment that handles the emissions in some sensible way. It is rather obvious that for example the amount of labour does not have a bearing on emissions reduction. The choice of raw materials and energy as well as the choice and age of technologies on the other hand are decisive. This analysis focuses on the pulp and paper industry in Finland. Due to the abundance of virgin wood fiber as raw material, non-wood fibers are not used in pulping or are used only to a negligible extent. The analysis here focuses on the effects of investments on both the emissions formation in the industry as well as on the use of wood fibers and the need for labour. It is assumed, a priori, that technological development is the most decisive factor in shaping the emissions profile of the industry.

The age of a mill or of its production equipment is a direct reflection of its level of technology: the latest technology is also the most advanced. Figure 5.1 shows the cumulative pulp production in Finland in thousand of tonnes on the horizontal axis and the BOD emissions per tonne on the vertical axis. The data points reflect individual mills. Figure 5.2 on the other hand plots the normalised values per unit output of four water emissions for the same 14 pulp mills in the sample in order of increasing mill age, i.e. mill 1 is the "youngest" and mill 14 the "oldest". In essence, figure 5.2 is a plot of the "age" of the mill against relative emissions. The age is a "guesstimate" combining data on actual mill age with major expansion, retrofitting and environmental investments. Clearly the oldest mills are the most polluting.

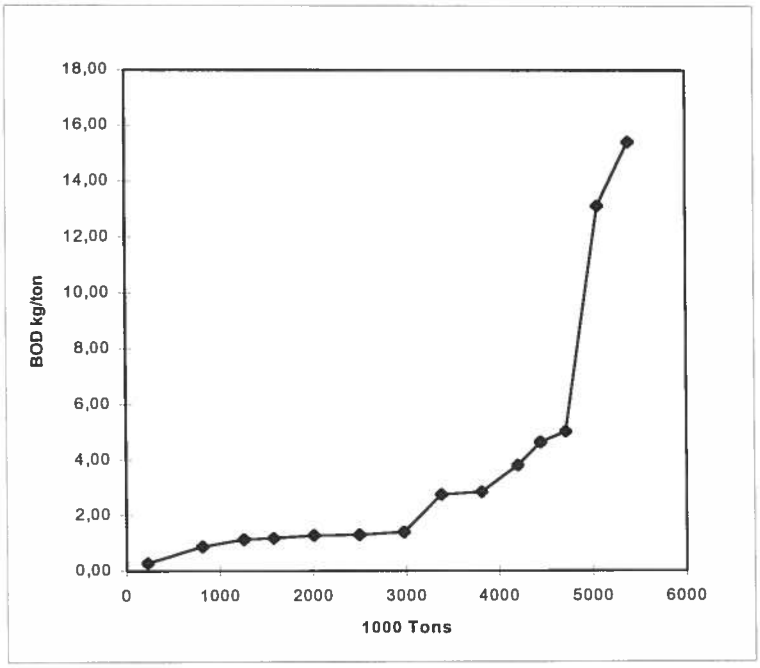

FIGURE 5.1 Cumulative pulp production and BOD7 emissions; a sample of 14 Finnish pulp mills in 1994.

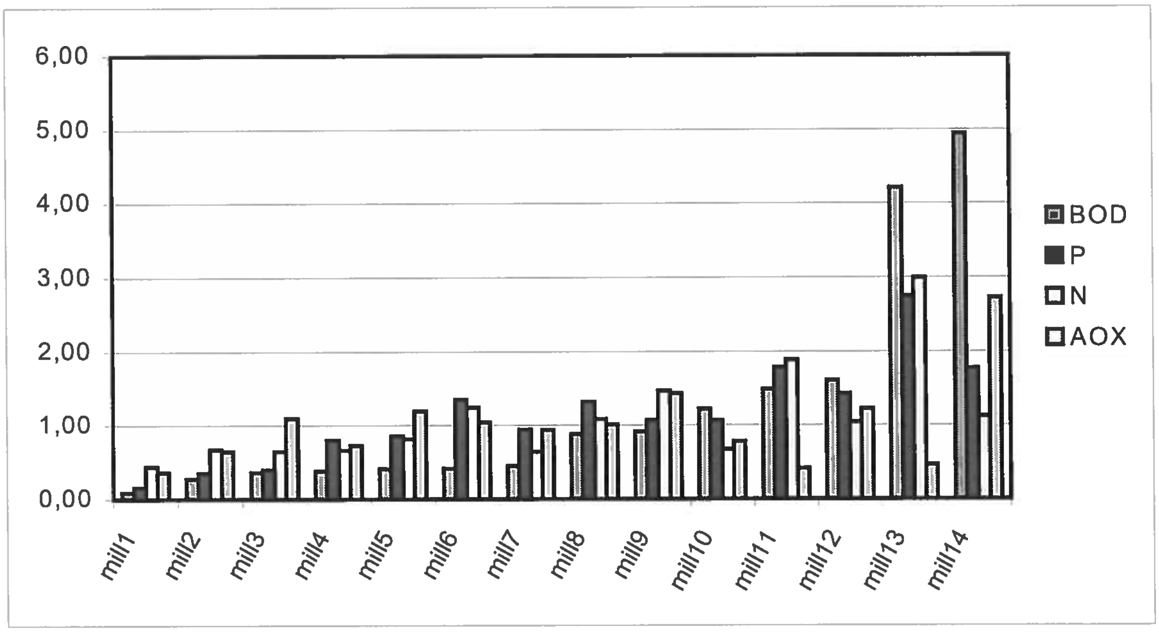

FIGURE 5.2 Normalised water emissions coefficients of 14 Finnish pulp mills in 1994; in order of increasing mill age.

Figures 5.1 and 5.2 are clear evidence that technological development, here reflected in the age of the mill, is the main determinant of the level of pollution. This paper starts on the premise that technological development, or mill age, is the determining variable with respect to the emissions profile of a modern pulp mill. Mill age is not a particularly straightforward variable to measure or to use.

As a result, the analysis here will focus on cumulative investments and their effects on the improvement of environmental performance.

Cumulative capital investments can be seen as a proxy variable of technical development. Indeed the age of the production equipment is strongly associated with the amount of effluents, which are emitted per each unit of output. Capital investments, rather than equipment age is selected as a variable here because of the ambiguities in defining the actual age of a digester or batch cooker, vis-a-vis the continuous improvement investments. There have been attempts at defining a so-called technical age of a production facility. However, those type of calculations abound in ambiguities and thus are not employed here. The main aim here is to build a quantitative model that describes the emissions production in the industry. Since the age of the mill is difficult to define universally, it cannot be used in the building of the model and therefore capital investments are substituted for age.

A production function is a technological statement or a model describing, through simplification, real life phenomena. Models are an essential tool for comprehension of complex systems and for choice making under alternative uncertain actions (Costanza and Ruth 1998). There is relative abundance with respect to environmental-economic production theory that ranges from the analysis of externalities (Pigou 1932) to the inclusion of the cost of emissions as a restrictive factor (Baumol and Oates 1988, Pearce and Turner 1990). Natural production functions have been introduced in conjunction with studies on optimal resource harvesting, mainly of fisheries (see for example Tahvonen 1989). These functions tend to describe, as a traditional production function does, the production of desired output, or the growth of the population, under polluted conditions.

Several different alternatives for presenting environmental variables, mainly emissions, in the economic theory of production have been suggested. They are helpful in demonstrating the logical sequence leading to the approach taken in this paper. Production functions are models, and based on these prior models, a new and hopefully improved model is developed here. This model takes a new approach to the problem of including environmental variables in production theory and includes emissions as a restrictive factor. The production of pollution is examined in the context of the normal operating of the system. In the next section the data as well as the variables used in the study and their composition is explained. The chapter then goes on to demonstrate how the new model is built and also shows the empirical estimation of the model parameters. The main concerns with respect to statistical regression analysis are dealt with. The chapter then concludes with a discussion of the main findings and conclusions.

5.2 The data and the variables

The study includes Finnish integrated and non-integrated pulp and paper mills for which time series data from 1972 to 1998 is used. The data on which the study is based has been collected by the Finnish Ministry of the Environment and The Finnish Environment Institute during permit compliance checks as well as the Finnish Forest Research Institute. According to Finnish legislation each mill receives a permit with plant specific standards for major air- and water-borne emissions and effluents to be updated every three years. Compliance with permit levels is controlled by regular measurements. The measurement data over a year has been first cleaned of the effects of other products, and then averaged for the mill over the year.

For the last decades the Finnish pulp and paper industry has been dominated by a few larger companies. Today Stora-Enso and UPM-Kymmene are the main players, which in 1998 constitute almost 80% of Finland's paper manufacturing capacity and almost an equal share of the pulp capacity (FFIF 1998). The pulp and paper industry presents a large portion of the Finnish industrial structure and is also the main environmental investor in the country.

The analysis here focuses on one effluent, BOD_7, which indicates the amount of oxygen necessary for bacteria to consume the organic material released into water. Discharged organic materials cause rapid increases in the growth of microorganisms that in turn deplete the oxygen resources available for aquatic life (Biermann 1993). The chemical pulp and paper industry still accounts for roughly half of the BOD load of Finnish water bodies (FFIF 1998). Publicly available data on two water emissions, BOD and solids, dates back to the year 1950. Here, the data has been obtained directly from the Finnish Forest Industries Federation. The water emissions, especially BOD, mainly result from the pulping stage and not papermaking as the latter is more able to utilise closed water cycles.

The pulp and paper industry is capital-intensive. The natural investment cycles are relatively long, ranging on average between 6-15 years in Finland. The effects of any new investments penetrate a number of years and not merely the year in which the investment was made. In fact, the real effect can oftentimes only be felt *ex post facto*, after the investment has been in operation for a certain period of time. This is especially true in the case of most investments with an environmental impact. This spreading of the effect over a number of years is partly a result of learning; i.e. it takes time before the best results from a new investment can be reaped. So a new investment will be able to increase efficiency for a few years before the effect levels off.

In this analysis, cumulative investments are chosen as one of the independent variables. It is assumed that cumulative investments reflect the development of the industry better than yearly investments, even if the latter were to be treated as lagged variables. Investment figures are obtained from the Finnish Forest Research Institute. The investment figures include traditional, both replacement and expansion investments, as well as environmental investments, both in end-of-pipe and process integrated technologies; in short, all capital expenditures in the industry. In this analysis it is assumed that each capital stock is used on average 25 years after which its value has depreciated substantially and the equipment is replaced. The cumulative investment is thus calculated as the sum of the investments of all past years, with an annual discount factor of 15% applied to all. This depreciation rate is rather high in international comparison. Investment figures are deflated with the base year of 1998. The deflator is adapted from the official general money value or price index tables of Statistics Finland. It was not seen as necessary to use specifically the deflator for investment goods.

Production figures are from the Finnish Forest Industries Federation. The variable "tonnes" is the combined production in thousands of metric tonnes of pulp, paper and paperboard in Finland. Most of the pulp produced in Finland is domestically made into paper and paperboard. Naturally some double-counting is introduced since pulp is used as the base raw material for papermaking. However, since the two processes are separate, double counting does not affect the results to any significant extent and it appears that the use of total production or pulp production only will yield highly similar results.

Labour figures are obtained from Statistics Finland and include the number of persons employed, full-time per annum in the pulp and paper industry in Finland. It does not include persons employed in supporting industries, such as forestry or transportation of the goods. A renewal to meet ILO and EU definitions was made in the labour force survey during 1997-1998. The data used here has been updated since 1989 to meet these definitions. However, the effect of the change in the accounting procedure is negligible and can be only mentioned here.

The wood raw material figures include industrial thinnings and seed tree, shelterwood and clear fellings. The main species are pine, spruce and birch. Wood raw material figures are reported in cubic meters (m^3). The data has been obtained from the Finnish Forest Research Institute.

Table 5.1 shows the descriptive statistics, the means and the variances of the variables.

TABLE 5.1 Descriptive statistics of employed variables

Variable	Mean	Std. Dev.
E, BOD_7 emissions, thousands of (metric) tonnes	197,89	143,82
K, indexed (1998=100) cumulative capital investments depreciated at 15%/a, FIM million	27 590,89	10 738,18
V, virgin raw material, m^3	3 045,85	1 136,09
L, labour, number of people	29 488,41	4 405,18
Q, combined production of pulp and paper, in thousands of (metric) tonnes	15 592,85	4 131,87

5.3 The theory of production

The traditional economic production function discards environmental interventions, and shows the maximal amounts of "valuable" outputs, which the producer can make of a given set of "costly" inputs (Cohen and Cyert 1965, Mansfield 1991, Chung 1994):

(5.1) $$g(O_1 \ldots, O_p) = f(I_1 \ldots, I_m)$$

The boundaries of this function are defendable on the grounds that the producer makes economic decisions, and free goods do not affect the outcome of the decision. However, this function is not applicable to most industries today, in which the cost of abatement of environmental interventions has become very high. For example, the rule of thumb is that the costs of installing air and water cleaning equipment adds an extra 15 percent to the investment costs of a modern pulp mill (Metsäteollisuus 1995), and the running of the equipment is a sizable and increasing cost to the mill. In response, the economic costs of the emission outputs have been included in (5.1) by considering them as a cost together with the inputs. Such formulations are common, for example, in studies whose objective is to define an optimal tax rate for polluters (Barbera and McConnell 1990, Färe et al. 1993, Hetemäki 1996). Work along this line has modified (5.1) by including unwanted outputs which have negative economic value to the firm, and by grouping them with inputs (Pittman 1983, Gollop and Roberts 1983, Jorgensen and Wilcoxen 1990, Barde 1995).

The other objection to using (5.1) is theoretical. Over twenty years ago Shepard saw the need to include both economic variables and emissions in production functions: *"Since the production function is a technological statement, all outputs, whether economic goods are wanted or not, should be spanned by the output vector y."* (Shepard 1974, p. 205). Environmental variables are rarely included in economic models in practice (Forssell and Polenske 1998, Pesonen 1998). It is also argued that the inclusion of an effluent in the production function, when treated as an input and priced at its tax, adds nothing essentially new to the traditional theory (Uimonen 1992).

A general economic-environmental production function, or EEP, of a production process (Pento 1998a) incorporates emissions in their physical units without assigning arbitrary subjective notions, such as money values. It can be expressed as the relationship between outputs with either positive or non-positive market value, and inputs that are either natural or man-made:

$$(5.2) \qquad g(O_1 ..., O_p; O_{p+1} ..., O_n) = f(I_1 ..., I_m; I_{m+1} ..., I_k)$$

in which the outputs O_1 ... O_p are products with non-negative economic value, and O_{p+1} ...O_N are emissions and waste, which may or may not have a negative value for the producer. The inputs I_1... I_k are human-made inputs, such as capital or labor, and I_{k+1} ... I_M are inputs from the natural environment. The outputs of non-positive value are not retained in the process and become environmental interventions in the form of emissions, waste, noise etc.

Optimization of the function (5.2) requires maximising the positive outputs (O_1, .., O_p) while at the same time minimising the environmental interventions (O_{p+1}, .., O_N) as well as those inputs, human-made and natural that have a positive market value (I_1, .., I_m, I_{m+1}, .., I_K).

The use of this function (5.2) as a technological statement in place of (5.1) can be well justified by observing how the technological frontier of a production process, or a product, is no more defined by economic and technical variables, but is effectively constrained by the environmental demands. The economic performance of engines or power plants would be much higher, were it not for the catalytic converters and scrubbers and like, and the yields of pulp mills would be higher if active chlorine could be still be used in bleaching pulp (Gullichsen, unpublished). Increasingly, the technological frontier is defined by environmental considerations, rather than economic.

Traditionally the objective has been to maximise the function output of the desired output product(s) or (O_1, .., O_p) following the earlier notation while respecting the limits set by economic demands. Concentration has been on estimating (5.1) whereas the focus on this paper is on estimating (5.2). Here the aim is on minimising the function outputs or emissions. Within a given production infrastructure, emissions and output quantities move in the same direction: when output increases so do emission levels, and optimal solutions in both terms are not feasible.

5.4 The Model

Distance functions have been used in the derivation of shadow prices for the 'bads' created in the production process (Färe et al. 1993, Chung et al. 1997, Hetemäki 1996). The main advantage of a distance function is that it allows the modeling of joint production of multiple outputs (Uimonen 1992). It also makes it possible to model 'bads' as not freely disposable, and to derive shadow prices for the undesired product (Färe et al. 1993). Distance functions have the main drawbacks of being tedious to execute and their relatively poor empirical applicability when compared with traditional cost and production functions (Uimonen 1992, Hetemäki 1996). Distance functions rely on monetary figures, which can introduce significant bias in studies, during analysis, interpretation and application and thus further reduce the applicability of results (Böning 1994, Vatn and Bromley 1994, Pento 1998b). The results of such an analysis are difficult to interpret and have questionable practical relevance.

Some literature has moved away from monetary estimation and started on the premise that discharged emissions (E) reflect the efficiency of a production process and defined emissions as some function of output or E = f (Q). This approach suggested by Clift et al. (1999) defines independent variables as the functional outputs ($x_1 \ldots x_i$) and the dependent variables as the environmental interventions ($B_1 \ldots B_i$). Inputs into the process are not included. The model then includes J such equations:

(5.3) $$B_j = \varphi(X_1 ... X_j) \qquad (j = 1 \ldots J)$$

However, in this formulation the reduction of environmental bads is only possible through the simultaneous reduction in the desired outputs as no other independent variables are included (Chung et al. 1997). This makes the approach unnecessarily restrictive.

In the early days of production theory development, natural capital variables did not restrict production whereas capital and labour posed limitations (Boulding 1966, Daly and Cobb 1990, Daly 1996). With current legislation and constantly increasing legislative and consumer pressure, environmental restrictions severely limit the firm's production choices. Moreover, most industries have become sufficiently automated to remove the availability of labour as a production constraint. This is not to say that labour is redundant but rather that labour resources no longer constrain industrial activity. It is argued that natural resources are rapidly declining (Meadows et al. 1972, WCED 1987, Tietenberg 1992). However, the observed fluctuation both up and down in most commodity prices can not be attributed to decreasing natural capital stock.

Emissions are regarded here as a restrictive factor of the production process along with investment capital. In this approach, emissions are valued in their physical units, i.e. not abstracting them into monetary terms. The familiar production function framework is used and the goal is to look at the implications emissions have on marginal factor productivity. The restrictive nature of emissions would justify their inclusion as a factor input rather than an undesirable factor output. Thus the general form of the studied function could be re-written

(5.4) $$Q = f(K, E)$$

However, emissions are not, and should not be treated as an independent variable as that would not reflect their true nature; i.e. that emissions are a function of the original production process, very much in the same way as the desired output. Thus if Q = f(K, L), and E = f(Q) then it must hold that

(5.5) $$E = f(K, L)$$

The optimisation of this function involves minimisation of E, emissions, which is the opposite of the traditional production function, which maximises output. From this (5.5) philosophical statement, there are two alternative avenues to proceed with. One is through simplification of the model and one through extension of it. The extreme simplification is justified by an economic analysis. However, to test the validity of the simplified model, it is necessary to also build and test models with multiple regressors and compare which of the models achieves greater accuracy in prediction of real values. Starting with the simplest model and going towards larger models makes it easier to see the real value of adding new regressors to the model.

Equation 5.5 serves as a starting point. As stated earlier, labour no longer restricts production and thus it can be excluded from the function reducing the equation to:

(5.6) $$E_{it} = f(K_t)$$

where E_{it} is emission i at time t and K_t represents deflated cumulative investments at time t. It is assumed, *a priori*, that a firm's investments in new type of production technology will decrease emissions per unit of output. This will lower the actual emissions, and will make it possible for the manufacturer to increase his production without exceeding the limits which are set for him by the authorities, thus effectively decreasing the restrictive impact of pollution and increasing marginal returns of other factors of production. As a result, in this framework any partial derivative of 5.6 must be negative, $\partial f_K < 0$.

This first simplified model, 5.6., as well as all the subsequent, elaborated, models are estimated assuming (i) linearity in the variables and (ii) linearity in the parameters but non-linearity in the regressors. The estimation of 5.6 is thus done here first in linear format

(5.7) $$E_{it} = \alpha + \beta \sum_{t=1}^{n} K_t$$

and according to the Cobb-Douglas production function, representing a first-order approximation:

(5.8) $$E_{it} = \alpha \sum_{t=1}^{n} K_t^{\beta}$$

Empirical estimation of 5.8 requires taking logarithms, transforming the EEP function to:

(5.9) $$\log E_{it} = \log \alpha + \beta * \log \sum_{t=1}^{n} K_t$$

For the purposes of being able to make predictions concerning the potential future level of emissions, the above Cobb-Douglas function with only cumulative investments may be too restrictive. As a result, another function is also estimated that includes the combined production quantities of pulp and paper (*Q*) alongside investments:

(5.10) $$E_{it} = f(K, Q)$$

Equation 5.10 serves as a basis for an elaborated more holistic model also, which through the inclusion of additional variables aims to gain better insight into the process. This solution includes as many variables as can be measured reliably, for which data is available and that are variables in the production process. In this case then the emissions are modeled as a dependent variable of production, investments, labour (*L*) and wood raw material (*V*):

(5.11) $$E_{it} = f(K, Q, L, V)$$

All models are empirically estimated in multiple linear regression with the ordinary least squares methodology. Table 5.2 shows the OLS estimation results; the goodness-of-fit, R^2-, values, and results of the main statistical validation tests. Most of the coefficients show no large surprises. As was expected the coefficient for investments is negative since they effectively decrease emissions. Production figures are a reflection of capacity increases through technological change, i.e. through investments in new technology. Here the productive capital stock has increased at a pace greater than the increasing production would have contributed to increased pollution, thus the coefficient is negative. The sign of the coefficient for production quantities seems intuititively odd, meaning we would expect increasing quantities to increase pollution. The negative results here reflect the fast pace of technological change.

TABLE 5.2 OLS estimation results for production functions. Standard errors and t-values in parentheses. * *p*-value in parentheses

Variable	$E=\alpha+\beta K$ (5.7)	$E=\alpha*K^{\beta}$ (5.8)	$E=\alpha+\beta K+\gamma Q$ (5.10)	$E=\alpha*K^{\beta}*Q^{\gamma}$ (5.10)	$E=\alpha+\beta K+\gamma Q+\lambda L+\omega V$ (5.11)	$E=\alpha*K^{\beta}*Q^{\gamma}*L^{\lambda}*V^{\omega}$ (5.11)
Constant	562,55 (12,8; 43,98)	18,87 (2,42; 7,90)	600,29 (16,40; 36,60)	36,84 (3,04; 12,13)	543,52 (116,78; 4,65)	-25,54 (18,45; -1,38)
K, capital investments	-0,0132 (,00043; -30,514)	-1,38 (0,24; -5,78)	-0,011 (0,001; -15,87)	-0,39 (0,206; -1,884)	-0,011 (0,0008; -14,489)	-0,47 (0,18; -2,48)
Q, production	n/a	n/a	-0,006 (0,002; -3,11)	-2,91 (0,432; -6,738)	-0,0045 (0,0031; -1,451)	-0,679 (0,75; -0,91)
L, labour	n/a	n/a	n/a	n/a	0,0014 (0,0026; 0,555)	4,05 (1,19; 3,41)
V, raw material	n/a	n/a	n/a	n/a	-0,00462 (0,004; -1,1187)	-0,01 (0,10; -0,15)
R^2	0,973	0,572	0,981	0,852	0,982	0,903
Adjusted R^2	0,973	0,554	0,980	0,840	0,979	0,886
Durbin-Watson	0,964	0,113	0,990	0,453	1,0199	0,444
F-statistic *	931,125 (0,000)	33,353 (0,000)	631,68 (0,000)	69,00 (0,000)	308,74 (0,000)	51,442 (0,000)
Breusch-Godfrey LM (for serial correlation) χ^2*	10,36 (0,006)	21,18 (0,000)	10,69 (0,005)	15,88 (0,000)	10,48 (0,005)	18,29 (0,000)
White's test for hetero-scedasticity χ^2*	4,67 (0,097)	8,7 (0,01)	4,44 (0,488)	5,51 (0,357)	12,69 (0,55)	14,94 (0,38)

5.4.1 Statistical validity

The more holistic model (5.11) with its high explanatory R^2 -value but relatively few significant t-ratios suggest multicollinearity between the variables, i.e. that there exists a linear relationship between one or more of the regressors. Multicollinearity is a characteristic of the data and results in large variances and covariance's for the OLS estimators and as a result, confidence intervals are wider and t-values lower. However, multicollinearity does not violate any of the assumptions of regression and only results in fewer coefficients with small standard errors (Achen 1982). This same problem can be equally well caused by a small sample size for example. In this case the correlation coefficients between the independent variables are between 0.3 and 0.8 in absolute values. For all practical purposes here, multicollinearity is not a problem but rather serves to validate the main argument.

Both the Durbin-Watson test for first-order serial correlation and the Breusch-Godfrey Lagrange multiplier test for general, high-order serial correlation are used. The B-G test multiplier is assumed to follow a χ^2 distribution under the null hypothesis of no serial correlation. The Breusch-Godfrey test overcomes some of the constraining assumptions of the Durbin-Watson. In all except one of the explored models there is presence of autocorrelation. This is only logical since the models employ a cumulative additive variable, investments. Since a cumulative variable is by definition non-decreasing it is only to be assumed that the residuals will be time-correlated.

Heteroscedasticity is tested using the White model, which calculates a regression of the residuals. The multiplier, reported in table 5.2, is assumed to asymptotically follow a χ^2 distribution. Results show that the H_o of no heteroscedasticity can be accepted at 95% confidence levels. This is expected because the data is of a dynamic time-series rather than a cross-sectional sample.

5.5 Discussion

The estimation results reported in table 5.2 confirm that the models have strong explanatory power, i.e. are able to give reasonably good estimates of the aggregate BOD7 production function in the industry. Indeed investments are the most decisive variable in affecting emissions formation, almost to the degree that they solely determine the emissions profile. This is especially true when investments are taken as a proxy for the age and capital structure of the equipment. This result is obvious from the strong multicollinearity of some of the additional regressors and the failure of the more holistic models to provide more accurate explanations than the simplest model.

Marginal returns have fluctuated over time. During the early years of the time period, marginal returns defined as additional reductions in emissions were relatively much higher than those of the latter years of the study. The late 70's and early 80's were still time for picking the so-called low-hanging fruit in terms of environmental protection and as the industry has progressed it has become increasingly difficult to further reduce emissions as they are already at a low level. The marginal returns of invested capital, or a partial derivative of the function ($\partial BOD_7/\partial K$), between 1972-1979 were multiples of those in latter years. Between 1972-1979 each markka reduced total BOD_7 emissions on average 7,0 grams, between 1980-1990 only 3,2 grams, and almost none, only 0,6 grams, between 1995-1998. This is graphically shown in figure 5.3a. The same trend is shown in figure 5.3b, which shows that marginal returns from the viewpoint of emissions per output unit, i.e. the reduction in grams per tonne.

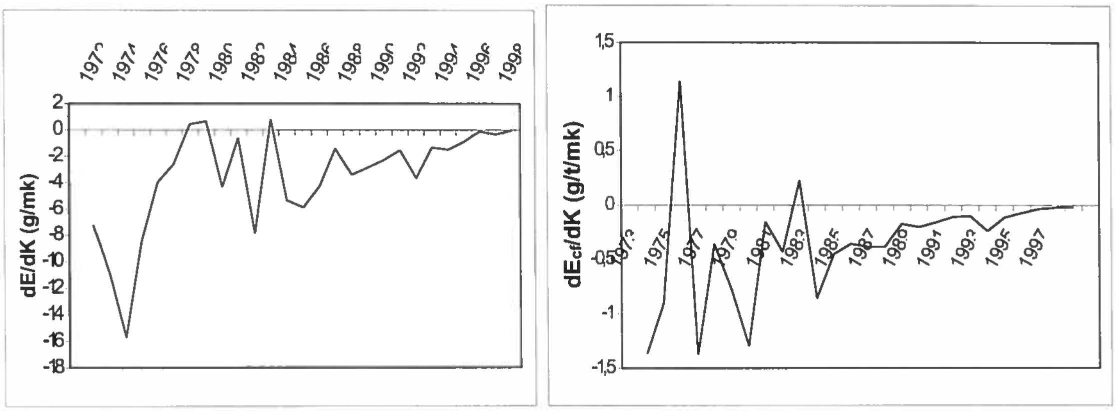

FIGURE 5.3a ∂BOD$_7$/∂K FIGURE 5.3b ∂(BOD$_7$/t)/∂K
FIGURE 5.3 Marginal returns defined as ∂BOD$_7$/∂K and as ∂(BOD$_7$/t)/∂K of the Finnish pulp and paper industry 1972-1998

Figure 5.3 points out times when large-scale investments were made in process technologies that changed the production structure towards paper grades with higher value added; from the production of newsprint to the production of coated fine and magazine papers[10]. The result of those investments is a positive marginal return. During the majority of the time period, however, marginal returns have been negative meaning that investments have resulted in decreasing emissions. The figure also shows, as discussed above, decreasing marginal returns on average; observations from the latter part of the time series are more clustered around the 0-line than those at the beginning of the time period.

Investments affect both the economic as well as the environmental aspect of production. Investments as a rule increase capacity and thus result in increased production given that capacity utilisation rates stay constant, increase or decrease only slightly[11]. If investments do not increase the total amount of production, they may result in production shifting to technically more advanced products with higher value added. Both result in an economically beneficial situation for the firm. In an environmental sense, advanced technology is more efficient and produces less effluents and waste per product unit than older, more obsolete technologies, i.e. emissions per tonne decrease. This decrease is sometimes, as is the case that has been studied here, large enough to offset for the increase in total output brought about by the technology. The marginal returns of investments on pulp production capacity are shown in figure 5.4. Clearly the marginal return in a productive sense has

[10] Fine and magazine papers (LWC and SC for example) require more use of chemicals and fillers. They also use more pulp (up to 50%) than does newsprint (with an average pulp content of 10%). It is precisely pulp manufacture that is the main cause of BOD.

[11] The average capacity utilisation rate in Finnish mills between 1980-1997 was 91%. (Source: Finnish Forest Industries Federation and Statistics Finland)

not been dramatic. This is partly due to the fact that the investment figures reported include investments in the paper industry as well. From figures 5.3 and 5.4 it is clear to see that the positive environmental marginal return has decreased, on average, during the studied time period whereas the positive, production capacity increasing, marginal return of investments has been relatively stable.

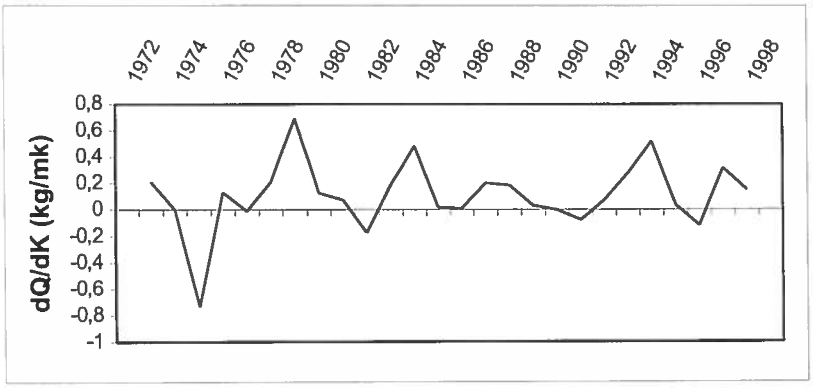

FIGURE 5.4 **Marginal returns defined as ∂Q/∂K of the Finnish pulp and paper industry 1972-1998**

The environmental performance and eco-efficiency of the Finnish pulp and paper industry has increased significantly between 1972-1998. Emissions of BOD_7 have decreased in total amounts by 92% and the same trend can be seen for other water-borne effluents. At the same time, production of chemical pulp has increased by 80% and production of paper and board more than two-fold. This results in a negative relationship between output and emissions. Technological innovation has decreased the emission-production ratio substantially both within processes and outside them. It is precisely the increasing effectiveness of technological improvements that permit growth with minimal increases in pollution (see Carraro 1998 and referred literature, Barbier 1999). Technological improvements affect the eco-efficiency of an industry, as illustrated in this case by allowing growth while decreasing, not merely maintaining constant, its environmental burden. Growth has not harmed the environment; in fact it has made the industry able to afford high levels of investments in environmental protection technologies. Productivity gain can here be defined as increased output per unit of emissions (Repetto and Rothman 1997). Productivity has increased consistently through the twenty years with technical advances. A similar result was found by Chung et al. (1997) for the Swedish pulp and paper industry between 1986 and 1990.

The decreases in BOD_7 have been achieved by increased utilisation of internal recycling of process water and by installing cleaning plants within the plant for water purification before it is released either into communal sewage systems or into lakes and rivers. Process modifications were also made by improving the bleaching processes in the oxygen and ozone stages. Increased internal recycling of important raw materials, such as certain chemicals, is also strongly encouraged.

Investment ratios of the industry have consistently been at roughly 10% (of revenues) except during the recession in the early 1990's. At the beginning of the studied time period, environmental investments were mainly in the so-called end-of-pipe technologies, often consisting of clean-up technologies. Later the trend has shifted more towards process-integrated environmental investments that improve the process in a way as to cause less pollution in the first place and thus reducing the need for clean-up technologies. However, between 1992-1996 still 53% (Statistics Finland 1998) of all environmental investments of the forest industry were in end-of-pipe- technologies. This domination can partly be explained by the nature of the industry itself; processes can not be varied to a great extent. Possibilities simply do not exist for such radical changes as for example in the energy sector where different ways of producing energy, for example low-NOx burners, are more abundant.

5.6 Conclusion

This paper presented the economic-environmental production function of BOD_7 emissions for the Finnish pulp and paper industry between 1972-1998. The theoretical basis of such a function was found and developed with traditional economic tools. The theoretical development was empirically tested with an application in the pulp and paper industry. It was demonstrated that estimating such an EEP production function for BOD_7 as a dependent variable of cumulative investments was both meaningful and provided easily interpretable results. Clearly such a function exists and provides a powerful tool in analysing the dynamics and interplay in the development of an industry. The application of EEP provided here, i.e. one that relies on physical SI-measurement units instead of monetary values successfully widens the perspective provided by conventional models and introduces a new basis for analysis.

Clearly investments and technological change are the main drivers for most types of changes in the industry. Most of the observed development in the different variables making up the profile of the industry, can be attributed to technical change, emissions are one example. This point is justified by the model parameter estimation which indicate strong linear relationships among all variables.

The EEP model provides a starting point and basis for different types of analysis. In this paper, it was only used to give an overview of the environmental effects caused by the industry during its growth and development. Applications of the built model need to be further explored. The

EEP may be very useful in policy settings and in general analysis of industry as well as in evaluating the potential of technological innovation to enhance the performance and environmental impacts of entire industries. Another further area of research is broadening the objective of the function to encompass economic, environmental and social performance simultaneously.

6 LONG-TERM DETERMINANTS OF EMISSION COEFFICIENTS AND THEIR EFFECTS ON LIFE CYCLE INVENTORY (LCI) CALCULATIONS

Pento, T. & Karvonen, M-M[12].

Abstract

This paper studies the emission coefficients and their determinants for the Finnish pulp and paper industry from 1972 to 1998 using official permit monitoring data for water emissions, and official industry statistics. Large non-linear effects of technology changes over time onto emission coefficients are first illustrated and their effects onto life cycle inventory calculations are discussed. Traditional economic production functions are then employed to establish the relationship between emission coefficients and investments. Results show that the four types of emissions, BOD7, TSS, N and P decrease exponentially as a function of the cumulative capital employed in the industry, and of time. The paper concludes with suggestions on how this information affects the reliability and validity of LCA studies as well as that of the decisions made on the basis of LCA study results. The basic argument shows that non-linear technical change poses very strict conditions on the design and use of LCAs, or may even render results invalid.

[12] This joint paper was presented at the 3rd SETAC World Congress in Brighton, 21.-25. May 2000. It has also been submitted for review in the International Journal of Life Cycle Assessment.

6.1 Introduction

An economic production function is a technological statement, showing the maximal amounts of outputs, which can be obtained with the existing technology of a production process using a set of inputs (Mansfield 1991, Chung 1994, Pindyck & Rubinfeld 1995). Traditional production functions consider only those outputs [O_1, .., O_P] and inputs [I_1, .., I_K], which have a positive economic value for the producer. They discard emissions and other outputs, which have a non-positive economic value, and pay no attention to the inputs of virgin materials, which are priced at zero. The assumption is that all production facilities are designed and operated only to maximize their production of valuable outputs:

(6.1) $$g\,[O_1, .., O_P] = f\,[I_1, .., I_K]$$

This viewpoint is too limited for today's industries, which have to maximize valuable outputs, but are also compelled by markets and permitting regulators to minimize the quantities of emissions and waste [B_1, .., B_N] and the use of some types of virgin materials [V_1, .., V_M]. These demands in essence create new boundary conditions and effectively constrain the production possibilities frontier (PPF) of the profit maximising firm. Such a multi-objective technological frontier of the modern industrialist can be expressed as an economic-environmental production function, EEP (Pento 1998, Karvonen 2000):

(6.2) $$G\,[O_1, ..,O_P, B_1, .., B_N] = F\,[I_1, .., I_K, V_1, .., V_M]$$

where O_1, ..,O_P, are outputs of positive value, B_1, .., B_N are outputs of zero or negative value, I_1,..,I_K are inputs of positive value and V_1, .., V_M are inputs of zero- or negative value[13]. Contrary to traditional economic production functions, (6.2) treats all the mentioned variables in their physical units to avoid the potential bias, which arises from changes in price levels.

LCA inventory is a collection of data on the production of emissions and the use of materials and energy of a product system (SETAC 1992, Weidema 1997). The LCI is based on a set of production functions of consecutive processes within a certain predefined boundary. Clift et al. (Clift et al. 1999) propose a theory of life cycle inventory calculation, which estimates the environmental interventions in an implicitly two-stage process. First, the

[13] Inputs may have a negative value when a producer is paid for taking a material into a process. For example, the price in Germany of A2 mixed sorted wastepaper was -60 DEM in 1993 (Matussek & Pappens 1996, p.247). Negative prices often relate to waste fractions etc. whose treatment would be more costly than their re-use in another industrial process.

traditional production function (6.1) is used to define the outputs O, and then another function is applied to determine the environmental interventions B:

(6.3) $$B = v(O), \text{ in which } g[O] = f[I]$$

The crucial question of this approach concerns the definition of what constitutes the outputs (O) of multi-product processes, as well as the type of the intervention function V(x). Most life cycle inventories (LCI $\approx$ B) employ the "main" product of each process. The potential error in this method is apparent, for example, in the CO_2 emissions of a combined heat and power (CHP) plant, which produces both electricity and steam for district heating. If the CO_2 emission is calculated as a function of GWh of electricity produced it gives highly misleading results in winter, when the plant minimises its production of electricity and maximises the output of heat.

Most LCIs assume a linear homogeneous relationship between the environmental interventions and the product output quantities in essence employing multiple equations such as (6.3) to arrive at the end inventory:

(6.4) $$B_i\,(CO_2\text{ kg}) = \Sigma_j\, b_{ij}\ (\text{kg / unit of output}) \times O_j\ (\text{units})$$

in which the vector of emission coefficients [b_{ij}] is presumed fixed.

The above formulations (6.1) - (6.4) focus on measuring outputs and environmental interventions across varying capacity utilization rates in a static context. They can well be applied in the analysis of the short-run production decisions of the firm. Their applicability is reduced in dynamic situations, in which changes in technologies invalidate static production functions, and change the emission coefficients of the LCI calculations.

Fixed emission coefficients [b_{ij}] in (6.4) are for pessimists, as they imply that the amounts of valuable outputs are the only determinant of environmental interventions, and that environmental improvements are feasible only through reductions in production (Chung et al. 1997). This negation of the benign effects to the environment by improvements in technologies and practices is clearly at variance with observed facts. Long-term statistics of many industries show large reductions in emissions, regardless of increases in total production. For example, the total production of the Finnish pulp and paper industry doubled between 1975 and 1998, while the water emissions decreased by approximately half in the case of nitrogen and phosphorus, and by over 90 percent in the case of BOD7 and total suspended solids.

This paper studies the emission coefficients and their determinants for the Finnish pulp and paper industry from 1975 to 1998 using official permit monitoring data for water emissions, and official statistics of industrial production. The non-linear effects of technological change and time on the emission coefficients are illustrated. The relationship between emission coefficients and investments is then explicitly established and quantified within the traditional framework of production functions. The resulting discussion then analyses the results and their effects onto life cycle inventory calculations. The paper concludes with the implications that the results have on LCI calculations and their interpretation.

6.2 The data and time trends

Emissions data for this research is derived from the official permitting measurements. The data from 1975 to 1998 are comparable, because measurement criteria and methods for monitoring water emissions in the Finnish pulp and paper industry have been standardised as a result of guidelines given by the authorities (PI-Consulting 1997). The monitoring is based on self-measurement according to permit stipulations approved by the authority. All monitoring data is subsequently available to the public and all permit holders are required to annually report emissions data. The study uses only water emissions data since the air emissions data is not available in a standardised, mill-specific format for the entire period.

Emission coefficients of the Finnish pulp and paper industry have decreased radically between 1972-1998, over 70 percent for nitrogen and 97 percent for BOD7. The emission coefficient of phosphorus was rather stable until 1989, but fell very rapidly and by over 75 % in the following ten years. Even the input of wood declined from 1983 to 1998, apparently because of changes in paper furnishes toward increased use of minerals, and also as a result of the production structure towards higher grade papers, which also use more fillers and coating materials than other paper grades. Similar reductions in emissions and virgin material use are observed in the pulp and paper industries of other countries, and also in other industries, regardless of production increases (Stanners & Bourdeau 1995).

Figure 6.1 shows graphically the time trends observed in the emission and wood consumption coefficients as well as in output growth. To enable simultaneous analyses of all variables, indexes are used based on the year 1975. The trends are very clear on all variables except nitrogen, which has not experienced constant reductions. Phosphorus emissions clearly increase until technological innovations made the reduction and removal of phosphorus possible in the early 90's.

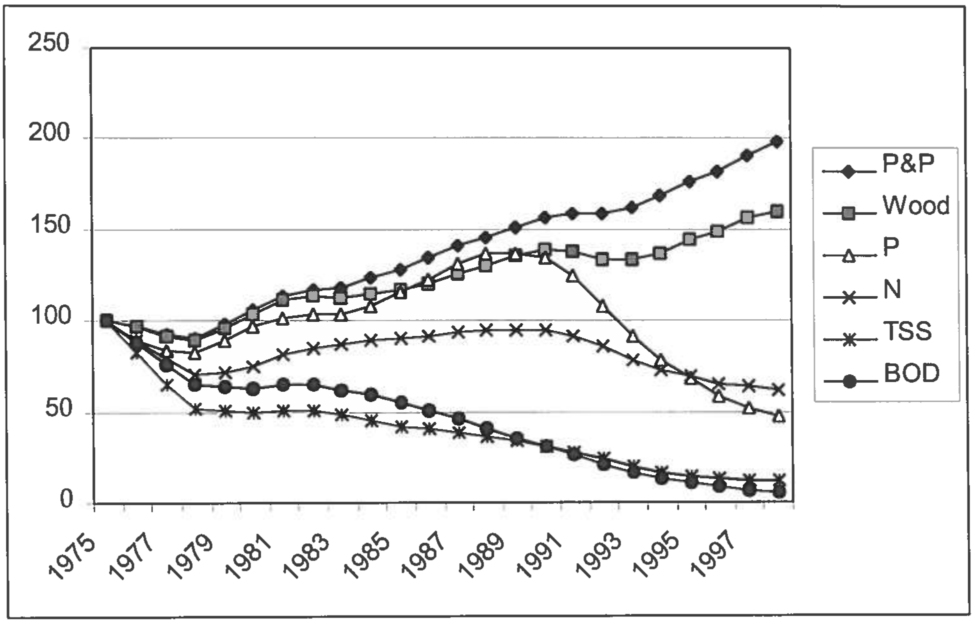

FIGURE 6.1 Indexes (1975 = 100) of four-year averages of the amounts of pulp and paper, emissions of P, N, total suspended solids and BOD7, produced by the Finnish pulp and paper industry. (Sources: Official Statistics of Finland, Ministry of Environment, Finnish Environment Institute.)

Rapid decreases in the emission coefficients of basic industries have a direct bearing on the accuracy of life cycle inventories. As figure 6.1 clearly demonstrates, the use of an emission coefficient of 1991 for phosphorus in 1995 in an LCI of the Finnish pulp and paper industry would overestimate the actual emission by almost 60 percent. Such errors in estimates would render LCIs unreliable and impractical for many uses in industry and in policy making.

6.3 Estimation & Results

The variant of the EEP (equation 6.2) which is proposed here for the estimation of the emission coefficients B_{ij} as a function of invested capital follows the example of economic production function theory, which has concentrated for half a century on establishing the technological frontier between outputs and the capital employed. If investments follow the modern requirement that they must increase production capacity <u>and</u> reduce emissions, they will have a pronounced effect on the emission coefficients:

(6.5) $$B_i = \text{Emission}_i \, / \, \text{Output} = f(K)$$

Little prior empirical information is available for the specification of the relationship in (6.5). Economic production function research has traditionally employed linear production functions or allometric Cobb-Douglas functions, $B_{ij} = \alpha \bullet K^{\beta} \bullet L^{\gamma}$. Recent research with the inclusion of environmental variables into production functions has applied in addition to those above, distance functions (Chung 1994, Hetemäki 1996). This paper will employ a two-parameter exponential relationship:

(6.6) $$B_i = \exp(a_i + b_i \bullet K)$$

in which

B_i = emission coefficient i, kg of emission / ton of pulp & paper produced
Source: Ministry of Environment, Finnish Environment Institute, official permit monitoring measurements

K = cumulative capital invested by the pulp and paper industry,
million FIM, deflated, 1972 = 100. Source: Official production statistics of Finland 1972 - 1998

This equation is amenable to the analysis of emission coefficients, because it is capable of both fast reductions in the coefficients, which are caused by early investments, and the indication of an asymptote, which might be eventually reached.

The results in table 6.1 confirm the picture drawn in figure 6.1 using indexes for emission coefficients. The lower r^2-value for phosphorus emissions was expected as the emissions curve is strongly kinked. In fact, a combination of two different functional forms would give very reliable estimates on P-emissions. The r^2-values of all emissions presented in table 6.1 are between 10-40% higher than the respective values for linear homogenous functions. Thus pointing out that an estimate with an LCA approach could indeed be drastically wrong and as a result, very misleading.

TABLE 6.1 Regression estimates of emission coefficients Y = e ** (a+b*K)

Emission coefficient kg/ton	a value	a error	b value	b error	R square
BOD	-0,8427	0.0239	-0.00002	7.0 E-7	0.985
TSS	-1.5681	0,0294	-0.00002	1.0 E-6	0.977
N	-0.8550	0.0293	-7.74 E-6	5.1 E-7	0.918
P	-2.8578	0.0632	-6.95 E-6	1.0 E-6	0.696

6.4 Discussion

6.4.1 Determinants of Emission Coefficients

Industries can reduce their environmental footprints by adopting new and environmentally better technologies and by changing their operative practices. Past mileposts in the development of environmentally benign technologies in the pulp and paper industry include the re-circulation of cooking liqueurs and the improved recovery of soda in pulp mills, the circulation of process waters to reduce the use of fresh water and, recently, the elimination of elemental chlorine from pulp bleaching. All of these changes have drastically reduced the emission coefficients of the industry, and all have required massive investments into new mills.

Changes in the operative practices of the industry have also had a direct bearing on the emission coefficients. Recovery rates of used papers have risen rapidly in most industrial countries, in Finland from under twenty percent in 1980 to over sixty percent in 1998 (Matussek & Pappens 1996, Karessuo 1998). The trend in paper furnishes has been away from the use of virgin and chemical pulps, toward recycled pulp and increased use of minerals. This trend has been made possible only by investments into new recovery facilities and equipment, and in new pulp production mills, such as de-inking plants.

The direct measurement of the effects of improved technologies and operating practices on emission coefficients is not possible, because technologies and practices can not be meaningfully placed on a scale. Following the tradition of economic production research, the capital invested in new production facilities is used here as a surrogate of technical development, with the expectation that investment decisions require new rather than old technologies. Environmental investments, i.e. the investments which are made to reduce emissions or lessen the use of virgin materials, would be a more appropriate measure of the effect of technologies onto the emission coefficients. Unfortunately, there is no standard as to what constitutes and environmental investment and, consequently, the available statistics are unreliable.

6.4.2 The model

It has been shown before (Karvonen 2000) that gross emissions are determined to a great extent by cumulative investments in an industry. The results here show that the emission coefficients, which decrease much more rapidly than gross emissions are determined to an even greater degree by cumulative investments. Therefore, other factors of production besides investments have little impacts in the long-run emissions profile of the industry.

In life cycle modeling, emissions are determined only as a factor of production quantities. This is in stark contrast with the results shown here, i.e.

that quantities alone are a poor predictor of emissions in the long run whereas cumulative investments are strong. These results imply that the LCA can only be used as a short-term proxy of emissions but fails in long-run use.

Usage of a fixed coefficient matrix for emissions implies a short-term production function in which the amount of capital is fixed. Thus, in the short run, the firm can only reduce its emissions through contractions in aggregate output. This is a very restricted view of emissions reductions as the only possibility is through reductions in the profitable product. This implies that a firm can not answer market demand changes in the short run if there is a limit on emissions production. In the long-term production function, also for emissions, the possibility must be for reductions through other means than contractions in output. This enables the firm to make strategic decision concerning the ways in which it chooses to reduce its pollution levels.

6.4.3 The role of LCA

The objective of LCA is to study the environmental impacts of a product throughout its life cycle from cradle to grave. The calculation of environmental impacts and their subsequent valuation should become a tool in the decision-making processes of both corporations and the public sector. A valuable tool will provide such information that is timely and truthful so that any decisions that are made can be considered optimal.

LCA field studies generally take a long time to complete, data collection is difficult and model building requires time. A time lag of 2-4 years between initial data collection and concrete modeling and reporting is not uncommon or even long. Moreover, as indicated in this paper, emission coefficients change rapidly over time, even during relatively short periods, such as those taken to complete an LCA study.

If validity is regarded as the ability of a measure to measure what is intended, it is clear to see that the current fixed coefficient matrix employed in LCA studies is not a valid measure of the environmental impact of a product system. It is only valid in retrospect for portraying the historical environmental impacts that occurred from a particular product system at time *t*.

In conducting LCA studies, the investment practices of the industry must be explored. The more frequently investments are made, the more likely it is that the emissions coefficients have changed sufficiently enough that old data cannot be used.

The results presented in this paper suggest that the use of LCA should not be to look at the emissions *per se*, or the environmental impact of a product from cradle-to-grave. Rather, the LCA can be used for comparisons of parts of the system under periods of no, little or equal technical change in the components of the system. The results also clearly point out that for any one study or comparison of two studies, coefficients from different time periods can not be used.

Technical change has currently in LCA been included in static comparative analyses; or analysing static LCAs of different time periods. In essence two or more fixed coefficient matrices are compared over time and the change in the results is considered as the advancement of technology. This still does not quite capture the inherent dynamism of industries. Even one static LCA, especially if the system boundaries are large, can include significant real data changes. For example, a model that uses data from 1995 for some modules and data from 1997 for other modules may artificially portray some parts of the system as environmentally less benign, although the real reason is the age of data.

It appears then, that the prevalent practices of making absolute measurements of a product's emissions, and the comparisons of such figures with those of other products are heading towards a dead-end. This study points out the source of incomparability. Some other uses of LCIs must be found if they are to remain in the box of practicable tools.

One potential area is to apply LCIs either dynamically or in a comparative static framework. Potential applications could be for example in the study of the effects of investments, of the effects of alternative technologies or of the effects of operating practices. Further application could then be in dynamic simulations of industries.

In a complete LCA the LCI is followed by different versions of impact analysis and assessment including some variation of valuation or weighing. The basic inventory data variations will only be multiplied in subsequent analyses. In decision-making and end-analyses only the results of the complete LCA are used. Clearly, then the decisions will be based on skewed data.

6.5 Conclusions

This paper demonstrated that rapid technological change and development, which characterises most industries today, quickly invalidates the results of LCA studies. Emission coefficient matrices in reality are not constant, refuting the very basic assumption underlying LCA. As a result, decisions made on the basis of complete LCAs or even on the basis of LCIs alone may not reflect optimum solutions or even acceptable solutions.

In order to have valid LCAs the investment tendencies of the industries under study must be closely scrutinised. If it can be shown that technological change has not been rapid and that investments have been slow or stagnant, an LCA may well be a valid basis for decisions. Otherwise, at the least, the possibility of data fluctuations needs to be clearly pointed out.

The benefits from life cycle analyses are not restricted to the study itself or its results. Conducting an LCA will have certain snowball effects for the corporations conducting the study. Certainly environmental awareness, cooperation among actors, environmental management practices, environmental management culture as well as communication and reporting can all be enhanced as a result of conducting or even attempting to conduct an LCA. Thus, even though the validity of the end results of the LCA may be questionable, the exercise as a whole benefits the corporation and the associated other firms.

7 NATURAL VS. MANUFACTURED CAPITAL: WIN-LOSE OR WIN-WIN?[14]

-A CASE STUDY OF THE FINNISH PULP AND PAPER INDUSTRY

Karvonen, M-M

Abstract

The effect of investments on environmental variables has been discussed through the win-win rhetoric specifically in micro-level analysis. On the macro-level the win-win rhetoric has been replaced by the arguments for and against the substitutability of natural and manufactured capital. Here these two concepts belonging to different levels of analysis are linked by looking at the environmental and economic effects of chosen investment strategies in a traditionally capital-intensive industry over time. The paper shows that, rather than generalise the existence of win-win situations or the substitutability of capital, these positions are determined by purely situational factors. As a result, in the assessment of substitutability, the specific operating context of the industry needs to be taken into account. This implies also that environmental policy needs to be designed to be adaptive and responsive to those situational factors to create beneficial outcomes for the economy and for the environment.

Keywords: capital substitution, win-win, policy, pulp and paper industry

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[14] This paper has been presented at the ISEE2000 World Conference in Canberra 5-7 July 2000. It is also forthcoming in *Ecological Economics*.

7.1 Introduction

The relationship between capital investments and economic growth as measured by GNP has long been realised (Kuznets 1930, 1955, Kaldor 1961, De Long and Summers 1991, Barro and Sal-i-Martin 1995). Consequently economic growth and environmental degradation have been studied and in 1992 the World Bank introduced the environmental Kuznets curve, EKC (for discussion see Arrow et al. 1995, Ayres 1997, Cleveland and Ruth 1998). The basic argument is that below a certain level of income, economic growth and environmental degradation are positively related whereafter the relationship turns negative, implying an inverted U-shape relationship. The rationale behind the EKC is that affluent nations can invest more in pollution abatement technology and that mature economies generally tend to support a less materials- and energy-intensive goods and services mix.

The EKC argument aggregates the trade-off on the level of an economy, rather than by industrial sector or by individual firm. More recently the basic ideas behind the macro-level EKC have been "transported" onto the micro-level of the firm. It has been suggested that even investments in purely non-productive technologies, meaning clean-up and pollution abatement technologies, can create situations of mutual benefit for the environment and the economy, or the firm, the win-win argument (Porter and van der Linde 1995, 1996). Clean-up technologies can be defined as non-productive as they do not, or only rarely, increase the output or efficiency of the production processes for the desired, marketable products. The economic benefit is argued to realise as decreased waste handling and transportation costs, decreased raw material costs, benefits accruing from improved image and so on. Investments in pollution abatement technologies may also create snowball effects in the same industry, or a related one, by boosting their demand and as a result, increasing employment.

Natural capital embodies those ecosystem services, which are provided by the earth's ecosystem whereas human-made or manufactured capital is all that accumulation which man has produced by his activities, such as technologies, productive facilities and products (Costanza and Daly 1987, 1992, Daly and Cobb 1990, Toman et al. 1995). Emissions and raw material use are a depletion of natural capital and investment in technology is an increase in manufactured capital. In the pulp and paper industry, natural capital is mainly wood, minerals and the assimilative capacity of the surrounding environment.

Consensus exists that natural capital, or resources, are rapidly declining (Meadows et al. 1972, WCED 1987, Miller 1992, Tietenberg 1992). In contrast, there is relatively high uncertainty concerning the future level of environmental regulation and also of ultimate environmental degradation. Companies are facing increasing demands from various stakeholder groups to improve their environmental performance in accordance with the principles of sustainable development. This compels firms to increasingly invest not only in new productive technologies but also in pollution prevention, even with uncertainty of their exact effect (Rugman and Verbeke 1998).

This paper studies investment decisions in the Finnish pulp and paper industry by placing them within the win-win rhetoric, i.e. demonstrating the different possible alternative outcomes in terms of benefits and disadvantages to the firm and the environment. This analysis is then combined with the notion of capital substitution versus complementation. As a result, a new theoretical framework for analysing the eco-efficiency of investments is developed. The applicability and validity of this framework is tested and conceptualised with the case industry. The analysis at the aggregate sectoral level can also be regarded as a sectoral eco-efficiency assessment. The discussion of eco-efficiency however, is beyond this paper and is discussed at length in other instances (see for example Schmidt-Bleek 1993, von Weizsäcker et al. 1997, OECD 1998, Reijnders 1998, Hawken et al. 1999). Some comparisons are made to North American investment strategies. However, uniform and reliable data on emissions in the American pulp and paper industry was not available for this study and thus only the general differences in strategies are highlighted.

The main contribution of the paper is to link two points of view; the ecological economics notion of capital substitution and the Porterian corporate environmental management concept of win-win. Thus widening the current academic discourse; discussion has mostly concentrated on each position individually, they have not been looked at together. The paper also contributes to the discussion concerning appropriate environmental policy actions. The aim is not to draw far-reaching conclusions but rather show how the adopted policy style has shaped the environmental footprint of what was for a long time Finland's main industry. The paper concludes with some implications also for corporate strategy.

The next part of the paper introduces the industry and its institutional operating context. This is followed by a theoretical analysis of investments reflecting on the win-win rhetoric as well as capital substitution. Here a new framework for analysis is developed. The fourth section combines a practical case with the theory. Finally results, discussion and conclusions are presented.

7.2 Industry & Data

The Finnish pulp and paper industry has traditionally been an important part of the national economy. Only recently its role has been taken over by the telecommunications and information technology industries. The share of the sector in the national economy equates roughly that of the entire public sector; in 1997 the pulp and paper sector's contribution to GDP was 3.9% excluding the share of forestry. Calculated together with forestry, the share becomes 6.5% (Sevola 1998). The share of exports associated with the pulp and paper sector was 34% in 1996 (Diesen 1998). Globally the Finnish pulp and paper sector contributes to 3.7% of total combined world production (in tonnes) of different pulps and paper grades. In comparison, North America dominates with a share of 35.7% (PPI 1999, Sevola 1998).

The Finnish pulp and paper industry is dominated by three large companies, Stora-Enso, UPM-Kymmene and the Metsäliitto Group, which in 1998 constitute almost 95% of Finland's paper manufacturing capacity and almost an equal share of the pulp capacity (FFIF 1998). Recently Stora-Enso has merged with Consolidated Papers of the US, forming one of the biggest paper conglomerates in the world. However, the data used in this study does not include the most current merger.

The data on which the study is based has been collected by the Finnish Ministry of the Environment, The Environment Institute and the Finnish Forest Research Institute during permit compliance checks. According to Finnish legislation each mill receives a pollution permit with plant specific standards to be updated every three years. This procedure is designed to accommodate regional and plant differences with respect to environmental effects. In this sense the policy is in line with the basic principles included in the Integrated Pollution Prevention and Control (IPPC) directive of the Council of the European Union (Council Directive 96/61/EC).

Firms are free to choose the locus of their operation, as long as a thorough, independently verified environmental impact assessment (EIA) is made. Once the EIA has been performed, and neighbours of the proposed plant have been heard, the firm can be granted the right to commence operations. The EIA is submitted to the local environmental authority; i.e. the local level has decisive influence on whether the proposed operation is accepted. The EIA guidelines require the inclusion of environmental, economic as well as social considerations in assessing the full impact of the proposed industrial activity.

The emission permit levels are decided at the national level and the decisions are given in the Water Court for water emissions. In theory, firms can appeal to the decision, which rarely happens. In practice, the permit level is set in cooperation with the firm and the national level authority after which it is made official in the court. Permits are not a marketable item, i.e. they cannot be traded, exchanged, saved, etc.

Almost all pulp and paper mills operating in Finland have adopted either the ISO14001 or EMAS environmental management system (EMS), creating an efficient barrier to any firm wishing to operate without one. Such a voluntary gesture has indeed created a climate in which every firm must invest in an EMS to be successful and to be able to do business.

7.3 The substitution of capital

Ecological economics argues that a preanalytic vision of a "full world" is a necessity and that this shared preanalytic vision separates ecological economists from the conventional or neo-classical economists (Norgaard 2000). Embedded in this vision is the idea that manufactured capital cannot be substituted for natural capital and as a consequence growth is not sustainable. Neoclassical production theory is criticized for its failure to treat factors of production as complements (Serafy 1991, Victor 1991, Kauffmann 1995, Repetto 1993, Daly 1996). This was expressed by Daly in 1996 "the idea that either natural or man-made capital could be a limiting factor simply can not arise if the factors are thought to be substitutes" (p. 78). Regarding natural and manufactured factors of production as substitutes implies, for example, that paper could be made without wood pulp or pulp from other natural fiber origin, if sufficient or offsetting investments were made in technology and machinery. In reality such complete substitution is often impossible and the limits to substitution are reflected, for instance, in the production possibilities frontier.

Natural and manufactured capital are sometimes regarded as substitutes in the short to medium term: for example more precise machinery can reduce wastage or increase efficiency decreasing the need for original natural capital (Pearce and Atkinson 1993, Solow 1997, Stiglitz 1997). This viewpoint has been challenged by Cleveland et al. (1984) and Kaufmann (1992) who argue that microeconomic substitution abilities can not be extrapolated on the macroeconomic level due to physical interdependence of the factors.

It is argued here that the notion of different types of capital complementing or substituting each other requires not a universal agreement on one position but rather a situation-specific assessment. Replacing an old mill with an investment in a new mill with high pollution abatement capacity reduces the environmental burden; manufactured capital complements natural capital. On the other hand, increasing production capacity with existing technology will increase environmental burden; a case of manufactured capital substituting for natural (manufactured capital being understood as production output, which has come at the expense of natural capital). Firms in the industry can choose either option or position through their strategic investment decisions. The latter point will be elaborated in depth in this paper.

From the complementarity-substitutability discussion arises the question of business-environment win-win or win-lose relationships (Porter and van der Linde 1995, Hart and Ahuja 1996, Repetto and Rothman 1997, Esty and Porter 1998, Jaffe and Peterson 1995, Walley and Whitehead 1996). The Porter win-win hypothesis is an alternative way of approaching the question of substitutability between the two forms of capital.

An investment or increase in human-made capital can have varying effects on natural capital, creating either win-win or win-lose situations. For example, new machines are usually more efficient in using raw materials and energy than are older ones (Xepapadeas and de Zeeuw 1999). Sometimes the opposite may happen, if for example new machinery produces a more toxic release than older machinery. A win-win situation is one of simultaneous benefit where for example a firm produces more products with less total emissions. A win-lose situation occurs when an increase in production results in increased total effluents.

The different possibilities for the effects of investments are summarised in the following table 7.1. In the table the effect is studied at a constant level of production so that no economies of scale or scope are accounted for. The table shows the changes in both types of capital as well as the change in the emission coefficient defined as emissions per product unit, E_i / Y_i, according to current LCA practices (SETAC 1992, Consoli et al. 1993, Xepapadeas 1997). In this first part of the analysis, production quantities are taken to reflect the economic outcome.

TABLE 7.1 **Investments, emissions and the change in natural and manufactured capital.**

	ΔY	ΔE	ΔE/Y	Effects on capital
Win - Lose	+	+	+ or 0	Positive for human-made capital; productivity increases leading to higher revenue. Strictly negative for natural capital; gross emissions increase although emissions per functional unit may remain the same. *Example*: any new investment which makes more product at same or higher emission rate, which is uncommon, or an investment that allows for the production of a more polluting product with a higher market price, mostly shifting from basic products to those with increasing complexity and value added.
Win-Lose	+	+	+	Positive for human-made capital. Negative for natural capital, decreasing it. However, if the investment in manufactured capital replaces production facilities with a higher emission rate, the investment will reduce the rate at which the natural capital is decreased, because emissions per product unit decrease. However, the decrease in the emissions per product unit is not enough to offset the increase in production capacity.
Win - Win	+	-	-	Positive for human-made capital, output increases. Positive for natural capital, gross emissions do not increase. *Example*: A new production line, especially when using BAT-techniques. A prerequisite for the win-win situation is that the new production line decreases the emissions coefficient more than the increased capacity will contribute to total emissions.
Lose-Win	0 or -	-	-	Negative for human-made capital; no increases in output result. Positive for natural capital as negative impacts are decreased. *Example*: A wastewater treatment plant for a pulp mill.
Lose-Win	-	-	+	Negative for human-made capital. Strictly positive for natural capital. *Example*: Shutting down an old polluting mill provided the environmental load from dismantling/ demolishing the mill does not exceed the benefits.

Figure 7.1 summarizes the ideas presented in table 7.1 and adds to them the notion of the substitution of natural capital for human-made capital. In a win-win-situation the two types of capital are clearly complements, as an increase in one type of capital will lead to an increase in the "opposite", or other, capital also. Complementarity also holds in the lose-lose-situation, as a decrease in capital will occur simultaneously for both types. Substitution situations arise when one capital is increased at the cost of decreasing another type of capital; i.e. in win-lose or lose-win situations. This implies that any condition of substitutability or complementarity is situation or investment specific.

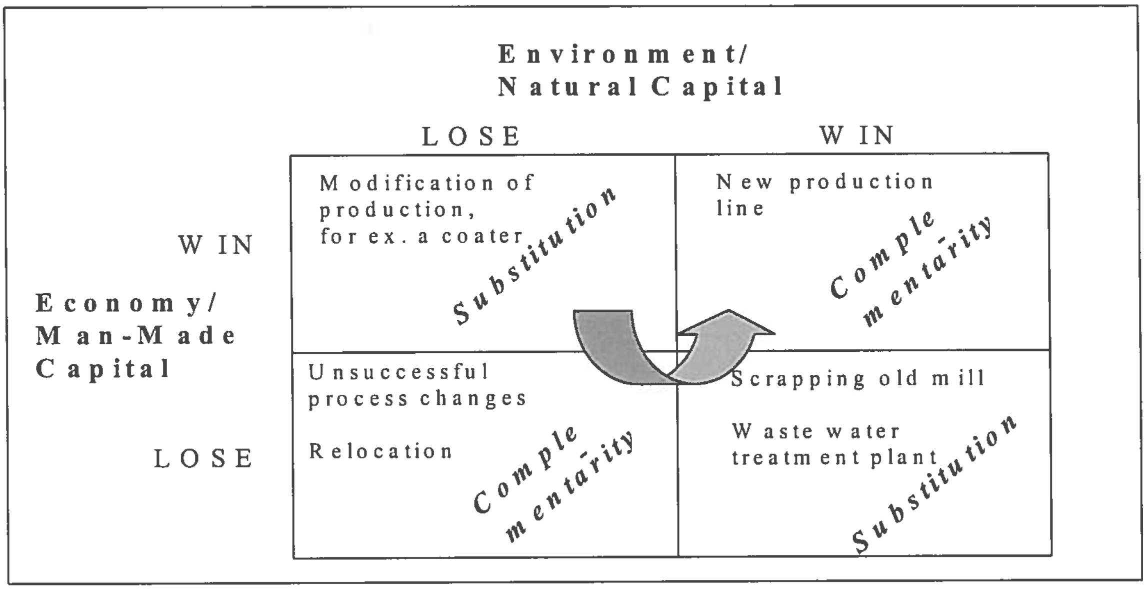

FIGURE 7.1 Natural and Man-Made capital: areas for substitutability and complementarity as well as for win-win and win-lose

The top right hand quadrant in figure 7.1 best describes a situation brought about by the adoption of BAT techniques (best available techniques) as required by the IPPC-directive of the EU. The adoption of BAT by industries is always subject to economic viability, as their adoption should not endanger other Community objectives such as the competitiveness of the Community's industry (EIPPCB 1999). Thus BAT techniques, as a rule, are more environmentally friendly and at the same time are more efficient in an economic sense. When the adoption of BAT techniques is allowed to progress within normal investment cycles, it does not pose a threat to the profitability or economics of the firm. The most effective way to create situations of complementarity for the two types of capital is to promote the use of BAT technologies. In general terms, the development should move from the other quadrants consistently towards win-win situations. The arrow in the figure indicates the preferred aim to be reached, not the route to be taken.

7.4 Results

7.4.1 Investment Strategy

Investment ratios in the Finnish pulp and paper industry have remained rather constant at around 10% within the past decade (Sevola 1998). The strategy has been to invest heavily and often to stay on the cutting edge of technological know-how. The latest technology often allows decreases in operating expenses and rapid reductions in most types of emissions when calculated per quantity of the output product, i.e. as emission coefficients. The opposite strategy of course is to invest infrequently and operate with a relatively older capital stock. This latter strategy allows for capital costs to be low whereas with older technologies, operating expenses tend to rise and emission coefficients are also relatively higher. The North American pulp and paper industry has followed this strategy; capital-intensity is regarded as a barrier to frequent investments (Diesen 1998, Ruth and Harrington 1998) and thus technologies are generally somewhat older than those used in Finland. The differences in investment strategies is pointed out in figure 7.2.

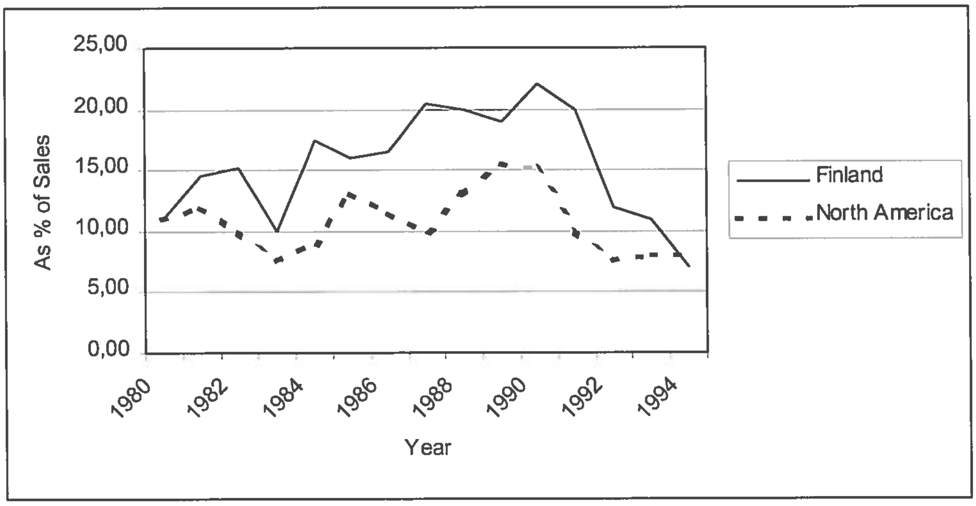

FIGURE 7.2 Fixed investment levels as a percentage of annual sales (Diesen 1998)

Given the historical traditions of frequent investments and focus on technology development, Finland has been an active member in the development of Best Available Technologies and BAT-reference documents (BREF) stipulated by the IPPC directive of the council of the European Union. Most of the Finnish industry is already operating on current BAT technology or on technologies that are defined as emerging technologies in the BREF documents of the pulp and paper industry (PI-Consulting 1997). Table 7.2 gives some examples of BAT technologies used in Finnish mills.

TABLE 7.2 Examples of Best Available Techniques in use in Finland. (Adapted from EIPPCB 1999)

BAT technique	Main environmental impact	Impact on process
Dry debarking	Reduces water consumption and water effluents	Enables energy generation in bark boiler
Extended cooking to low kappa	Reduction in COD and AOX, reduction in chemical demand for bleaching	Energy generation
TCF (totally chlorine free) bleaching	Elimination of AOX emissions, reductions in COD	negligible
Partial closure of water cycles	Reduces water emissions	Reduces water consumption
Biological and tertiary wastewater treatment	Reduces water emissions (slight increases in solid wastes)	negligible; possibility for sludge burning and energy generation
Evaporation of black liquor (increasing dry content)	Slight decreases in SO_2	Energy generation (in excess)
Incineration of odorous gases (in recovery boiler, lime kiln or separate furnace)	Reduces air emissions, total released sulphur	Energy generation
Low NOx burners	Reduces air emissions, NOx	negligible
Electrostatic precipitator on bark boiler and lime kiln	Reduces air emissions, mainly dust	negligible

The investment strategy has effects on the technology strategy. The production structure in the industry has changed towards higher paper grades; i.e. graphic papers (Sevola 1998) as demonstrated in figure 7.3. Previously more capacity was devoted to newsprint and board. The shift has involved upgrading of the productive facilities; graphic papers require use of more non-wood materials and chemicals than newsprint. Even such a consistent trend of win-lose investments, following the earlier notation, has not resulted in overall further degradation of environmental quality as measured by water emissions by the Finnish pulp and paper industry. On the contrary, emissions have constantly decreased even while production has shifted to theoretically less environmentally benign products. The industry expansion combined with the shift to a clear dominance of graphic papers has also increased the revenues of the industry since the 1970's.

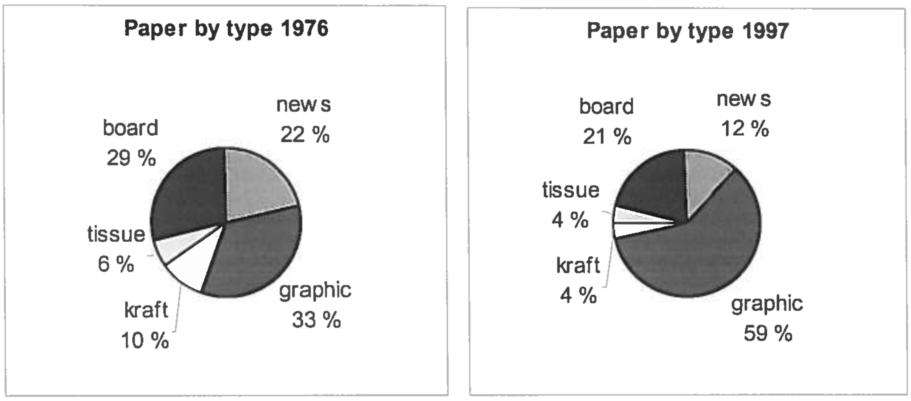

FIGURE 7.3 Paper production by paper grades in 1976 and 1997.

7.4.1.1 Environmental effects of investment strategy

The official emissions data indicate that between 1976-1996 emissions of major water-borne effluents, BOD_7, nitrogen, phosphorus and solids have decreased in gross amounts between 20% and 92% while at the same time production of chemical pulp has increased by 80% and the production of paper and board more than two-fold. This results in dramatic decreases in emission coefficients over time of as much as 96%. Coefficients are defined here per product unit of combined pulp and paper production· The question of data aggregation according to weight is discussed further in section 7.5.

Gross emissions of BOD_7, nitrogen, phosphorus and total suspended solids were in 1997 only 4.2%, 79%, 76% and 20% respectively of those in 1976. Table 7.3 presents these effluent data. The changes in the eco-efficiency of the Finnish pulp and paper industry over the past two decades reflect the effects of technological development. Frequent investments have resulted in both consistent decreases of the industry's contribution to environmental degradation and increases of operating capacity to meet higher demand.

TABLE 7.3 Yearly production quantities, total emissions of BOD, solids, nitrogen and phosporus as well as emissions coefficients for all mentioned emissions in the Finnish pulp and paper industry.

Year	Total production	BOD7	SS	N	P	BOD7/ tonne	SS/ tonne	N/ tonne	P/ tonne
	1000 t	1000 t	1000 t	1000 t	1000 t	kg/tonne	kg/tonne	kg/tonne	kg/tonne
1976	9 944	265	105	326	42	26,6	10,6	32,8	4,2
1977	9 867	231	88	286	47	23,4	8,9	29,0	4,8
1978	11 228	231	88	333	50	20,6	7,8	29,7	4,5
1979	12 788	259	101	359	56	20,3	7,9	28,1	4,4
1980	13 165	263	98	391	59	20,0	7,4	29,7	4,5
1981	13 479	262	98	407	57	19,4	7,3	30,2	4,2
1982	12 609	224	84	389	54	17,8	6,7	30,9	4,3
1983	13 551	219	83	399	57	16,2	6,1	29,4	4,2
1984	15 349	222	76	424	68	14,5	5,0	27,6	4,4
1985	15 423	199	77	433	75	12,9	5,0	28,1	4,9
1986	15 477	154	72	417	68	10,0	4,7	26,9	4,4
1987	16 479	147	66	429	76	8,9	4,0	26,0	4,6
1988	17 647	139	62	447	80	7,9	3,5	25,3	4,5
1989	17 872	111	56	440	74	6,2	3,1	24,6	4,1
1990	17 853	87	50	408	64	4,9	2,8	22,9	3,6
1991	17 263	71	42	377	53	4,1	2,4	21,8	3,1
1992	17 681	61	35	337	46	3,5	2,0	19,1	2,6
1993	19 329	40	27	295	38	2,1	1,4	15,3	2,0
1994	20 871	37	25	310	34	1,8	1,2	14,9	1,6
1995	21 029	30	25	316	32	1,4	1,2	15,0	1,5
1996	20 135	23	21	258	n/a	1,1	1,0	12,8	n/a

Figures 7.4a-7.4d each project two different scenarios. The solid line refers to the actual situation in Finland, i.e. shows the decreases in total emissions as a result of a heavy investment strategy. The dotted line shows the potential level of emissions if no technological investments and improvements had taken place during the studied time period. In this scenario, emissions per unit output have been assumed to stay constant throughout the time period. This is a reflection of the effect of an infrequent investment strategy. According to the latter scenario, the total BOD_7, nitrogen, phosphorus and total suspended solids emissions in 1996 would be 24 times, 3 times, 3 times and 10 times, respectively, the actual emissions of 1996. A similar trend was suggested by Carraro (1998).

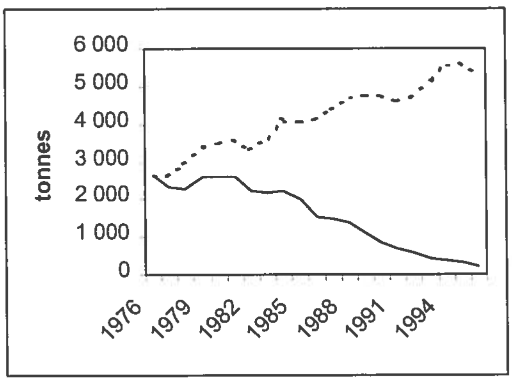

FIG 7.4a BOD_7 emissions

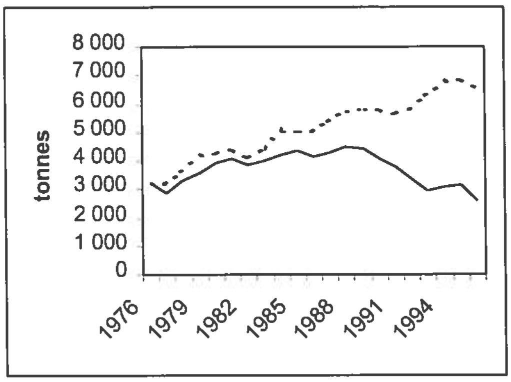

FIG 7.4b nitrogen emissions

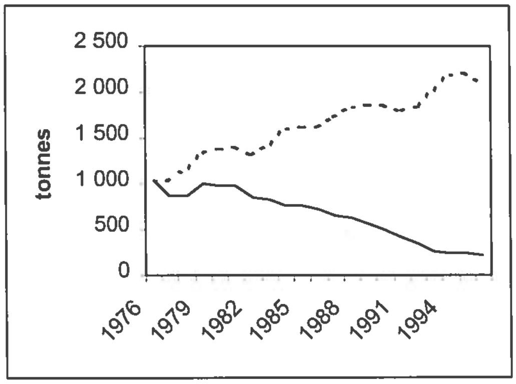

FIG 7.4c TSS emissions

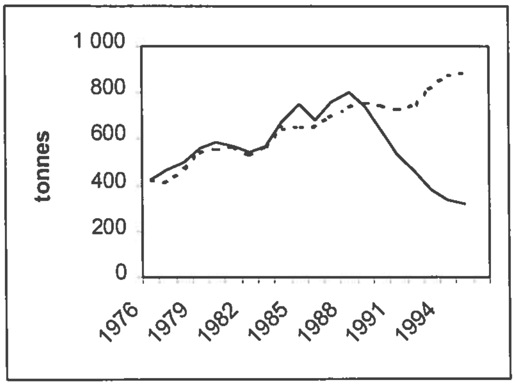

FIG 7.4d phosporus emissions

FIGURE 7.4 Actual (—) emission levels and those projected (----) by constant emission levels of 1976 in tonnes per annum.

The development proves that with a heavy investment strategy, even occasional so-called win-lose -investments at the micro-level, i.e. individual mill, can be offset at the industry-wide macro-level to result in an overall win-win tendency. In general and over time older, more polluting capacity has been replaced by more eco-efficient capacity decreasing the emissions coefficient at a rate greater than the offsetting rate of production increases. In the Finnish case this has been possible with industry growth rates of roughly 5-15%. In the pulp and paper industry this is not a particularly low rate of growth. However, if output were to have increased in excess of this, i.e. faster than emission coefficients decline, the result would have been an increase in total emissions. It can be argued to be self-evident that technical change will lower the emissions coefficient over time. However, the rate of the improvement will be related to the frequency of investments. If investments are infrequent, the rate of improvement will not be fast enough to offset the growth in gross emissions from higher production figures.

7.4.1.2 Economic effects of investment strategy

Measurement of the environmental component of the win-win situation is, in principle straightforward, especially at the level of a specific effluent, such as BOD or solids. However, the measurement for the economic side of the win-win situation is not as simple. Here total production is taken to resemble the economic side. Production and revenue are strongly correlated as shown in figure 7.5. Revenue includes the notion of volume since it is a function of volume and selling price. World commodity prices are unstable and as a result revenues fluctuate more than production.

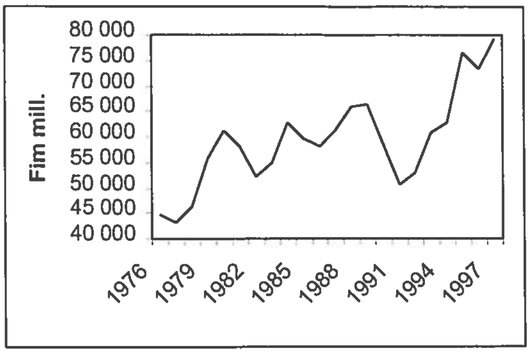

FIGURE 7.5a Deflated turnover

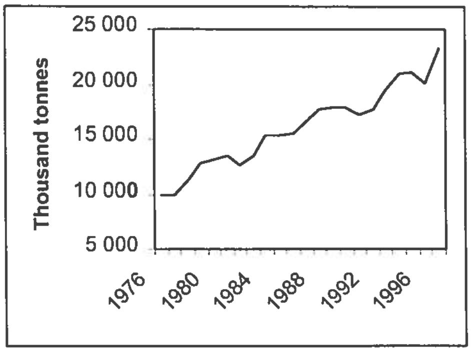

FIGURE 7.5b Growth of production volume

Firms define economic win as profit. Net profit is calculated as revenue less operational costs, financing costs and depreciation. Profits in an industry fluctuate and vary according to numerous situational factors of which those arising from environmental issues are just one subset (Brännlund et al. 1995, Rugman and Verbeke 1998). Hence, production volume is perhaps the most objective, although not perfect, measure of the economic component. The results of the analysis are slightly different when the net profit ratio is used. In figure 7.6 the net profit ratio is shown as a function of total BOD and BOD/tonne.

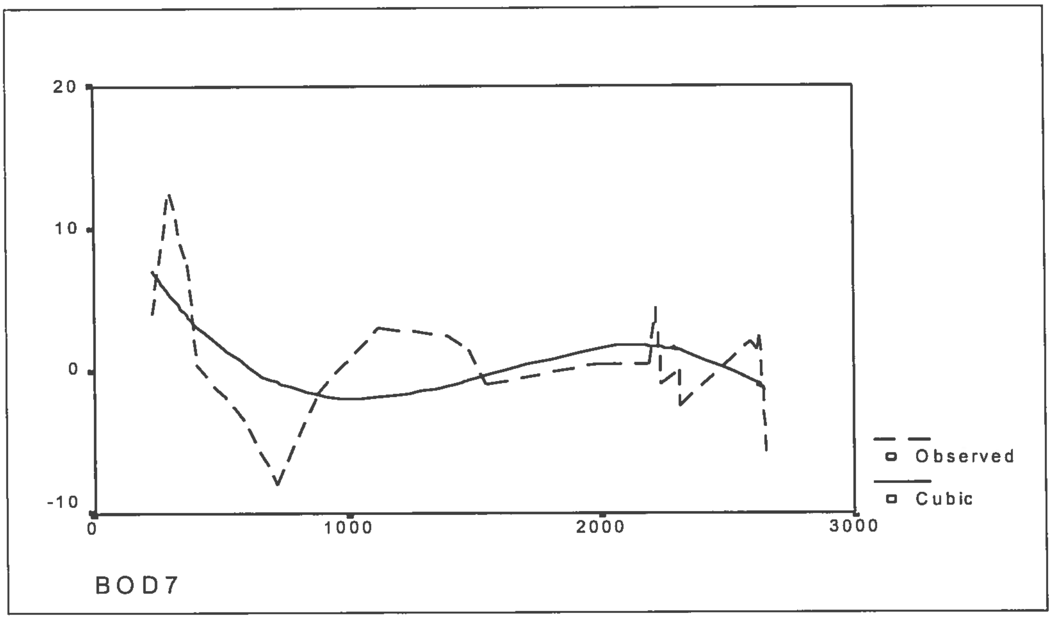

FIGURE 7.6 Net profit ratio as a function of total BOD7 releases.

Representing net profit as a function of emissions only is an overly simplified assumption. However, it demonstrates well diminishing marginal returns on the one hand and the existence of low-hanging fruit on the other. Figure 7.6 shows that pollution prevention or environmental quality protection is most successful and most cost-efficient in its mid-stages, where improvements can still be realised and the basic pollution prevention infrastructure is already in place.

In this analysis the qualitative changes in the production structure of the industry were not taken explicitly into account. However, in terms of emissions, dematerialisation or for example the so-called closed-loop economy, qualitative changes may be far more important than the quantitative. Changes in the chemicals and fillers used in papermaking affect the recyclability of paper, amongst others. Qualitative changes may also mean more profound impacts on the economy of the firm compared with quantitative changes. Usually the trend is towards higher value-added production, meaning that even with slight quantitative decreases, a qualitative change (increase) could yield higher revenues.

7.5 Discussion

It has often been argued that pollution prevention crowds out investment in productive technologies and results in productivity decline or slow-down in the rate of productivity growth (Gollop and Roberts 1983, Pittman 1983, Barbera and McConnell 1990, Jorgensen and Wilcoxen 1990). In fact, the productivity slow-down experienced in the United States after the wars has, among other reasons such as poor investment decisions and lack of information technology, been explained by the increased requirements for pollution prevention technology from tightening environmental regulation (Christainsen and Haveman 1981). The arguments imply that win-win situations cannot be achieved. These studies have analysed mainly US industries.

An opposite story is told in this paper with the Finnish pulp and paper industry and its two post-war decades of win-win situations. Effluent discharges have been minimised to a level below that required, whereas the reference industry in the US is still struggling to meet the pollution prevention requirements of local authorities (Jorgensen and Wilcoxen 1990, Esty 1994, Ekono 1996, 1997, 1998, Ruth and Harrington 1998). Clearly the difference in investment strategies has resulted in relatively different development paths for essentially the same industry in two different localities. The US regulatory system has long employed the command-and-control approach stipulating the target level of emissions reduction and the technologies to be employed (Jaffe and Peterson 1995, Nehrt 1998). Policy design has partly encouraged the choice of investment strategy. The paper shows that firms can promote either complementarity or substitutability of natural and manufactured capital through their strategic core business decisions, which in turn can be influenced by the regulatory climate.

Firms will primarily invest in such situations that yield beneficial situations for the corporation, i.e. either win-win or win-lose investments. Few corporations can be argued to invest in natural capital for its own sake; firms must bear in mind the main objectives of profitability and continuity. Both legislation and public awareness expressed as pressure will influence the firm and steer them from choosing win-lose towards win-win investments.

Availability of resources and payback times are examples of investment barriers. Another barrier is the availability of BAT technology. Policy planning needs to overcome these and other barriers by making the adoption of BAT technologies attractive. This can be achieved through lenient adoption time frames and the possibility for plant specific solutions. Encouragement could also come for example in the form of lower permit fees for high investing firms and early adopters as well as investment subsidies for BAT techniques. Similar findings were encountered by Ruth and colleagues (Ruth et al. 2000) for the US pulp and paper industry. National environmental policy needs to consider the natural investment cycle of industry. Flexibility of adoption schedules is necessary since the diffusion and adoption of best techniques may not be as instantaneous and costless as expected by economic analyses (Barde 1995, Nehrt 1998).

The IPPC directive was issued in 1996, towards the end of the time frame included in this study. However, the development demonstrated by the Finnish industry over the past twenty years coincides with the objectives of the directive and represents the kind of situations that the directive is intended to promote. During the twenty years the Finnish pulp and paper industry has operated on system of plant specific effluent standards updated every three years that have not been based on specific reference technologies. Finnish environmental legislation has ensured that no mill is faced with permit levels that are unnecessarily restrictive and difficult to comply with. The development in the win-win direction has not been stipulated by a legislative clause but rather by the industry itself.

The reasons that have led to these specific outcomes in Finland are a result both of environmental and industrial policy and permitting as well as the strong development initiatives of the pulp and paper industry and the entire related forest cluster. The cluster is a support network providing machinery, chemicals, automation, and engineering services to the pulp and paper industry. The forest cluster has historically had intimate research and development cooperation between actors in different but relted industries. The cooperation initiative has been internal and the main motivator has been to increase efficiency and boost sales. The high domesticity of the forest sector combined with the domestic complimentary industries creates a strong national and competitive advantage for the industry. These advantages are further accentuated by advanced energy and power technologies. As a small country, Finland is dependent on export markets. An important competitive weapon in international markets is product quality, and recently also environmental quality. These factors together explain why the industry has embarked on a path that may seem obscure.

The choice of accounting units has a profound impact on the resulting analysis. Accounting units also have implications on data aggregation issues.

Here the choice was made to use physical weight measurements. Aggregating different production types under the single denominator of weight disregards aspects in that production that may be significant in an environmental sense. Aggregation by weight is misleading in its ignorance of material quality (for a discussion of the aggregation issue see Cleveland and Ruth 1998). Different paper grades with the same weight have distinctly different physical and chemical properties. These properties increase in importance in the latter stages of the life-cycle with waste management issues. The truth may be that there is no reliable aggregation option for material flows, as suggested by Hinterberger et al. (1997). Aggregation according to weight was chosen here for initial simplicity perhaps more than due to rigorous analysis and testing of its appropriateness. A logical next step would be to see how results change or hold under different types of aggregation schemes.

The discussion concentrated on emissions and not directly on natural capital. The approach is justified on the assumption that emissions result directly in decreases of natural capital. Thus, emissions can be taken as a proxy for natural capital. Naturally emissions do not incorporate or capture all the intricate relationships and interdependencies of natural systems. However, emissions are perhaps the easiest component affecting natural capital to be measured. The study concentrated solely on water-borne emissions, for which the data is available for a longer time period. This focus neglects important natural capital variables on both the input and output sides, such as air emissions and raw material use. A next step would be to incorporate all natural capital variables in the analysis and compare the findings with those presented here.

7.6 Conclusion

The philosophical attractiveness of universal capital complementarity of manufactured and natural capital is no doubt sizeable and the basic argument convincing. This study, however, shows that such argumentation is limited and fails to take into account specific attributes of investment situations that really determine the economic and environmental outcome. Several examples are given of different types of investments situations and their effects both on environmental and economic variables.

This paper looked at the Finnish pulp and paper industry over the past two decades showing how the adoption of new technologies has helped to create win-win situations. It demonstrated that the creation of such win-win or win-lose situations is plant or investment specific as is also the notion of capital substitution on a sectoral level, thus bringing new light into the discussion on an academic level. On a practitioner level it provided a new framework for analysing the effects of investments. The papers' suggestions for environmental policy show that it should be designed in a way that takes the situation specific factors into account and that can be adjusted as necessary. In Finland this has been achieved through the use of the plant specific permit system, that through its flexibility ensures the competitiveness of the firms.

8 INTEGRATED MODELLING FOR THE STUDY OF SUSTAINABILITY -THE FINNISH PULP AND PAPER INDUSTRY 1979-1997[15]

Minna-Maari Karvonen

Abstract

Integrated modelling of economic and environmental issues is becoming increasingly important. Often the tools for such analysis are lacking. One proposed tool is the environmental-economic production function (EEP), which can be used to study the interaction of technology and the environment. It is applied here in the case of the Finnish pulp and paper industry between 1979-1997. The model provides a framework for analysing the development and its underlying driving forces and subsequently for assessing the question of sustainability in this context. The results reflect the development of the industry in a sustainable direction.

Keywords: environmental-economic production function, sustainability, pulp and paper industry

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[15] This paper was presented at the 3rd SETAC World Congress, 21-25 May, 2000 in Brighton, UK.

8.1 Introduction

Sustainable development, a concept introduced in 1987 (WCED 1987), has gained wide acceptance as a new paradigm. Sustainability has been quoted as the new goal of communities and also of industrial activity; current needs should be satisfied without sacrificing the possibility of meeting needs in the future. In essence the ideas making up sustainability are not new (Dietz et al. 1992) and can in fact be regarded as the very ideas of successful corporate management, i.e. securing future income generating possibilities. The idea of sustainability is also in line with the definition of Hicksian income at the level of the individual consumer. Income, according to Hicks is an amount the consumer can use in a given period of time without sacrificing his wealth. This can be considered sustainable consumption. However, the main effect of the Brundtland Report was to bring the idea of sustainability into the global political arena and to further emphasise the differences between South and North on the issue of economic growth. The Brundtland definition of sustainability was thus more in accordance with political ideology compared with previous definitions.

Sustainability is usually regarded as having three dimensions; economic, ecological and social sustainability. For real achievement of sustainability, all three characteristics of the development process need to meet the goals of sustainability, i.e. be "in harmony and enhance both current and future potential to meet human needs and aspirations" (WCED 1987, p. 46). The measurement of sustainability, especially according to its political definition is difficult. Often science has come up with analytical instruments and tools that have only questionable practical relevance (Dietz and van der Straaten 1992). There is no lack of environmental information but often the nature of that information is too detailed to have practical applications (ten Brink 1991). As a result, sustainability has rarely been measured.

Further characterisations have been made in order to more precisely define the concept of sustainability. Sustainability is seen as being either weak or strong (Neumayer 1999). According to strong sustainability the stock of all forms of capital, natural (K_n), social (K_s), man-made (K_m) and human (K_h) must stay constant or increase. According to weak sustainability the aggregate stock of capital must be constant or increasing, allowing decreases in one type of capital as long as they are compensated for with a similar increase in another type of capital. The sustainability equation is expressed as:

(8.1) $$\sum K = K_m + K_n + K_h + K_s$$

The function (8.1) satisfies the ideological foundations of the sustainability concept. However, it does little to help in its actual measurement. (8.1) in essence implies addition of variables with fundamentally different accounting units, if the variables are not first unifromaly normalised. This is the main accounting problem associated with the sustainability concept.

In order for sustainability to become a goal, it needs to be quantifiable and measurable. In this way, progress towards it can be analysed. Ten Brink (1991) places the following conditions on appropriate information for the assessment of sustainability

- it should clearly express if set goals are met
- includes the entire system
- is quantitative
- can be understood by non-scientists
- includes parameters that can be used in the long run.

This paper takes a production function framework to study the development of the Finnish pulp and paper industry during 1979-1997. It is suggested that a function such as (8.1) can be estimated to a certain degree with conventional microeconomic tools. Attention is drawn especially to the presented idea of sustainable development and how it is manifested in the chosen industry. This first section provides an introduction into the topic as well as presents the microeconomic background employed later in the paper. The model and data are then presented in section 8.2. Section 8.3 shows the results derived from the use of the model; both with respect to the model itself and with respect to the main development characteristics in the industry. The discussion centres around the usefulness of the conceptual framework presented here as well as on the possibilities for reducing the ambiguity surrounding the sustainability idea. Finally, in section 8.5, the main findings are summarised in the conclusion.

8.1.1 Neo-Classical Economic Theories

Traditional economic theory approaches the study of the production process from a monetary point of view in which a production function is used to express the relationship between the maximal amounts of valuable outputs, which the producer can make of a given set of "costly" inputs (Cohen and Cyert 1965, Chung 1994). A prominent example of this line of thought is the Cobb-Douglas production function. Environmental impacts are not included in the model as they are perceived as free goods that do not effectively restrict the production decisions of the profit maximising firm. Increasing environmental demands have later transformed the traditional function to include those costs arising from the reduction of environmental impacts as cost functions (Pittman 1983, Jorgensen and Wilcoxen 1990, Barde 1995). For example environmental taxes or the cost of pollution abatement technology has been included. In the absence of clear prices, the functions have been used to derive so-called shadow prices for the unwanted by-products of production processes or environmental impacts (see for example Färe et al. 1993).

Life cycle assessment (LCA) literature operates or is written within a distinctly different framework: modelling of environmental impacts is accomplished through the use of emission coefficients describing the environmental performance of a process. LCA coefficients provide a static "recipe" for a defined system (SETAC 1992, Consoli et al. 1993, Lindfors et al. 1995). Current LCA practices do not allow for dynamic modelling of systems where the emissions coefficients change over time (Schaltegger 1997, Clift et al. 1999).

A general economic-environmental production function, or EEP, of a production process (Pento 1998a) incorporates emissions in their physical units without assigning arbitrary subjective notions, such as money values. It can be expressed as the relationship between outputs with either positive or non-positive market value, and inputs that are either natural or human-made:

(8.2) $$g(O_1 ..., O_p; O_{p+1} ..., O_n) = f(I_1 ..., I_m; I_{m+1} ..., I_k)$$

in which the outputs O_1 … O_P are products with non-negative economic value, and O_{P+1} …O_N are emissions and waste, which may or may not have a negative value for the producer. The inputs I_1… I_k are human-made inputs, such as capital or labour, and I_{k+1} … I_M are inputs from the natural environment. The outputs of non-positive value are not retained in the process and become environmental interventions in the form of emissions, waste, noise etc.

Since the EEP includes both natural capital and manufactured capital variables, it lends itself better to an analysis of sustainability than a traditional neo-classical production function. As a result, this EEP is employed here, providing a good basis for an integrated modelling approach.

8.2 The Model

As no common measurement criteria or reporting units exist, assessment of sustainability according to (8.1) is difficult. For the purposes of this paper, social and human capital are omitted. On a general level it could be argued that increases in manufactured capital and increases in natural capital (meaning decreases in emissions) will both increase human and social capital. Increased production will lead to more jobs, higher income and thus a higher standard of living. On a more detailed level, inter- and intragenerational distributional issues need to also be considered. Increased natural capital will result in a cleaner environment increasing opportunities for spending leisure time, which in turn may increase the social capital stock. Arguably there are many other components also of social capital including for example culture, language, sense of community and belonging. It can also be argued that an increase in manufactured capital such as that indicated here will increase the well-being of only part of the population while making the rest of the people not better off: in essence widening the divide between the well-off and those less so. Here, the analysis is only on Finland, which can be characterised as a welfare society. Studies have shown that in countries where the welfare ideology has been strong, there has been a move towards convergence across social groups (Castles 1998). In line with this thinking, an increase in manufactured capital can be seen as a proxy for also increased social capital. However, these hypotheses are only left to a mention here.

Manufactured capital, in this paper, is regarded as investments and production whereas natural capital variables include emissions to water and raw material use. The model is thus:

(8.3) $$\sum K_t = Q_t + C_t - E_{it} - \Delta V_t$$

where K is the sum of capital stock, Q is production, C is capital investments, E_{it} is emission i and V is change in the stock of virgin raw materials, all at time t. Change in capital or sustainability is then the change in $\sum K$ between two different time periods. In this paper sustainability is assessed as relative changes during 1979-1997 and not sustainability *per se*. Variables are included in the model as indexes of each sub-capital set based on the year 1979. Thus the figures show the change in the particular variable relative to the base year 1979. Reducing change to indexes, or in essence percentages, makes it possible to compare differences and to arrive at an aggregate sum of and between the units. The model then becomes

(8.4) $$\sum(K_t - K_{t-1}) = (Q_t - Q_{t-1}) + (C_t - C_{t-1}) - (E_{it} - E_{it-1}) - (\Delta V_t - \Delta V_{t-1})$$

The study uses time series data from 1979-1997 of Finnish integrated and non-integrated pulp and paper mills. The data have been collected by the Finnish Ministry of the Environment, The Environment Institute and the Finnish Forest Research Institute during permit compliance checks. Emissions are reported in publicly available databases.

8.3 Results

8.3.1 On the development of the industry

Table 1 shows the changes in all the sub-capital components during 1980-1997 relative to the base year 1979 (= 100). All changes are represented as indexes. Production quantities refers to the joint production of pulp and paper of the entire industry. No differentiation is made between sole producers of either pulp or paper or integrated mills producing both. There is also no distinction into different pulp types or paper grades but rather they are all aggregated with weight as the common denominator. Although pulp is the raw material of paper making, there is no double accounting here since pulping and paper-making are two distinct and separate processes each having their own environmental impact profiles.

Cumulative capital investments include all investments of the industry in any technology. No distinction is made between environmental and productive investments. A cumulative figure is taken as opposed to yearly, stand-alone figures, since capital investments increase efficiency and have also other impacts in more than just the year in which the cost is incurred. Cumulative capital investments are depreciated at 15% per annum giving an average operative life-span of roughly twenty years: in twenty years, the investment will have depreciated to 3,9% of the original value and can be assumed to be replaced by the latest.

The forest balance figure shows the change in the overall forest stock calculated as the natural regeneration or growth rate deducted with fellings, giving the real growth rate. An increase in the forest balance index indicates a year in which the growth rate exceeds fellings whereas a decrease in the index indicates a year in which forest reserves were depleted at a pace greater than the natural growth.

The last column shows the change in sustainability each year relative to 1979. This last column is calculated according to equation 8.4. It is an accumulation of the other indexes. As shown, sustainability has grown considerably during the entire time period and between 14% and 56% annually even allowing for periods of unsustainable growth[16].

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[16] An unsustainable period is one in which the sustainability index of the last column of table 1 has decreased relative to the previous year. An example is the period 1987-1988.

TABLE 8.1 **Relative changes in sustainability and its sub-components in the Finnish pulp and paper industry 1979-1997. Figures represent indexes based on the starting year of the time series (1979=100). Sustainability represents the aggregation of the variables according to (8.4).**

Year	Total production quantities	Depreciated cumulative capital	Labour force	Forest balance	BOD	TSS	Nitrogen	Phosporus	***Sustainability***
1979	100,0	100,0	100,0	100,0	100,0	100,0	100,0	100,0	***0,0***
1980	102,9	111,4	100,0	89,0	101,5	97,3	108,7	105,4	***-9,6***
1981	105,4	123,1	100,0	118,6	101,2	97,0	113,1	102,0	***33,7***
1982	98,6	131,3	100,0	130,3	86,4	83,0	108,2	97,3	***85,2***
1983	106,0	132,2	88,1	138,7	84,6	82,2	110,8	102,0	***85,4***
1984	120,0	134,9	86,4	130,8	85,6	75,4	117,8	120,8	***72,6***
1985	120,6	141,8	84,7	113,6	77,0	76,1	120,5	134,0	***53,2***
1986	121,0	146,5	84,7	125,0	59,7	70,8	115,8	121,3	***109,7***
1987	128,9	156,3	83,1	118,0	56,8	65,4	119,4	136,3	***108,2***
1988	138,0	168,0	76,3	106,6	53,6	61,8	124,3	143,8	***105,4***
1989	139,8	188,2	78,0	107,5	43,0	55,7	122,2	133,1	***159,4***
1990	139,6	201,1	79,7	114,6	33,7	49,4	113,6	114,7	***223,5***
1991	135,0	201,3	78,0	135,3	27,6	41,3	104,7	95,2	***280,8***
1992	138,3	199,8	76,3	131,7	23,5	34,8	93,8	82,5	***311,5***
1993	151,1	185,0	76,3	108,2	15,6	26,5	82,1	67,8	***328,6***
1994	163,2	180,8	74,6	91,8	14,1	24,8	86,2	60,5	***324,9***
1995	164,4	192,0	71,2	94,5	11,5	24,3	87,7	57,2	***341,4***
1996	157,5	209,0	71,2	98,8	8,8	21,1	71,6	57,0	***378,0***
1997	181,7	204,7	67,8	70,1	8,0	21,0	71,0	57,0	***367,3***

Output in the industry has increased by 80% and 200% for pulp and paper respectively in twenty years. Growth has averaged 3-4% annually. Increased volumes have meant higher sales and higher revenues. As a result, the industry has invested heavily in new process and environmental technologies. Investments have been, on average, 10% of turnover annually.

Even with growth in production volumes, gross emissions have decreased. Water-borne BOD, total suspended solids, nitrogen and phosphorus emissions have decreased by 92%, 77%, 17%, and 46% respectively during the entire time period. The introduction of paper recycling has decreased the virgin raw material requirement of the industry. Between 1976-1997 virgin wood consumption per tonne of combined pulp and paper production has decreased by 16%. However, the total virgin wood use has increased by 95% reflecting the increasing operating volumes. The main issue with respect to renewable resources is the rate of harvesting and ensuring that it does not exceed the natural regeneration rate of the resource. So far, a sustainable yield within the Finnish forestry sector has been ensured. During 1986-1997 Finnish forest reserves grew at an annual average rate of 77.6 million cubic metres. Of this, on average 50 million cubic metres was harvested as raw material wood for industrial use. As a result forest resources have increased yearly although the rate of increase in the past few years has declined.

8.3.2 On the model

The last column of table 8.1, the sustainability index calculated as the sum of all indexes, was employed for further analysis. The objective was to find a sustainability equation and explore its qualities. If such an EEP (8.2) function can be found and estimated, then clearly the EEP is a relevant instrument for the study of sustainability. From a defined set of variables, the sustainability index correlated significantly (at the 0.01 level in 2-tailed test of significance) with both depreciated capital investments and with production volumes. However, in stepwise regression, only capital investments were retained in the model. A linear, logarithmic and quadratic function were estimated. Table 8.2 shows the regression estimates for the estimated function forms. From the results, it seems that the linear and logarithmic functions are most reliable for the calculation of the sustainability index.

TABLE 8.2 Regression estimates of different sustainability function coefficients. Standard errors and t-values in parentheses. S is the sustainability index, K represents depreciated cumulative investments and α, β, γ are coefficients.

	$S = \alpha + \beta K$	$S = \alpha + \beta \ln(K)$	$S = \alpha + \beta K + \gamma K^2$
α	-392,7 (63,9; -6,143)	-5374,83 (664; -8,085)	-26,37 (347; -0,076)
β	0,0152 (0,0016; 9,100)	528,4 (63,26; 8,353)	-0,0059 (0,0198; -0,298)
γ	n/a	n/a	2,9E-07 (2,7E-07; 1,072)
R^2	0,830	0,804	0,841

The results show that over a relatively long time period, a sustainability function can be determined that resembles to a great extent the traditional production function. This sustainability function defines an index of sustainability through the investment tendencies of the industry with an accuracy of 84%, leaving only 16% of the variation in the index unexplained. Thus the function is relatively accurate in predicting the real index values.

8.4 Discussion

8.4.1 The sustainability function

An augmented traditional microeconomic production function can be used on the aggregate macro level to study sustainability. It can be used to study the past development and the main characteristics of that development but it can also be used to show a proxy for future situations. However, the function presented here will only show results for the index and not at the exact composition of that index. As a result, it can only be regarded as an indicator of weak sustainability. In this example the index was only simple addition and subtraction of variables without weighting, so substitution among the variables is possible.

Simple tools are often also the more powerful tools. The suggested sustainability function is not intended to be a thorough analysis but rather a first step in what can be considered the right direction. It provides a starting point for a more thorough analysis of sustainability of the firm or of the industry. For intra-firm use, the function can be used to assess and compare the performance of the firm in terms of sustainability in different time periods. This will help in evaluating business decisions and their impact on the environmental performance of the firm. The function could also be used in evaluating different industries. First, it needs to be checked whether the function holds in another industry and then a comparison can be made of different industries together.

8.4.2 Sustainability

Traditionally the pulp and paper industry is not viewed as particularly sustainable (Ruth and Harrington 1998, Abramovitz and Mattoon 1999). It is claimed to be one of the biggest users of energy and fresh water of all manufacturing industries and it is also said to promote a wasteful, throwaway, lifestyle. The pulp and paper industry, by its nature, also relies on forest reserves for its supply of virgin fibres.

Often sustainability is assessed in terms of emissions or raw material use only and the economic component is omitted. This leaves the 'big picture' rather unrealistic and vague; present needs are a cornerstone of the definition for sustainable development. Therefore, in this analysis, economic indicators are allowed to play a more prominent role.

The results presented in this paper contradict the unsustainability assumption of the pulp and paper industry by showing that it has moved in a sustainable direction for the past twenty years. The industry has produced more output, i.e. it meets more needs while at the same time decreasing the burden on the environment. Thus the ability of future generations to meet their own needs has not decreased. By employing the EEP it can be shown that increased sustainability is a result mainly of capital investments in productive technologies and in pollution abatement technologies.

8.4.3 Eco-efficiency and dematerialization

The World Business Council for Sustainable Development (WBCSD) has been the forerunner in the eco-efficiency discussion. It has argued that eco-efficiency can be reached by "*the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing* *ecological impacts and resource intensity throughout the life cycle, to a level in line with the earth's estimated carrying capacity*" (www.wbcsd.ch). In essence, the argument is that more should be made from less. Several measurement methods and targets have been suggested with respect to eco-efficiency, the most well known being the factor-x debate (von Weizsäcker et al. 1997, Reijnders 1998, Hawken et al. 1999). Factor-x concerns reducing the material intensity of products by a factor between 4-100. This has also been introduced as the MIPS (material intensity per service unit) concept, which calculates all the materials required for the production of a certain product or service (Schmidt-Bleek 1993). Dramatic reductions in the usage of materials is seen as the only possibility for ensuring sustainable development. The factor-x argument and the MIPS concept are almost synonymous with dematerialization.

Eco-efficiency is one way of looking at sustainability. Often though, it is argued that merely increasing eco-efficiency does not adequately meet the sustainability challenge and that such goals do not answer the underlying problems promoting unsustainable practices (Ottman 1998, Belz 1999). The pre-occupation with making more from less also ignores limits to growth and in fact supports the neo-classical paradigm or perpetual growth. However, it is the authors opinion that eco-efficiency, measured with for example the EEP presented here, can effectively be used to measure sustainability or give an indication thereof.

The results for the Finnish pulp and paper industry can be viewed from the eco-efficiency perspective. The unwanted side product, emissions, can be regarded as a 'negative input', which should be reduced to the minimum possible amount, i.e. by a factor of x. If we look at the results in table 8.1 and in figure 8.1, we can clearly see that the industry has been able to achieve factors of almost 100 in terms of emissions per product unit. The reduction in raw material use has not been quite so dramatic, only 16%, which translate into factors far below two. This is also a result of the nature of the product, which requires a certain minimum amount of wood. The amount and type of combination of wood fibres and fillers also defines the printing and other qualities and end-uses of the paper.

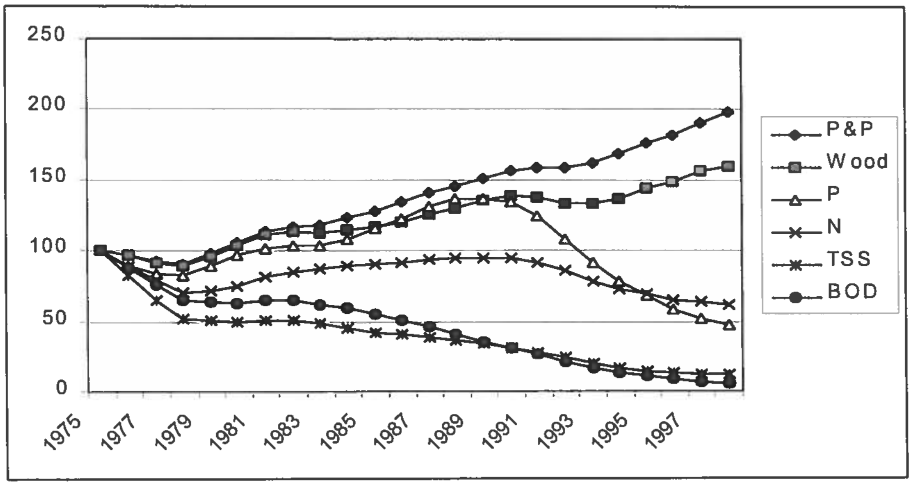

FIGURE 8.1 Indexes (1975 = 100) of the amounts of pulp and paper and virgin wood as well as emissions of P, N, total suspended solids and BOD7, produced by the Finnish pulp and paper industry.

The ultimate challenge of sustainable development is changing consumption patterns (Pickett et al. 1995, Ottman 1998, Belz 1999). However, global forecasts made for the paper industry reflect increasing consumption at least for another decade (see for example Suhonen 1999). Perhaps further into the future alternatives to paper can become more available and accepted and then begin to pose a threat to the paper industry.

8.4.4 The consumption of energy and other raw materials

As stated, the focus of this paper leaves out important variables that affect the sustainability of an industry. The pulp and paper industry consumes relatively large amounts of heat energy and also of electric power. Power production, again, is a major polluter and user of non-renewable resources. The pulp and paper industry uses 29% of the total consumption of primary energy (Mtoe) and 33% of total electricity generation in Finland (PI-Consulting 1997). However, in chemical pulping the recovery of cooking chemicals and the incineration of bark and other wood residues also generates energy; amounting to roughly 10% of total primary energy production. The mechanical pulp industry on the other hand, uses extensive amounts of energy. On average 55% of primary energy is produced from renewable resources, or is not overly dependant on fossil fuels. Figure 8.2 presents the fuels used in plants by the forest industry in Finland in 1999. Clearly, only a small minority of fuels are from non-renewable resources. This is especially significant when comparing the fuel profile of the industry to that at national level, where a much larger share belongs to non-renewables, or fossil fuels.

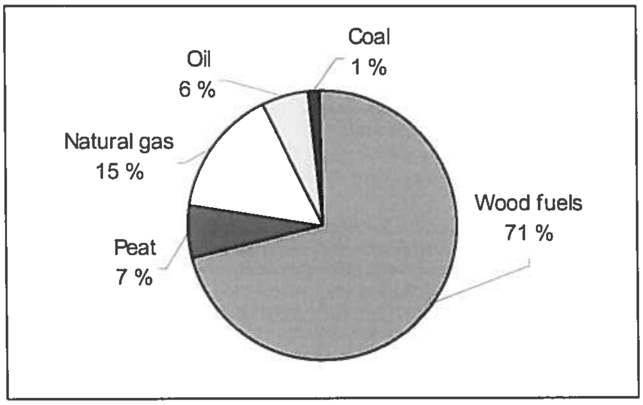

FIGURE 8.2 **Fuels used in plants by the forest industry in Finland in 1999.** (*Source: www.forestindustries.fi)*

Energy consumption is always a sensitive topic. All industrial activity requires energy and all industrial activity is driven by market demand. Weighting the energy consumption and, in this case also generation, against sustainability criteria and against other environmental effects has been neglected in this paper. A source of unsustainability is really energy production (of course driven by consumption, but there are also more sustainable ways of generating heat and power). In the Finnish pulp and paper industry 71% of energy consumption is met by wood fuels and only 7% by oil and coal together as shown in figure 8.2. The 71% in this study is already included in the calculations of the index (includes mainly wood bark, chips etc), also the emissions from fuel generation are included. As a result in this case inclusion of the affects from other forms of energy was not necessary. This omission could be taken up in future. An in-depth study of sustainability of the industry would in fact require inclusion of all variables; an avenue of potential future research.

The move towards higher paper grades has meant the increased usage of fillers, mainly calcium carbonate and other minerals. Their increased use increases the environmental effects characteristic of extraction and mining. Otherwise, and at least until lately, there is no shortage on the supply of these raw materials and thus slight increases in their use cannot be regarded as a significant decrease in sustainability.

8.4.5 Qualitative versus quantitative changes

The output of the industry has doubled in weight terms in the past twenty years. In this analysis no qualitative changes in the production structure of the industry were taken into account. However, in terms of emissions, dematerialisation or the so-called closed-loop economy, qualitative changes may be far more important. Changes in the chemicals and fillers used in paper-making affect the recyclability of paper, amongst others.

Qualitative changes could also be assumed to change the emissions from production, mainly water-borne effluents, as most chemicals would leave traces in the process waters. In the sustainability analysis here, four main water effluents were studied. In this sense then, at least the effects of qualitative changes on emissions have been captured.

Qualitative changes may also mean more profound impacts on the economy of the firm compared with quantitative changes. Usually the trend is towards higher value-added production, meaning that even with slight quantitative decreases, a qualitative change (increase) could yield more turnover.

Indeed then, qualitative changes will affect the results of the sustainability analysis though different variables as discussed. The sustainability function here, although not explicitly, does incorporate qualitative changes through the variables, i.e. the effects of qualitative change on the different variables in the model. The model is rather emissions-oriented; to get a more clear picture of the effects of qualitative changes versus quantitative changes would require a more rigorous analysis with additional variables providing more insight.

8.4.6 Environmental policy

The reasons that have led to these specific outcomes in Finland are a result both of environmental and industrial policy and permitting. Finnish environmental legislation has included issuing plant specific permits that have been periodically updated. The permits have allowed for mill-specific attributes to be considered in the permitting process thus ensuring that no mill is faced with permit levels that are unnecessarily restrictive and difficult to comply with. This type of policy approach has been employed for the entire time period under study here. The approach differs from that of for example the UK where a certain base level is prescribed and each mill is expected to perform as well as or better than the base level, regardless of the specific attributes of the mill.

The presented case then, is good for analysing the policy outcomes of flexible permitting allowing for individual, mill-level specifications. This is in fact the approach that is intended with the EU IPPC directive aiming for the integrated prevention and pollution control without placing economically unnecessarily restrictive boundary conditions on any plant. The IPPC directive specifically calls for special consideration of mill age and employed technology when deciding on emission levels (Council Directive 96/61/EC).

8.5 Conclusions

This paper has demonstrated that an integrated approach to looking at the environmental effects of technological change is useful. It is shown that the Finnish pulp and paper industry's environmental effects have been dramatically decreased and the environmental performance or eco-efficiency of the industry has improved as a result of technological development. The impetus for the observed technological development has not been only legislative pressure but also intra-firm desire to serve an increasingly environmentally conscious and aware market. The flexible regulatory regime employed in Finland has obviously helped in creating an atmosphere for promoting sustainability in the industry. The case implies that those strategic decisions that have been made in the industry, whatever their motives, have been beneficial in environmental terms, or in terms of sustainability.

The results provide a convincing counter-argument for those claiming the industry to be highly unsustainable. The pulp and paper industry could benefit from this type of face lifting, especially if these issues could be incorporated into communications or marketing. One important point against the usual criticism is that the industry, besides consuming, also generates substantial amounts of energy and from renewable resources.

The presented case shows a rather clear development of the industry towards increasing sustainability. In this analysis no weights are attached to the different capital sub-components and as a result the development is characterised as strongly sustainable. However, without any weighting the statement is subject to value judgements. A similar study using different weighting scenarios would provide more valuable input for the discussion. Performing the same type of analysis also on another industry and comparing the results would perhaps make the results easier to comprehend.

The weakness of the model is that it is not all encompassing. Undoubtedly many natural capital variables are left out, for example the increases in the use of "fillers" occurring with the decrease in virgin wood use per tonne. Neither are air emissions, including CO_2, included in the model. The main rationale for excluding them has been the completeness, credibility and accuracy of available data. The general trend in air emissions has also been declining, with the exception of CO_2.

The main purpose of the paper was to explore and demonstrate the application of the economic-environmental production function in the study of sustainability. The findings suggest that the function can be applied for this purpose but that the function itself falls short of showing a complete proxy for sustainability. Sustainability itself still lacks adequate indicators. The proposed EEP is one model that could be used for assessing sustainable development. This paper has taken the first step in introducing the EEP application; further research and testing is required to operationalise the model and to test its robustness as well as wider application possibilities.

9 DISCUSSION

This chapter summarises the discussions of each of the separate research articles. Results and conclusions of each are presented although not in the same detail as in the preceeding chapters to avoid repetition. This discussion chapter serves to provide answers to the research questions provided in chapter 2 of this thesis.

9.1 On the model itself & the choice of methodology

The empirical estimation of the economic-environmental production function clearly shows the existence of such a function. Often elaborate models can be written without much regard to their empirical existence or applicability. In this sense the study has proved an important point; that emissions can be modelled through a traditional production function framework. Moreover, the insight was provided that production quantities alone are not the best measure for the formation of pollution but instead other variables play a deterministic role, mainly capital investments in both productive as well as non-productive technologies. The fact that the more holistic models were uneable to provide a better estimate of the actual situation, showed that the effects of technological development span over a number of variables and are deterministic.

In fact a very similar function with the same variables was introduced by Xepapadeas and Petrakis (1999). They proposed that emissions are a function of the quantity of main product (q) output and of the abatement effort (w) or

(9.1) $$E = f(q, w)$$

This function format is almost the same as was estimated in chapter 5 (equation 5.7). However, the above (9.1) implicitly assumes monetary valuation of the variables, and a distinctly different starting premise was taken in this thesis with physical measurement. The work of Xepapadeas and Petrakis is theoretical whereas in this thesis the same function format was arrived at through empirical modeling. Hence demonstrating that the original idea of modeling is valid. The theoretical modeling also arrived at the increasing cost of marginal innovation; the same empirical results as was stated in chapter 5 as decreasing effectiveness or decreasing marginal returns of capital on environmental quality improvement.

The application, especially since the functions have strong predictive power, implies that the joint modelling of environmental and economic variables in mixed units is possible and provides results that are easily understood and interpreted. The model can be used by practitioners and policy-makers and can also be used to predict the potential future level of emissions. One presented model included the production quantities of pulp. The coefficient for pulp is negative implying that the variable to some extent endogenises technological change and advances.

The empirical estimation of the EEP model presented here combines variables of different accounting units together to form a coherent whole. This can be thought of as a sort of pluralism; most production functions treat only variables of equal units. However, the mixing type of approach is well established in other fields, for example in the study of worker or labour productivity. Moreover, natural accounting units make the models more objective avoiding at least some measure of bias.

The models, or different functions, are used to arrive at some potential future levels of emissions. The results show that given that production increases and investments stay at constant annual levels, it is not realistically possible to reduce emissions significantly any longer. However, the effect of the growth of production volumes can be offset by investments, meaning that emissions can be kept at current levels. On the other hand, if investments are seized, emissions will quickly double and reach levels representative of the early 80's.

The first research article answers the first main research question:

> *"How to describe, explain and potentially predict, the reaction and pro-action mechanisms of the Finnish pulp and paper industry to recent changes in the external and internal operating climate, especially with respect to environmental issues?"*
>
> *"Can the recent developments be presented in the production function framework?"*

Traditional neo-classical economic frameworks can be widened to take into account environmental variables in their natural units.

9.1.1 Capital vintage analysis

In the pulp and paper industry machinery has a relatively long life-span. As a result, it is defendable that the ageing of the capital stock should be explicitly captured in any model. This is especially important since, as was shown in chapter 5, the age or capital structure of the industry has a big impact on the emissions profile. Thus for a model to be fully applicable, one would need to incorporate the wearing off, i.e. deterioration, and replacement of capital in the model.

One such approach is suggested by Jorgensen with the notion of capital vintage analysis (Jorgensen 1968, 1996). Jorgensen studies the optimal capital investment behavior of the competitive firm using present value accounting. For this, he sets certain criteria on the net investments flows. He defines net investments as total investments less replacement investments where replacement is proportional to capital stock, i.e. the rate of depreciation is constant. Jorgensen's approach treats the capital infusions in monetary units. The use of capital vintage accounting explicitly in a model gives justification to the fact that investment behavior and qualitative changes in the industry together form the emissions profile.

In the model here Jorgensen's capital vintage accounting methods are not explicitly used. Instead, a standard rate of depreciation of all old capital is assumed where the same annual discount factor is used for all types and ages of capital.

9.1.2 The EEP model versus reality

It was stressed earlier that one aim in this research is to incorporate natural capital variables and consideration of the biophysical environment into the economic production function. It was also noted that an economic production function should comply with thermodynamic constraints given that economic activity takes place within the natural environment. However, as can be seen, the model that is eventually arrived at is not thermodynamically compliant. Some of the apparent exclusions of important variables from the EEP function may seem irrational. Arguably then, the link to the biophysical environment is partly missed and as a consequence the function could no longer be called an economic-environmental production function.

However, the main point of a production function is to show and highlight those production factors which influence the outcome or functioning of the process; in this case the formation of emissions. As a result, in the presented EEP the "recipe" component of the production process, with the exception of wood raw materials, has been omitted for increased simplicity. The recipe describes very stringent "engineering" constraints on production, for example that to produce one tonne of newsprint requires 1.2 tonnes of spruce and 0.0147 GJ of total energy (KCL-ECO 1999). The recipe can be changed only with radical technological innovations and in the case of the pulp and paper industry, not significantly at all. Changes in recipes are not sudden or large, rather they are incremental. Thus, this recipe has no such, or at least not dramatic, effect on the emissions profile of the industry as investments do. The effect of a recipe change; i.e. implying significant structural change in the industry, will be captured in the macro-level emission statistics.

Another philosophically significant omission of the some of the function estimates, is labour. In the early days of microeconomic production functions, capital and labour were often the only included variables; they were seen as the most important constraints on the production process. In the Finnish pulp and paper industry the gross amount of labour has remained relatively unchanged with only minor decreases. Productivity, on the other hand, has increased dramatically as in any manufacturing activity in post-war OECD (Castles 1998). Labour no longer effectively restricts the production process and thus it can be omitted in the models without introducing significant bias. Labour has also been omitted in other studies when it has been considered constant and the focus has been elsewhere (Eriksson et al. 1984). However, for the sake of safeguarding the interest of stakeholders, it may be wortwhile to retain labour in the models although it provides no additional accuracy.

Another possible criticism is the fact that the model portrays future based on the past. As mentioned already, the retrospective may not be an adequate basis for making assessments of potential development. However, making predictions based on past development for the near future is arguably better than making predictions based on either intuition or nothing. Often time-series data is used not only for an analysis of the past but also to gain insight into what may happen in the future.

As stated, the practical application of the EEP here does not comply with thermodynamic constraints. The industry analysed here can be regarded as an open sub-system of the closed global system, and as a result its growth must come at the expense of decline in another system component. Chapter 8 assessed the situation from a sustainability perspective and showed that on the input side, natural resources (forests) have not declined even with industry growth. Proper forest management practices have ensured efficient and sustainable growth of the forests. The assumption then would be that the decline, if it has occurred in the natural sphere, has been on the output, or waste management, side. This latter part of the life-cycle has not been studied here. In addition, only sustainable fiber yields are studied, not the sustainability of the forest eco-system as a whole.

9.1.3 On the choice of accounting units

The choice of accounting units has a profound impact on the resulting analysis. Accounting units also have implications on data aggregation issues. In an ideal situation, if all variables could be denoted in the same way, their aggregation, comparison and analysis would be very easy. Unfortunately especially in the case of economy and environment interactions, variables rarely if ever can be expressed with the same terminology. Here the choice was made to use physical weight measurements for variables of matter and monetary values for investment goods. It was argued that monetary values for non-monetary goods, such as emissions, will include too much arbirtration to be of any relevance in such an analysis.

Aggregating different production types under the single denominator of weight disregards aspects in that production that may be significant in an environmental sense. Aggregation by weight is misleading in its ignorance of material quality (for a discussion of the aggregation issue see Cleveland and Ruth 1999). Different paper grades with the same weight have distinctly different physical and chemical properties. These properties increase in importance in the latter stages of the life-cycle with waste management issues. The truth may be that there is no reliable aggregation option for material flows, as suggested by Hinterberger et al. (1997).

Perhaps the best aggregation option in this study would have included both weight and prices to arrive at a more truthful picture (Cleveland and Ruth 1999). Aggregation according to weight was chosen here for initial simplicity perhaps more than due to rigorous analysis and testing of its appropriateness. This aggregation scheme enabled the author to test and explore her ideas. A logical next step would be to see how results change or hold under different types of aggregation schemes.

9.2 On connection to LCA

The natural production function was empirically estimated for emission coefficients of the industry. Static emission coefficient matrices are used in LCA modeling. The results contradicted this practice by showing that emission coefficients change rapidly over time as a result of technological change. Thus any LCA studies may be subject to large variations if data from different time periods is used in one study or in one comparison.

The paper suggested that the results of an LCA should be used with caution and the investment tendencies of the industries included in the study need to be carefully pointed out so that data fluctuations can be judged appropriately. The main finding in the paper was that LCA may be an invalid basis for decision-making on both levels, public and private. However, it was also discussed that the benefits of conducting an LCA are not limited to the results produced by the study and thus an LCA is not an altogether useless exercies.

One of the additional research questions asked:

> *"how should the dynamic nature of industry development be accounted for in LCA studies?"*

This question is not sufficiently answered. While chapter 6 is helpful in pointing out the deficiencies in the current LCA practices and in showing the effects of dynamic technical change, it gives little suggestions on how these should be incorporated into current practices. Here, the author admits her own limits. Dynamic functions do not fit the current framework of LCA; they simply cannot be incorporated. A solution would include an almost paradigmatic shift in LCA practices, something that will not be advocated here. Suffice to say, the best way to account for dynamism is to approach LCA results with caution and an inquiring mind with respect to data quality and age.

9.3 On the win-win thesis and the substitution of capital

The study demonstrated that the suggested win-win argument of improved environmental performance enhancing the economic performance of the firm (Porter and van der Linde 1995, 1996, Esty and Porter 1998) does or does not hold universally but rather is strongly situation specific. Both sides of the argument have been heavily debated in current literature proving either that improved environmental performance enhances or hinders firm's economic performance. This study shows that such argumentation is limited and fails to take into account specific attributes of the investment situation that really determine the economic outcome. Several examples are given of different types of investments situations and their effects both on environmental and economic variables.

The paper shows that clearly there are realistic win-win situations but that there are also investments in non-productive technologies that can not be described as win-win. The results clearly demonstrate that firms will be influenced to invest in cleaner and in clean-up technologies only under a flexible policy program, or such that ensures their competitiveness. A command-and-control policy will only compel firms to invest the minimum required amount and not reaching the true potential of technological advances for neither the environment nor the firm. Xepapadeas and Petrakis (1999) had the same finding, although theoretical, concerning monopolistic firms and their willingness to innovate under command-and-control versus a more market oriented approach.

The third research paper also combines the win-win discussion of the micro-level with the capital substitution discussion at the macro-level. The philosophical attractiveness of the idea of universal capital complementarity of manufactured and natural capital is no doubt sizeable and the basic argument convincing. It is, however, shown that the design of environmental policy is in a position to steer industries towards development that is in line with the capital complementarity thesis. Unsuccessful policy will in the worst scenario result in substitution of manufactured capital for natural. The opposite substitution, i.e. of natural capital for manufactured would mean closing down productive industrial activity and contracting industrial output to a minimum.

Chapter 7 combines the micro-level issue Porter hypothesis with the macro-level discussion of limits to capital substitution. The combination was presented in graphical format providing a good and suitable framework for analysis on both levels. The policy maker can analyse the possible outcomes of policy changes on both the societal level as well as the firm level at the same time. This makes the examination of for example the effects of environmental policy on national competitiveness easier.

The second additional research question was

> *"Do so-called win-win situations really exist and what could the nature of the relationship between economy and the environment be?"*

The third research paper answers the second research question in demonstrating the relevant and achievable alternative situation between the economy and the environment. Its contribution lies mainly in providing food for thought for policy-making as well as for practitioners, as will be discussed later in this chapter.

The discussion in chapter 7 concentrated on emissions and not directly on natural capital itself. This approach is justified on the assumption that emissions result directly in decreases of natural capital. Thus, emissions can be taken as a proxy for natural capital. Naturally emissions do not incorporate or capture all the intricate relationships and interdependencies of natural systems. However, emissions are perhaps the easiest component affecting natural capital to be measured and so it is used here. Chapter 8 then extends the modelling to incorporate also virgin raw materials in the function to be studied thus including natural capital more fully.

9.4 On sustainability

The developed model was applied to the study and measurement of sustainability. Sustainability has various definitions depending on the definer. As a result, the measurement of sustainability, is a muddled and unclear field that as yet lacks proper tools. The many variables making up sustainability can not be equated under a common denominator, although most definitions of sustainability, or at least the most common and widely used ones, require additions of those variables, or capital sub-sets. The EEP model, as discussed in chapter 5 and in 9.1 includes variables of different accounting units and hence it was used as a starting point to look at sustainability. Dollars, tonnes and cubic meters were however, not added up. Rather sustainability was looked at as relative changes, or indexes based on the starting year of the time series, in the different variables. Examining indexes, or in essence percentage changes, makes comparison of different accounting units both possible and meaningful.

Results of the paper indicated the existence of a sustainability function, or a neo-classical interpretation of sustainability. The function was relatively accurate in showing the profile of past development and it could thus also be used with some error margin to predict future levels of sustainabilty, as measured by the used index.

Results showed that technological development has helped the industry to move towards sustainable development. Even though there were clear periods of unsustainable growth in the sample, the overall results showed a sustainable tendency. The measurement instrument included also additional variables to those presented in chapter 5. However, no hypothetical weighting was used. In reality weights would need to be placed on the different forms of capital to reflect the interests of society; not all the different values are viewed equally. The results indicate that industrial activity can be encouraged into sustainable practices given a flexible policy profile, such as the one enjoyed by the industry under study.

The general arguments against production functions with regard to environmental issues hold also in this case and it is admitted that the presented model falls short of being a perfect proxy for sustainable development in its exclusion of several important variables. However, as sustainable development and the discussion around it, is desperately in need of concrete measurement criteria, the model provides one possible alternative for approaching a complex issue. It would be relatively easy to widen the model to include new variables provided the data was available. The main purpose of the paper was to demonstrate that sustainability can be measured in quantitative terms in contrast to those mainly qualitative approaches and charters seen until lately. The simple tool provides a starting point for further developments of the function in a hopefully more holistic direction.

The research question pertaining to chapter 8 was:

> *"Is the Finnish pulp & paper industry sustainable? Can its growth be characterised as such?"*

Chapter 8 on modelling for sustainability also answers one of the additional research questions set out at the beginning. The Finnish pulp and paper industry in its current state is sustainable. Moreover, the development leading to the present day situation from 1970 can also be characterised as sustainable generally, although "windows of unsustainability" have also occurred.

9.4.1 Growth versus development

Herman Daly (1992, 1996) has distinguished between quantitative increases as growth and qualitative changes as development. According to his view, economic, or other, growth cannot be sustained indefinitely whereas development potentially could. In general and at least in the long run and when considering non-renewable or only slowly renewable resources this is true. The results here would indicate at least the possibility for, in this snapshot in time, sustainable growth of a sector based on renewable resources. It would then be important to distinguish and define the limits of such growth and to find out when and under what conditions short-term sustainability turns into long-run peril. This would be a good subject for further research.

The research question set out in section 2.1 asked whether the industry and its development can be characterised as sustainable. Qualitative growth, or more precisely development, is not measured here. Contrary to many presuppositions, even quantitative growth in this case is sustainable. These results hold with the model employed here, noting that it is not a perfect model. In the case of the paper industry, distinguishing between quantitative and qualitative growth has some pitfalls. For example, a qualitative changes, when narrowly defined, could mean a shift to the production of higher paper grades with more value-added per tonne of product. However, this shift, besides meaning a positive qualitative change in some terms, may mean a negative change in environmental terms as higher paper grades require more use of chemicals and fillers. Clearly, there is a need for defining qualitative and quantitative changes in the context of the pulp and paper industry first. Then an analysis of growth versus development and their possibilities may provide more fruitful.

Daly also addresses the issue of fairness and just distribution of wealth. In essence, concentrating on some aspects of social sustainability, mainly distributional issues and the ethics of growth or development. Daly argues for an economics that is just and fair; which with today's terminology can be taken to mean sustainable. Sustainability has also been discussed in this thesis, although, as mentioned, not at such a fundamental level as Daly's arguments would require.

9.5 Implications of study for policy makers

The last two research question were:

> *How should environmental policy be planned to encourage eco-efficiency?*
> *Are there application possibilities for the emissions production function in the public sector?*

This study, especially as illustrated in chapters 5 and 6, showed that the emissions from the pulp and paper industry correlate strongly with investments and that investments in turn do not necessarily correlate so strongly with tightening permit levels. If it is assumed that changes in permit levels are the sole driver of investments, it would be rather odd that the industry is consistently performing well below levels stipulated by permits as illustrated in figure 9.1.

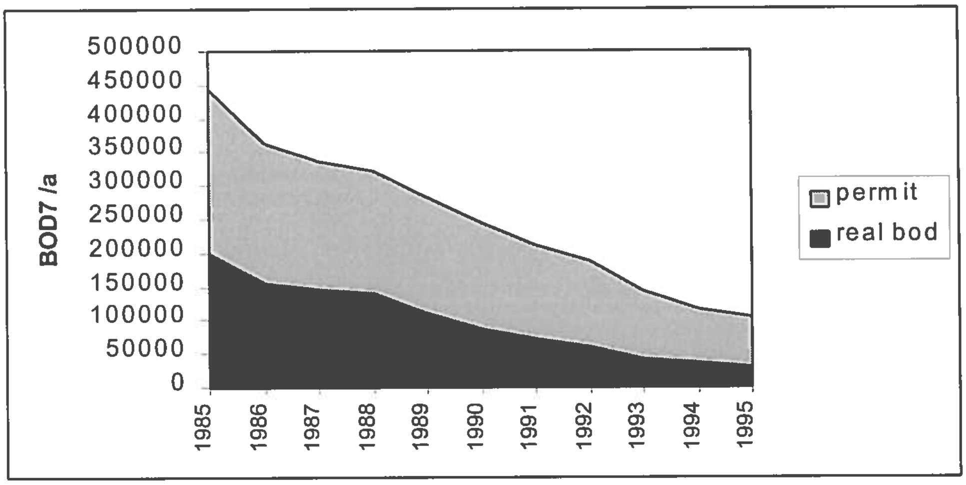

FIGURE 9.1 **Observed BOD levels and the averages of permit levels 1985-1995 of Finnish chemical pulp mills.**

Rautio (1997) in his qualitative interview study of Finnish chemical pulp mills reached the conclusion that the major driver behind investments were tightening permit levels. There is a certain bias in conducting interviews and people tend to give answers that are believed to be "right" or "good". It is the author's assumption that while many investments are driven to an extent by environmental demands, it is still the main purpose of the competitive firm to stay in business and to make a profit. Thus any investments will promote those objectives, which may or may not coincide with environmental considerations.

Naturally one can argue that decision-makers prefer to have some safe margin of error in their decision leading to performance below the permit level.

The margin presented in figure 9.1. are, however too large to be considered a safety margin on the decision-makers part. There are many other, mainly economic, factors that also affect the level that the mill will be compelled to reduce its emissions to. Environmental policy or tightening permit levels are only one of the many factors resulting in the reduction of emissions (Mickwitz 2000). Other reasons may be for example image or improved competitive advantage in international markets. Pre-empting regulation has also in some cases been proven to lead to first-mover advantages as the pioneering companies are able to affect the policy in their favour (Porter 1985, Xepapadeas and Petrakis 1999). A margin of error –thinking may be a motivator for the companies that can be described as followers.

Environmental considerations have become a part of almost any investments decision as new machinery as a rule is more eco-efficient than old. Hence the trend that can be observed with the EEP and presented in chapter 5 and discussed further in 9.1. The model includes all investments, productive and non-productive and still shows a clear correlation and explanation for the decrease in emissions over time. If there were clear environmental investments and clear non-environmental investments, this trend would not realise.

The costs of flexibile and decentralised decision-making need to be weighted against the benefits. This study clearly shows the benefits of flexible permitting that allows for specific considerations in setting emission levels and for consideration in adoption time schedules. The strict and stringent environmental demands forced on Finnish industries have not significantly decreased their competitiveness as policy implementation has been carefully planned. Perhaps accountable to its strategic position in the Finnish economy, the pulp and paper industry has been blessed with such policy, where complex regulations have in fact been replaced by motivating standards as suggested by Hawken (1996).

The EU has several on-going research programs aimed at the development of appropriate environmental policy. The results of this study could be reflected on in those developments. The model may well be worth adopting in other countries also.

9.5.1 The problem of transboundary pollution

Most air pollutants are not local and travel long distances creating adverse environmental impacts far away from the source, or the polluter. As stated in chapter 7, environmental degradation and economic development seem to be inversely related to a certain extent and this relationship has been explicitly introduced as the environmental Kuznet's curve, EKC. This often then results in a flow of transboundary pollution from less-developed countries into countries with higher economic development, provided both countries are industrialised, or on the latter part of the EKC.

Water pollutants, which were under study in this thesis do not travel as well as air pollutants. The most well-known and recent example of transboundary water pollution is the case of the river Danube. However, the case that is demonstrated here does not give rise to such similar problems. As a result, the multilateral discussion on the reduction of air emissions is much more vivid, as exemplified for example by the recent Kyoto round of discussions, than those for the control of water pollution. However, cooperation across national borders would have tremendous potential in the reduction of water emissions as a whole.

As shown throughout this study, the marginal returns in terms of emissions reductions per each infused markka of capital have reduced. It simply is not technically possible to achieve dramatic reductions anymore and complete zero-pollution may not feasible. The emissions in Finland are already on a low level, or at least such that causes relatively very little, if any, real damage. On the other hand, neighboring former eastern block countries are still at a level of economic development and at such a stage in their industrialisation that creates relatively much environmental degradation. Hence, the marginal returns that could be achieved with the same capital outlays would be much higher than those in Finland, perhaps reflecting the situation at the beginning of the 1970's in Finland. Thinking holistically and globally then, as has been advocated, it would make much more sense for Finnish forest conglomerates to invest in pollution prevention elsewhere, beyond national borders, to be able to make the biggest contribution.

This type of investment behavior is not endorsed by public environmental policy. A firm's investment in another country does not change the treatment in the home country thus discouraging extending a helping hand. Consideration could be given as to how such policy could be designed and implemeted that would encourage firms in different countries to cooperate on the environmental challenge. This kind of policy would not only make the pay-off or return of environmental investments higher, but it would ensure that the quality differences in marketed paper would be less thus removing the competitive disadvantages currently imposed on companies in countries with strict regulation and high environmental quality standards.

9.5.2 A comment on policy success

Any policy needs to be designed with the best possible knowledge of the problem it is intended to solve. Often environmental policies need to solve and prohibit problems endorced and created by other, for example, industrial policies. For a policy to be successful it needs to be based on a valid theory of effects and causes, the link between which should be direct and free of intervening links (Gouldson & Murphy 1998). Incomplete information leads to decisions that cause unintended or unexpected consequences in potentially a different area, something Beck (1992) introduced with his concept of reflexive modernity. Incomplete information together with vested interests of the concerned parties bounds the rationality of the decision-making process. One of the aims of this thesis was to broaden the information basis so that environmental policy decisions could be made more objectively. The presented results show a clear, and valid, cause and effect relationship. Hopefully, then, the results could be applied in the design of policy, i.e. the results clearly show that investments and the resulting capacity increases cannot automatically be regarded as detrimental to the environment. Thus environmental policy should be designed taking this into account and encouraging investments instead of penalising them.

9.5.3 The potential of multi-criteria analysis in policy formation

The increasing environmental and differing social concerns in society have created a situation in which any decisions have become highly complex. The number of people affected by any decisions has also grown, and as a result, the relevant stakeholder groups to corporate or public decision-making have become larger and more varied. A decision cannot be made in isolation to its surroundings or those people to directly or indirectly come under its influence. Public planning, administration and decision-making have evolved into an interdependent process in a broader framework of social, economic and also environmental demands and motives (Nijkamp and van Delft 1977). Societal structures and processes are highly heterogenous and reflect substantial spatial and temporal variation, which together make any uniform approach inapplicable.

Environmental planning or environmental policy design is one example of a societal level decisoin-making process that could be characterised as essentially conflict analysis; value judgements have to made concerning social, aconomic and environmental criteria of the different stakeholders. Often in a conflict situation, the best choice is to seek a compromising or satisficing, rather than an optimising, solution.

The most common analysis tool of public policy has traditionally been the cost-benefit analysis (CBA). The CBA is based on the assumption of rational behavior of the individual and the capacity to understand and compare marginal utilities and to make choices on that premise. The CBA maximises one dimension, assumed to reflect welfare, which itself includes multiple dimensions. Current CBA aims to calculate and evaluate all direct and indirect costs and benefits associated with a planned activity so that a decision can be made which maximises the social return. One of the main critiques to the use of CBA is the fact that it relies on a monetary evaluation of externalities and intangibles, which is often impossible and arbitrary at best. As a result, the multiple components making up welfare are not adequately accounted for and thus decision-makers cannot focus on all relevant constituents of societal well being.

Multi-criteria evaluation methods aim to overcome the short-comings of traditional, economic based, decision-support tools by providing a systematic and holistic basis for evaluation of differing yet relevant criteria. Multi-criteria methods do not aim to optimise a problem but rather to arrive at a compromise with main emphasis placed on the way in which the process itself is carried out (Nijkamp and van Delft 1977, Funtowicz and Ravetz 1990, Funtowicz et al. 1999). Characteristic of situations where multi-criteria decision making is called for is uncertain basic data as well as numerous decision-makers and interest groups. Stakeholder involvement through proper dialogue, in environmental decision-making is something desired and called for in principle and now also more concretely in for example the pan-European Local Agenda 21 development. Including various intesrests creates legitimacy and resilience for the outcoming decision that an otherwise imposed action could not enjoy. Thus the advantages of multi-criteria analysis are clear. The basic interactions in public environmental decision making are depicted in figure 9.2.

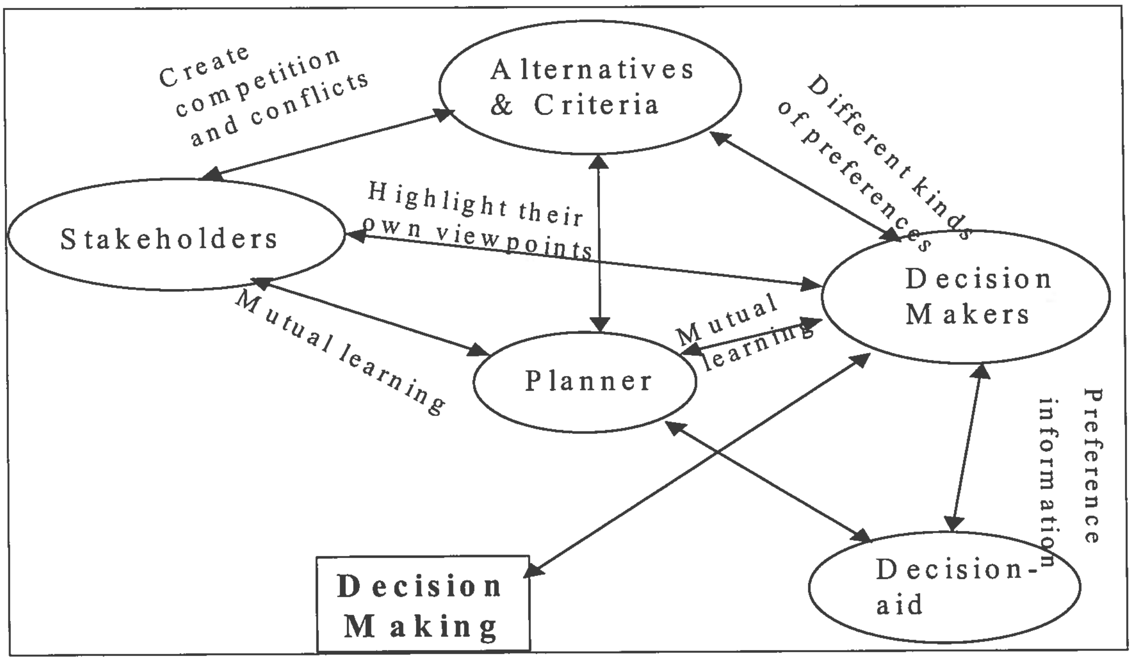

FIGURE 9.2 **The basic interactions in public environmental decision making.**

Multi-criteria analysis is a way of incorporating diverse viewpoints and vast amounts of data into the decision-making process without creating distortions and while maintaining control of the process itself. In line with traditional planning processes, the multi-criteria situation evolves from identification of relevant stakeholders to compilation of alternatives to identification of criteria finally through to the comparison stage. Typically the alternatives and the criteria are used to build an impact matrix. Any individual cell in the matrix need not be defined in monetary terms, but can be either quantitative or qualitative information or a combination thereof.

Multi-criteria analysis is ideally suited as a decision-support tool for (environmental) policy design and planning. It makes it possible to include a high degree of cooperation and integration at early stages in decisions that affect a larger public. Being a holistic instrument, it should also be possible to use multi-criteria analysis in retrospective studies of policy success or failure. This would of course require the inclusion of the relevant stakeholders in the evaluation phase, which may not be desirable when thinking of policy or cost-effectiveness. Naturally the involvement of relevant stakeholders could aid in the understanding of the complexities involved in the (unsuccessful) decision. This would help to reach an as complete picture of the situation as possible, also of the reasons leading to the failure of the decision, whether lack of appropriateness or acceptance.

In this thesis, the relevant stakeholders of environmental policy are not taken into account, nor are they discussed at length. Multi-criteria decision making is not attempted either for creation or for the evaluation of policy. The main focus has been on trying to explain and predict the innovation and reaction mechanisms in the Finnish pulp and paper industry. However, the case brought forward here bears many elements in common with multi-criteria analysis.

Rigid multi-criteria modelling was developed in the early seventies to mid-eighties and the development still continues. The Finnish water permit system has been in place for over three decades. It is argued here, that the Finnish system can be viewed as a decision-making process utilising multi-criteria analysis, although not perhaps in its most sophisticated form. The fundamental basis of the permit system is plant specificity. All relevant environmental and economic criteria should are taken into account in an integrated manner. Recently also the voice of neighbours and other stakeholders, whose lives are affected by the decisions have had the chance to voice their views. The systme is also in line with the IPPC –integrated pollution prevention and control directive which calls for a holistic, integrated assessment of all relevant decision-making criteria.

9.5.3.1 Multi-criteria models in this thesis

In the case put forward here, an industry is assessed and no fragmented studies of individual actors is undertaken. Multi-criteria analysis as a decision-support instrument deals with complexity of the process, making it easier to incorporate and handle. Complexity, at least in the pulp and paper industry, is relative and thus multi-criteria tools can only be applied in a local-level study. As stated earlier, environmental problems or decisions, as a subset of societal decisoin-making, exhibits strong spatial differences. In the pulp and paper industry, and especially in Finland, the locus of operation or proposed operation makes a vast difference in the way the proposal is received as well as in the real environmental impacts; for example the issues faced by plants in inland locations by freshwater areas also used for recreational purposes are very different from those faced by plants operating in coastal locations. Therefore, as this study is macro-level, it cannot successfully employ a tool that is in the case of this industry more or less limited to use at the local or regional level.

In this specific case, multi-criteria analysis could be applied in an in-depth case study of for example one permit decision, or an application for a new mill. In such a case study, all relevant stakeholders could be involved and the proposed action/ permit could be then evaluated according to all criteria and alternatives, as suggested by multi-criteria analysis. In an ideal case, the situation could be repeated with a permit renewal when the real effects and benefits of the multi-criteria approach could be evaluated. However, this kind of analysis is well beyond the research that is undertaken here. Mcda would be an altogether different approach, which in the worst/best case scenario would call for the inclusion of institutional/ agency theories etc.

The main focus of this research has been to determine, explain and if possible predict the reaction mechanisms in the Finnish industry towards changes in the operating environment, including environmental policy. Clearly multi-criteria analysis could help in the evaluation of policy or in the planning and choice of alternatives. The main findings here show that a frequent investment strategy has helped to bring about dramatic changes in the emissions profile. The choice of investment strategy has been a result of many factors, of which innovative and bold environmental policy design and execution is one. Other potential factors are own industry initiative, consumer pressure and stakeholder or pressure group concerns. Within this framework of analysis, it is impossible to determine which factor has been most influencial and which relatively less so. If the analysis of policy had been done with the help of multi-criteria methods, the relative importance of the different factors might have been possible to determine. Clearly then, the use of multi-criteria analysis methods could potentially help in analysing the relative weights of different factors in the decision-making process.

9.5.3.2 Multi-criteria analysis as an instrument for investment appraisal

Successful environmental investment leads in the private sector setting to an economic-environmental win-win-situation, i.e. a situation in which the corporation benefits financially through increased efficiency and profitability and where the natural environment becomes better off, or less worse off. An environmentally sound or successful investment helps in the public sector setting to meet the interest of the public, as by definition such an investment will result in improved environmental conditions as well as improved economic conditions. An investment that is perceived as beneficial in the eyes of the public will create satisfaction and perhaps results in "qualitative" growth helping to chart the course to sustainability.

This thesis has pointed out, or proven even, that successful environmental investment in the private sector is caused, in part at least, by smart public policy, in this case the permit system. The design and implementation of the system has lead to a clear dominance of win-win- instead of win-lose -investment situations and thereby, due to the overlapping outcomes and various externalities, i.e. economic growth, environmental quality enhancement, to improvement in public goods.

The success of the permit system in Finland is perhaps more a coincidence than systematically planned based on rigorous and thorough analysis of the multiple outcomes of different alternatives. As mentioned, the permit procedure reflects the elements involved in multi-criteria tools and is documented proof that muli-criteria approaches have vast potential in public planning. Multi-criteria-analysis is a tool to reduce complexity in decision-making and should help the decision-maker in finding the appropriate policy before having empirical proof on its effectiveness. This case has helped to demonstrate the opposite also; empirical evidence of a succesful policy provides support for multi-criteria analysis as a decision-making tool or philosophy. In essence, the permit system is a multi-criteria decision achieved through a democratic decision making process.

9.5.3.3 Multi-criteria analysis to avoid data aggregation bias

Multi-criteria methods are not used to assess environmental impacts per se, i.e. to examine and compare the potential harmful and/ or beneficial environmental effects of a proposed action. Those analysis are done mainly with life cycle analysis (LCA), environmental impact assessment (EIA), material flow modeling (MFM) and environmental input-output analysis (EIO). All the mentioned tools face the problem of data aggregation of diverse data that does not fit under a single denominator; for example the problem of adding or comparing product output measured in wieght to noise levels measured in dB. One potential application, intrinsically at least, would be to develop multi-criteria methods for use in the evaluation of diverse environmental impacts, which present a small sub-set of a political decision-making process. Thus, multi-criteria methods could be useful in accompanying traditional life-cycle analysis.

MCDA methods aim to reduce uncertainty in complex decision making situations where there are a number of alternatives, outcomes, stakeholders, criteria etc. They would seem to be best suited to a comparative analysis of different policies/courses of action etc, much in the same way as LCA is currently used as a decision support tool. In this case there are multiple attributes/variables that could explain what has happened in the industry. Thus it would seem natural that there would be some way of reducing ambiguity by application of MCDA tools.

On the other hand, it is not clear to see how fundamentally different mcda is from traditional LCA impact assessment. LCAIA also assigns weights to different emissions (=criteria) to reduce complexity in the decision making (interpretation) situation. Naturally the framework or scope that is usually associated with mcda is broader than that of lca but basically there is no fundamental difference. Both methods are weighting exercises in some sense. The LCA approach, and consequently also the MCDA approach as is argued here, are not compatible with the methodology used in this study and thus are not included explicitly.

9.5.4 Actual policy relevance ...?

The above discussion only reflected on the potential policy relevance of the research, the model and the main findings of this study. It cannot be regarded as a truthful measure of the extent of real policy applicability. Assessment of the real potential in public policy making would require participation in the policy making process itself and real attempts at incorporating these findings into those decisions. Such complete policy integration is not attempted here and rather it is left open whether the study will be utilised in the policy arena.

Moreover, there are many factors affecting the success of the policy process. The decision-making tools that are used are only one subset and their appropriateness has only limited effect on the goodness of the policy outcome. The process itself and the persons involved in the process determine to a great extent how well the policy will eventually be accepted by those affected directly by it, as e.g. protagonists of more bottom-up-policies justify this decision-making procedure by the higher acceptance among the concerned population (Tomic 1992, de Fonseca et al. 1994, Barry 1996, Mallya 1998). An altogether different research would incorporate the results of this research in the public policy decision-making process and then objectively evaluate the potential.

9.6 Implications of study for practitioners

The last part of the last research question asked:

> *"Are there application possibilities for the emissions production function in the private sector?"*

This study did not contain any quantitative firm-level data on emissions. This type of data is not readily given to outsiders or for use in a public study. This fact should not exclude corporations from using the developed ideas and models. A firm could derive its own emissions production function, which would to a great extent reflect an eco-efficiency function. After all, the EEP function presented here can be thought of as an industry level eco-efficiency function. Production functions traditionally are a suitable tool for business decision making. Representing past development with such a tool will help businesses in making new decisions concerning the future level of investments and the general direction of strategies.

Especially relevant for firms would be to derive and use the function for purposes of modelling potential development. Environmental legislation is generally tightening and firms have to perform under increasingly strict limitations. Firms could model hypothetical future situations with the model and on the basis of that, judge the need for new pollution prevention equipment. The use of such modelling could also be applied in dialogue with stakeholders.

Different investment situations and alternatives could be looked at through the win-win framework on the corporate level. Calculating the changes in the presented coefficients as a result of an investment would concretely help managers to realise the nature of the development. Firms could also calculate "hits" in each of the four quadrants to draw a profile of the tendency of their investments.

The results can also help a firm to benchmark against the entire industry. Clearly an empirical estimation of the firm's own emissions production function could be compared to the ones presented here. The corporation could then see whether it is performing on par, below or above average. This, in turn, is information that could be used for lobbying, which will, however, not be discussed more here.

10 THE CRITICAL EYE

10.1 Validity, reliability and objectivity

Any research has to be subject to evaluations of its dependability and credibility. Especially in quantitative studies internal and external validity, reliability and objectivity need to be ensured (Uusitalo 1991, Soininen 1995). Internal validity refers to the results of the study being a consequence of the studied system or phenomena, or true (Tuckmann 1988). Internal validity has more significance in social science studies using primary data. External validity refers to possibilities to generalise the results to other situations or groups. According to Tuckmann, external validity can be ensured by scrutinising the effects of testing, of selection bias, of experimental arrangements and multiple treatment interference.

In statistical regression analysis autocorrelation, multicollinearity and heteroscedascity need to be considered to ensure a valid and reliable study (Wonnacott & Wonnacott 1970, Greene 1997). Statistical methods sometimes also suffer from an interpretation bias as illustrated in the following anecdote:

> *'Two women both receive a large bouquet of flowers. Upon receiving, the other exclaims loudly "lovely, lovely, lovely, lovely!". The other woman removes the wrapping paper and says nothing for ten seconds, and then whispers barely audibly "lovely".*
> *Is the first woman then four times happier than the second woman as measured by objective, systematic, quantitative analysis?'* (Chomsky 1959, cited in Remes 1983)[17].

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[17] Author's translation from Finnish text.

One problem in quantitative studies is the choice of variables to be included and the choice of variables to be excluded from the analysis. In this research a number of important environmental and economic variables have been excluded as they are argued to provide little or no new explanatory power. Some variables have been excluded on the basis that no reliable, accurately measured data is available as measurement instruments and methods are still in their infancy. Some variables have been originally included but have been removed after insignificant results in stepwise regression. This study used both linear and non-linear regression models; their advantages and disadvantages and the problem associated with the models are discussed more in depth in the first research article. Also the validity and reliability of the employed statistical methods and models is discussed in Chapter 5.

10.2 Limitations of the study

This thesis can be critiqued for an occasionally partial vision on an issue that in reality demands a very holistic and broadest possible approach. Mainly the study has relied on estimating water emissions from the Finnish pulp and paper industry and has ignored other emissions as well as other environmental variables on for example the procurement side. Inclusion of all related variables would be necessary to be able to judge the problem displacement dilemma (Jänicke & Weidner 1995) and the notion of problem transfer along life cycle of a product (Andenberg 1996). These two problems are the main stumbling stones of environmental policy up-to-date. However, any study can only be as good as the data that it is based on; unfortunately in the case the availability of comparable and trustworthy data on all environmental variables limited performing the analysis. After all, discussion of the results in the same context would not be possible since the results would have been arrived at through different and incomparable means if uncomparable data is used.

The study suffers from a lack of micro-level data and results. The model, as presented above, would doubtlessly have applications also at the firm level. Those applications are difficult to demonstrate given that there is no data to support the claims that are made.

11 CONCLUSIONS AND FURTHER RESEARCH

The main contribution of this thesis is theoretical in pointing out the possibility for simultaneous environmental and economic modelling in the same neo-classical framework. This is something that has been widely suggested in literature earlier but no empirical verification of the applicability has been given. However, the other contributions of the paper should not be overlooked. Since the majority of the thesis has concentrated on macro-level issues, it follows naturally that the contributions are more general in nature and thus could potentially be suited to policy makers and public administration. The findings include suggestions for the planning and design of national environmental policy in a direction that encourages sustainability and benefits for both the environment and the economy.

The thesis gave a rather thorough presentation of the development and current state of the Finnish pulp and paper industry and the factors that have shaped the industry and its ecological footprint. The presentation is useful in combating the general idea that the industry is a major cause of environmental degradation by its tendency to release vast amounts of pollutants. In fact, it is shown here that the industry has made considerable progress towards increasingly sustainable practices. In addition, it relies on a renewable natural resource, which is currently still harvested well below limits ensuring a sustainable yield. The findings of the thesis can be used as a basis for discussion and debate concerning the forest sector and its environmental impacts.

The study also demonstrated that mutually beneficial situations for the economy of the firm and the environment are possible. These situations coincide with the complementarity of natural and human-made capital. Such beneficial situations are brought about by careful policy design and implementation, which motivates corporations towards eco-efficiency.

The thesis also made a sidestep into the life cycle assessment field demonstrating the need to account for industry dynamics in LCA studies. The model developed here can be applied both for identifying the need for dynamism in LCA and for consideration in incorporating it to LCA: The LCA excursion is a modest one as the problems of current LCA can not be solved overnight.

Further research would be needed to judge the real applicability in the decision making process. This could perhaps be attempted with an in-depth case study of and with some policy decision making group. It is often easy to state that the results can be applied in policy but that application needs to be perhaps examined more thoroughly. Another obvious area of further research interests is exploring the model itself; can it be useful for other emissions and for other industries and under which conditions. Also it could be tested whether an elaboration of the model to a group of functions and with perhaps the inclusion of new variables would provide a basis for optimisation of those functions. The measurement of sustainability is a relevant societal issue currently. The presented research provided one viewpoint on the issue but this avenue could be explored further and the built model could be compared to other presented models.

The research no doubt opens up many new questions in answering the basic research questions that it originally set out to answer. However, it is only through a dialogue of answering and posing questions that science can proceed. This thesis has taken one step in the development of science and hopefully new theses and research interest take the next step and provide yet new insight into an area that can no longer be ignored in business, political or societal decision making.

12 YHTEENVETO (FINNISH SUMMARY)

Teollisuus murroksessa -Strategisten suuntausten ympäristöllinen merkitys Suomen sellu- ja paperiteollisuudessa

Sellu- ja paperiteollisuudella on perinteisesti ollut merkittävä asema Suomen kansantaloudessa. Viime vuosikymmenien aikana tämä teollisuudenala on joutunut kasvotusten uusien, lähinnä ympäristön suojeluun ja ympäristöjohtamiseen liittyvien, vaatimusten kanssa. Vaatimuksia ovat esittäneet yritysten eri sidosryhmät, yhä enenevissä määrin päivittäisen liiketoiminnan ulkopuolella olevat sidosryhmät, kuten esimerkiksi kansalaisjärjestöt. Toisaalta myös sekä kansallinen että EU:n ympäristölainsäädäntö lisääntyy ja kiristyy jatkuvasti, mikä osaltaan myös lisää yritysten toimintaan kohdistuvia paineita. Tämä kaikki on lisännyt uusien päätöksentekoa tukevien mallien, tekniikoiden ja apuvälineiden tarvetta. Ainoastaan ottamalla riittävän kattavasti kaikki päätöksentekotilanteeseen liittyvät asiat ja mielipiteet huomioon, voidaan ratkaisuja pitää perusteltuina, jolloin niihin myös sitoudutaan. Ensisijaisen tärkeäksi onkin tullut huomioida taloudelliset realiteetit sekä ympäristöasiat samanaikaisesti eikä toisistaan erillisinä kuten usein on tapahtunut.

Tässä tutkimuksessa tunnistetaan, analysoidaan ja osittain pyritään myös ennustamaan niitä strategisia suuntauksia, joita Suomen sellu- ja paperiteollisuudessa on otettu viimeisen kahdenkymmenen vuoden aikana. Strategiset linjaukset ovat olleet joko ennakoivia tai reagoivia liiketoiminnallisia vastauksia niin ulkoisen kuin sisäisenkin toimintaympäristön muutokseen. Ulkoisen toimintaympäristön muutoksen suurimmassa roolissa on ollut ympäristöpolitiikka kun taas yritysten halu ja tarve palvella vihertyviä markkinoita sekä tehostaa prosesseja ovat olleet suurimmat sisäiset muutostekijät. Yksi tämän tutkimuksen tärkeimpiä tavoitteita on hälventää rajoja ja välttää kategoriointia sekä tunnistaa riippuuvuussuhteita taloudellisten, poliittisten sekä ympäristöllisten muuttujien välillä.

Työn fokus on tarkennettu yhden teollisuudenalan vesipäästöihin. Tämä mahdollistaa syvällisen tarkastelun, jolla voidaan myös havainnollistaa tärkeimpiä käsitteitä luonnonvara- ja ekologisessa taloustieteessä sekä yritysten ympäristöfilosofiassa ja -johtamisessa. Tutkimus on luonteeltaan kuvailevaa, deskriptiivistä, ja siinä hyödynnetään aiempaa kirjallisuutta, loogista päättelyä sekä kvantitatiivista mallintamista.

Tutkimuksen ensisijainen kontribuutti on teoreettinen; ympäristö- ja talousmuuttujien yhtäaikainen mallintaminen perinteisissä neo-klassisissa malleissa on mahdollista. Tätä on ehdotettu useaan otteeseen aiemmassa kirjallisuudessa, mutta toistaiseksi ehdotuksia ei ole testattu tai todistettu empiirisesti. Tutkimuksessa kehitetyn ja todennetun mallin avulla on mahdollista analysoida erilaisten muuttujien välisiä riippuvuussuhteita ja sitä kautta vetää johtopäätöksiä esimerkiksi ympäristöpolitiikan kehityksestä. Tässä tutkimuksessa osoitettiin myös että on samanaikaisesti mahdollista saavuttaa sekä luonnonympäristön että yrityksen liiketoiminnan kannalta edullisia tai voitollisia, nk. win-win, tilanteita. Tämankaltaisissa tilanteissa useimmiten yrityksen toiminta tehostuu ja toisaalta päästöjen määrä pienenee. Win-win tilanteet useimmiten heijastavat ihmisen ja luonnon pääomien toisiaan täydentävää luonnetta. Win-win tilanteiden muodostuminen on huolellisen ympäristöpolitiikan suunnittelun ja täytäntöönpanon tulos. Kuvatun kaltainen ympäristöpolitiikka motivoi yrityksiä parantamaan ekotehokkuuttaan. Tässä tutkimuksessa tarkasteltiin myös elinkaarianalyysiä (englanniksi life cycle assessment, LCA) ja osoitettiin tarve huomioida teollisuuden kehityksen dynaamisuus LCA tutkimuksissa. Tutkimuksessa kehitettyä mallia voidaan käyttää toisaalta tunnistamaan dynaamisen mallintamisen tarve elinkaarianalyyseissä sekä toisaalta antamaan ehdotuksia siitä, miten dynaamisuus tulisi huomioida LCA tutkimuksissa.

Koska suurin osa tästä tutkimuksesta on keskittynyt teollisuudenalan, eli makrotason, ongelmiin, on luonnollista että tutkimuksen pääasiallinen anti on yleisempää ja soveltuu paremmin julkishallinnon poliittisiin päätöksenteon prosesseihin. Tutkimuksen tulokset antavat suosituksia siitä, miten kansallinen ympäristöpolitiikka voitaisiin suunnittella kestävää kehitystä tukevaksi ja edesauttamaan taloudellisesti ja ympäristön kannalta järkevien ja hyödyllisten tilanteiden syntymistä. Tämän tutkimuksen johtopäätökset ympäristöpolitiikan suhteen eroavat jonkin verran aiemmista yleisemmistä suosituksista, mikä muodostaa mielenkiintoisen lähtökohdan keskusteluille ja mahdolliselle lisätutkimuselle.

Luonnollisesti tutkimus avaa useita uusia kysymyksiä vastatessaan muutamaan alkuperäiseen tutkimuskysymykseen. Tässä tutkimuksessa on otettu yksi askel tieteen kehityksessä; toivottavasti tämänkaltainen tutkimustraditio saa seuraajia ja syntyy uutta perusteltua tietoa aihepiiristä, jota ei voi enää sivuuttaa sen enempää yritysten kuin poliittisessa tai yhteiskunnallisessakaan päätöksenteossa.

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