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Economic Growth and Abatement of Carbon Dioxide Emissions in Swedish Transport Policy

by

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Abstract

This thesis examines the Swedish carbon dioxide abatement policy in the transport sector. The purpose is to investigate whether this is done in a cost-efficient way, in particular in a long-term perspective. An underlying objective is to bring thoughts on environmental concern and economic growth together. In order to do this a number of scientific reports, economic articles, and policy documents have been studied. Specific attention is given to the potential of economic instruments to create incentives to invest in research and development. R&D is expected to lead to technological change which in turn is important for economic growth as well as reduced carbon dioxide emissions, particularly in the long-term. The results indicate that there are large short-term efficiency gains to be made from coordinating policy with other countries. But also in the long-run. There are also indications that a strategy that indirectly stimulates R&D investments through adjusting the opportunity cost of carbon dioxide emissions is a safer principle to base policy on than direct subsidies of abatement or governmental investment in R&D. Although it is yet difficult to say anything specific about the effects of including induced technological change when evaluating the carbon dioxide policy in the transport sector, there are strong indications that doing so would lower the long-run costs of abatement policy substantially due to the long-term dynamic technology effects.

Key words: Carbon dioxide emissions, abatement, economic growth, transport policy, technological change.

Thank You!

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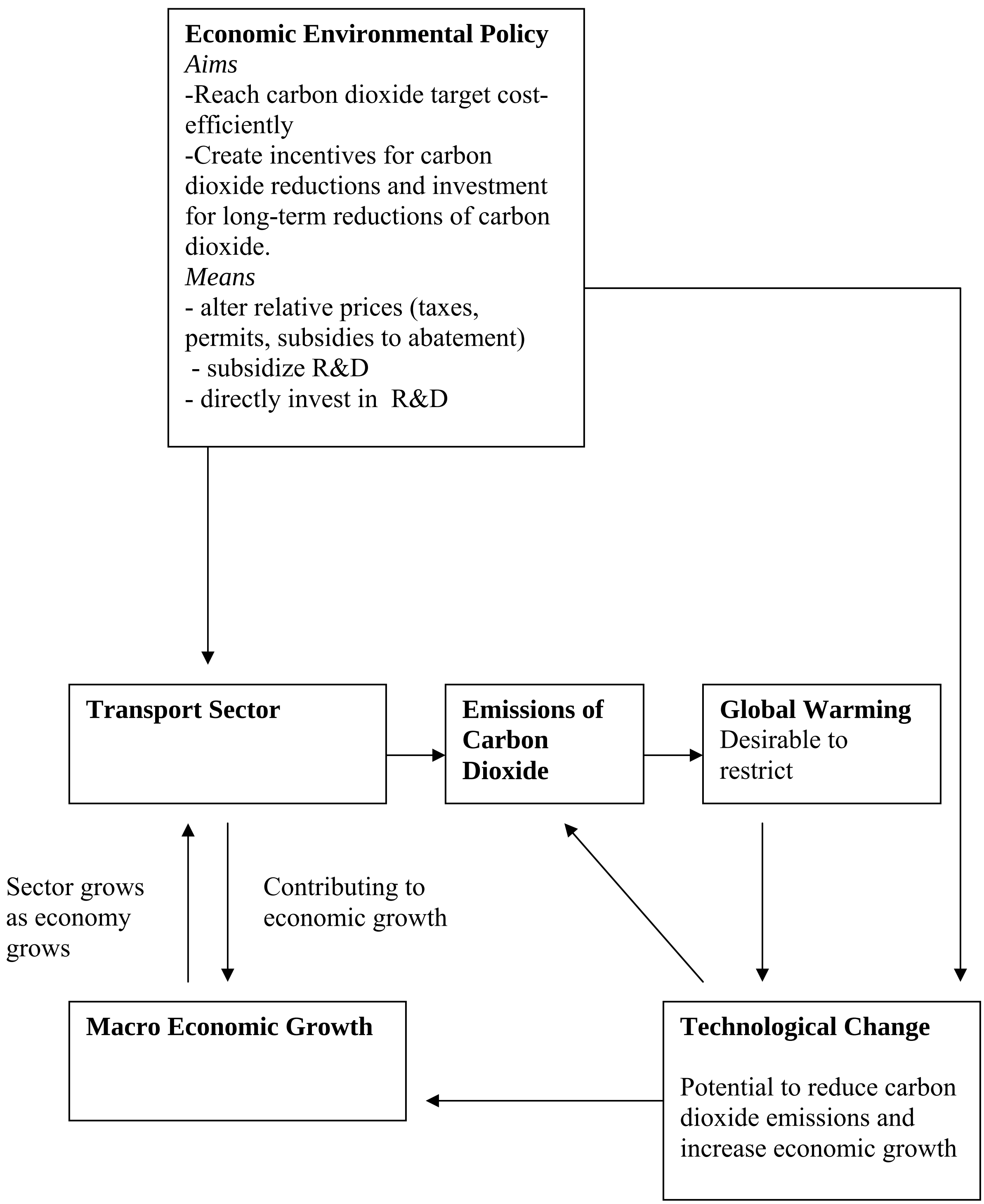
Figure 1: Illustration of Idea behind Thesis



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1 Introduction

1.1 Problem

An increasing concentration of greenhouse gases, primarily carbon dioxide (CO_2), in the atmosphere causes global warming. This is likely to incur huge problems and costs to humans world-wide. The greenhouse gases are mainly wastes from human production. In this thesis the Swedish policy to create price incentives to reduce emissions of carbon dioxide in the transport sector is evaluated. The transport sector is an important part of the economy and of importance for macroeconomic growth. The focus is on long-term reductions and specific attention is given to technological change as a means to simultaneously abate carbon dioxide emissions and to foster economic growth. In accordance with the induced technological change literature, policy can influence technological change, which is a driver of economic growth. Technological change is also a condition for decoupling economic growth from carbon dioxide emissions. The potential for decoupling is what is ultimately of interest.

The costs of abating carbon dioxide emissions are often referred to as a reason why abatement does not proceed more swiftly. Estimates of abatement costs vary substantially. Predictions of high abatement costs have been presented as an argument for why the government of the United States has chosen not to sign the Kyoto protocol. In one study Nordhaus argues that abatement policies to reach Kyoto targets will have large negative impacts on economic growth and welfare. This is even if induced technological change towards cleaner energy sources is taken into acount. (Edenhofer et al. 2005 p. 278). At the same time, the necessity of restricting global warming is acknowledged in UN agreements such as the United Nations Framework Convention on Climate Change (UNFCCC) (Edenhofer et al. 2005 p. 277-278). Abating carbon dioxide emissions is not done in an instant. It takes both time and monetary resources, and this can imply restrictions on economic growth. There is thus a connection between reducing emissions cost-efficiently and economic growth in that cost-efficient abatement decreases the costs in terms of growth forgone to the minimum. Abatement should be done at the lowest cost possible so that resources are used as efficiently as possible.

Economic growth is an important requirement for long-term development. At the same time economic growth has so far been accompanied by growth of carbon dioxide emissions. Although in general, emissions per unit of economic output have decreased, this unit reduction has been offset by growth of the economy, leading to increased aggregate emissions. In particular growth of the transport sector has more or less leveled with economic growth, and sector growth has offset per unit emissions reductions (The European Environment-State and Outlook 2005). Economic growth can be thought of in two separate ways in this thesis. On the one hand it is desirable because it increases richness and thus the possibilities to change society, including making changes which benefit the environment. Environmental improvents benefit people. On the other hand economic growth represents a threat to the environment since growth has been coupled with increased use of natural resources, in this case implying increased emissions.

The consumption of fossil fuels and the resulting carbon dioxide emissions in the transport sector is a good example of an issue where these economic and environmental considerations meet. The relevance of the problem can be brought to its head when considering the massive growth in rapidly developing countries such as China and India. Economic growth is accompanied by huge environmental problems. Some of these problems are likely to be solved as income increases. This is what the Kuznetz hypothesis suggests. (Perman et al. p. 37-39). Carbon dioxide pollution in the transport sector has not yet shown any such clear tendencies to decrease as income grows.

Reports on climate change indicate that human driven global warming is more rapid than previously believed. (The European Environment-State and Outlook 2005, IPCC Climate Change 2001, Naturvårdsverket 2004). This means that the need for action is even more acute than previously recognised. In such a situation, the carbon dioxide targets specified in the Kyoto protocol and nationally can be expected to become more ambitious in the future. Under such circumstances the author is convinced that the relevance of adressing questions of the sort raised in this thesis will increase.

In order to achieve long term economic growth and at the same time reduce carbon dioxide emissions it is assumed to be important to have a system providing clear price incentives in which direction Swedish policy is heading. This claim is based on that the business world has stated that it wants clear and long-term rules for the game in order to optimise their actions. (SOU2001:20 p. 121). It is also based on elasticity estimates showing higher elasticity the longer the time frame. This will be returned to in chapter 5. Such a system should aim at cost-efficient reduction of emissions in the short-run and stimulate to creative solutions in the long-run. A dichotomy between a passive price incentive policy and an active public policy directed towards technological change is considered. It is argued that an underlying choice between the two views may be crucial to the success of reaching the long-term carbon dioxide targets cost efficiently. However it might not be possible to completely exlude one or the other. The reader is asked to keep in mind that although this is a study of a specific sector in a specific country, it is the aggregated concentration of carbon dioxide in the atmosphere that really matters. The hopes are that the insights can be somewhat generalised and indicate solutions applicable for the entire Swedish economy and perhaps even for other countries.

1.2 Focus

To investigate the problem which this thesis deals with two questions are focused on:

1. Does Swedish policy reduce carbon dioxide emissions in a cost efficient way?
2. What is the most efficient policy for long-term reductions of carbon dioxide emissions?

Usually cost-efficiency of abatement refers to static cost-efficiency. But since more focus is put on the long-term development of the economy and emissions, dynamic efficiency of policy will also be discussed. It is here that technological change becomes relevant. Throughout the text short-run efficiency will be referred to as cost efficiency and long-run efficiency as dynamic efficiency. The subordinated intention of this thesis is to present a coherent comprehensive paper, linking economic growth and the environmental issue of carbon dioxide emissions to technological change.

Throughout the paper carbon dioxide emissions refer to emissions originating from a fossil fuel source. The Swedish policy to reduce carbon dioxide emissions in the transport sector is part of a policy to generally reduce emissions in society. The policy targets are to a great extent the result of international agreements such as UN conventions to restrict climate change, the Kyoto protocol and EU agreements such as the Lisbon strategy. But Swedish policy sometimes deviates from these agreements, usually in the way that the national targets are more far reaching than Sweden's commitments to the international community. Whether this is economically justified is disputable but will be left for others to determine.

In order to deal with the issue at hand and answer the questions, climate and technological change literature, environmental –and other economic literature has been studied. The report "The European Environment-State and Outlook (2005) from European Environment Agency (EEA), serves as the major source on the state of the environment. Studies from Swedish Institute for Transport and Communications Analysis (SIKA), Konjunkturinstitutet, and Naturvårdsverket give a picture of the economy, the transport sector, emissions, and transport policy.Given the state of the environment, the economic literature, together with the different policy reports are used to evaluate Swedish transport policy primarily in the shape of economic instruments. The idea is to investigate if policy is formed in line with what, given economic theory in the field, seems to be most reasonable. Not the least, the textbook *Natural Resource and Environmental Economics* by Perman et al has functioned as a reliable source of information.

1.3 Disposition

The remainder of this chapter frames the problem by describing and restricing concepts like time, technological change investment incentives, economic growth, and the transport sector. *Chapter 2* discusses why abation of CO_2 emissions and economic growth are desirable. A brief review is made of how some economists come to the conclusion that CO_2-abatement implies losses in terms of economic growth. *Chapter 3* accounts for how induced technological change and learning-by-doing work and can be modelled. In *chapter 4* decoupling of economic growth and CO_2-emissions is discussed, and how technological change plays a central role for its achievement. Results from the literature on the possibility of reducing costs of abatement with the assistance of induced technological change are presented and drawn on. Critique against decoupling is then briefly discussed. The chapter ends by summarizing the insights gathered. *Chapter 5* presents three instruments important for abatement: an emissions tax, an emissions subsidy, and a system of tradable permits. Elasticities of demand determine how well the instruments function. Short- and long-term cost-efficieny of abatement are central. In particular dynamic technology effects are recognised as important. *Chapter 6* presents Swedish transport policy by first giving an impression of the characteristics of the sector. The most important instruments and measures aiming at reaching the emissions targets are discussed. *Chapter 7* sums up the results and drawas some conclusions about the efficiency of policy. A few tentative proposals how policy could be formed in the future, given the results of this thesis are presented.

1.4 Framework

In this study a number of restrictions are made to make the investigated problem appear clearer. It is stated that Sweden has an economic growth goal. GDP is chosen as a proxy for growth as it is considered the best and most relevant measure. Sweden wants to reduce carbon dioxide pollution. The transport sector is studied because it is important both for economic growth and is a major source of CO_2 emissions. The long-term development of the economy and the environment are considered to be important. This framing of the problem will be examined in more depth along the course of the paper.

1.4.1 Focus on long-term developments

One way of justifying a focus on a long-term perspective is adopting an extended version of utilitarianism. (Perman 2003). If you view your children and their children as extended versions of yourself it will be rational to care about the world they get to grow up in and see to it that they are given the maximum opportunity of a life at least as good as your own. Taking such a stand-point it will sometimes be neccesary to restrict the freedom of action today to gain something tomorrow or day after tomorrow. It will of course be a question of how utility in different time periods is valued. This thesis assumes that a balanced utility path, with the focus on long-term development of economic growth and environmental quality without making unneccesarily large sacrifices in present time is desirable. Potentially large losses of utility in the future are important even if they occur after the death of current generations. It could thus be assumed that the discount rate of future utility is very low. This is an assumption reflecting the authors convictions, and although disputable, hardly very controversial.

1.4.2 Technological change-common denominator

The burning of fossil fuels frees several gases that in different ways affect the environment and human health. The one in focus here is carbon dioxide. Carbon dioxide abatement can be achieved in several ways. Apart from reduced consumption of fossil fuel, the literature suggests that two important ways are through factor substitution and technological change. According to Vollebergh and Kemfert (2005) this optimism regarding technological change and substitution represents a shift in the economic literature. Technological change has also been identified as a main driver of economic growth. Innovation enhances the productivity of labour or capital, which is crucial for economic growth (Jones 2002). Technological change is thus a common denominator for achieving both CO_2 abatement and economic growth, implying a possible double dividend from technological change. (Vollebergh, Kemfert 2005 p.133). It is here assumed that investment in R&D has an impact on technological change, an assumption which receives support by “new growth theory” or “induced technological change literature”. (e.g. Vollebergh, Kemfert 2005). The discussion on induced technological change is extended in chapter 2.2.

1.4.3 Incentives to invest

Because both economic growth and reduced carbon dioxide emissions are expected to be dependent on technological change it is especially the price incentives to investments in research and development that are investigated. Intuitively it ought to make a difference where the investments take place. However, it is simply assumed that investment takes place where incentives to invest exist. In addition, substitution is an important concept in this context of economic growth and the environment. In the short run, incentives can lead to substitution, e.g. of resources or means of transport, creating opportunities for abatement of carbon dioxide emissions. In the longer run technological change may create new and increased opportunities for substitution. The notion of dynamic efficiency effects are important here. Price incentives can encourage actors to invest and thus create long run increases in technological change, which reduces the long run costs of abatement.

1.4.4 Definition of Economic Growth

Economic growth can be measured as growth of GDP. GDP can be defined as the value of output produced within a country over a twelve month period. But there are several other indicators of the well being of nations. There have also been great advancements in the development of green economic growth measurements, trying to integrate exhaustion of natural resources and environmental damages into the measurement of well-being.[2] The choice of GDP as a proxy of growth in this study, in spite of all its fallacies, can be motivated by its wide spread use and well established statistical foundation.

1.4.5 Definition of the transport sector

The transport sector includes rail, road, sea, and air means of transport. Both private and enterprise transports are included. Most attention will be given to transports by road since it constitutes the largest share of all transports, it is by large the greatest emitter of CO_2 emissions in the sector and is growing. Most economic instruments to restrict CO_2 emissions are also directed towards road transports. Aviation is largely unregulated in terms of CO_2 emissions instruments and also constitutes a large CO_2 problem. Although emissions from aviation are still relatively small compared to road emissions they are increasing. It is currently an issue whether a lump-sum passenger tax is to be introduced. Rail and water transports will largely be left out of the discussion. The specific characteristics of Swedish transports is dealt with in chapter four. But a few general things can be said here.

1.4.6 Why the transport sector?

In order to make this thesis achievable it is necessary to make a number of further restrictions. As already clarified focus is on one sector: the transport sector. Although the use of fossil fuels in the sector generates several other pollutants, only the CO_2-emissions are investigated. There are good justifications for making these restrictions. The reduction of carbon dioxide emissions is one of the most important challenges in our times, both from an economical and environmental point of view. The choice of the transport sector makes sense since it is one of the major

[2] For accounts on attempts to construct green GNP see e.g. Yong-Yil Choi Journal of Economic Studies, vol. 21, no. 6 1994,p.37-45 or Vincent, Jeffrey R.: Environment and Development Economics vol. 5 2000 p. 13-24

polluters of CO_2 gas. The transport sector is one of the most difficult areas in which to reduce carbon dioxide emissions because of the large dependency on oil as a factor input. (The European Environment-State and Outlook 2005 p. 82). It is also a rapidly growing sector in Sweden as well as in the EU. Importantly, the transport sector is an essential contributor to economic growth. The Swedish Environmental Protection Agency (Naturvårdsverket) states that the transport sector is of great importance to the public economy and that modern society is dependent on efficient transports of goods and people. (Naturvårdsverket 2004, p. 23). Playing with the thought of not being able to transport goods over great distances makes one realise that this would imply large restrictions on trade and the globalised economy. Achieving substantial CO_2 abatement in the transport sector would be an important step towards limiting global warming.

The transport sector possesses a number of properties making it suitable for study and making the issue comprehensible. 1. It is easy to see how technological advancements of vehicles and substitution of fossil fuels for non-fossil or non-carbon fuels could benefit reductions of CO_2. 2. Fuel is one of the major production factors in the sector, which means that tax changes will have important implications for the sector. This could in turn influence the aggregated economic growth. A low price elasticity on fuel may counteract policy interventions to reduce emissions. Empirical evidence of price elasticity in the transport sector will be presented in chapter 5.

2. CO_2-Emissions and Economic Growth

2.1 Why abate CO_2-emissions

The claim that there is a need to abate carbon dioxide emissions from fossil fuels is based on the fact that they really cause problems desirable to avoid, and that the costs, which these problems are expected to incur are high. Today there is wide agreement that this is the case (IPCC Climate Change 2001). The use of fossil fuels as a factor inputs and consumption goods result in at least two major problems which have led to attempts to reduce its use[3]. 1: they are depletable, and 2: they are associated with negative externalities. The first problem, that fossil fuels are depletable and that it is unclear for how long the resources of fossil fuels will last implies a restriction on economic growth, since the world economy is currently dependent on fossil fuel. (Tsur and Zemel 2005 p. 485). But, ceteris paribus, rising fossil fuel prices due to scarcity will decrease opportunity prices of alternative renewable fuels, and create incentices for pushing the technology frontier forward. There will thus be a natural switch away from fossil fuels. But this might not happen for a long time. It is thus not the depletability condition which motivates this study but the second problem of externalities that is in focus.

2.2 Climate change-a negative externality

The negative externalities, in the shape of emissions, can be viewed as a market failure associated with the burning of fossil fuels. Alarming reports on worldwide climate change caused by the emission of greenhouse gases such as carbon dioxide have been published (see e.g. the EEA State and Outlook 2005). There are thus fact-based arguments for a reduction of dependence on oil and other fossil fuels that are distinct from the depletability of these natural resources. There exists a market failure in that the market does not manage to incorporate the full costs of using fossil fuels. The environmental and welfare costs are not fully included in the price. This means that price adaptations due to scarcity might take too long, seen from an environmental perspective. A

[3] Obviously other categorisations are possible but it seems logical to approach the issue in this way.

faith in market powers to adjust to price incentives is the foundation for believing that an active policy towards correcting market failures is effective.[4]

Harmfull pollutants cause a variety of costly damages to humans and the environment. Some of the gases emitted are directly harmful to health and the environment on a local level. The closer you are to the emissions, the more harm they cause. An example of one such gas is nitrogen dioxide. Carbon dioxide on the other hand, is uniformly mixing and damages are independent of where the pollutors are. (Perman 2003, ch. 6). Nevertheless it clearly constitutes a negative externality. Climate change is the most important and emphasized externality associated with CO_2-emissions. From now on it will be accepted as a fact[5] that an increasing concentration of carbon dioxide causes a human driven global warming.

There are several properties of CO_2-emissions that make it hard to evaluate the effects and costs, thus making attempts to reduce emissions complicated. As mentioned there is strong evidence of a correlation between the concentration of CO_2 in the atmosphere and global warming. But there is great uncertainty about the magnitude and timing of the damages and to the costs incurred by the damages. It is also common practise to discount future events, which would mean that even if it were possible to say exactly when damages would occur it is not certain that this would imply that drastic measures are taken. Also the global character of the CO_2-problem makes it difficult to abate emissions. As mentioned above, damages from CO_2 are independent of where geographically the gas is emitted. This makes CO_2-emissions an international issue and they can be viewed as a global public good. Those affected may not even live on the same continent as those polluting. Attempts to bring about sustainable international agreements are strongly influenced by game theoretical considerations. The delay of the negative externalities and the prospects of short-term gains from non-compliancy to agreements create conditions for free-riders. However great progress has been made in overcoming problems of uncertainty and international co-operation as scientists acquire more knowledge, as data improves and

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[4] This fact is sometimes lost in the political debate where actors who claim to embrace market values devalue economic instruments such as congestion fees and CO2 taxes to be nothing but trade distortions.(see Veckans Affärer no 5 2006, p. 23)

[5] For more information about global climate change see e.g. The European Environment, State and Outlook 2005, European Environment Agency, or Climate Change 2001: Synthesis Report, Summary for Policymakers.

international agreements such as the Kyoto protocol are formed. Awareness of the issue has also been strengthend 'thanks to' more apparent climate change and catastrophies such as hurricanes, often stimulating the global warming debate. Albeit the global dimension of the problems penetrated in this paper, for the most part a national context has been chosen in order to carry out the study.

2.3 Economic growth desired

In September 2005 the European Commission proposed that all efforts in the EU were to be directed towards two aims: to create a stronger, sustainable growth, and to create more and better jobs. (Meddelande från Kommissionen till Rådet och Europaparlamentet 2005 p.2). The Lisbon Strategy defines the general goal of an annual economic growth rate of 3 percent. (Giljum, Hak, Hinterberger 2005). There is thus an outspoken political aim of attaining economic growth in Europe. It has even been suggested (e.g. by the President of the European Commission: Barroso), that the Lisbon strategy, of which Sweden is one of the most enthusiastic proponents, with its three components: economic, social and environmental, should be replaced by a two step solution. This would be to start with market oriented reforms, which would generate growth. The growth could then be used to finance social ambitions and environmental protection. Such a change of strategy has however been rejected by the European council. (Regerings skrivelse 2005/06:23, p. 6-7).

Usually the need for economic growth is not questioned among macro economists, although there are those who are sceptical about the way it is measured. (For more information about critique against measurement of economic growth see e.g. Brekke 1997). As mentioned there is a general commitment in the European Union and its member states to direct attention towards economic growth. As mentioned this commitment is articulated by the Lisbon strategy. However since this emphasis on macro economic growth receives much criticism, particularly by non-economists (see e.g. Meadows et. al 2005) a comment is justified. It might be easier to see the need for economic growth in developing countries where often a majority of the population lives in poverty. For some it might be less obvious why focus is so strong on the growth of the economy in the rich parts of the world where proportionally fewer people are considered poor.

Generally, economic growth is strived for because it is considered an indicator of increased richness and expanded possibilities for governments and individuals. It is also a sign of competitiveness, which is one important objective of the EU. An important reason given for the general commitment to growth in Sweden and among the leaders of the EU is, that it is needed in order to maintain the social welfare systems. Financing environmental reforms may also require growth of the economy, depending on the perspective adopted. A dilemma, some would argue even a paradox, occurs. In order to maintain social welfare systems the economy must grow. The EU as a region has been lagging behind the rest of OECD in terms of economic growth. But growth is slowed down partly by inefficient social security systems and incapability of reform. There is considerable fear among key players in European policy that reducing carbon dioxide emissions will further slow down growth, which is also partly why the two-step solution mentioned above has been suggested.

There are certainly many reasons apart from structural problems why growth in much of the EU has been very modest. It is not an objective of this paper to disentangle causes for European or Swedish economic development but it is interesting to note that OECD identify high oil prices as one reason for modest short run growth in several European countries (OECD Economic Outlook 2005 p. 2). Such indications may further spur worries about costs of carbon dioxide abatement.

The reason why it is relevant to discuss growth in an EU-context in this thesis, is that the abatement of CO_2-emissions, as will become increasingly evident, is an issue, which clearly benefits from cooperation over national borders. European cooperation will be returned to in chapter 5.

2.4 Costs of CO_2-abatement

In Sweden the fear of an ambitious abatement policy having large adverse effects on growth has not been great, which is confirmed by Göran Östblom at Konjunkturinstituet. (28-12-05). Such worries do however influence the coordination and achievement of a common European environmental policy. In order to better understand why this thesis discusses what effects carbon dioxide abatement policy may have on economic growth it is helpful to consider the models leading to conclusions that environmental economic instruments, such as a tax on carbon dioxide can cause economic growth losses.

According to Ekins (2000) there are three ways of estimating CO_2-abatement costs: global models, single country models, and detailed calculations of the costs and environmental performance of different carbon-saving technologies. (Ekins 2000 p. 260). Models can be divided into two groups of models: general equilibrium models, and macroeconomic models. The first type focuses on long-term equilibrium resource allocations and relative prices. The second emphasises more on short term adjustments and disequilibrium. (ibid p. 260). Because of the long-term focus of this thesis the first type will be further discussed here. Ekins writes that

> Whether the reduction in demand for carbon-based fuels induced by energy price increases results in reduced output (GDP) depends in the first instance on possibilities for substitution, efficiency improvements and technological development, so that the 'costs' of CO_2-abatement will depend very largely on how these factors are modelled. (ibid 2000 p. 261).

General equilibrium greenhouse modelling is often based on a production function approach (ibid p. 261). Ekins describes it as

$$X=F(C,E) \qquad \text{(Eq. 1)}$$

where X represents output, E energy, C all other factors, and F(.) the production function. A base run is established, including assumptions about the future supplies of natural resources, demands and prices of all production factors and parameters like energy demand elasticities and autonomous energy efficiency improvement. There are no unemployed resources under the base run scenario. The price of energy rises as a carbon tax is introduced, which reduces demand for energy. With supply of other factors unchanged, lower demand for energy converts into lower output through the production function. A carbon tax thus causes lower GDP in the model. (Ekins 2000 p. 261-262). Models of this sort use energy elasticities derived from past experiences of energy price changes. (ibid p. 263). But a gradual introduction of a carbon tax can be expected to differ from unexpected oil price shocks which have occured several times in the past 30 years in that price changes will be anticipated and imply higher elasticities. (ibid. 263).

These types of models usually do not incorporate the dynamic effect that a change in relative prices may have on investment behaviour and thus technological change.

3. Technological Change and Learning-by-Doing

> *Current production modes, with their associated levels of fossil fuel consumption, cannot proceed at present rates. No one really believes or is ready to accept, however, that the solution of the climate change problem consists of reducing the pace of economic growth. Instead, it is believed that changes in technology will bring about the longed decoupling of economic growth from generation of pulluting emissions.* (Castelnuovo et al. 2005, p. 261)

3.1 Induced technological change

Technological change is defined as ideas or innovations. They are in themselves thought to be costless. One important assumption made in this thesis is that technological change can be induced. This builds on a rapidly growing literature supporting the possibility of endogenous growth and induced technological change. A main difference between the neo-classical literature and the endogenous growth literature is that the former assumes that technological change is exogenous whereas the latter assumes that technological change can be induced through changed investment behaviour, in for example research and development. (Vollebergh and Kemfert 2005 p. 135). Without induced technological change, economic policy will not speed up innovations in environmental or other technology. With induced technological change on the other hand, investments in research and development can influence economic growth and lead to emissions reductions. Although technological change is assumed to be costless, investments in R&D obviously are not.

Research and development is expected to lead to technological change. Like the burning of fossil fuels it is also characterised by market failures of importance in the context of long-run CO_2-mitigation. It might not be possible for a firm developing technology or new ideas to prevent others from using these, i.e. a limited excludability. Ideas thus have public good characteristics, which are likely to imply that too little is invested in R&D from an aggregated perspective. Jaffe et al. state that "It is well known that such public goods will tend to be underprovided by ordinary market activity." (Jaffe et al. 2005 p. 168). Returns to investment will be uncertain due to the possibility of spill-over. Jaffe et al. write that there are two market failures important in the context of pollution: that pollution represents a negative externality, and that R&D generate positive externalities (spill-over effects). These spill-over effects are of course desirable from a macro economic point of view. New technology, from an analytical perspective, will therefore be doubly underprovided by markets in the absence of public policy to counteract this. (ibid. p. 168). They continue by suggesting that the efficiency of environmental policy depends on its consequences for technological change, and that there might be scope for a policy aimed directly at stimulation of environmentally beneficial technological change. (ibid. p. 168).

3.2 Learning-by-Doing

It is difficult to speak of technological change without mentioning the learning-by-doing (LbD) effect since it might enhance the effect of technological change and make substitution sensible although initial costs of substitutes might be high. Instruments creating price incentives to reduce CO_2-emissions may potentially stimulate LbD by reducing the opportunity costs of environmentally friendly substitutes. Although LbD is seen as distinct from technological change, a price incentive policy can make it economically justified to employ new untested technology substitutes. Such untested innovations can then become more efficient due to LbD effects. LbD implies that knowledge accumulates "...not as a result of deliberate (R&D) efforts, but as a side effect of conventional activity." (Castelnuovo et al. 2005 p. 263). LbD is by many considered a costless activity. New technologies tend to be more expensive in per unit cost than conventional ones. "Learning-by-Doing entails the acceptance of high near-term costs in return for an expected lowering of future costs." (Castelnuovo et al 2005 p. 263). LbD can be assumed to occur as a side-effect of accumulation in new physical capital which brings about a production function exhibiting increasing returns to capital. (ibid. p. 263). The production costs are reduced through a refinement of existing techniques. It is not a result of any technological break-throughs. An example of where learning-by-doing is considered to have taken place is in wind-power. Typical learning rates for wind-energy are 18 per cent (referring to cumulative installed capacity) (Edenhofer et al. 2005 p. 279).

3.3 Modelling of Induced Technological Change and LbD

A combination of R&D and learning-by-doing can be used as policy options to induce economic growth and reduce emissions. It can be helpful to consider how this can be modelled. Castelnuovo et al.'s extended version of Nordhaus and Yang's climate-economy model RICE of intertemporal optimal economic growth coupled with a climate module presents an example. (Castelnuovo et al. 2005, p. 263-264). In the original Nordhaus-Yang model a policy game between six regions is played. In each region a social planner chooses the optimal level of the instruments fixed investments and rate of emission abatement. They also consider a Kyoto trading scenario (emissions trading systems will be discussed in chapter 5 and 6) in which the additional instrument of permits held can be chosen by each country. (ibid p. 264).

The model is extended to include two separate formulations of R&D-driven technology and of LbD. A LbD-driven stock of knowledge enters the output production factors and affects the relationship linking production to emissions. (Castelnuovo et al p. 262). This happens as a side-effect of conventional economic activity and is costless. R&D investments on the other hand is a policy variable which increases the stock of technological knowledge. (ibid p. 262-263).

The modified RICE production function is

$$Q(n,t) = A(n,t) K_R(n,t)^{\beta_n^R} \left[L(n,t)^{\gamma} K_F(n,t)^{1-\gamma} \right] \quad \text{(Eq. 2a)}$$

where Q is output, A- exogenous rate of technology, K_R-inputs from knowledge capital, L – labour (evolving exogenously over time), K_F –physical capital (n and t index country and time).

The knowledge stock accumulates according to

$$K_R(n,t+1) = \text{R\&D}(n,t) + (1-\delta_R) K_R(n,t) \quad \text{(Eq. 3)}$$

where R&D represents expenditure in R&D, and δ_R –rate of knowledge depreciation.

R&D included in the fundamental identity of sources and uses makes

$$Y(n,t) = C(n,t) + I(n,t) + \mathrm{R\&D}(n,t) \tag{Eq. 4a}$$

where C is consumption, *I* gross fixed capital formation and Y output net of climate change effects.

When LbD is introduced the idea is formalized by modifying the Cobb-Douglas coefficients, so that returns to scale result to be increasing, owing to the augmented capital-output elasticity. (2a) is modified to:

$$\begin{aligned} Q(n,t) &= A(n,t)\left[L(n,t)^{1-\gamma} K_F(n,t)^{\gamma}\right] K_F(n,t)^{\beta^L} \\ &= A(n,t)\left[L(n,t)^{1-\gamma} K_F(n,t)^{\gamma+\beta^L}\right] \end{aligned} \tag{Eq. 2b}$$

where β^L is the LbD coefficient.

Under LbD, (4a) reverts back to its original RICE form:

$$Y(n,t) = C(n,t) + I(n,t) \tag{Eq. 4b}$$

implying that knowledge creation does not require additional resources in the LbD approach, ceteris paribus.

The original version of RICE emissions-output relationship is

$$E(n,t) = [1-\mu(n,t)]\sigma(n,t)Q(n,t), \quad 0 \le \mu(n,t) \le 1 \tag{Eq. 5}$$

where μ is the domestic abatement rate and σ the exogenously given emissions-output ratio. In (5) knowledge affects factor productivity but not the emissions-output ratio. When instead accounting for endogenous environmental technical change (5) modifies to:

$$E(n,t) = \left[\sigma_n + \chi_n^{R}\exp\left(-\alpha_n^{R}K_{R}(n,t)\right)\right] \times [1-\mu(n,t)]Q(n,t) \qquad \text{(Eq. 5a)}$$

where α_n^R is the region-specific elasticity through which knowledge reduces the emission-output ratio, χ_n^R a scaling coefficient, and σ_n is the value to which the emission-output ratio tends asymptotically as the stock of knowledge increases without limit." (Castelnuovo et al 2005 p. 265). Investments in R&D affect K_R which in turn enhances environmental technical change.

With LbD-based knowledge accumulation, (5a) is replaced by

$$E(n,t) = \left[\sigma_n + \chi_n^{L}\exp\left(-\alpha_n^{L}K_{F}(n,t)\right)\right] \times [1-\mu(n,t)]Q(n,t) \qquad \text{(Eq. 5b)}$$

where knowledge capital is substituted for physical capital. K_F here contributes to output productivity and affects the emissions-output ratio and thus overall level of emissions. K_F has the same effect as did K_R under R&D. The model does not consider hybrid knowledge formation with both R&D and LbD at the same time. In the real world, both technological change and LbD will happen at the same time and will interact. It might be impossible to distinguish them from each other. The model is not ideally fit for the problem investigated in this thesis, for example since it does not model a separate sector or country. It does however add to the understanding of the empirical roles of technological change and LbD.

4. Decoupling of Economic Growth and CO_2-Emissions

The role of technological change is twofold in this thesis: it plays the role of stimulating economic growth. Together with LbD and substitution it also plays the role of decoupling economic growth from carbon dioxide emissions. Decoupling is an important concept in this thesis. The pursuit of economic growth is by some considered one of the main problems of bringing about environmental improvements. Typically when the economy grows, more and more natural resources are used. As previously acknowledged, growth of the economy has so far implied growth of the transport sector which has resulted in increased emissions (The European Environment-State and Outlook 2005, ch. 35). Unless this relationship between growth of transport and environmental decay is breakable, economic growth will be accompanied by higher emissions of CO_2. With more vehicles more petrol is needed, and more carbon dioxide is emitted. Economists and natural scientists speak of a decoupling between economic growth and environmental decay. "Absolute decoupling refers to a development where the environmentally relevant variable is stable or decreasing, while the economic driving force (for example GDP) is growing." (Skou; Andersen 2005 p. 79). Relative decoupling on the other hand is when the environmentally relevant variable, in this thesis carbon dioxide, grows but at a slower rate than economic growth. In the case of climate change, absolute decoupling is needed. (ibid p. 79).

The objective of decoupling economic growth from transport demand has been adopted as a strategy by the Council of Ministers in Helsinki in 1999. It is also articulated in the "Sustainable development strategy" adopted by the European Council in Gothenburg in 2001.(EEA 2005, p. 395). But technological development could make it unnecessary to restric growth of transport demand. A decoupling could be brought about in different ways. It may be through actual technological progress, e.g. if growth implies more cars but these cars emit less CO_2 through new technological solutions. Or it could happen through substitution, possibly by the help of technological change, LbD or a combination of all three. In the transport sector such a substitution might be of factor inputs, say a switch from carbon-based fuel to non-carbon based fuel. Or through a switch from road transport to train transport running on energy generating less carbon dioxide emissions.[6]

The concept of decoupling is very popular among politicians, economists and others, since it implies that there need to be no dramatic altering of the fundamental market economic structures or consumption life style. This decoupling is to be brought about by technological innovation and substitution. Although generally accepted on a policy level there is no agreement among scientists that it is actually possible to decouple economic growth from environmental damage. Evidence that general decoupling is actually taking place is limited. However knowledge of the links between the economy and the environment is rapidly growing. It is increasingly possible to test the occurrence of decoupling. The limited evidence of success so far has not disillusioned scientists. An important aspect in this context is, however, that even if a decoupling of carbon dioxide emissions and economic growth can be achieved, this does not automatically imply an actual decoupling of all environmental damages and growth. For example imagine a rapid and badly prepared switch from fossil fuels to bio-fuels. Such a shift might imply a swift deforestation in order to produce bio-fuels, which would be problematic for other reasons than just issues related to carbon dioxide.

4.1 Empirical results in the literature on costs of climate policy

A number of studies have investigated the scope of endogonised technological change to reduce costs of climate policies. Gerlagh and Lise (2005) study carbon taxes' effects on fossil-fuel and carbon-free energy use and carbon dioxide emissions. To do this they develop an economic partial equilibrium model for energy supply and demand with capital and labour as production factors, and endogenous technological change through learning by research and learning by doing. They carry out a policy analysis, simulating the reduction in cumulative carbon dioxide emissions over a 100 year period as a response to a constant 25 $/tC (tons of carbon) carbon tax. Induced technological change is shown to enhance cumulative emissions reductions over the 100 year period by a factor of 3. The authors add however that the model they use focuses on the energy transition from fossil-fuels to carbon-free energy sources, while neglecting energy savings as an option to reduce carbon dioxide emissions which would probably have shown factor

[6] Trains are to the greatest extent driven by energy from hydropower and nuclear power.

substitution to be more important than induced technological change. (Gerlagh; Lise 2005 p.241-260). The study is of interest in this thesis because it shows how a recognition of induced technological change can add a dimension to the discussion on abatement costs and carbon dioxide policies.

Weber et al (2005) use a multi-actor dynamic integrated assessment model (MADIAM) of induced technological change and sustainable economic growth to investigate the interaction between climate and the socioeconomic system. They find that all actors exert significant influence on induced technological change and mitigation of global greenhouse warming. Their impact on long-term economic growth is however small in all scenarios. A delay in GDP-level of 1-2 years due to mitigation over a 100 years is expected. The strongest impact on climate change was obtained from investments of business in increased energy and carbon efficiency. Weber et al conclude however that the effect cannot be separated from governmental regulation policies in the form of carbon taxes which influence business investment decisions. Recycling of carbon taxes into subsidized investments in mitigation technologies can enhance economic growth by freeing business resources then available for investments in human and physical capital. (Weber et al. 2005. p. 306-327). The small delay of GDP due to carbon dioxide mitigation and the recognition of that carbon taxes influence business investment decisions are particularly interesting to note here.

Castelnuovo et al., who's model was presented earlier in chapter 3, use an extended RICE model to simulate different policy scenarios and compare the results focusing on consumption, physical capital, emissions abatement rates and R&D expenditures (Castelnuovo et al. 2005). Their results indicate that R&D-driven and LbD-driven knowledge frameworks may lead to qualitatively similar findings. Endogenising environmental technology lowers costs of meeting emissions caps like the Kyoto protocol, which enhances the considered regions' welfare. There are also indications that R&D provides an additional control variable available to optimising agents, possibly providing them with a better outcome as opposed to a pure LbD framework. R&D is however likely to be a costly instrument to employ. A weakness with the model is that it does not allow R&D and LbD knowledge at the same time, which would probably have enhanced their importance.

Also the results from Castelnuovo et al. speak in favour of the line of argument put forward in this thesis. R&D and LbD are both important in order to reduce abatement costs. The indication that R&D works, but is a costly option to achieve targets is valuable information and corresponds to the conclusions made by Parry et al (2003). They assess whether the welfare gains from technological innovation leading to abatement cost reductions are larger or smaller than what they call the "Pivouvian" welfare gains from optimal pollution control. (Parry et al. 2003 p. 237). The relative welfare gain is said to depend on three factors: the initially optimal abatement level, the speed with which innovation reduces future abatement costs (the optimal innovation path), and the social discount rate (Parry et al. 2003 p. 252). Under most parameter scenarios they account for, the welfare gain from innovation is smaller than that from pollution control. For the opposite to be true innovation must quickly reduce abatement costs by a substantial amount, roughly 50 per cent in 10 years, and the initial optimal amount of abatement must be modest.

The authors draw attention to that their results contradict some economists asserting that technological advance might be more important than achieving optimal pollution control in the design of environmental policies. They also express concern about the efficiency of the current US plan for abatement of carbon dioxide emissions mainly by the assistance of technology subsidies rather than by direct emissions controls. They stress however, that a policy directed towards technological innovation may still be motivated by other concerns, such as ameliorating economic/ environmental conflicts for unborn generations. They also note that when an environmental goal has been decided on, the "Pigouvian" gain is no longer relevant and the importance of innovation is unlimited (Parry et al. 2003 p. 253).

Edenhofer et al. formulate their own integrated assessment model, the Model of Investment and Technological Development (MIND), in order to analyse the relationship between specific mitigation options and the costs of ambitious climate protection objectives. Their calculations show that technological change in different sectors reduces the cost of climate protection substantially. Technological change is believed to be triggered by investments in sector specific capital stocks. Reallocation of investment, especially in the renewable energy sector and the carbon sequestration sector, enables an economy to implement ambitious climate protection goals while guarranteeing stable economic growth. Backstop technologies and learning-by-doing are considered very important. A backstop technology implies a technological breakthrough when it comes to reducing emissions. An example of a much longed for backstop technology would be hydrogen powered cars. Without backstop technologies a climate protection goal can only be achieved through reduced economic output and enhanced energy efficiency (Edenhofer et al. 2005 p. 290). They write that "The existing studies clearly show that learning-by-doing in backstop technologies reduces macroeconomic mitigation costs." (Edenhofer et al. 2005 p. 279).

The results from Edenhofer et al. are encouraging when it comes to reducing abatement costs through technological change. However the transport sector is not among the sectors included in the study. There are clear empirical indications that it has been more difficult to reduce emissions in the transport sector than in other point-source emitters. One possible explanation for this might be that there are less evident learning-effects in the transport sector than in e.g. the industrial manufacturing sector.

Buonanno et al put forward an interesting, but complicating version of the RICE model with technological change. Investments in R&D not only reduce carbon intensity but also create an external effect which increases total productivity of the whole economy. This implies that decoupling of economic growth and carbon dioxide emissions can only occur if the parameters are chosen so as to allow the reduction in carbon intensity to dominate over the growth-enhancing effect of R&D investments. (Edenhofer et al. 2003). The conflicting effects of technological change which are central in this thesis thus become very evident. On the one hand economic growth is desirable and induced by technological change. On the other carbon dioxide abatement is strived for and expected to be brought about by technological change. But the CO_2-reduction effect must be larger than the growth effect. Otherwise total CO_2-emissions will not be reduced.

A countering argument though, is that economic growth might be biased towards green technology. Lately it has often been claimed that there is great growth potential for "green growth" in Sweden. If investments can be managed and directed to environmental technology the chances for this might increase. A way of doing this could be through price incentive instruments.

Nordhaus shows that improving energy efficiency through R&D investments is less efficient in reducing greenhouse gas emissions and minimise welfare losses than output reduction induced by a carbon dioxide tax (Edenhofer et al. 2005 p.279), which would speak in favour of using price incentives rather than direct R&D investments.

4.2 Critique against the decoupling approach

Technological change is considered the key to sustained economic growth (Jones 2002). It is also considered essential for reducing pressure on the environment including pressure in the shape of CO_2-emissions, much due to beliefs in decoupling and a more efficient utilisation of natural resources in production as new methods and technology develops.

Some ecological economists, above all one of the fathers of the discipline Georgescu-Roegen, have criticised the whole idea that substitution and technical change would be the solution to the physical restrictions of limited resources and carrying capacity of the world. (Vollebergh and Kemfert 2005 p. 134) Vollebergh and Kemfert write that "According to Georgescu-Roegen, our limited understanding of technological change not only demonstrates how little economists have to say about the really important issues of life, but also leads us to the false belief that solutions exist to the fundamental limits on resource availability." (ibid, p. 134). There will always be a need for raw material no matter what method of production or technology utilised. Thus the notion of decoupling growth from environmental damage does not hold. It is argued that those who think that ultimate solutions are found in technological innovation and substitution fail to see the environment as a whole and integrated system. Serious scepticism against the prospect of solving limitations of natural resources and the environment's capacity to handle human waists through technological change and substitution has thus been expressed. Sollow and Stiglitz have been targets for much critique by some ecological economists who accuse the two authors (among others) of falsly claiming that exponential growth can continue forever. (See Ecological Economics no 22, 1997). This discussion can be said to be an extension of the limits to growth debate which was triggered by the book Limits to Growth (Meadows et al 1972, also the 30 year update 2005). The authors of Limits to Growth argue that the world is in "overshoot", approaching its carrying capacity. Exponential growth at current rates is unsustainable and will result in environmental collapse unless measures are taken. Other ecological economists express hope and confidence in the potential that decoupling through substitution and technological change provides.

The general view today is that decoupling is possible and that technological change does provide a solution to many environmental problems and scope for a continued economic growth. This is the position held by the Swedish government as well as much of the international community. As already stated decoupling is incorporated into environmental and economic growth policy. It is accepted as something which ought to be strived for in this study. Whether it provides a final solution to the fundamental problem of resource limitation, and not just a solution to the carbon dioxide issue, is a much wider question not examined here.

4.3 Summary of chapters 2-4

Chapter 2 considered the need to reduce CO_2 due to the negative externality of climate change. The rationale for economic growth was taken as given, because it expands possibilities for the individual and society. A group of models with conclusions that carbon taxes imply losses of GDP growth were presented. Chapter 3 started with a discussion on how induced technological change can be brought about through R&D investments, how induced technological change and LbD can reduce abatement costs, and how induced technological change can also induce economic growth. An example of how to model induced technological change and LbD was presented. In the model R&D enhances the knowledge capital which in turn reduces the emissions per unit of output, whereas LbD enhances the productivity of the physical capital. The double role of technological change as both stimulating economic growth and a way of decoupling economic growth from CO_2-emissions was discussed. Decoupling is part of the EU strategy for sustainable development. This thesis takes a positive stand towards the feasability of decoupling.

The 4th chapter reviewed empirical results from the literature. Most of the studies discussed indicate that induced technological change and LbD can reduce mitigation costs. However, the development of backstop technologies may be important for coming to this conclusion. One article indicates that under most circumstances induced technological change is a more expensive way of reducing emissions than through e.g. emissions taxes. The authors point out, however, that concern for future generations might make technological change efforts worth while. The conflicting role of induced technological change is recognised, implying that the emissions reducing effect of R&D must outweigh the growth enhancing effect. The information received from Weber et al, that GDP-level is delayed with 1-2 over a 100 year period as a result from mitigation, and that carbon taxes influence business investment decisions may be valuable for answering the questions asked in this thesis about cost-efficiency of transport policy in the short and long term.

It can be concluded that there seem to be proof that R&D provides a route towards growth and CO_2 reduction but that the results are inconclusive as to whether it is more efficient to put efforts directly into R&D investments rather than concentrate on price incentive instruments such as emissions taxes which are expected to influence private investment decisions. The approach that technological change and substitution would lead to decoupling of economic growth from emissions has recieved critique. The main point of this critique was accounted for in 4.2.

5. Economic Instruments

This chapter examines three economic instruments of particular interest to the abatement of CO_2-emissions. In the short-term it is mainly the cost-efficiency of the instruments that matters. In the long-term whether they constitute a reasonable incentive framework for the encouragement of technological change is also important. A discussion about long-term dynamic effects of instruments ends the chapter. The effect of a given policy is dependent on the elasticity of demand, which is the subject of the first section of the chapter.

5.1 Elasticity

The actual occurrence of a reduced demand for fossil fuels or a substitution away from fossil fuels is dependent on the price elasticity of demand for the fuel, which in turn to a large extent is conditioned on the availability of substitutes and the price of such substitutes, as well as preferences of course. Cross-price elasticity of demand for different means of transport is also important. The longer the time span the more elastic demand is likely to be which can be seen in table 1 for price elasticity on petrol below.

Table 1. Price elasticity on Petrol for car possession, annual distance covered, specific petrol consumption and total traffic activity and total demand for petrol.

Price elasticity on petrol for	Very short run	Short run	Long run
Car possession	0.00	-0.05	-0.10
Annual distance covered	-0.10	-0.15	-0.20
Specific consumption	-0.11	-0.11	-0.41
Total traffic activity	-0.10	-0.20	-0.30
Total demand for petrol	-0.21	-0.31	-0.71

Source: Kågeson p. 12, originally from Jansson and Wall, Bensinskatteförändringars effekter, Rapport till ESO, Expertgruppen för studier i offentlig ekonomi, Ds 1994:55

Tab.1 The elasticities increase with time as different actors adapt to price changes.

With zero notice it will be hard for affected actors to change their behaviour: elasticity is low. In a slightly longer perspective it will be possible for different actors to adapt. They can substitute means of transport, fuel or factor intensity. Demand may also simply fall. Car producers have time to modify supply of products to target consumers' changed preferences. However only substitution within the frames of existing technology can be employed. Different actors also have different potential to substitute to lower carbon alternatives. A private individual is not able to adapt in response to prices changes in the same way as a firm. A firm may have a larger potential to pass the burden on to consumers.

If the policy is likely to be predictable and constant, in the yet longer term, all actors have increased possibilities of substitution: elasticity increases. There will also be time and price incentives for the development of new solutions, i.e. technological change. There are of course innumerous differences and ways in which different actors can or cannot adapt to changed relative prices. There is no possibility mapping them here and that is not the idea. Those mentioned here are only to clarify the route of thought. In fact the plentiful options and difficulty for someone not an expert in the field to identify the first best solution to the carbon dioxide problem is one of the strongest arguments for keeping an open attitude towards different options. Many scholars have pointed towards the importance of avoiding a technological lock-in, or favouring of one certain technology (see e.g. Jaffe et al. 2005 p. 169). At the same time, affected actors want to know which way to go before making costly adjustments and investments in the capital stock, which was indicated in section 1.1. Therefore they demand a clear and long-term strategy from the authorities. There is thus a balance between keeping options open for creative solutions, letting actors know which routes will be favoured, perhaps through subsidies, and achieving socially optimal solutions. The relevance of technological change is more in a long-term perspective. Technological change may influence elasticites in the longer run, providing low, or non, carbon alternatives previously not realised or economical. An example of an option previously not realised is carbon sequestration. It is interesting because it implies there need not be a shift away from fossil fuels which is usually seen as an ultimate necessity for CO_2-abatement.

5.2 Efficiency of Instruments

There are a number of politically set up targets specifying CO_2-emissions reduction. These targets will be further discussed in chapter 6. A question central in this section is how such targets can be achieved at lowest cost, i.e. cost efficiently. As already mentioned particular interest will be directed towards the long-run efficiency of the instruments. The long-run effects may deviate somewhat from the short-run effects. Whether these targets represent economically efficient levels of carbon dioxide abatement, maximising social net benefits is not of interest here, although this is a valid question. The targets exist, so how can they best be reached. The focus on long-run effects and thus technological change makes it highly relevant whether the instruments create incentives for investment in R&D.

A condition for cost efficieny of an instrument to abate emissions is that the marginal cost of abatement is equal across the whole market. (Söderholm; Hammar 2005 p. 51). This is however a static condition which does not take in consideration the long-term cost development. For example there may be dynamic learning or technology effects, which will be further discussed in section 5.6. In this section three types of specific economic instruments important for reducing the level of CO_2-emissions are examined theoretically: a tax on carbon dioxide emissions, a system with tradable emission permits, and a subsidy to abatement. All three instruments have the potential of meeting the cost efficiency criteria if they are properly applied. They work through incentives to altered behaviour and aim at reducing the externality market failure by correcting the price of the externality. It should be noted that there are several other instruments of interest for the sake of abating CO_2-emissions, in particular as complements to the three specifically discussed here. Those three are however argued to be of most interest. "Employing incentives to make behaviour less polluting can be thought about in terms of prices and markets." (Perman et al 2003 p.217). Profit maximising firms will alter their behaviour taking into account the opportunity costs generated by the prices in the markets for the pollution externality (ibid. p. 217), in this case, the pollution externality being carbon dioxide. More about the actual economic instruments in Sweden will be presented in chapter 6.

It is not entirely simple to determine the purpose of each economic instrument in the transport sector. It is generally accepted in the economic literature that at least one instrument is needed for each goal. (SOU 2004:63, p. 172). The actual consequences are even more dubious to evaluate, although easier with the carbon dioxide tax and tradable permits than with subsidies. While clear on a conceptual level an instrument may very well have actual effects other than only the intended. Considering for example an emissions tax, reducing the level of emissions will not be the only effect. Side effects are always to be expected, and may be distortionary or beneficiary, in the best case creating a double dividend.

5.3 A tax on emissions

A principle in environmental economics is that the polluter should pay for the damages of the pollution he causes. In the case of a carbon tax, the tax should integrate the external costs of the pollution in the price. However the tax level may be set according to other principles. The CO_2-targets makes it desirable to use the tax to achieve a certain reduction . in order to predict which tax level a certain reduction corresponds to, the demand elasticities must be determined. Such estimates are usually associated with uncertainty, and thus the actual abatement level cannot be know for sure. This would have to be determined through trial and error.

A tax on carbon dioxide emissions is commonly applied on the fuel according to the level of carbon which it contains and not directly on the emissions. The reason for this is explained by Common: "Consider the use of taxation to control emissions from fossil fuel combustion. Whereas monitoring and enforcement present great problems if emissions are targeted directly, the knowledge that those emissions must have some material basis directs attention to fossil fuel inputs as tax point." (Common 1997, p. 278-279).

An emissions tax, such as a carbon dioxide tax is intended to make it more expensive to emit and thereby reducing demand for the taxed good. But a CO-tax could also be expected to increase the incentives to invest in R&D if it is believed that such investments could lead to cost reductions. However if other distorting taxes or subsidies are present this effect will not be as large as desired. Is it not a new invention to tax the good causing the emission according to the contents of harmful pollutant. This is the idea behind the Pigouvian principle of setting a tax equal to marginal environmental damages. (Bovenberg; Goulder 1996, p. 985). It has however proven one of the more efficient ways of reducing CO_2-emissions in Sweden, which will be discussed in chapter 6.

"[I]t is generally agreed among economists that, in a situation where the production or consumption of some good results in a negative external effect (i.e. one that is not reflected in the price of the good in question), then social welfare can be improved by imposing a tax on the good." (Ekins; Barker p. 78). Environmental taxes such as a CO_2-tax are sometimes criticized for being distortionary. But as Ekins and Barker point out, "...the whole point of an environmental tax (at a rate at or below the optimal level) is that it wholly or partially corrects a distortion from a pre-existing environmental externality. (Ekins; Barker p. 78).

If the environmental protective agency does not know the location of the aggregate emission abatement cost function with certainty it cannot be known which amount of abatement that will be generated by a specific rate of an emissions tax. In this sense marketable emissions permits differ in that the quantity of emissions can be set. The cost of the emission abatement will however be uncertain. (Perman et al p. 252). With uncertainty the regulating agency will have to adjust the tax rate as new information arrives. (Perman et al p. 253).

5.4 A tradable emissions system

The type of system for tradable emissions described here is a so called cap-and-trade system, which means that the authorities set a ceiling for the aggregated emissions allowed. According to Perman such a system in the case of a uniformly mixing pollutant, such as carbon dioxide emissions involves:

-*A maximum quantity of allowed emissions equal to the total amount of permits issued*
-*A rule restricting emissions to the amount of permits held.*
-*A monitoring and penalty system controlling that emissions do not exceed the amount of permits held.*
-*An allocation procedure for the initial allocation of permits*
-*A guarantee that permits can be freely traded*
(Perman et al 2003 p. 223)

The attractive properties of a tradable permits system are generated by the transferrability of permits, creating a market for emissions and an opportunity cost of pollution. (Perman et al 224). Polluters will trade permits until an equilibrium price occurs where marginal abatement costs will be equal among all polluters. This is the same for all three instruments here presented and is what ensures that targets are reached at least cost. (ibid. p. 224).

The permits can be allocated either through an auction where the market actors place a bid according to their valuation of the emissions, or through free distribution of permits according to some distribution rule, e.g. previous emissions, a so-called grand fathering principle. It is usually considered to be better to auction permits rather than to hand them out for free since the initial allocation is unlikely to be the desired and to correspond to marginal abatement costs. In a competetive market the price will however adjust and be the same as if permits are auctioned. (Perman et al 225). There is also the difference in that an auction will imply a transfer from polluters to the government, whereas with a free allocation there will be only a transfer between polluters. (ibid p. 227).

5.5 Subsidies

Subsidies to emission abatement and taxing emissions have very similar effects in terms of abatement. But there are two important differences: the distribution of gains and losses, and the long-run level of pollution abatement. (Perman et al 2003 p. 219). While a tax means net transfers of income from polluters to government, subsidies transfer money from the government to polluters, implying a need for additional tax revenues to finance the subsidy. (ibid p. 219). “This has important implications for the political acceptability and the political feasability of the instruments.” (ibid p. 219). There is a possibility that subsidizing rather than taxing will enlarge the polluting industry in the long run, which might offset the short-run emissions reduction. (ibid. p. 220). Further discussion on long-run effects is the subject of the subsequent section.

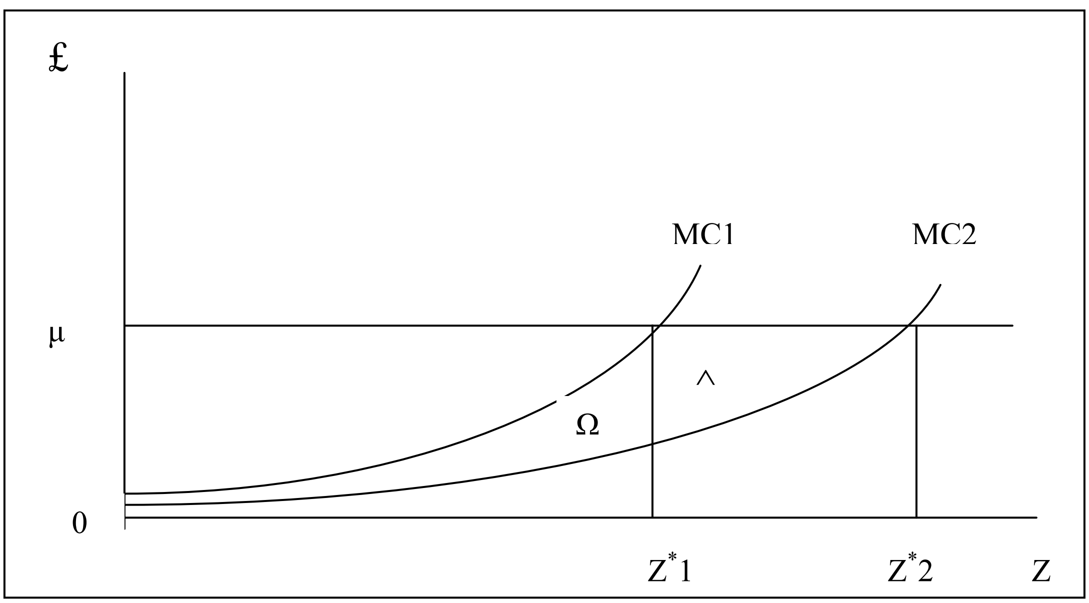
5.6 Long-term effects of instruments

The choice of instrument can be dependent on whether dynamic effects are considered important or not. If the dynamic effect, that price incentives are likely to lead to increased investment in R&D, and thus technological change, is taken into account this will lower the present value of expected costs of policy and make it more attractive. The problem with dynamic effects is that they are difficult to model with certainty and therefore to appreciate.

“The long-run effect of an instrument depends mainly on two things: net income effects and technological innovation effects.” (Perman et al 2003 p. 236). A subsidy as briefly mentioned above might imply that the targeted industry is allowed to grow in size due to the positive net income effect. (ibid. p. 236). The usefulness of the subsidy in such a case should be dependent on the long-run benefit of what is being subsidized. If there is a risk of sponsoring the wrong option it is probably better to tax the harmful one than subsidize the uncertain one. An example applied to the transport sector could be that subsidies to environmentally preferred fuels would mean that the gain of reduced emissions is offset by a growth of the subsidized businesses leading to increased aggregated emissions. The new tax reduction on diesel powered vehicles in Sweden might for example be questionable from this long-term point of view. From the net income effect point of view, both the emission tax and the tradable permit instruments are probably more efficient than abatement subsidies.

The technological innovation effect means that technological innovation can be induced in the long run. An emissions tax or abatement subsidy can create dynamic efficient incentives to change behaviour. The tax or subsidy will create incentives to reduce emissions, and every unit of emissions reduction is rewarded by a tax saving. (Perman et al 2003 p. 236). A figure of how dynamic incentives may work under an emissions tax is presented below.

Figure 2: Dynamic incentives under emissions tax controls



Source: Perman et al 2003, p. 236

Fig. 2 An emissions tax can make it profitable to invest and apply new technology if the costs of doing so are expected to be lower than the tax costs of pollution. This is an example of a dynamic price incentive to develop abating technology.

In figure 2, Z stands for abatement level. μ is the tax-level. Ω represents the saving from lowering the marginal costs from MC1 to MC2 and the emissions level is left unchanged. If MC shifts downward, the firm's profit maximising emissions abatement level rises from Z^*1 to Z^*2 and so the firm would be rewarded an additional saving of ^. There thus exists an incentive for firms to develop new technology to abate emissions as long as the total costs of development and application of technology are smaller than the present value of Ω + ^ accumulated over the existence of the firm. (Perman et al 2003 p. 236). An objection to this idea could be that many companies have rather short planning horizons. (SOU 2001:20). However larger companies with a large R&D budget are likely to plan for long terms. A subsidy will aslo have technolgy effects, in that the firm has a potential extra income from development of technology. There is however the risk that these technology effects on emissions are offset by the net income effects on the sector.

Under emission trading the technology effect will depend on the emission cap and the price of permits. If long-term allowed level of emissions is expected to fall, and the price of permits to rise, there will be incentives to invest in R&D if the expected cost savings from diong so are greater than the expected permit price. Effects will vary within the trading system according to the firm's marginal cost of abatement.

5.7 Summary

In this 5th chapter the importance of elasticity of demand was first discussed. Low elasticities imply that price incentive instruments have limited effect on emissions. Then theoretical properties of three economic instruments which are employed or could be employed as part of a policy to reduce carbon dioxide emissions in the transport sector were examined. Emissions taxes, tradable permits and subsidies have similar effects but it could be seen that differences exist, in particular between emission taxes and permits on the one hand and subsidies on the other. Although short run effects of the instruments may be identical, the long-run effects may differ in that abatement subsidies can actually lead to an expansion of the targeted sector and thus a long-run increase of the emissions desirable to prevent.

6. Swedish Transport Policy

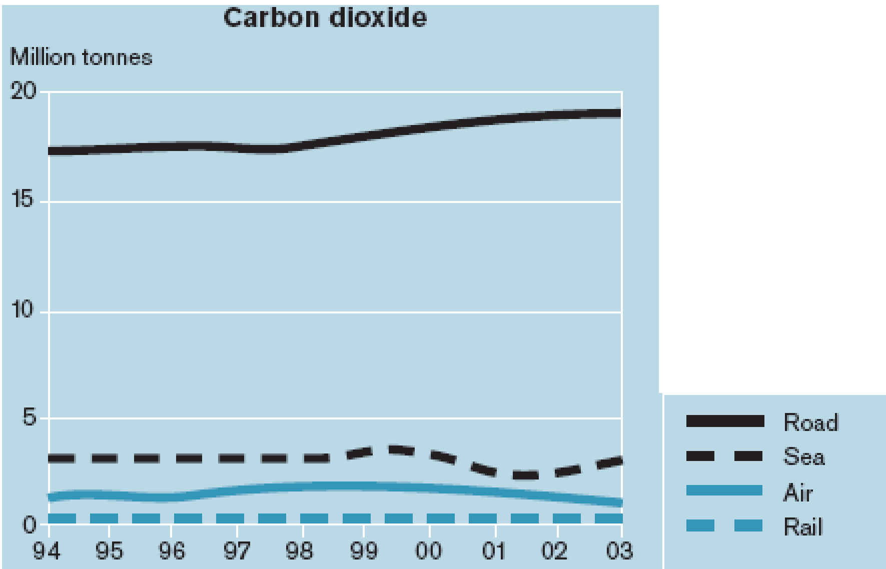
6.1 Transport in Sweden: Background information

The economic incentive structure in the transport sector in Sweden is investigated. As already mentioned transport is tightly linked to economic growth and constitutes one of the main CO_2-polluters in Sweden (Naturvårdsverket 2004 p. 23) and in the world. Whether economic incentives are efficiently set up and whether they are effective or not is thus crucial for the economy and the reduction of CO_2-gas. According to SIKA, transport is responsible for a third of all emisssions of greenhouse gas in Sweden (SIKA Year book 2005 p. 9). of which carbon dioxide is the absolutely most important one. The transport sector has constantly increased its CO_2- emissions during the past ten years. Road transport has increased by 9 per cent, and is expected to continue growing unless further measures are undertaken. (Naturvårdsverket 2004 p. 23). Road and sea traffic cause the highest emissions of CO_2 among the means of transport which can be read out of figure 3 and table 3.

Additionally it is interesting to note that "The fuel consumption of new Swedish cars was 24 per cent higher than the European average (EU-15) in 2002" (SIKA Year book 2005 p. 11-12). The main reason for this is that 25 per cent of the Swedish car fleet belongs to the heaviers vehicle class. The EU average is 5 per cent. In Finland with generally similar conditions to Sweden, the share is 7 per cent of the car fleet (Kågeson 2004 p. 9). An explanation for this often put forward is that the share of diesel powered cars in Sweden is low in comparison to other European countries. But according to Kågeson the higher emissions in Sweden can only be explained to 1/5 by the low proportion of diesel cars (2004 p. 9). If fuel consumption from private cars equalled the average European level, emissions of CO_2 from road traffic including heavy vehicles would be around 10 per cent lower than today (Kågeson 2004 p. 9). A heavily contributing cause for the high proportion of heavy cars is that almost 50 per cent of all cars belong to companies (or 25 per cent of new purchases (Kontrollstation 2004 p. 62)) and are leased to employees without there being any real connection to their work tasks. The leasing gives the users low variable costs which implies long driving distances. (Kågeson p.10).

Achieving a change in the preferences for cars thus ought to be important in reducing emissions in the sector.

Figure 3: Carbon dioxide in different sectors



Source: SIKA Year book 2005 p.113

Fig. 3 CO_2-emissions from road transport constitute the greatest share of transport emissions and are increasing.

Table 2.

6.2. Emissions of carbon dioxide by the transport sector, million tonnes.

Source: Sector and annual reports from the National Rail Administration, the Civil Aviation Administration, the Swedish Maritime Administration and the National Road Administration, 2003.

	Road	Sea	Air	Rail	Total
90	17.4	2.8	1.6	0.1	21.9
95	17.5	3.2	1.4	0.1	22.2
00	18.3	3.0	1.6	0.1	23.0
01	18.5	2.6	1.5	0.1	22.7
02	18.8	2.8	1.4	0.1	23.1
03	19.0	2.8	1.3	0.1	23.2

Source: SIKA Year book 2005 p. 113

Tab. 2 Aggregate emissions from transport have been increasing. Road transport constitutes the lions share of transport emissions.

In 2001, 70 percent of all personal transport was made by car. According to SOU2005:10 in the absence of additional instruments the carbon dioxide emissions from the transport sector will have increased by 20 percent by 2010 compared to the 1990 level. (p. 213). There will be a continuous demand for increased travelling when the income increases. (Naturvårdsverket 2004 p. 23). Kontrollstation 2004 however states that it is very difficult to determine the development in the transport sector due to the uncertainty about e.g. the oil price development and increased use of diesel and bio fuels. (Kontrollstation 2004 p. 45-46).

6.2 Targets for Transport in Light of Agreements

6.2.1 General climate policy

As mentioned in the introduction of this paper the policy towards carbon dioxide reduction is to a large extent the result of international agreements and commitments. But also of national considerations. That agreement of the most direct importance is the Kyoto protocol. In the EU the Lisbon strategy specifies how Europe is to achieve its obligations within the Kyoto protocol. Nationally there are the 16 environmental goals (regerings proposition 2004/05:150) and a national transport policy with a climate dimension (SIKA Year book 2005). The resulting targets make it possible to largely discard the discussion on optimal levels and whether a cost-benefit analysis should be performed, and instead concentrate on how to reach the reduction targets and other goals. Given the targets, what are the most cost efficient paths getting there?

The Kyoto protocol specifies that the EU is to decrease its aggregated carbon dioxide emissions by 8 percent from 1990 to 2008-2012 (as an average for the period). (SIKA Year book 2005 p.9). The main instrument for achieving this is the cap and trade emissions permit system, which does not however include the transport sector in the trading, although emissions from the sector are included in the overall target. According to the national burden sharing Sweden is allowed to increase its emissions by 4 per cent. But a Swedish parliament decision says that the average level of total emissions for the period 2008-2012 should be at least 4 percent lower than the emissions level in 1990. (SIKA Year book p. 9). This is an example of a situation where Sweden has decided to go further than the Kyoto protocol The Government's strategy to reach its aims is:

-Continued green tax reform with increased carbon dioxide tax rate and reduced tax rate on labour
-Measures in the transport sector, among other tax reductions for environmental cars and bio-fuel
-Information to increase awareness of climate changes
-Climate investment programs with the opportunity for municipalities and companies to apply for subsidies for measures to reduce emissions of greenhouse gases
(http://www.sweden.gov.se/sb/d/3188)

The 16 national environmental goals decided on by the Swedish parliament are to be achieved until 2020[7]. The first one is "Limited climate influence and thus the one of most concern for CO_2-emissions in the transport sector. In order to control the progress towards these environmental goals control stations are to take place every four years. The last one was in 2004 and the coming thus in 2008.

[7] See www.regeringen.se, regerings proposition 2004/05:150 for more information on the environmental goals.

6.2.2 Transport policy

The transport policy target for carbon dioxide is that emissions in 2010 should not exceed the level in 1990. (SIKA Year book 2005 p. 9). According to Kågeson there is no national plan for how this is to be achieved. (Kågeson 2004). There is also a Riksdag resolution on a long-term aim to reduce greenhouse gas emissions by half until 2050. (SIKA Yearbook p. 10). This means that emissions should be no higher than 4.5 tonnes of CO_2 equivalent greenhouse gas per year and capita and should thereafter be further reduced. Several institutions have come to the conclusion that the 2010 transport target is very unlikely to be reached. (SIKA Year book 2005, Naturvårdsverket 2004, Kågeson 2004). SIKA has suggested a revision of the targets allowing a 10 per cent CO_2 increase until 2010 compared to in 1990, and a 10 per cent reduction of emissions until 2020 compared to in 1990. (Kågeson 2004 p. 2). These revisions have not been accepted however.

6.3 Economic Instruments in the Transport Sector

Prognoses are not optmistic about achieving the long-term target for the transport sector (Naturvårdsverket 2004 p. 25). An increase of carbon dioxide is to be expected between 2010 and 2020. There is thus a large need for increased management in order to break the long-term negative trend. (Naturvårdsverket 2004 p. 26).

According to Naturvårdsverket central measures and instruments to achieve a shift in the transport development are:

1. The Carbon dioxide tax on fossil fuels
2. Continued green tax shift for improved use of resources
3. The energy tax system
4. Increased environmental relating of taxes and fees on cars
5. Development of combustion regulation for motor vehicles, processing machines and machine tools.

(Source: Naturvårdsverket 2004 p. 23-24)

In this thesis 1,3, and 4 are considered.

6.3.1 Road transport

Measures undertaken in the transport sector include recent increases in the petrol tax by 15 öre and the diesel tax by 30 öre. (SOU2005:10, p. 20). Carbon dioxide neutral fuels, e.g. bio-fuels are exempt from CO_2 and energy taxation until 2008. Relating to point 4 above, the annual vehicle tax has been differentiated according to the level of carbon dioxide emissions of the the vehicle. The energy taxation of cars is now related to carbon dioxide emissions instead of weight which was previously the case. The assessed rental value on environmentally friendly considered company cars has been reduced. A road fee has been introduced on heavy vehicles (over 12 tonnes) running in international traffic. (Kontrollstation 2004, p. 52-53).

Changed tax rules according to Prop. 2005/06:1 say that from April 2006 private diesel cars with low particle emissions receive a tax reduction of 6000 kr per year. At the same time vehicle taxation on light trucks and busses is raised by 60%. There has been an environmentally directed reform of differentiated vehicle taxation on light and heavy vehicles. (Uppdatering av 2004-års prognos för utsläpp av växthusgaser 2010. 2005 p. 70-72).

There are also voluntary agreements between the Swedish Government and the business world. For example there is an agreement from 2000 between the truck and car manufacturers in Sweden and the Government for the development of more environmentally adapted vehicles. The project involves a joint Government-business R&D effort. (SOU2001:20 p. 125).

There are some EU common initiatives relevant for the transport sector. The general guidelines in the EG directive 2003/30/EG, about promotion of bio-fuels or renewable fuels say that each country is to set national indicative targets for bio and renewable fuels. Riksdagen decided that 3% of the purchased fuels should be bio-fuels by 2005 and 5.75% by 2010.

There is a contract with the European car industry organisation (ACEA) to reduce CO_2-emissions from new private cars to 120 grams/ km by 2010. Similar contracts have been signed with the Japanese and Korean car industry organisations. (Kontrollstation 2004 p. 52-53). So far however, there has been little progress.

From January 2006 new rules for petrol stations say that all stations of a size of over 30 000 m^3 petrol or diesel must provide at least one renewable fuel.

6.3.2 Aviation

Aviation has so far been exempt from carbon dioxide taxation. Some European countries have however introduced CO_2-taxation on flights. Recently, a passenger tax on flight travel has been introduced in Sweden in spite of critical reports from SIKA and loud protests from the airlines. The purpose of the passenger flight tax is to correct for distortions in the functioning of the market today (SIKA Flygskattens effekter PM2006:2 p. 18). The estimated effect is a reduction of air travel by at least 2 per cent, and a reduction of total travelling by at least 1 per cent. This is expected to result in a reduction of carbon dioxide emissions by 1-2.5 per cent. (Ibid. p. 20).

SIKA states that a fuel tax on aviation would be superior to the proposed passenger tax and that an introduction of the passenger tax should await the ongoing investigation of a fuel taxation. (SIKA Flygskattens effekter PM2006:2, p. 18). An incorporation of flight transport, as well as the whole transport sector, into the tradable permits system would be preferable to the proposed national taxes. However if there is an urgent need to introduce some kind of taxation, SIKA's preference ranking for air travel is thus

1. Introduction of transport including air travel into the EU trading system
2. A fuel tax on air travel
3. A passenger tax on air travel

(SIKA Flygskattens effekter PM2006)

It thus looks as if though the least preferred alternative will be the winning candidate. Aviation constitutes a growing climate threat, although still small in comparison to road transport. After studying SIKA's reports it seems clear that there are better options than the passenger tax. Due to lack of space, nothing more specific will be said about aviation then that it seems highly relevant to use price incentives to reduce its emissions. Apart from that, the general conclusions in chapter 7 apply also to aviation.

6.3.3 Other measures

Apart from these measures there are the LIP/KLIMP: Local investment programs/Climate investment programs which may be of some relevance to the transport sector. Communes can apply for governmental funds for measures towards improved environment and climate, and increased employment. However, given the character of the problem, there seem to be limited possibilities to act locally. But local initiatives should not be discarded on before hand.

A decision to try to allocate freight transports from road to rail and water has been taken. But SIKA comment that “If the costs of emitting carbon dioxide increases, we can thus expect that it will lead to intensive development activity to reduce emissions of carbon dioxide. The consequence of this is that a shift from car to railways may not be necessary to achieve the carbon dioxide objectives” (SIKA Year book p. 10)

A green tax reform is currently being undertaken amounting to 30 billion SEK over the period 2001-2010. The intention is to increase taxes on environmentally damaging activities and correspondingly reduce taxation on labour. (Naturvårdsverket 2004)

6.3.4 Inclusion of transport in the trading system

There are discussions on if, how, and when the transport sector should be included in the trading system. There are two ways in which this can be done. Either Sweden can apply for a so called opt-in of only the Swedish transport sector after 2008. Or all EU member states decide on a harmonised inclusion of the transport sectors. (SOU2005:10 p. 55). It is likely that air transport, where in most countries no carbon dioxide taxation has previously been in place, will be incorporated in the coming years. By the looks of it this will however take time. Recently under Austria’s EU presidency, the EU failed to come to any conclusions on a timetable for when air transport will be incorporated. It is not yet clear whether also other means of transport will be included in the future.

A harmonised inclusion is not likely to happen until at the earliest in 2013 (SOU2005:10 p. 21). The FlexMex2-Commission, which was formed partly to investigate the inclusion of the transport sector into the trading system, does not recommend an opt-in of the Swedish sector before this date (SOU2005:10 p. 21). The main reason being that due to legal considerations such an inclusion would have to be a so called "down stream" procedure or "polluter pays principle", which in practise is more or less impossible with an emissions permit system. The FlexMex2-Commission does however recommend the Swedish Government to strive towards a harmonised inclusion of the transport sectors in all member states. An example of the what the emissions shares between the sectors in an expanded trading system would look like is presented in table 4.

Table 3

Trading sectors' carbon dioxide emissions in an expanded trading system

Sectors	Emissions in percent 2000
Electricity and heating production	13.0
Industry	21.1
Refineries	4.9
Total according to EU directive	39.0
Transports	36.5
Remaining sector	14.4
Total expanded trading system	89.9

Source: Kontrollstation 2004

Tab. 3 An inclusion of the transport sector in the trading system would mean that additionally 36.5 per cent of total emissions were handled within the system.

6.4 Concluding remarks

It is clear that additional measures are needed in the transport sector in order to achieve the targets for carbon dioxide emissions. A number of steps have been taken, in particular towards the introduction of environmentally friendlier vehicles and fuels. In the theoretical discussion about economic instruments in chapter 5, three instruments were surveyed. Of these, the emissions taxes: the fuel taxes empirically including carbon and energy taxes, have had the most influence in Swedish transport policy to abate carbon dioxide emissions. The tax exemption on carbon free -and neutral fuels can be thought of as an example of a measure which resembles a subsidy to abatement. Kontrollstation 2004 considers the complete tax exemption an unneccessary over subsidy of bio-fuels, functioning in reality as a subsidy to imported tropical ethanol, mostly imported from Brasil where the rain forest is being harvested to give room for production of ethanol. The tradable emissions permit system was discussed because it provides an often praised option for cost efficient abatement of carbon dioxide emissions.

Table 4. Reduction Need until 2010 in Relation to Business-as-usual

Initial Position and Measures	**Million tons CO_2**
Reduction need in comparison to business-as-usual	3-5
Further introduction of bio-fuels	0.6
Other measures (excluding tax modifications)	0.5
Effect of differentiated sales tax (until 2010)	0.2
Effect from km-tax	0.1
Needs to be achieved through raised fuel-tax	1.6-3.6

(Source: Kågeson 2004 p. 11)

Tab. 4 According to the calculations above, in order to reach the 2010 CO_2-target for transport 1.6-3.6 million tons of emissions would have to be reduced through raised fuel-taxes.

According to the business-as-usual scenario (in table 4 above), it can be seen that there is a need for a 3-5 million ton reduction of CO_2. The target for 2010 is not likely to be achieved through the measures taken so far. The only real chance of doing this cost-efficiently is through increases in diesel and petrol tax (Kågeson 2004 p. 11). Estimates from Naturvårdsverket indicate a 3 kr/kg of CO_2-tax need for decoupling of economic growth from increased emissions until 2030 (Naturvårdsverket 2004, p. 26). In spite of this Riksdagen has so far been unwilling to raise real taxes on fuel to levels sufficient for achieving the targets (Kågeson 2004 p. 15).

A reason why the reduction until 2010 needs to be achieved through increased fuel taxes is that the other measures take longer to reach their full abatement effect. Kågeson sees the inclusion of the transport sector into the EU-trading system as an alternative to raised fuel taxes (ibid p. 15). This would however imply that suppliers of fuel to the transport sector need permits for supplied quantities which would be in contrast to the the down-stream principle which is employed today. An inclusion of the transport sector is not likely to occur until at the earliest 2013.

7. Discussion and Conclusion

The results of this thesis indicate that technological change is important for economic growth and for reducing carbon dioxide emissions abatement costs. Additionally, learning-by-doing was recognised as important in many sectors, which might make it economically justified to support initially uneconomical technologies. R&D is an available policy instrument which influences technological change and thus abatement costs and economic growth. In the short-term R&D as an instrument is surely not a cost-efficient instrument for abatement since it takes time for the investments to have an effect. In the long-term it is highly uncertain whether a policy aiming directly at R&D reduces abatement costs more than a policy consisting mainly of price incentive instruments such as fuel taxes, emissions trading and emissions subsidies is more cost-efficient compared to price incentive instruments uncertain.

Price incentive instruments constitute a vital part of Swedish transport policy . The fuel taxes have been of most importance for restricting emissions increases so far. They are likely to be of dominant importance also in the future, since other instruments lack the same potential for abatement. Differentiation of the carbon dioxide and energy taxes between sectors implies that short-term cost-efficiency is far from as high as it could be. A differentiated taxation of vehicles according to environmental class and of fuels in practise implies subsidies of certain technologies which are not entirely positive. They do however increase the opportunity cost of polluting transport and speed up the replacement of the vehicle fleet and the introduction of bio-fuels. Such measures will have a positive impact on abatement in a longer time perspective. The harmonisation of policies across Europe would imply large short-term efficiency gains. Closest at hand lies an extended emissions trading system including also the transport sector, since the system already exists. The efficiency gains result from that abatement occurs where marginal costs for abatement are the lowest.

Long-term cost-efficiency of instruments is highly dependent on the dynamic technology effects. Technological change has been recognised as crucial for decoupling of economic growth and carbon dioxide emissions. It enhances growth and reduces abatement costs. In the absence of backstop technologies however growth might imply increased emissions.

The questions asked in the beginning of this thesis were

1. Does Swedish policy reduce carbon dioxide emissions in a cost efficient way?

2. What is the most efficient policy for long-term reductions of carbon dioxide emissions?

The short concluding answer to question 1 is that abatement policy in the transport sector could be made more cost-efficient by having the same level of taxation of carbon dioxide emissions in all sectors. The efficiency would be even greater if all European countries also had the same tax level on carbon dioxide emissions. European harmonisation of carbon dioxide emissions policy provides great potential efficiency gains, either by harmonising all carbon taxes or by including all transport sectors in the trading system.

The response to question 2 is that the most efficient policy for long-term reductions should primarily focus on price incentive instruments rather than direct subsidies to R&D. Also subsidies to abatement are to be viewed with scepticism in the long-term although they are also an incentive instrument stimulating substitution away from pollution, and might be helpful sometimes. At present the fuel tax is the most important instrument. Technological change is stimulated through investments in R&D. Technological change is considered necessary for growth and for abatement. Since the short term efficiency of R&D is low it is safer to use taxes to restrict emissions in the short term. But the returns to investment in terms of technological change are uncertain also in the long-term. The opportunity cost favouring low-polluting alternatives resulting from a carbon tax policy will stimulate investments in R&D. It is therefore possible to direct investments to R&D through alternative price control.

In the beginning of chapter 1 it was stated that there is a dichotomy between a policy focusing on technological change and one focusing on price incentives. It was claimed that an underlying choice was necessary, although elements from both sides might be of value. Because of the uncertainties connected to the returns of R&D and the need to start abating immediately this thesis argues in favour of a price incentive policy. There are other reasons for this. It is believed that the market is more creative than the state, given the right price incentives. If some projects are heavily subsidiced there is a risk of of technological lock-in, possibly leading to a slower development of technologies which might be better. Sometimes this risk is worth taking, in particular if there are likely to be learning effects and economies of scale, but often the subsidy might do more good than bad, mostly distorting competition.

Given these considerations the policy recommendation is to primarily use the carbon related fuel taxes to abate emissions and create incentives to invest in carbon abating alternatives. This secures short-term reductions and creates a rational framework for long-term abatement through technological change. Other taxes and tax reductions can be used to strengthen the price incentives, always keeping a cautious attitude not to support technologies without long-term potentiality. In this way investments ought to be made in environmentally friendly technology which in turn should mean that if the transport sector grows and GDP grows as a result of environmental investments or otherwise, this growth is less likely to imply a growth of carbon dioxide emissions.

Decoupling of economic growth and carbon dioxide emissions in general and transport growth and CO_2-emissions in particular must be the economic and environmental goal of policy in order to avoid that drastic changes in our way of life in Sweden become necessary. It is ultimately to be achieved through technological change and other innovative solutions. It would be up to the sector and consumers how they want to avoid the policy triggered costs. Be it through more efficient transports, substitution or technological change. Absolute emissions must sink, therefore absolute decoupling must be achieved if we want to allow the transport sector to grow. No matter what policy is undertaken there are however no guarantees of a decoupling of economic growth and emissions. But a policy shaped in this way creates the best prospects for it. And if decoupling fails, if technological change does not occur as rapidly as hoped, the steps here suggested have at least cost-efficiently restricted the growth of emissions in the short run, not making things worse.

The suggestions above for short-term and long-term policy do not differ much. There may be certain short-term costs implying negative short-term growth effects, but these ought to be of limited importance in the long-term. This is a view supported by Göran Östblom (28-12-05) at Konjunkturinstituet who says that even drastic increases in the carbon tax would have very limited economic growth effects, and that with inclusion of the transport sector in the trading system the growth losses will be even smaller. He refers to studies investigating the possibility of achieving the national reduction target only through increases in CO_2-taxes. The increases needed are big, sometimes a doubling of the existing tax rate, but still, the effect in terms of GDP are small. Only about 0.1 percent of GDP per year for carbon CO_2-taxes. If the tradable emissions system is used the loss would be only around some hundredth part of a percent. (28-12-05). The conclusions presented here are based on an optimistic, but risk-averse, view about the potential for investment-induced technological change and a likewise optimistic attitude that the market responds creatively to price incentives. Presenting actors with the appropriate price incentive will be the real challenge of future policy.

8. Future Research

Along the course of writing this thesis, several interesting side-tracks have been noted but have not been possible to follow up. These might be interesting areas for future research. For example it would be interesting to investigate whether the increased labour productivity in certain sectors in Sweden can be explained by the stricter environmental taxation. The specific investment behaviour, i.e. where investments take place. There is likely to be a conflict between different sectors and areas of research in need of investments. Another relevant research area would be the ongoing green tax reform and how the tax revenues can best be used. Sweden goes further than its obligations to the international community demands in some environmental areas, e.g. carbon dioxide abatement. A closer look at the economic rationale for doing this would be interesting. A last research area deserving more attention is the burning of fossil fuels releases several other gases and particles which are directly harmful to health on a local level. Within the emissions trading system, emissions in some areas will be much higher than in others. If these other harmful pollutants are considered this might not necessarily be the best solution. Some of the mentioned issues have already been investigated, but could undoubtedly do with more attention.

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