Incentive Based Climate Policies under Uncertainty

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Title Page

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Abstract:

The project considers incentive based climate policy under uncertainty. It considers how tax programmes and permit programmes perform when uncertainty about the future is introduced. When there is no uncertainty, tax programmes and permit programmes yield the same result. It is argued that climate change is uncertain and may carry big irreversible damages, which may be an argument for a precautious policy. When uncertainty is introduced, the result of taxes and permits differs. Taxes perform better in the short run and permits perform better in the long run. People's time preferences become important, when the dynamics of climate change is introduced. A high discount rate seems to favour a tax programme, as its lowers the uncertainties about the abatement costs, and a low discount rate seems to favour a permit programme, as uncertainty about the future matters when it is not discounted. Furthermore it is discusses how different parameters affect the model result. Lastly the price level of tax and permits is considered. It is argued that a precautious policy may seem reasonable, which leads to a sharp rise in emission reduction. Other views argue that the abatement cost is too high compared to damages primarily because they assume high discount rates.

The main result is that a permit programme seems to be better in tackling uncertainty about the future, as its sets the emission directly so that there is less uncertainty about the damages in future. It finds that if the government is concerned with short-term price fluctuations, it may be possible to use a hybrid that sets a price valve on the permits. The second result is that a precautious policy seems reasonable, as there may be big irreversible damages in future, which lead to a high abatement.

Resume

Dette projekt omhandler incitementgivende klimapolitikker. Det omhandler, hvordan udledningsskatter og -kvoter håndtere usikkerhed. Når det antages, at der ingen usikkerhed er, er resultatet af skatteprogram og et kvoteprogram det samme. Der argumenteres for en forsigtig politik, da klimaændringer kan bringer nogle store irreversible ændringer med sig. Når usikkerhed bliver introduceret, giver skatter og kvoter ikke længere det samme resultat. Skatter klarer sig bedre på kort sigt, mens kvoter klare sig bedre på lang sigt. Projektet rykker videre til at se på dynamikken i klimaændringer, hvor det bliver klart, at folks tidspreferencer for forbrug bliver essentiel for den førte klima politik. En høj diskonteringsrate vil favorisere et skatteprogram, da skatter mindsker usikkerheden omkring omkostningerne ved at reducere udledningen, der er i nutiden. En lav eller en nul diskonterings rate vil favorisere kvoter, da usikkerhed omkring fremtiden får betydning og dermed også usikkerheden omkring klimaændringerne. Projektet diskuterer ydermere forskellige praktiske effekter på det foretrukne instrument. Til sidst diskuteres prisen på en skat eller prisniveauet på en kvote. Der bliver argumenteret, at en politik, der lever op til forsighedspricippet vil være passende. Dette vil føre til skarp reducering af udlednings- og reduceringsomkostningerne. Andre argumenterer for at omkostninger er for store i forhold til fordelene, hvilket primært er, fordi de antager en højere diskonteringsrate.

Hoved resultaterne er, at et kvoteprogram ser ud til at klare sig bedre angående usikkerhed omkring fremtiden, da programmet diktere niveauet af udledning direkte sådan at der er mindre usikkerhed omkring omkostninger ved klimaændringer i fremtiden. Ydermere argumenteres der for, at hybrid programmer, der har et prisloft, er et godt alternativ, hvis regeringerne er bekymrede for kortsigtede prisfluktationer. Det argumenteres for at forsigtighedsprincippet bør anvendes, da der måske er høje irreversible omkostning ved fremtidige klimaændringer, dvs. at der er behov for signifikante reduceringer i carbonudledningen.

1. Introduction

Global warming has recently been debated and policymakers have to figure out how they are going to handle the issue. The costs of emission will mostly be in the future and the current generation is not going to experience the more severe costs. Most of the costs are going to affect future generations, which have no bargaining power. That is to say that they cannot compensate the present generation for reducing their emission of Green House Gases (GHG).

Policy is needed, as climate change is an externality caused by carbon emission. An externality is when an agent action or decision affects the third party with out that he directly can affect the decision. Externalities often arise when goods or services which people care about are not sold in the market. The atmosphere is a public good, which is a good that is non-rival and non-excludable. This means that you cannot exclude someone from the atmosphere and that the value of someone using the atmosphere does not decrease the value of others using it. This means that the incentive to reduce emission for one country is small if the surrounding countries keep their current emission, as the country will share the benefits with the surrounding countries. Furthermore, the current generation's emission is affecting the welfare of future generation, while the future generation has no influence on the current emission decisions. This means that there are two kinds of externalities when looking at Global warming. The first is an externality where firms or countries make their emission decision without considering the wellbeing of other countries. Secondly, there is an externality consisting of a current emission which affects future generations who are without any possibility to do something about it. A solution to externality problems is to internalise the externality, hence forcing firms to pay for the externality that they did not pay for beforehand. Externality often arises when property rights are vague, which means that it may be possible to internalise the externality by assigning property rights to the externality. This project considers how to make a policy that makes the firms take account for the cost of emission.

The externality is an intergenerational externality, as it affects future generation. To an extent intergenerational equity is a moral question and most people have a social conscience which leads them to want to leave at least something to future generations (B. C. Field & M. K. Field 2006). When it comes to the ecosystem and natural resources, it is not something that the current generation has produced by itself, but something that this generation has inherited from the earth. It seems unfair that the current generation has the right to claim all the earth resources and leave the earth in very bad state for future generations. (Frischmann 2005). The current generation does not owe future generations a certain share of the resources. It may owe them a certain living standard (Solow 1986). We may not be able to leave the earth in the same state as we got it, but future generations may be compensated by better technology that makes it possible for them to increase their consumption. When deciding on investing for future generations, the current generation's welfare also has to be considered, as an overinvestment may pillage the current generation. This means that I am looking at how to make a sustainable climate policy over time, which will secure future generations welfare and give the current generation an acceptable welfare.

It may be possible to substitute the earth's wellbeing by consumption. There is a declining marginal utility of goods, which means that if you get one more unit of a good, you are going to value it less than the previous unit. This may lead to that as people get more consumption, they may give priority to earth's wellbeing rather than to an extra unit of consumption. This effect will be enhanced if consumption harms the environment so that the earth is less well and that the environment, due to climate change, may carry on some unpleasant surprises. It is clear that to some extent consumption can make people feel better even though it may hurt the environment especially when the consumption is low and the environment is good. But if consumption is very high and the earth is in a bad state, we may lower consumption and give more priority to the earth. This means that as consumption increases while the earth deteriorates, people are going to increase the preference for the environment and start giving it priority.

This means that policymakers have to find out how they value current costs and benefits compared to future costs and benefits. Furthermore, they need to find out how people value the wellbeing of the earth compared to consumption. This is to say that policymakers essentially have to weigh up the discounted costs and benefits.

Policymakers need to find out what action they are going to take facing the Global Warming. This will depends on the costs and the benefits of a given policy. Global Warming depends on the accumulated stock of GHG in the atmosphere. So the severity of the global warming depends on current stock of GHG in the atmosphere and future emission. This means that the benefit of emission reduction in a certain year will depend on emission of future years.

The costs of abatement are also surrounded by a high degree of uncertainty, as it is impossible to predict future technology improvements and the climate sensitivity, and its impact on society is highly uncertain. It is also impossible to predict how structural changes are going to reduce costs.

It is clear that there is a high degree of uncertainty, and policymakers cannot know what future costs and benefits are. The uncertainty is bigger than other policy issues because the costs of global warming are far out in the future and we still have limited information of how the climate works. This means that policy makers need to make policy even though they do not completely know what the consequences of their policy are whereas failing to take action may have severe consequences. Policy makers need to act, but how do they make an appropriate policy when the consequences stretch far out in the future and the future is unknown. This means that I reach the following research question:

How can policy makers design a sustainable policy when uncertainty about the future is taken into account?

By policymakers, I mean the people who are in charge of the policies in countries and international authorities. Uncertainty refers to the uncertainty about the costs of the climate change and the cost of abatement in future.

There are two major questions that need to be answered. First, which level of emission is appropriate when uncertainty is present? This is a question of weighing up abatement costs and the damages of a policy. Furthermore it is also a question of which uncertainties different emission paths have, as the selection of emission will depend on risk averseness and the time preferences of the populations. The second question is what kind of instrument will be best in attaining this goal? This is a question about the cost efficiency of different instruments and how well different policies are able to reach the selected emission goal. Furthermore it is also a question about how different instruments perform when there is uncertainty about the future.

2. Methodology

The project is built up in three major sections. The first section looks at the simple model that analyses efficient levels of emission. It introduces a static model and later uncertainty in the model. In the second section a dynamic model is introduced and many practical issues are raised and discussed. The last part considers the appropriate price of carbon, which is essentially a question of selecting the appropriate emission paths.

Firstly, I will look at the static model without uncertainty. This will show that the efficient level of emission is found where the marginal cost of abatement is equal to marginal damage of climate change. It is shown that both taxes and permits are able to reach this level of cost efficiently. Uncertainty is introduced and the difference between risk and uncertainty is discussed. The static model is extended with uncertainty about the abatement costs to see how it may reduce the efficiency and it becomes clear that taxes under uncertainty no longer have the same net benefits. The favourable instrument will depend on the slope of the marginal abatement cost curve and the marginal damages curve. A hybrid model is introduced, as it may be able to take advantages of how permit programmes and a tax programmes perform under uncertainty.

I move on to look at the uncertainty in a dynamic model. In this section discounting is going to be introduced as an important concept in comparing net benefits over time, and different arguments are weighed up for and against discounting. In the dynamic model a tax programme seems to perform better than a permit programme. But the discount rate is assumed to be high and this may undermine the uncertainty of the future. This section also considers practical issues of permits and taxes. This chapter ends with a discussion of which policy performs best when there is uncertainty about the future.

Lastly I discuss the right price of carbon either using a tax programme or a permit programme. It is becomes clear that there are many reasonable estimates of the costs and benefits for different emission scenarios. It argues that there are essentially two views; one which wants to take a precautious view, which leads to a high abatement, and another which argues that the abatement costs by being precautious is higher than the benefits.

3. Policies

This chapter sets up the framework to analyse environmental policy. Furthermore it compares and discusses different policies in the framework.

3.1 Model

The marginal damage (MD) curve measures the damage per unit of emission in a specific period. Damage is measured by how much people are willing to pay to avoid a specific level of damage. The next logical step is to figure out the actual cost for emission reduction. The marginal abatement cost (MAC) is measuring the cost per unit of reducing emission. The model weighs up the damages of emission and the cost of reducing emission.

The damage of emission depends on the level of emission and the initial stock of emission. This is because as long as the earth emission is under the level that the earth is able to absorb the consequences will be relatively small, as the concentration of green house gases (GHG) in the atmosphere is not increasing. As the emission increases to a level that the earth is not able to absorb the concentration of GHG in the atmosphere starts to increase, which leads to temperature increases. The temperature increase impacts earth and society, as flooding, droughts, hurricanes and the weakening of the ecosystem become more severe.

The MD is considered to be increasing as the emission increases. When carbon emission is very small, emission will hardly have any effect. But if there is a high level of emission it may cause that the temperature increases to level with big consequences. The damages is more severe per unit when the emission is high, which means that MD is increasing when carbon emission is increasing.

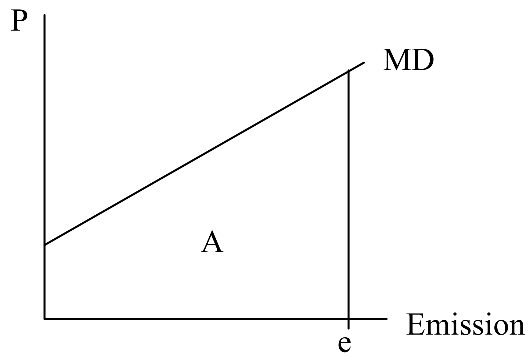

Figure 1: Marginal Damages

Figure 1 shows that the MD is rising as the emission is rising. It also shows that under the current emission level the damage is area A. This is because every point of the MD curve measures the marginal damage of each emission level. So the total damages are the continuous sum of every point of the MD curve.

There are costs of reducing emission. There are limited resources in the world so the governments need to decide how to use their resources. Opportunity cost is an important concept in this case. Opportunity cost measures the maximum of other outputs that could have been produced if we had not produced a certain product (B. C. Field & M. K. Field 2006). The opportunity cost is important when deciding on one policy measure compared to alternative policy measures. When looking at the abatement cost of carbon emission the cost of reducing an extra unit is considered to be increasingly expensive. This is because as emission is reduced the firms cannot use technologies that produce a lot of emission. This means that the firms may end up using increasingly expensive technology and reducing emission may require that firms install a device that was not necessary before the reduction. The MAC curve is showing the smallest cost to make a certain reduction. That is to say that every reduction has to be cost efficient. This means that the MAC curve is falling if the firms are allowed to use more emission.

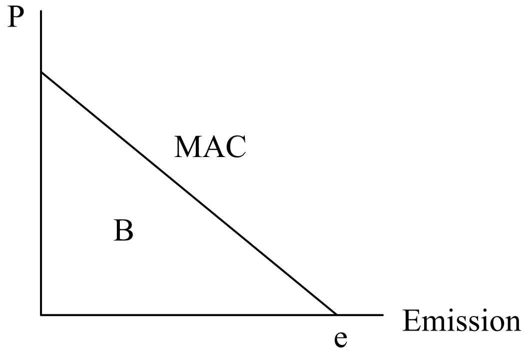

Figure 2: Marginal Abatement Cost

Figure 2 shows that the MAC is falling as the government allows a higher emission level. It also shows that the total cost of reducing emission to zero is the area B when the current emission before any abatement is e.

Figure 3 shows the MAC curve and the MD curve. From this figure it is possible to state which policy is efficient.

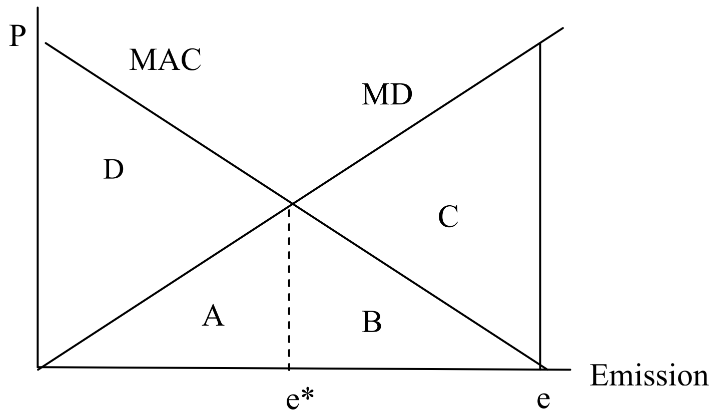

Figure 3: Efficient Policy

It can be seen in the figure that it is not optimal to reduce the emission to a zero level. It is optimal to reduce to a level where the MAC is equal to MD. The reason is: if we reduce the emission to a level where MD is higher than MAC, then the reduced damage from reducing the emission one more unit is less than the cost. In the same way, if the level of emission is reduced to a level where the MAC is higher than the MD, then it would be better to increase the emission as increased damage is less than the saved cost. The efficient level of emission is in figure 3 is e*. That is to say that the abatement cost and the damage is equal for last unit of emission they reduce. A reduction to e to e* reduces the damages by C+B, but a reduction will have a cost of B. This means that the total net benefit is C.

MAC and the MD curves is time specific. The MD depends on people's preference for reducing damage in a period. The MAC curve will depend on the current technology. One way of looking at this is to assume that all damages occur in the same period as the emission. Another assumption is that the damages curves represent the total value of current and future damages. (B. C. Field & M. K. Field 2006). When it comes to climate change the latter assumption seems more applicable as emission now may create damages that stretch far into the future.

3.2 Cost Efficiency

For a policy to be efficient the emission abatement has to be made cost efficiently. For a reduction of emission to be cost efficient the marginal cost of every firm must be equal. This is because if a firm, which has higher MAC than another firm, increased its abatement with 1 ton of emission it would be able to compensate another firm to reduce it emission with 1 ton and still have saved the difference in the MAC between the firms. This is known as the equimarginal principle.

Reduce	**1 ton**	**2 ton**	**3 ton**	**4 ton**	**5 ton**
Cost of Firm A	4	6	8	10	12
Cost of Firm B	8	10	12	14	16

Table 1: Equimarginal principle

Table 1 illustrates the equimarginal principle. In this case there are two firms in the country and they have to reduce their emission by 6 tons a week. In this case the equimarginal principle says that it is cost efficient for Firm A to reduce its emission by 4 and for Firm B to reduce by 2 tons a week. For firm A the cost of reducing the first ton is 4 the second ton is 6 etc. This means that the total abatement cost is 4+6+8+10=28. Firm B cost is 18, which means that the total cost is 46. If we try to compare this level to the equiproportional principle where both firms reduce 3 tons then the cost for Firm A will be 4+6+8 =18 and the cost for Firm B will be 8+10+12=30. That is to say that the total cost is 48. The equimarginal principle builds on the understanding that it is optimal to reduce emission where it is cheapest. (B. C. Field & M. K. Field 2006)

3.3 Standard

A policy standard is a policy instrument, which directly sets the standard of how firms should reduce their emission. A standard can be set as an emission standard, an ambient standard or as a technology standard. An emission standard is setting the upper limit for the emission of GHG. An ambient standard is setting a limit for how much pollution there can be in our surroundings. This means that the amount of possible emission of carbon depends on temperature and wind in the area. A technology standard is forcing firms to use a certain type of technology to reduce emission. Global warming is a problem that depends on the total emission in the world, therefore an emission standard would be a logic choice. An ambient standard is more useable in cases where local air quality is of concern, because this will depend on temperature and wind. It has recently been discussed by the G8 countries to set an upper limit to the temperature, so it cannot increase to a level above 2 ° C, as it is argued that consequences over this threshold are more severe. However, it may be argued that the temperature standard may be good as an overall goal, but it has, for practical reason, to be transformed into emission goals for the individual countries in the world, because the there is a long distance from the action of emission that cause the temperature increase. A technology standard may also be used to lower carbon emission as the government can force firms to use a technology that reduce carbon emission.

Standards give the government the possibility to control the emission directly. The government could in principle also set the standard of emission at the efficient level of emission. The problem is that the efficient level of emission relies on the understanding that the level is reached with the lowest cost possible. If the policy makers implement a uniform standard every source has to reduce its emission accordingly. This is not cost efficient because it easier for some sources to reduce their emission. That is to say that it does not live up to the equimarginal principle. It is, however, possible to try to estimate the costs of each source and to make an emission standard for every individual source. This is, however, more complicated, but it can be established by firms reporting their cost back to the authorities. There are, unfortunately, incentives for firms to lie about the actual costs. Governments may be inclined to implement uniform standard because it easier than standards that distinguish among sources. (B. C. Field & M. K. Field 2006)

The way that the standard is set is also important. The following equation shows which different factors that can be manipulated and how they affect total emission:
Total emission = Total output x Input used per units of output x emission per unit of input

If, for example the government sets the standard by the emission per unit of input then it is not targeting the two other ways of reducing emission. This means that, if output increases enough to offset the lower level of emission per input, emission will still increase. (B. C. Field & M. K. Field 2006)

Another problem is that standards do not create incentives beyond the standard. When the firms have reached the standard there is no reason for it to lower its emission beyond the standard. If there is a technology standard that forces firms to use a specific type of technology there is no incentives for the firm to improve technology to lower its emission. The only possible way to reduce emission continuously through an emission standard is by making the standard so strict that the firms have to innovate and create new technology to avoid fines if they don't live up to the standard. B. C. Field & M. K. Field 2006)

3.4 Tax Programme

A standard gives the government direct control, but it does not take advantages of the private information that polluters have and does not create any incentives for the firms to reduce emission below the standard. As we should see in this section a tax that charges firms for every unit of emission they use will create incentives and continuously reduce emission and improve technology. It is assumed that there is free competition so that the firms cannot just pass the emission charge on to the consumer. Due to free competition another firm may steal the whole market by selling at a price that is equal to the marginal cost. (B. C. Field & M. K. Field 2006)

If a tax is set at a certain level the firms will reduce the emission until the MAC is equal to the tax that is charged. Because the firm pays tax per unit of emission, and as long as the MAC is under the tax it is better for the firm to reduce its emission rather than pay tax for the unit. Figure 4 shows how a tax will affect the firm. If the government charges for every units of emission the firm will reduce its emission to e. The firms reduce their emission until the abatement cost for the last unit is equal to the tax. If they reduce it more than to this level then the cost of abatement for the last units is going to be higher than the tax and it is not beneficial for the firm. The firms have to pay tax for all the units that they emit. In this case it is paying the tax (t) multiplied with e. This creates extra cost for the firm and it is one of the reasons that firms may prefer a standard rather than a tax.

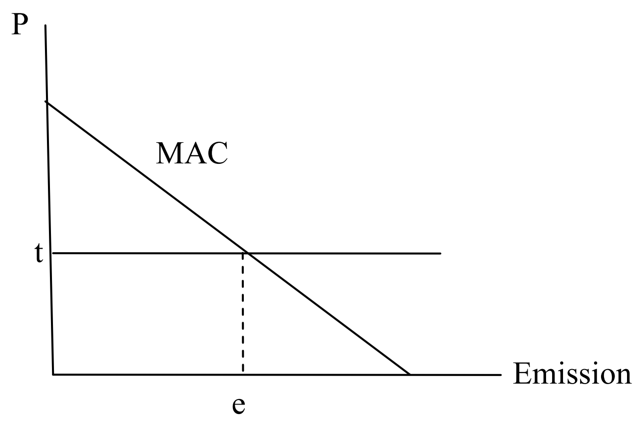

Figure 4: Tax programme

A tax programme is also a cost efficient way to reduce emission because every firm will reduce its emission until the charge is equal to the MAC, which means that it satisfies the equimarginal principle. The reason is that every firm decides it own level of emission. The problem with a tax is that you do not know how much the emission is going to be reduced. As the government does not know the exact abatement cost and if policy makers change the policy all the time, if they turned out to be wrong about the abatement cost, the firms cannot plan their investment. The steeper the MAC curve is the less pollution will be reduced. (B. C. Field & M. K. Field 2006)

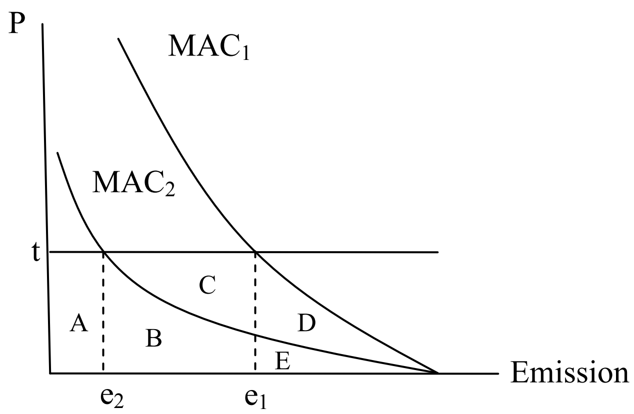

Figure 5: Tax programme and incentives

A tax system will also create incentives for firms to try to innovate. Figure 5 shows that if the emission tax is t, then the firm will under its current technology (MAC_1) reduce its emission to e_1. In this case the firm pays A+B+C in taxes and pays E+D in abatement cost. If the firm is able to invent a technology that reduces its cost from MAC_1 to MAC_2 it will be optimal for the firm to reduce its emission to e_2. When the firm improves its technology its saves B+C in taxes and saves D in abatement cost but increases the abatement cost with B. This means that if the firm improves its technology it will save a cost of C+D, which means that under a tax system the firms have incentives to try to innovate. (B. C. Field & M. K. Field 2006)

3.5 Permit Programme

Another way for government to reduce emission is to issue permits that allow firms to use one unit of emission. The permits are allowed to be traded among the polluters. The difference between tax programme and permit programme is that the permit programme sets the quantity and the tax sets the price. Firms may prefer a permit programme because the tax makes people pay for something that earlier was free and with the permit programme people get the right to pollute by being awarded permits. A permit programme allows the firms to sell the permits, if they reduce emission more than they are obliged to do by regulation. The buyer might be another firm that wants to expand or a firm that wants to start up. This means that expansion can be done without any increase in emission. (B. C. Field & M. K. Field 2006).

The permit programme is cost efficient due to the gains of trade. This means that those who have high MAC will buy permits from those sources that have a flat MAC. Figure 6 illustrates how a permit program will work.

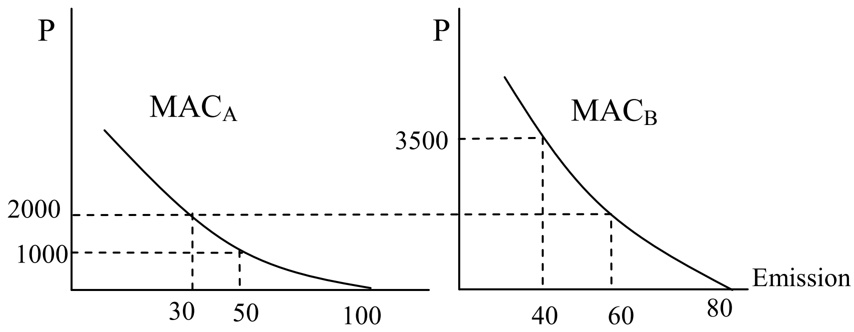

Figure 6: Permit Programme (B. C. Field & M. K. Field 2006)

Initially firm A is emitting 100 units of emission and firm B is initially emitting 80 units. The government is implementing a permit programme where they want the firms to reduce their emission by 90 units and every firm gets emission permits that account for half their current emission. This means that firm A is allowed to pollute 50 where their MAC is 1000 and firms B is allowed to pollute 40 units where their MAC is 3500. It is clear that this is not optimal because the MAC is not equal, but it is remembered that the firms are allowed to trade in a permit programme. This means that firm B is willing to pay 3500 for an extra unit of emission and firm A is willing to sell one permit for 1000. In this way trade will take place until the MAC is the same and all gains of trade has been exploited. In this case it is where the MAC is 2000 for both firms and firm A has 30 permits and firm B has 60 permits. This means that a permit programme is cost efficient. In practice where there are many firms the price will be set by the market which means that there is one market price for permits. (B. C. Field & M. K. Field 2006)

Under a permit programme firms will have the same incentives to reduce their emission and to invest in emission reducing technology as under tax programme. This is due to the fact that the firm can sell its permit when it reduces its emission. This means that benefits end up being exactly the same as in a tax programme

Firms have the incentive to make sure that no one pollutes with out a permit, because if somebody pollutes without permit they are reducing the value of the permits, as the demand for permits will be smaller.

4.0 Uncertainty

Everyday individuals and governments make decision under uncertainty. Whenever they make a decision about the future there must be some elements of uncertainty in the decision. Hulme (1999) argues that uncertainty essentially rises from two sources, which are incomplete knowledge and unknowable knowledge. Incomplete knowledge is going to affect our models both when looking at climate models and impact models. Incomplete knowledge is more likely to become available through research. Unknowable knowledge rises from the fact that it is impossible to know how the society and the climate system are going to evolve. (Hulme & Carter 1999).

In this section I will look at and define uncertainty and discuss its effect on economic analysis and policy. I will then move on to look at the main uncertainties about climate change to illustrate that there are severe uncertainties when it comes to climate change.

4.1 Uncertainty and Risk

There are different kinds of uncertainty. Firstly, you can talk about outcomes, which it is possible to put mathematical probability on. Secondly, you can talk about outcomes that can be grouped and the expected outcome for a group can be determined. This is due to the law of large numbers. While it not possible to put probability on whether an individual is getting cancer, it is possible to look at historical evidence to figure out whether a person in certain group is getting cancer. It is possible to insure yourself against the two first kinds of uncertainty. The third type of outcome is an outcome that cannot be grouped and it is not possible to determine the probability of an event of this kind. The first and second type of outcome are characterised as risky while the third type of future outcome is characterised as uncertain. An uncertain event is an event where there is no reliable evidence of the event happening. (Brooke 2006)

An interpretation of risk and uncertainty is that it is possible to insure yourself against risk but it is not possible to insure yourself against uncertainty. Insurance assumes that a time independent activity is carried out a large number of times and that the underlying statistic parameters are stable and the stochastic process is known. Uncertainty can be fully reduced to risk if the following three conditions hold. Firstly, all the outcomes must be known. Secondly, the probability of outcome is known and constant. Thirdly, there is independence between other activities and the outcome. If a certain activity can be carried out a large number of times, risks can be reduced to stochastic certainty. There will, however, still be uncertainty at the individual level if the event cannot be carried out a large number of times by the individual. The establishment of insurance can remove risk in the cases where the process is reversible, which particularly applies to cases where there only are material damages. If on the other hand the process is irreversible, such as uncertainty of death under an operation, insurance cannot remove the uncertainty. (Jespersen 2008)

In situations where we do not know the probability of outcome or even do not know the possible outcomes uncertainty is present. Keynes distinguishes between two kinds of uncertainty, which are Ignorance and Improbability. Outcomes that are uncertain can be describe by total ignorance, which is like looking down into black hole where you know there is something down there, but you have no idea or only a vague idea of what it is. Improbability is when outcome is known, but it is not possible to put probabilities on different outcomes. For example it may be possible to say that a certain interest change is more likely than other changes. (Jespersen 2008)

Another interpretation of uncertainty is that uncertainty refers to all instances where only subjective estimates of the future are possible. Uncertainty is a necessary condition for profit, as you cannot cheat the market if everything is sure. If you make a risky decision you may earn more, but this is factor payment for risk. Brooke (2006) argues that risks only exist when the expectation of the future does not depend on subjective belief. Risk only refers to cases where the distribution is known, which is only in theory with perfect competition. The difference between Keynes´ thought and this line of thought is that Keynes argues that it is impossible to put subjective probabilities on uncertainty as you cannot put probability on uncertain events.

Neoclassic economists argue that analysing under uncertainty do not offer much to economic analysis. They argue that if risk refers to the situation where the distribution of future outcomes is known and the uncertainty refers to a situation where distribution is not known, then allowing people to form subjective belief about the future overcomes the problem of the distinction and the distinction has no longer meaning. This is because peoples' subjective belief is formed in the same way as when people face risk.

When nothing else is mentioned uncertainty refers to a situation where it is not possible to put probability on an event and thereby it cannot be insured against. Risk refers to a situation possible to put probabilities on outcomes and where all possible outcomes are known

4.2 Expectation and Uncertainty

Expectation is important, because people act on what they think is going to happen in the future. A neoclassical way of describing expectation is rational expectation, when assuming rational expectation it means that the agent acts as though he knows that he is right on average. This means that the agent is able to foresee the expected outcome of the economy. In this case it clear that there only can be risk, because if there is uncertainty agents cannot be right average. When using rational expectation people will know the models forecast and expect it to happen which reinforces the forecast. (Rosser, Jr 2001).

Brooke (2006) argues that the innovator clearly does not define his expectation on historical data. Decisions made by an innovator are generally uninsurable (Brooke 2006). Post- Keynesian economists argue that investment is not driven by rational expectation but by a subjective ultimately irrational spontaneous urge to action facing uncertainty. While expectations may be stable for long periods they are also subject to sudden shifts due to shift in psychology. Uncertainty according to Keynes is unquantifiable, as it impossible to measure something that you only have a vague idea of. An important view by Keynes is that subjective probabilities are developed by an internal logic rather than mathematical probabilities. It may be argued that subjectivity converts to objectivity the more observations there are. Keynes accepts that this is the case if the experiment can be repeated many times, but in many real life cases the experiment cannot be repeated. Keynes argues that people form expectation based on how much weight they put on different outcome, which is not the same as the actual probability of the outcome. This means that weight of an outcome can only be measured by comparing to other outcomes. Keynes rejects that you can put statically quantitative probabilities on the weight. (Rosser, Jr 2001)

Group dynamics are important in forming expectation, as it may be argued that people watches the average of other peoples expectation when forming they own. It may be for no other reason than if you are wrong you are definitely not the only one. Further more it can be argued that if you consult other people's expectation you gain more knowledge. This dependence of each expectation opens up for sudden mass changes of expectation, hence mob psychology. (Rosser, Jr 2001)

Bounded rationality is the case where people are unable to rationally analyse the complexity of the world. People are not able to form rational expectations weighing up all things and options. People try to learn from the people around them and try to form their expectations from events that are most salient for them, as they are unable to understand everything. Keynes does not disagree with the opinion that people are going to form rational expectations subject to the information they have. Some economists may argue that uncertainty induces predictable behaviour as people rely on convention or the rule of thumb when the world is uncertain. It may although be argued that convention is only applicable in situations which are routine based. (Rosser, Jr 2001)

How can there be such predictability of social outcome if uncertainty is profound. Shackle 1954 argues routine decision may have a degree of predictable, which include much consumer behaviour. But investment decision is surprising and uncertain, as investment decision is not routine based. (Rosser, Jr 2001).

Even though there is uncertainty about the future, people are able to know about certain facts about the current situation and able to get by without knowing probabilities of all outcomes of all possible actions. Lawson (1985) argues that investment decisions are made by relying on convention. When making investment we take the current situation and project it into the future modifying it only by the changes that we expect. It may be argued that falling back on convention is to rely on the rest of the world, which may be better informed. Making decisions from convention may also make the world more stabile. (Lawson 1985).

People have extensive knowledge about social practices in the society where they find themselves and knowledge obtained by participating in society. Behaviour is dependent on which context the knowledge is attained in. People face uncertainty in not being able to predict future outcome of all actions, but they have extensive knowledge about social practises, which can help them to get by. Sometimes there are structural changes in the world and conventions will change, so using convention may only be applicable in the short run (Lawson 1985)

4.3 Individual Uncertainty and Macro Uncertainty

Individual uncertainties are the kind of uncertainties that is bound to the individual. Individual uncertainty is also affected by macroeconomic uncertainty and it also affects macroeconomic uncertainty. Macroeconomic uncertainty is for example unemployment, interest rate, inflation and climate change, events that would affect the individual but are not directly related to individual decisions even though many individual decision would affect the macro level. There will always be uncertainty about individuals' decisions, as we do not know the future and other people's reactions. The further into the future the more a decision relies on expectation. The macroeconomic landscape will continue to change because expectations are disappointed or revised. The further away in the time horizon the greater the changes are. (Jespersen 2008)

Equilibrium is defined as a state where economic forces are balanced and in the absence of external factors the economic variables will remain stable. If an economy has a long run equilibrium, the economy returns to, people will know that the economy eventually will move towards this equilibrium and are able plan thereafter.

If there is no equilibrium there is room for subjective expectations, because the economy does not return to a specific state, which means people have no common fix point to which they can expect the economy to return. This means that people's expectation may differ according to the individual's feelings about the future. (Jespersen 2008). In modern society there is good reason to expect changes, as the macroeconomic development is a dynamic process, which is driven forward by the decisions of thousands of individuals, which base their decisions on uncertain expectations. These decisions cannot entirely rely on the law of large numbers and must be subject to revision. Expectations and reality are under constant revision because of success or failure of decision. For example big investment result is unlikely to affect future investment strategies. (Jespersen 2008)

Individual decisions are made even though the outcome of the decision cannot be reflected by anything that resembles probability theory. The possible outcomes are not completely known let alone the probabilities of different outcomes. Furthermore many of the decision are irreversible and cannot be repeated. This is especially the case with investments.(Jespersen 2008)

Macroeconomic uncertainty may cause individual uncertainty as an exogenous event may affect macroeconomic variables. But the expectations and actions of individuals also affect macroeconomic variables thereby causing macroeconomic variables to become endogenous. This is not characterise an equilibrium economy (Jespersen 2008)

4.4 Uncertainty and Efficiency

To make an efficient decision you need to have perfect information. Individuals cannot make a decision that maximise their utility without perfect information. For example, a consumer need to know all the different products, all the different prices and how all the different products are going to affect his utility. This is not possible as humans have cognitive limitation. As it is impossible for an individual to be efficient it must also be impossible for groups to be efficient. When there is a group of people they do not only need to maximise the utility of all individuals, but need also to take into account that one individual's decision may affect other's utility. (Rothbard 1979). Profit maximisation under uncertainty is meaningless. As the world is uncertain we do not know the exact outcome of a decision. The success of investment can only be measured by comparing it to other investment. (Alchian 1950).

People learn from their decisions and failures, which may mean that a decision that seems efficient at the moment it is made, may turn out to be inefficient in the following moment. This means that an efficient decision made at one time may not be efficient at another time. (Rothbard 1979)

Efficiency is only a theoretical concept that only exists in a model. There will never be a calculable efficient solution. Although it in many cases is possible say that one outcome is more likely than other outcomes and research may increase the level of knowledge. A good example is climate change, where early stage of climate change there was scientist that argues that policy should be laissez faire while others wanted immediate action. Research has in the meantime been so convincing that almost every scientist is convinced that political action is necessary.

4.5 Climate Change and Uncertainty

There is uncertainty about the damages of climate change; there is uncertainty about how the GHG will accumulate in the atmosphere, what temperature this will lead to and how this will impact the earth and society. (Congressional Budget Office 2005). At what degrees do the west Antarctic Ice sheet or Greenland start to melt irreversibly and what impact does it has on the earth. Do we lose the Artic tundra or the Amazon? If this is the case how will this affect society? These are some of the big uncertainties. Furthermore there are also uncertainties concerning the uncertainty of how climate change may affect sea level, storm severity and rainfall, health, droughts, species and agricultural crops. (Stern 2006)

There are also uncertainties about abatement cost, which depends on the magnitude of future emission. The lower the emission is in absence of a policy the easier it is for policy makers to reach their goal. A policy success will depend on how the individuals will react to the policies and knowledge of increased macroeconomic uncertainty. Future emission is uncertain, it depends on economic growth, population growth and technology growth and the demand among other variable. (Congressional Budget Office 2005). Forcing firms to obey a strict emission policy may make firms invest more in technology with the result that the country may become leading in environmental friendly technologies. (Stavins 2000). To what degree the individual firms are going react to the policy is uncertainty. How does the technology develop and what energy innovation is going to be dominating in future and how will new innovations change society. There may be many structural changes during such a period, as climate change affects the world over very long term.

It may be argued that the uncertainties about the damages of climate change are higher than the uncertainty about the cost of abatement, as the uncertainty about the damages is far out in the future.

4.6 Climate Change and Policy

When dealing with uncertainty policy makers have two options. They can either bound the uncertainty or manage the uncertainty. The first is to try to make the unknown known. This can be done through data collection and modelling. The uncertainty about cost and benefit of the climate change is very high. Research may help us learn about the future, but research cannot uncover all the uncertainties about the future. Many factors in future are unknown, which means the policy makers need to handle the uncertainty about future (Schneider et al. 2002)

In climate change there is a risk of making early and unnecessary actions. This has to be compared to the risk of failing to take actions which would have been appropriate when looking back. (Stavins 2000) It is important that policy makers make a decision even though information is not complete and uncertainty is surrounding climate change. Science does, however, argue that action is needed. Policy has to use current information and make decision on how to tackle climate change. When new information arrives then it may be sensible to amend the decision.

When it comes to climate change it may be irreversible and it is not possible to repeat the experiment. Climate change may changes the macroeconomic environment and it is impossible to foresee how. Furthermore climate change is a problem that will have effect over a very long period. Much longer than economists normally make forecast over. It is not possible to put probability on a certain emission path compared to others. It may be possible in the beginning of the path to foresee the next few years' emission. But as we look 100 years out in the future it is very difficult, as technology change fast and structural changes may affect society.

It may be possible to say that temperature increases of one emission path will be more likely than of others. It is, however, not possible to put mathematical probabilities on. At small changes in temperature it may also be possible to say what impact a temperature increase is going to have. Scientist have to investigate deeper into the effects of climate change in order to say more about how likely the impact is going to be in the future. To some degree we also need to manage the future, which may mean that climate policies have to be more precautious than otherwise. But it may, therefore, mean that policy makers have to plan in order to handle the consequences if the damages turned out to be more severe than we expected.

4.7 Precautionary Policy

When there are big consequences that are irreversible it may be better to take a risk averse position rather than a risk neutral position. A risk neutral person is person who is indifferent concerning a choice between a bet where probability of doubling you money is 50 % and the probability of losing your money is 50 %. A person who is risk averse will not accept this bet as a risk averse person feels a welfare loss which he needs to be compensated for. A risk averse person feels better if he has 50% chance of having 6 and a 50 % chance of having 4 rather than the previous bet. A risk neutral person would be indifferent between the bets.

The precautionary principle builds on cases such as the asbestos case where it suddenly was discovered that the cost of using asbestos was much higher than expected. The precautionary principle states that if there is a threat of serious irreversible damages, these damages should not be overlooked or discounted because they are uncertain. The principle states that the scientists have to prove that a product does not cause or create damages rather than the scientists have to prove that these cause damages. (B. C. Field & M. K. Field 2006)

Policies should include risks in their analyses, as some policies may have an expected higher variance than other policies.

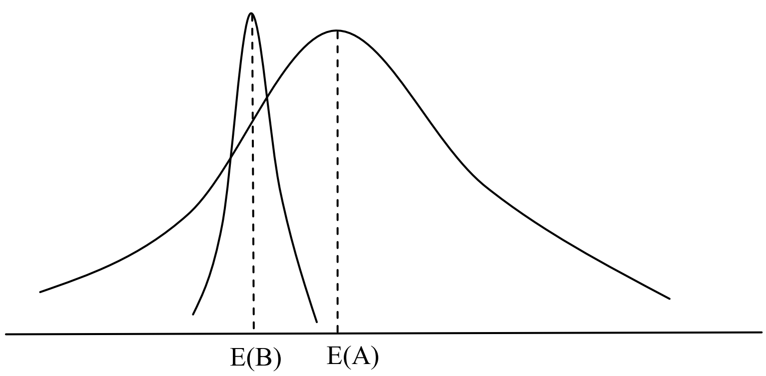

Figure 7: The Precautionary principle

Figure 7 illustrates the expected benefits and the expected distribution of the two policies to a given problem. It is clear to see that the policy A would have a higher expected net benefit than policy B and that is why a risk neutral government will chose this policy. Policy B has a lower expected benefit but has also much smaller distribution. That is to say that risk about the policy seems, with the information that is available, to be much lower than in policy A. If the government is risk adverse, policy B may not be an unreasonable policy to choose, as the variance is smaller. Especially if the net benefits of the lower 5 percentage of policy A are irreversible and have catastrophic consequences.

Falling back on convention when it comes to climate is not possible because it is the first time that the humanity faces such problems. It may, however, be possible to look at how the health sector tackles decision where uncertainty is present. In the health sector when introducing new medicine they are very cautious and try to make sure that there are no unforeseen consequences. In the same way climate policy should be cautious. Furthermore climate change is irreversible and there may be consequences that we do not expect, which advocates for a precautious policy. Policy makers may find it better to set the level below the risk neutral level according to current information, because when new information turns up it may bring some unpleasant surprises.

Policy makers should take uncertainty and their population's risk averseness into consideration. However, if the precautionary principle is overused it may result in some significant costs. Therefore, it is reasonably argued that there are potential severe costs. This means that scientist have to try to evaluate what cost there may be and try to use existing data in their argument.

4.8 Policy under Risk and Irreversibility

Social welfare is normally assumed to be the aggregate of individuals' welfare. It is generally assumed that people are risk adverse and are willing to pay insurance to limit their potential losses. Individuals do not only consider the expected return but also the distribution of the return, hence individuals are willing to pay to reduce their risk.

Arrow & Lind (1970) argue that spreading the risk on many individuals will reduce the individual risk. They assume that there are a number of identical individuals that share the risk equally. The result is that when the number of individuals increases, the risk carried by each individual decreases and so the welfare loss of making risky decision. They also

prove that the total welfare loss will decrease. On the margin when the number of individuals increases to infinity the risk does not affect the welfare at all. The assumption of the theory is, however, unrealistic. It is unrealistic to assume that there is infinity of identical individuals and risk cannot be spread over infinity of individuals. Most projects are likely to expose some people to more risk than others. Furthermore the risk spreading argument breaks down if the risk takes form of an externality that is affecting everybody equally. Climate change is going to affect all individuals independently of the number of individuals in society. When risk takes the form of a public good then risk will not be reduced as the number of individuals increases in society. (Stæhr 2006).
When the population is risk adverse the government may consider how different projects are correlated to each other. If two project are perfectly negatively correlated and has an expected positive benefit, then the government will be guarantied a profit. Seldom will this be the case but it may be possible to make a project portfolio that reduces risk. The theory behind this is that risk can be pooled in such a way that the risk of the portfolio is going to be less than the individual project. This means that co variance between the projects becomes important. The co variances between projects are, however, seldom considered in the social sector. (Walls 2004).

When future is uncertain and the outcome is irreversible, it may be possible to postpone the decision until more information is available. Many environmental projects may have irreversible effect. Let's consider two projects where there are two periods. The project depends on information that becomes available in the second period. The decision to undertake the project can be done either in the first period or in the second period where the information is realised. Postponing the decision will remove the uncertainty and the decision-makers will know exactly know what to do. The downside of postponing the decision is that society loses the net benefits of the project in the first period. Postponing a decision also includes uncertainty of what we lose in the first period. (Stæhr 2006)

When looking at Climate change policy we are looking at a policy where the results are uncertain and essentially irreversible. Even though the project is irreversible, the idea of postponing a policy decision seems to bring on huge cost. Most scientists are of the opinion that emissions have to be reduced in the near future to avoid catastrophic changes. The policy makers will need to take a decision to take advantages of the net benefits of reducing emission in the early period.

5.0 The Model under Uncertainty

This section considers a tax programme and the permit programme under uncertainty in a static model in the short and the long. It is also introduces a Hybrid policy that has its origin in the performance of a tax and permit programme under uncertainty.

5.1 Short and Long Run Policies

There is uncertainty about the marginal abatement cost (MAC) curve and the Marginal Damage (MD) curve. No one knows exactly how high the abatement cost is because we do not know future technology. Furthermore we do no how the climate is going to change and what impact it will have on society.

It can be argued that the slope of the curves is different in the short and long run. It is assumed that MD curve is flat in the short run. This reflects that emission in one single year may not have a significant affect on the accumulated emission over time. The sloop of the MAC curve is steep in the short run, as it will become increasingly expensive for firms to reduce their emission without technology improvement that reduces emission intensity of the production. (Stern 2006)

In the long the MAC curve is less steep, as it is it possible for firms to implement new technologies that make it easier to abate and better technologies may be discovered. The MD Curve is in the long run steep as the emission over long periods will have a significant effect on the accumulated stock of emission. (Stern 2006)

The abatement cost will affect how the firm makes its abatement decision, as discussed earlier the tax will be reduced until the MAC is equal to the tax. Furthermore under a permit programme where the quantity is set the MAC sets the actual price of abatement that the firms face. Figure 8 illustrates how a tax or a permit programme works where the real MAC curve ends up being higher than the expected MAC curve in the short run. In this case the government estimates that the MAC curve is MAC_E curve. This means that they set the tax to be t. In this case MAC_R turned out to be the real curve which means that firms only reduce their emission to a level where MAC_R intersect with t. It is clear that there is a welfare loss because it would have been optimal if the government had set the tax at a level where the MD curve intersects with the MAC curve. In this case the welfare loss is the triangle marked A. The welfare loss is the difference between the MD curve and the MAC_R for every emission unit the emission is above the optimal level. The welfare loss is also known as dead weight loss.

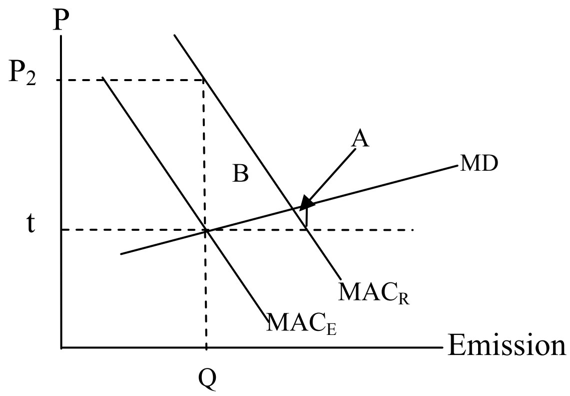

Figure 8: Tax programme and Permit programme in the short run

In a Permit program the government thinks that the optimal quantity of emission is Q. But MAC turned out to be higher than expected, which means that the firms instead of facing the price t they are facing price P_2. Again here it would have been optimal for the government to set an emission level where MD crosses MAC, which means that there is a deadweight loss. The deadweight loss is the difference between the MAC_R and the MD for every unit of emission that the emission is under the optimal level. In this case the deadweight loss is the triangle B. It is clear to see that the welfare loss in the short run is higher under a permit program than under a tax program. This is because of the assumption that the slope of the MAC is steep and the MD curve is flat in the short run.

Figure 9 illustrates the long run result of the government getting the abatement cost wrong. In the long run the MD curve is steep and MAC curve is flat. Under a tax program the government set the tax at t due to that MAC_E intersects with MD at this point. But as the true MAC curve is MAC_R and the optimal tax level is a tax level that secures this level there is a dead weight loss. The firms reduce the emission until the tax is equal to the abatement cost, which means that it creates a dead weight loss of the triangle A.

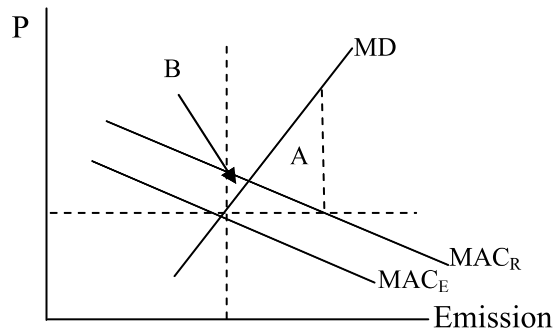

Figure 9: Tax programme and Permit programme in the long run

There is also a deadweight loss under a permit programme in the long run, because the quantity is set lower of the optimal level. In this case it is the triangle B, which is the difference between the MAC_R to MD from the government set quantity to the optimal quantity given by the real MAC and the MD curve. This means that in the long run the deadweight loss under uncertainty is higher under a tax programme than under a permit programme.

It is clear that the long and the short run results are different. In the short run the tax programme seems to be the better choice under uncertainty, but in the long run the permit programme seems to be a better choice under uncertainty. It may be argued that a tax policy is better in the short run. (Stern 2006). From this it is hard to say which policy that is preferable.

5.2 Slopes and Non Linearity

Fishelton (1976) also looks at the case where uncertainty is on the slope. Fishelton (1976) finds that the favourable programme depends on the realised slopes and not the expected slopes. This means that if the real MAC curve is steeper than the MD curve the tax system has a lower deadweight loss than the permit program and vice versa. (Fishelson 1976). When uncertainty is put on the slope the policy that produces the smallest deadweight loss is dependent on the uncertainty. This means that there may be a situation where it is impossible to know which policy performs best as the slope is unknown.

The MAC and MD curve may be convex. This means that when the emission goes against 0 the MAC will go against infinite and it means that when emission goes against infinite

MAC goes against 0. When the emission goes against infinite the MD goes against infinite. The linear MAC and MD is a good approximation when there are small changes, as a convex curve approximates a linear curve when looking at a small area of the curve. That is to say that the linear curve may perform accurate results when changes are small. Once non linearity is introduced it may change the result. This means that for example the MAC will have a higher slope when emission is very high than when emission is low. The MD curve will have a lower slope when the emission is very high and steeper slope when the emission is very low. This means that the optimal policy may depend on the level of emission. If there is an intersection at a very low emission where the MAC is steep and the MD curve is flat then a tax programme will have a lower social loss than a permit programme, but if two curves intersect in a point where the MD curve is steep and MAC curve is flat, which is more likely at high emission levels then permit program will produce lower welfare loss under uncertainty. (Fishelson 1976)

5.3 Hybrid Programme

The hybrid model builds on that efficiency loss under uncertainty depends on the slope of MAC and MD curves.

The hybrid programme essentially starts out as a permit programme, but when the price of the permits reaches a certain level then it is possible to buy extra permits at a certain price. This means that there is a sort of safety valve preventing that the price increases too much. It is also possible for the government to set a lower price. (Pizer 2002)

Figure 10 illustrates the hybrid programme supply and the demand curve. The government have distributed a certain S* of permits according to their expectation. If D_1 is the true demand curve then the price is going to be P*. As long as the price is between P_1 and P_2 then the hybrid programme is working as a permit programme and there is not distributed more permits than the initial number. If for some reason the demand curve turned out to be D_2, hence the MAC would turn out to be higher than expected. Then it may not be cost efficient to stick to the permit programme. In the hybrid model when the price reaches P_1 then firms has the option to buy as many permits as they want for the price of P_1. This means that the hybrid programme in this state changes to a tax programme. At the same time if the government has distributed too many permits and the demand curve D_3 then program also becomes a tax programme. The problem with a lower level is that the government has to withdraw some permits, which may be harder than giving new permits, as firms may be reluctant to give up their permits.

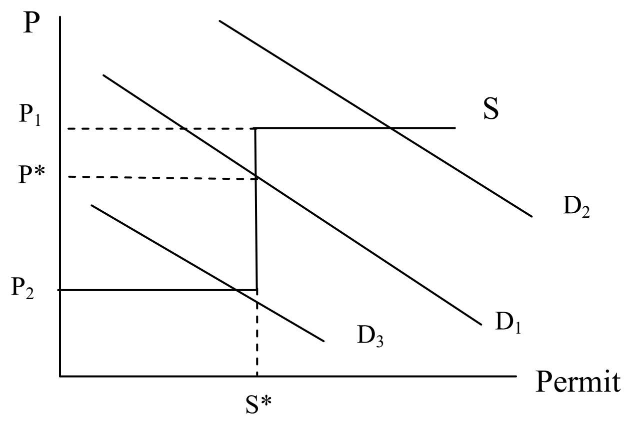

Figure 10: Hybrid Policy

The advantages of using a hybrid model are that the efficiency loss is lower than when using tax or permit programmes under different circumstances. It may be possible to prevent efficiency losses if the government for some reason is wrong. Since the policy is imitating a permit programme or a tax programme it will always do at least as well as the pure program. (Pizer 2002)

5.4 Discussion

The obvious idea when policy makers want to lower emission is simply set a standard that every firm cannot emit more than up to a certain level. But a standard does not seem to be able to be cost efficient and it has no ability to create incentives beyond the standard. A tax programme or a permit programme seems to be able to solve this, as they have economic incentives to improve the technology. Furthermore taxes and permits are cost efficient, as they are able to live up the equimarginal principle. Under a tax programme or a permit programme it is not even necessary for the government to know the cost of abatement for the policy to be cost efficient, as long as the firms know it. Taxes and permits seem superior to a standard because they create incentive and are cost efficient. In the rest of this report standards will no longer be considered.

Tax programmes and Permit programs are symmetric without uncertainty in a way that if the quantity in a permit programme were set at a level that certain tax produce, then the price of the tax will be equal to the price of the permit. The uncertainty about climate change and abatement cost is severe. Climate change is surrounded by uncertainties, which cannot be reduced to risks, as there are unknowable factors due to the limited understanding of climate change and because damages stretch far into the future. This means that it is impossible to know the abatement costs and damages both for the firms and the policy makers, which means that policies cannot be compared to an optimal level, but can only be compared to each other. Severe uncertainty about irreversible effects may lead to a precautious policy, as the population is risk averse. It may be argued that there is more uncertainty about the MD curve than the MAC curve, as damages are in the future and consequences of climate change may be severe. This means that a precautious policy may lower the emission below a risk neutral level.

When there is uncertainty about emission the tax and the permit programmes are no longer symmetric. It is argued that if the slope of the MD curve is steep and MAC is flat then a permit programme will perform better than a tax programme and vice versa. Furthermore it was argued that when the slopes were uncertain the best policy depends on the realised slopes. As there is uncertainty it may be argued that a hybrid model can take account for the uncertainty about the slopes, as it puts in a safety valve that prevents the price of the permit to increase too much. It is argued that a hybrid model will always perform as well as the pure policy model. As damages are linked to the quantity of emission a precautious policy maker may select a permit programme, because it locks the emission, rather than a tax programme. A hybrid programme makes precaution against surprisingly high costs under a permit programme. A precautious policy that reduces the emission below the expected efficient level may reduce the uncertainties about the damages.

6.0 Discounting

In this chapter I am considering how to make intertemporal choices. Different views on how to compare costs and benefits that appears at different times are discussed. Furthermore it is also discussed how uncertainty is affecting intertemporal choices.

6.1 The Discount Rate

The discount rate is a key variable in climate policy, as discounting is necessary in valuing net benefits that occur on different times and as climate change affects the world over a long period. Discounting is explained by consumption time preference and alternative return on investment. (Hansen 2006) The discount rate determines how much people value future benefit and cost compared to present benefit and cost. The following formula shows the discount factor (D(t)) at time t where s(t) is the discount rate:

$$D(t) = \frac{1}{(1+s(t))^t}$$

A constant discount rate would mean that the discount factor is declining approximately exponentially, which means the weight of the cost and benefit is declining exponentially the further out in the future they are. Normally it is assumed that the discount rate is bigger than 0, hence people prefer present benefits rather than future benefits, as people have to be compensated for waiting. This may have a huge effect on policy decision because if every net benefit has to be discounted back over a long period it will become relatively insignificant. For example if a man has a cost of 1 million pound in real value in 50 years and his time preference is reflected in a discount rate of 3 %, the present value is 1000,000/((1+0.03)^50) 228,107. In this case he is indifferent getting 228 thousand pound now or getting 1 million in 50 years.

Figure 11 shows the present value of a 100 in every single period for 100 years when it is discounted with a discount rate of 4%, 3% and 2%. It is seen that the discount factor is falling exponentially. When the discount rate is 3 % the value of 100 in year 99 is just worth 5.4. At a 2 % and 4 % discount rate it will be respectively 14.1 and 2.1 in year 99. This means that a person, whose time preference can be reflected with 3% discount rate, will be indifferent as to 5.4 now and 100 in period 99. Over a period of 100 year it is clear that even small variations in the discount rate are going to change the present value of a benefit significant.

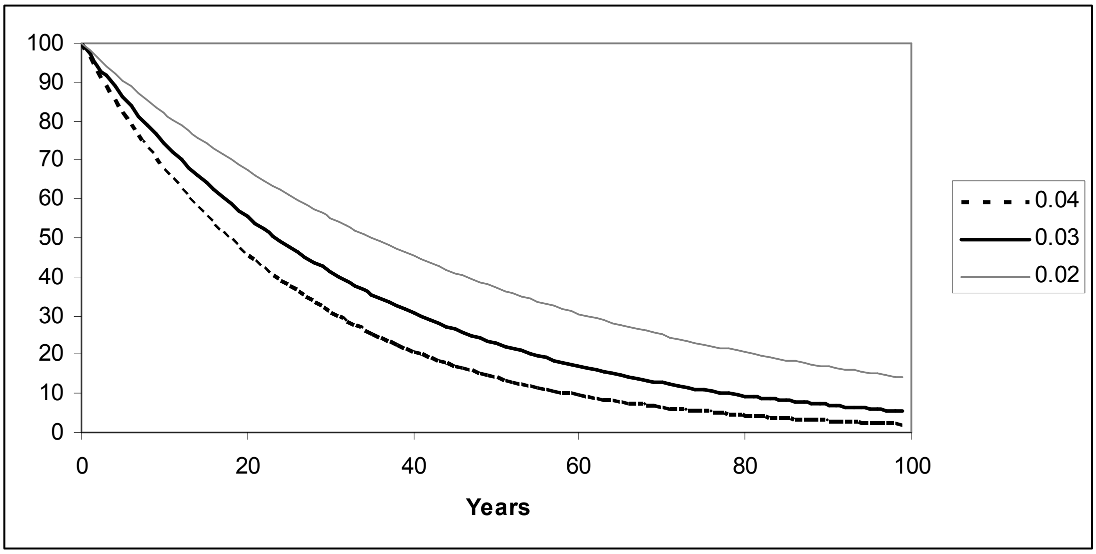

Figure 11: Discounts rates

6.2 Background

Samuelson 1937 developed the discount concept in 1937 and it is a widely accepted concept. However, Samuelson had some reservation about the concept. He was concerned if the mathematical form can reflect people's time preference, as it is completely arbitrarily selected. He argues that people's time preference may not only depend on consumption at that time, but may also depend on the change in consumption. If you lately have improved you consumption significantly, you may feel a bigger satisfaction of that consumption level than if the consumption level has been constant for a long time.

Furthermore, Samuelson argues that that the equation only holds for an individual who in the beginning of the period decides how to allocate his consumption. It is hard to find evidence of man whose taste does not change and who tries to maximise the value of some functional form. Samuelson adds that it is doubtful that we can learn anything useful from analysing such a man in a world where everything is certain. The functional form will be dependent on parameters which are determined socially such as desire for social prestige, length of human life, life cycle of economic activity, corporate structure, institutional and banking structure etc. He argues that these parameters are not parameters that return to an equilibrium, which means that these parameter changes over time, which further means that the discount rate will change over time. Samuelson argues that discounting is a theoretical term that will serve little in direct study of data (Samuelson

1937). Paradoxically the concept is today widely used in economic policy evaluations to reflect people's time preference.

Up until the Samuelson article in 1937 time preference was viewed as having many different motives, which by Samuelson condensed into one concept. Intertemporal preferences became apparent in John Rae 1834. Rae mentions that people have an effective desire for capital accumulation, which is a factor that determines how society is willing to save and invest. The two main factors promoting the effective desire for capital accumulation is the bequest motive (the motive to leave something for the next generation) and the propensity to exercise self-restraint. A limiting factor was the uncertainty of human life. A second limiting factor is the excitement of immediate consumption and the discomfort of deferring consumption to the future. (Frederick et al. 2002)

There are two major ideas behind these factors, which became dominated by the intertemporal theory of that time. The first view is the anticipation theory where people only care about immediate consumption and it explains farsighted behaviour with the anticipation of consuming something in the future. The second view is the abstinence theory where people treat the present and the future equally as a natural baseline for behaviour and it explains the higher weighting for the current generation by the miseries of self denying pleasures by delaying consumption to the future. Both the anticipation theory and the abstinence theory share the thought that the level of discounting will depend on people's feelings. The anticipation theory explains the variation of intertemporal choice by people's ability to imagine the future of different consumption possibilities and mentally compare different images of future. The abstinence theory explains discomfort in postponing consumption. A high discount rate will be observed when people have a high discomfort in postponing consumption. (Frederick et al. 2002)

Irving Fisher 1930 argues that intertemporal choice depend on time difference and diminishing marginal utility of consumption, because as people get richer in future, they value the same increase in consumption less than the present generation. Until Samuelson 1937, intertemporal choice was viewed as having many different motives. While using a Samuelson discount rate all the motives for time preference were condensed in to one single parameter, which may not reflect all the different motives for time preference. (Frederick et al. 2002)

6.3 Different Forms of Discounting

Two approaches have arisen. One uses the consumption discounting and the other opportunity cost discounting. The consumption discounting uses the social rate of time preference, which is defined as the sum of the pure time preference and the marginal increase in welfare which results from increasing consumption. The pure time preference is defined as how people will value a good now compared to future if there is no income change. The other way is the opportunity cost of discounting which uses the social opportunity cost, which normally is derived from a sample of market rate return on investment. (Hansen 2006). Often the market rate is chosen as the discount rate as this may reflect profitable investment, because otherwise you could just invest and receive a better yield. (Schneider et al. 2002). However, there are very different views on which observations there should be used and how the transfer into a discount rate should take place. If the social rate of discounting is used, what growth rate do we expect in the future and which marginal utility elasticity of consumption should we assume? If we are using the social opportunity cost of consumption, some consumers borrow on their credit card at a high rate while other consumers save at very low rate. How can you extract an aggregated discount rate that reflects all consumers' time preference? Should you include tax in the calculation? If tax is included the two social rate of time preference will differ from the opportunity cost in the country, as there is a tax wedge between consumption and investment. (Hansen 2006)

6.4 The Level of the Discount Rate

Neoclassic economists argue that social investments should be evaluated by a discount rate that reflects the typical return on a corporate stock. In this view, setting a lower discount as evaluation may crowd out private investments that would have been more profitable. (Spackman 2002)

The US recommend a discount rate of 7 % as it is has been the real return to investments over long in the period of 1926 – 1990. There is little consensus as to which rate should be used partly due to the tax wedge between private investment and the after tax return for the consumer. They argue that the real return for the consumer is closer to 4% than 7%. Equities have had a return of 7% and bonds have had a return of 4 % and after tax return of 2%. Because risk and uncertainty is involved in social projects it may be good to separate the risk and uncertainty from the discounting. It may be more appropriate to useful to use a discount rate that has a lower risk premium. In this case it may be more useful to use US bond as it has lower risk than equity. (Newell & Pizer 2004)

Other economist argues that it may be better to use the yield that is actually used on consumption rather than the interest rate of investment. This is because the climate change essentially concerns the welfare of people not firms. As people pay high taxes of their income the effective interest rate that go for consumption will be significant lower than the yield of firms. (Newell & Pizer 2004)

6.5 Climate Change and Discounting

The discount rate is critical because the abatement cost is primarily in the short run while the damages is primary in the long run. This means that there is more weight on the abatement cost than the cost of damages. (Schneider et al. 2002)

Table 2 shows how the discount rate will affect a policy if a cost of the policy is in the beginning and the benefit is in the future. For simplicity it is assumed that there are costs of 100 for the first 50 periods starting in period 0 and after that there are no costs. It is assumed that there is no benefit the first 50 periods, the benefits are 100 in the in the last 50 period. This means that the undiscounted cost is equal to the undiscounted benefit. It is clear that the benefits are discounted more, as they are in the future. The B/C is calculated by dividing the benefit with the cost. At 3 % discount rate the benefit amount to only 22.8% of the discounted cost, while at 1% discount rate benefits is 60.8% of the total cost.

Discount rate	**Cost**	**Benefit**	**Net benefit**	**B/C**
5.0	1916.872	167.1584	-1749.71	0.087204
3.0	2650.166	604.5216	-2045.64	0.228107
1.5	3552.468	1687.439	-1865.03	0.475005
1.0	3958.808	2407.109	-1551.7	0.608039
0.0	5000	5000	0	1

Table 2: Discounted benefit and cost

When it comes to climate change the cost of climate change are in the future. This means that when you have lower discount rate abatement is going to be more favourable. Choosing the discount rate is essential, as it to a degree will dictate the appropriate level of abatement, as it decides how we are going to weight benefits and costs.

There are, however, a couple of arguments against using the long-term interest rate as a discount rate. Firstly, if there are market imperfections, such as externalities and imperfect information the market price will give a misleading result. Secondly, it may be argued that the government has responsibility not only to the current generation but also to future generations. The market will only reveal the preference of the current generation. (Hepburn 2006)

Other economists argue that standard discounting in climate policy is inappropriate. It is argued that using pure time preference for long-term decisions is inappropriate, because it is based on individuals' impatience as to their own consumption. Hepburn (2006) argues that investment for people in distant generations have to be considered as foreign aid. This means that investment to reduce GHG should not be looked at as savings, but be looked at as transfers from our selves to people in a far future. (Hepburn 2006). A 0 % pure discount rate may be applicable here. In such a case the discount rate will only reflect that people get richer in future.

Generally, people both have personal interests and moral conscience. People may value accrued consumption more if they accrued it for themselves than if they accrue it for people in future generations. This may mean that people have a higher discount rate, when they save for somebody in a generation far into the future than if they save for themselves. Davidson (2006) distinguishes between positive and negative duties. Negative duties mean that you should not interfere in other peoples business and not harm other people's property or health. Positive duties oblige you to take action to help people, maybe through the government. A positive duty could be unemployment benefits where the government actively supports you. People have a higher social conscience when considering not hurting other people in the future than when considering positively improving the future; hence people may value negative duties higher than positive duties. Climate change is a consequence that we impose to others which means that it is more likely to be a negative duty. This means that the consumption interest employed in this case may differ from normal investments such as bridges and industrial centres; hence the discount rate is different. As people feel a higher responsibility for not hurting future generations, the discount rate may be smaller than for normal investment. (Davidson 2006)

It may also be argued that the environment has higher income elasticity than normal goods. When people have a low income they care about their next meal, their living conditions etc, they do not care so much about the future effect of climate change. When people become so rich that they do not need to care about their next meal and have good living conditions they start caring about the environment. It may be argued that with our current income we would have preferred that previous generation has polluted less, as there may be irreversible changes in the climate. (Fisher & Krutilla 1974). At the same way it may be argued that future generations, as they may have more material goods, care more about environment than we do. This increased preference for climate change, which is not be reflected in the current generation's time preference. This may mean that we need to discount at lower discount than the current generation normally have, because the future generation will value the environment higher than us and to some degree it is not possible to restore the climate after the damage is done.

Weitzman (1994) argue that the evolution of environmental effect may lead to systematically lower social return over time, hence a lower discount rate. The externality increases as economic activity rises and as people get richer people are going to value environmental damages more. This means that the future generation is going to put a higher value on the same damages than the current generation. This means that the real growth adjusted for the environmental drag is going to be slower, which lead to a lower discount rate. (Weitzman 1994)

6.6 A 0 Discount Rate

Discounting at a constant rate over long periods may be problematic. A Heterodox view is Ramsey's that the pure discount rate should be 0, because he argues that it is not moral to value future generations' benefits less than our own.(Ponthiere 2003). Stern (2006) argues that the only reason for discounting in his opinion is that there is a probability that future generation is not going to exist or that people in the future are going to be wealthier than the present generation.

Neoclassic economists argue that discounting is appropriate. Turner (2006) argued that having a 0 discount rate may be a threat to the well being of society today and it makes more projects profitable, which might strain resource capacities. In this way the current generation will be pillaged by future generations.

(Sinn 2007) argue that it is not the philosophers that make the policy, but the politicians. If the current generation discount when they make private decision then they will also select politicians who do the same. He argues that discounting also take account for future generations, as parents consider their children and grandchildren when they make they consumption decision. He finds the argument of Stern and Ramsey unconvincing and believes that future benefits and costs should be discounted.

6.7 Policies and the Level of Discount Rate

Different discount rates may lead to very different policies. A low discount rate may mean that immediate action against climate change is needed. A high discount rate may, however, mean that limited action is going to be taken as cost and benefit in the future is valued very little. The Stern review finds that the appropriate policy would be immediate action and the appropriate level of emission can be reached at a cost of 1 % of global GDP yearly. He estimates that this policy could avoid damages that might be up to 20% of GDP. The Stern Review build on very high ethical statements that pure time preference should be 0 and a discount rate of 0.1.

There are two ethical values that should be reflected in the discount rate. First there is the trade off between the wellbeing of future generation compared to our own wellbeing. This is looking at people’s time preference and the risk of people getting extinct. The second factor is looking at growth, how we discount if we expect the consumption of future generation to get higher or lower. (Dasgupta & Ramsey 2006). The Stern review assumes that the discount rate is equal to 0.1 % each year, which is a very low figure compared with what other scholars assumptions. This leads to strong and immediate action. Nordhaus uses in the original version of the DICE model a remarkably higher discount rate. He starts with a discount rate of 3% and the discount rate declines to 1% over the next 300 years. Generally neoclassic economists assume a higher discount rate than the heterodox economist. Nordhaus's reaches the result that little should be done at the moment even though there are serious threats in the future. (Dasgupta & Ramsey 2006). Nordhaus (2008) argues that action against Global warming should be put in a gradually increasing manner. In his most recent analysis Nordhaus (2008) uses a 1.5 % discount rate. In this report he argues that action is needed beyond the current Kyoto protocol, but he still argues that action should be taken sequentially to lower the cost of abatement. (Nordhaus 2008)

6.8 A Declining Discount Rate

Other economists argue that there is evidence that people have a higher discount rate in the short run than in the long run. Firstly, it seems to when people are asked to value consumption over time, they seem to have a higher discount rate in the short run than in the long run. Secondly, some economists find that a declining discount rate seems to fit the data better than a constant discount rate. Thirdly, economists have found that people's preferences for two rewards in future can be reversed when they come closer in time. (Frederick et al. 2002). It also argued that a constant discount rate cannot reflect the finiteness of the earth, as a constant will be in line with a constant growth rate. (Hansen 2006)

Adopting a declining discount rate could be a possibility, because it is argued that it fits better with policy goals and the sustainable management of natural capital. It is argued that some empirical evidence shows that people value cost the same way in the medium and the long run. This is due to that people do not value the cost or benefit of something continually through time and may revise they valuation. (Turner 2007). This may mean that it is more accurate to have a higher short run discount rate and a lower discount rate for the medium and the long run.

A certain discount factor may only apply to marginal changes in the consumption path. Big sudden changes in cost or benefit may lead to different discount rates. As climate change may involve large cost it may lead to an abrupt change in the consumption path and thereby also in the discount factor. This means that a constant discount factor is only be applicable to marginal changes. (Hepburn 2006)

Hepburn (2006) argues as climate change is expected to slow down in the future a declining discount rate may be appropriate. It is possible to write the discount factor in the following way.

$s(t) = \delta + \mu g(t)$

Here δ is the pure time discount rate, μ is the elasticity of marginal utility and g(t) is the rate of growth of consumption at time t. Even though people weight current utility and future utility the same, which means that the pure discount rate is 0, the total discount rate will not be 0. The discount rate will still be positive if μ and g(t) is positive. This means that if climate change is expected to slow down future growth then the discount rate should be declining. In the case where growth is negative it may be appropriate to use a negative discount rate. (Hepburn 2006)

6.9 Time Inconsistency

The neoclassic economist argues that a declining utility discount rate can lead to time inconsistency. Time inconsistency is when a policy, which is optimal at one date is no longer optimal considered at a later date. This is because the government discount at a certain time and the next government discount at another time the net benefit will be discounted differently. This means that the optimal policy depends on the evaluation date. It is important that the time inconsistency only arises from a time varying utility discount rate, and if a consumption discount rate were declining with a constant underlying utility discount rate there will be no time inconsistency. This means that policy makers take into account that successive governments have the incentive to change the policy. (Hepburn 2006).

Hansen (2006) is of the opinion that risk of time inconsistency is not much higher under the declining discount rate than when using a constant discount rate. It may be argued that the policy is more likely to be changed due to the fact of uncertainty, because as time goes more information becomes available. Even though policy may be time inconsistent and it may be changed it may still be consistent with the optimal use of resources at the time when it is implemented. Time inconsistency only arrives when the actions are totally independent from each other. For example often 90% of an investment is not going to worth 90% of the total investment. This means that a half bridge is not going to worth half of the whole bridge. Partly climate change is the same; a policy that almost succeeds in saving the ecosystem is not almost as good at saving the ecosystem. If the investment each year is independent of each other there was no reason for planning in first place. As investment plan is dependent on the action that follows there is limited risk of time inconsistency.(Hansen 2006).

Hansen 2006 argues that as a programme is started and it is revaluated the programme will be increasingly more attractive, as the programme sunk cost previously will increase the present value of the net benefit for the remainder of the programme. This will especially be true when it comes to climate change where the cost is in beginning of the period and the benefits are in the long run. There may occur time inconsistency when costs are delayed. This could mean the big part of emission reduction is delayed until period 2. If this is the case policy makers need to make a commitment to stick to the plan. (Hansen 2006) A volunteer commitment may be broken as we move closer to the cost. But it is important that time inconsistency does not primarily come from the way of discounting, but more from that we learn more over time as climate change is surrounded by uncertainty.

6.10 The Discount Rate and Uncertainty

It may be argued when there is uncertainty individuals will rather be sure of having something now than unsure about having something later. Neoclassic economists use this as an argument for a higher discount rate. Another argument for this is that it is easier to forecast benefit in early periods rather than in later periods. A higher discount rate under uncertainty than certainty assumes that risk and uncertainty is increasing geometrically over time. The method is unappealing as does not account for the true risk aversion, as uncertainty that is assumed to be on the cost and benefit. (Stæhr 2006).

Heterodox economists argue that risk adverseness makes the discount rate lower, as people are risk adverse they may put more consumption aside for later to secure the future. This means that the discount rate is going to be lower. Hepburn (2006) argues that peoples' risk averseness decreases the discount rate. How much will depend on the uncertainty of the growth rate and the marginal utility of consumption and how risk adverse are people? This means that the discount rate is going to be lower because of precautionary savings. (Hepburn 2006)

The private discount rate reflects that there is a risk premium. If an asset is risky the expected return should be higher to compensate for the risk. The Heterodox economist may argue that people want to pay a negative risk premium, as climate policy can be look at as reducing the uncertainties about the future. The argument is that people are willing to buy insurance to protect them against losses even though the insurance on average pays less than a deposit in the bank. This implies that insurance policies have a negative risk premium. It may be argued that policies that provide insurance benefit, hence they reduce the uncertainty faced in the future, should be discounted less than the risk neutral discount rate. I may be argued that climate policies can help to lower the uncertainties of the future as uncertainty increases the more temperature increases. A policy that lowers the temperature increase will essentially reduce uncertainty about climate change, as climate change is going to be less severe. (Howarth 2004)

Using the interest rates from bounds is normal procedure. The problem is that bonds normally just run 30 years, which means that the interest beyond that point becomes uncertain. Furthermore the other problem is that investment over such long periods is not only going to effect the current generation preferences but also future generations preferences. (Newell & Pizer 2004)

Newell & Pizer (2004) argues that it is not unlikely that interest changes for more than 3 % point over a period of 100 years. They argue that there have been significant increases in the 70s and 80 s followed by a sharp fall of up to 1 % or more that remains for a decade or more. From the 1950 to now there seem to big difference between real and nominal rate, especially in the 70s. Furthermore it may be argued that there is evidence of a decline in the interest rate from the 1800 where it was 6 – 7% to today where it is around 3 – 4 % for US government bonds. (Newell & Pizer 2004)

Spackman (2002) argues that the discount becomes more uncertain the further out in the future that it is, as we become uncertain about per capita growth and peoples time preference in the future. As people are risk averse a higher uncertainty in future will lead to a declining discount rate.

Incorporating uncertainty about future discount raises the valuation of damages far out in the future. Newell & Pizer (2004) assume that the initial rate should be 4 %, but it may be argued that over the next 100 years the rate could decline to 1 % or increase to 7%. If we use rates from the lower path, $100 in the 2100 will be worth 20.08 in year 2000. But if using the higher path $100 in 2100 will only be worth $0.20. The average of these two will be $10.24. An interesting analysis shows that the effective discount rate will be closer to the lower discount rate. Suppose that we did the same analysis for 1% discount rate in 2101, it would mean that the discounted value in 2000 will be 20.08. If we did the same for 7% discount the discounted value in 2000 will be $0.19. Taking the average of 0.19 and 20.08 we get 10.13. The expected value thus declines by 1 % (10.24/10.13=1.01). This means that the effective discount rate 100 years into the future is very close to the lower discount rate. This is because it is the discount factor and not the discount rate that one should average. This distinction makes a big difference over long periods. Discounting 100 years means that the high discount rate becomes insignificant and that the average of the discount will only depend on the lower discount rate. The expected value will be approximately be the same even if the discount rate were 110 %. (Newell & Pizer 2004). It may be an argument for at declining discount rate, as when there is uncertainty about the long run, the expected value seems to approach the lower rate.

6.11 Modelling the Discount Rate

Newell & Pizer (2004) look at the discount rate from an opportunity cost perspective. From the interest of the US bond over the past 200 years they find that the interest and thereby also the discount are highly uncertain. They work with two assumptions in two runs. In the first run they assume that interest rate returns to equilibrium. In the second run they assume that the interest rate is statistically ambiguous.

Should the discount rate be modelled as a Random walk or should it be modelled as reverting to a long run mean? Random walk is usually applied to Stock prices, as the best guess of future stock price is the movement up and down from the current value plus an average return. When discounting is means reverting random movement remains, but they tend to move towards a certain mean. Statistical data do not favour the one or the other model. The choice of model will, however, make an enormous different future effect of uncertainty, as mean reverting models assumes that interest cannot remain high or low indefinitely. (Newell & Pizer 2004)

Table 3 shows the discounted values of the results from Random walk and Mean reverting discount factor. From statistics and previous trends they estimate future interest. They repeat the experiment 1000 of times and uses average. The path has an initial discount rate and from each year they compute a discount factor. The value in each year is $100.

Years	**Constant 4%**	**Mean reverting**	**Random**
0	100	100	100
20	45.64	46.17	46.24
40	20.83	21.90	22.88
60	9.51	10.61	12.54
80	4.34	5.23	7.63
100	1.98	2.61	5.09

Table 3: Discount Mean reverting discount rate and random walk discount rate (Newell & Pizer 2004)

When a variable is uncertain the values far out in the future become more significant. This difference is higher when there is no equilibrium uncertainty. This is explained as the lower discount rate becomes dominating far out in the future. It is seen that in a 100 years they value the cost or benefit over twice as high when discount is a random walk, as when using a deterministic discount rate of 4 %. When uncertainty is introduced in discounting net benefits in future is going to be valued higher. (Newell & Pizer 2004)

The next step is to value the climate change using the discount factor found. Table 4 shows the social cost of carbon in year 2000. They find that using random walk discount rate raised the present value of reducing carbon emission from around $6 to around $10 in 1989 dollars. The relative effect of uncertainty is larger when the initial discount rate is higher. This reflects that there is more room for the discount rate to fall in the future. All is measured in 1989 dollars.

Initial discount rate	**Constant**	**Mean reverting**	**Random**
2%	21.73	23.32	33.84
4%	5.74	6.52	10.44
7%	1.48	1.79	2.88

Table 4: Climate change with mean reverting discount or random walk discount rate

First of all it is seen that the smaller the discount is the smaller is the incentive to reduce emission increases. As there is uncertainty about the discount rate the more beneficial it becomes to reduce emission. Especially if it is assumed that if there is no equilibrium.

7.0 The Dynamics of Climate Change

This section will discuss the dynamics of climate change policy. The dynamics of climate change are important as damages from emission in a year do not only depend on the level of emission that year, but on emission in future periods and the initial level of green house gases (GHG) in the atmosphere.

7.1 Short Run and Long Run Policies

Policy instruments should distinguish between short and long run. The short run policies have to be consistent with long run policy goals. This means that the short run policy has to be in line with the long run stabilisation goal of GHG in the atmosphere. This is because the marginal damages (MD) of emission will rise over time as the GHG accumulate in the atmosphere and that the marginal abatement cost (MAC) curve will be relatively flat in the long run because it is possible to improve technology. The government should implement a flexible approach in the short run, as the MD curve is relatively flat in the short run and there is a risk that cost of abatement would be high when forcing firms to reduce emission too fast. (Stern 2006). This means that there should be set a long term stabilisation goal that establishes a quantity ceiling that limits emission over time. The short term policy should be driven by a common price signal across countries and should not be too rigid. (Stern 2006). It is important that the price signal moves across countries and sectors as it then will secure the lowest abatement cost across the world. A price signal can be set either by permit programme or by tax programme. A tax sets the price directly. A permit programme sets a price as its sets the quantity and then the demand will set the price.

The problem with taxes is that they are hard to get to work across countries as these are hard to harmonise and as countries have very different tax systems which may make it difficult to agree on a common tax of carbon emission across countries. Permits may be better at establishing a common price signal. As these embraces both sectors and countries. (Stern 2006)

A long term stabilisation goal means that the short term price signal has to increase over time. This because the marginal damage is likely to increase as the concentration of GHG rises in the atmosphere. This means that there is a need to establish clear rules of how to revise the prices on carbon. (Stern 2006). If the policy maker was able to revise the policy every time he learns more about the damages and abatement cost he may be able to make a better policy, but if he changes the policy too often it will make it hard for the firms to adjust to the policy.

7.2 Emission Reduction over Time

The damage of emission depends on future emission, as it is the accumulated stock of GHG in the atmosphere that creates global warming. This means you cannot draw a MD curve without having an assumption about future emission because the actual damages depend on the future emission. (Stern 2006) The social costs of carbon emission may rise to a level where emission is lowered to a level that the earth is able to absorb, as the increased concentration of carbon in the atmosphere increases the social cost of emission. If the concentration of GHG in the atmosphere stabilises the price should stabilise, as the social cost of carbon is stabilised. This means that there will be an increased abatement year after year until the level GHG in atmosphere is stabile or starts to fall. This effect is going to be enhances by the fact the technology may improve and it becomes easier for firms to reduce their emission.

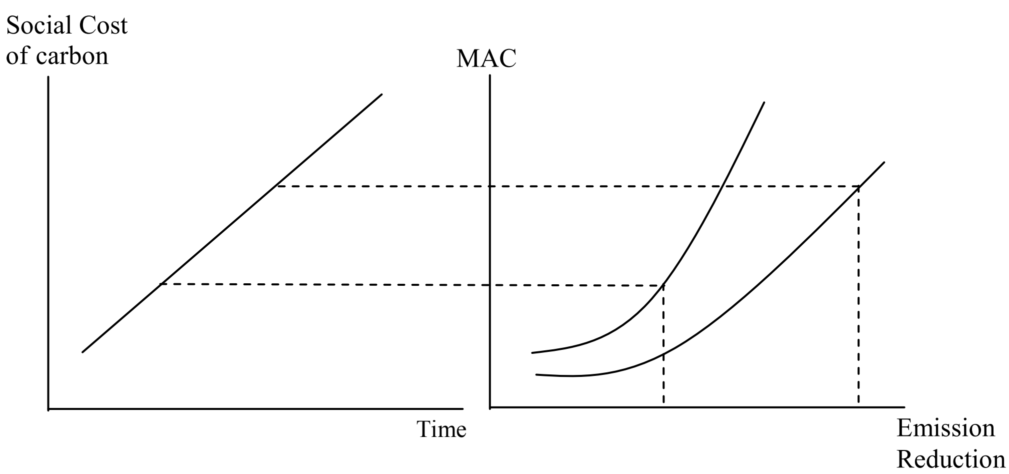

Figure 12: Emission reduction over time (Stern 2006)

Figure 12 illustrates in the right panel the social cost of carbon rising over time, as the world have not yet reach its stabilisation level. In the left panel the MAC curve is illustrated and on the x -axes the optimal emission reduction can be read. Furthermore the second panel also illustrates that technology improves. This means that the curve over time switches down. This means that there are two effects that make the yearly reduction increase over time until the stabilisation level. The first is that the social cost of carbon emission increases and the second is that the technology improves. It is important to take account of the dynamics in climate policy due to that the problem accounts for that the cost of emission depends on the future emission and the stock GHG.

Introducing uncertainty to a dynamic analysis makes it more complicated. If there is uncertainty in any period it has to be asked if this will affect the appropriate path emission reduction and the appropriate stabilisation goal. If the abatement cost is cheaper than expected it may be appropriate to lower the stabilisation goal and reduce emission even more. In this case it would reduce the social cost of carbon emission, which means that the social costs of the carbon curve moves down. It is important to say that one surprisingly good period does not mean that following period is going to be good. It may depend on that there can be a persistently faster technical process than expected. (Stern 2006)

7.3 Dynamic Models with Uncertainty

This section looks at the result of dynamic models under uncertainty. I will primarily look at a model by Hoel & Karp from 2000

7.3.1 Uncertainty

Climate models normally introduce uncertainty as either additive or as multiplicative. When uncertainty is additive uncertainty it is added to the expected value. It could have the following form.

$$q = y + \theta\eta$$

Where y is the expected value of q and $\theta\eta$ is the uncertainty, where the expected value of η is 0 and the variance of q is θ.

When uncertainty is multiplicative, uncertainty will enter multiplicatively and it could have the following format.

$$q = vy$$

Where v is a random variable that has an expected value of 1. (Alghalith et al. 2002). There is no reason to assume that the one kind of uncertainty is more realistic than the other.

Additive uncertainty is mathematically convenient, but it also has implications on the result. Hoel & Karp (2000) argues that under additive uncertainty the ranking of the policies are independent of the variance of the random variable, as the optimal solution can be found by using the means of the random variable, and it may be argued that uncertainty does not play a role in the policy decision. Secondly, the ranking of the policies does not depend on the stock, because the uncertainty is independent of the stock. Thirdly, the optimal emission path is the same for either a tax programme or a permit programme. (Hoel & Karp 2000). Hoel and Karp (2000) argue that it the optimal policy depends on the stock and it seems plausible that the optimal policy depends on the magnitude of the variance. Multiplicative uncertainty allows these variations.

7.3.2 Assumption

Hoel and Karp's model from 2000 assumes that there is multiplicative uncertainty, which is included on the abatement cost side. This is because they look at uncertainty from an asymmetric information viewpoint, which means that the government do not know what the real abatement cost is but the firms do. The firms ignore the flow of damages, but the government cares about damages.

In the model it is possible for the policy makers to change their decision after each period (h), when they get new information. When h is small, information arrives faster and decision can be changed faster. All variables are constant within the time h. This means that h cannot be too long, as there is no discounting and decaying within a period.

7.3.3 Analysis

Similar to the static model taxes are favoured when the slope of MAC is steeper than the MD curve and permits are favoured when the MD curve is steeper than the MAC curve. The advantages with taxes are that abatement is negatively correlated with the cost. The advantages with permits are that the stock of carbon in the atmosphere is deterministic. It can be argued that if the government is more concerned about the stock they should use permits, but if the governments are more concerned about the abatement cost they should use taxes. (Hoel & Karp 2000)

The governments are trying to maximise the present value of people's utility, which means that future benefits and costs have to be discounted. Permits reduce the uncertainty about the stock and therefore damages in future, as its sets the quantity of emission. Taxes reduce the uncertainty about the abatement cost, as it sets the cost of a unit of emission. The uncertainty under a tax system is placed in future as the cost of the stock is in future and the uncertainty of a permit program is placed in the present, as the current abatement cost is unknown. At a low discount rate permit will be favoured as uncertainty about the future becomes important. A higher discount rate will favour a tax programme, as uncertainty about the future is valued less.

Another main parameter in the model is the decaying rate, which is the rate of the stock of pollution in the atmosphere that persists until the next period. This depends on how must carbon the earth is able to absorb in each period. Furthermore, if the stock decays slowly in the atmosphere it may be important to have better control over the emission, as current emission will have a huge effect, as it is not absorbed by the earth. (Hoel & Karp 2000). This means that the uncertainty about the long run stock will be affected by the decay rate, and as uncertainty about the long run stock is more severe under a tax system it argued that a permit programme may be better when the decay rate is high. That is to say when the earth removes GHG from the atmosphere slowly it will favour a permit programme.

Hoel and Karp's (2002) simulation shows that a larger initial stock will favour permits. This is because that the MD increases linearly with the stock, which means that MD is high when stock is high. Reduction becomes more important when the stock is high. A permit programme targets the level of emission directly and may, therefore, be the preferable tool when the stock is high. (Hoel & Karp 2000)

Taxes tend to lead to a higher steady state of stock in the atmosphere, as the uncertainty is placed on the amount of emission. Under a tax system a long living shock is going to change both marginal cost and benefit. This is due to the fact that an increase in abatement costs is going to increase the emission as the firms under a tax programme adjust their emission. The stock is stochastic under tax and damages are convex in the stock, which makes the expected damages higher under tax. (Hoel & Karp 2000)

Hoel & Karp (2001) argue that when it is possible for the government to change the policy often (h is significantly small) it may be more optimal to use tax programme rather than permit programme. They argue that the governments get more information under taxes than under permits, as they learn about the emission a certain tax level produce, while the stock under a permit programme is deterministic. Furthermore they argue that firms easier can adjust to abatement cost shock under taxes than permits. (Hoel & Karp 2002).

7.3.4 Result

In calibrating the model Hoel & Karp (2000) assumes that the discount rate is 3 %. The decaying value is set to 0.995, and h is 1. Hoel & Karp (2000) find that the steady state of stock is higher under taxes than under permits. But they find that taxes lead to the highest present value of net benefit in all their simulation. It may be argued that the high discount rate may neglect the uncertainties of damages of emission in the future. A lower discount rate may favour a permit programme.

Pizer (1997) also makes a simulation, in this model they are assuming that uncertainty is additive. He makes a simulation over the next 100 years from 2010. He finds that in the optimal permit programme the emission should increase 9.2 Gtc to 13.1 Gtc due to economic growth. This policy generates a benefit of $69 billion compared to a business as usual policy. If the government implemented a tax policy the tax should start at $7 tC and rise to about $45 tC in 2100. This policy will have the net benefits of $337 billion in expected net benefits. This is around five times the result of a permit policy. (Pizer 1997). A tax has to rise because it gives a proportional emission reduction, if the economy double under the same tax the emission is going to double. Pizer (2002) argues that although an increase in emission may be desirable as the economy increases, a proportional change is not desirable. (Pizer 2002)

In simulation the hybrid model has only a performance that is marginally better than a tax program. But the hybrid has the same political attractiveness as the permit programme has. It easier to control over borders and sectors than a tax program and it also gives the government a more direct control over the emission. (Pizer 2002)

8.0 Practical Problems

This chapter looks at some of the practical problems that arise when introducing and managing a permit or a tax programme.

8.1 Supply Side

In the previous section we looked at policies that lower the demand for emission. This section tries to look at some of the supply side effects of different policies.

The idea of the policies in the previous section is that if a group of countries cut their emission by an amount, the overall emission is going to fall by the same amount. But if the oil producers just decide to keep on supplying the same amount then the only effect is that the prices will fall in all the other countries, which will mean that the world wide emission is going to be the same. This is a situation where the supply curve is vertical, so even though the demand curve falls, which can be due to a tax, the emission stays the same while the price fall. (Sinn 2007)

Exogenous supply may be a sound assumption as fossil fuels is not something that is produced but something that earth has produced and the only cost is the extraction cost. This is because if firms react to different demands by lowering the supply they must extract more tomorrow. A sound policy will be to lower the supply of resources now and increase them in far distant future. (Sinn 2007)

The owners of an oil field will like to maximise their profits. If the owner extracts the resource too rapidly then the price will fall, because the supply increases. If you extract very slowly then the profits are going to be higher because the yearly supply is very low, but then the firm has to wait for the profit. (Hotelling 1931)

Considering the supplier it is clear that he should earn more per unit if he sells in future, because he needs to be compensated for waiting having his income at his disposal, cf. chapter 6 discounting. This means that he should extract more now than in future so that the price will go up as supply gets smaller. Hotelling (1931) shows that under free competition, it is optimal for the owners to extract the resource in such a way that the price rises with the discount factor. Intuitively if the price of selling one unit of fossil fuels discounted 1 year forward falls below the selling price that it is possible to sell it for in one year, then it optimal for the supplier to wait 1 year with extracting the resource. (Hotelling 1931).

In the following model it is assume that there is an extraction cost. In the model below I look at a discrete model. I assume that there is a representative resource owner, who owns an oil field, which has S amount of resources. The resources have different amount of accessibility, which means that the extraction cost can be written as g(S)R. The resources extracted is equal the change in S. That is to say that $R = -\dot{S}$. The resource owner wants to maximise the present value of his cash flow $(P - g(s))R$, where P is the price of the resource at time 0. If the resource owner extracts one unit of his resources today he will earn $i(P - g(s))$ and if he leaves it in the ground he will receive the change in price $\dot{P}$. This gives us the following model.

$$i = \frac{\dot{P}}{P - g(s)}$$

This means that it is optimal for the owner to extract his resources following that equation. The model will collapse to the Hotelling's rule if extraction cost is equal to 0. (Sinn 2007)

Insecure property rights may accelerate the extraction, as resource owners want secure their yield before it is too late. This may arise from that many of the oil fields are in countries where government is more or less unstable. This could be the Middle East, South America, Nigeria and Russia. As owners may think that there is a risk for them to lose their oil fields they may want to extract to secure the profits now. This means that there is going to be added a risk parameter to the discount rate called π.

$$i + \pi = \frac{\dot{P}}{P - g(s)}$$

An increasing tax may accelerate the emission as suppliers may expect that prices are going to increase. This is because the change in tax will be added to the discount factor. If we imaging that the tax is going to increase by $\hat{\theta}$ then the owner has to extract in a way where the following condition is met.

$$i + \pi + \hat{\theta} = \frac{\dot{P}}{P - g(s)}$$

That is why if a tax has to start high and have to fall over time, as a falling tax will be subtracted from the discount factor. A falling tax may, however, not be trustworthy as it means that government tax revenue over time is lowered. Furthermore, it will also increase the cost in the short run where it is hard for firms to adjust to alternative measures as capital is more or less fixed. Furthermore, as the MD increases over time and technology improves it will not be efficient to have a falling tax. Sound policy should focus on flattening the extraction path of fossil fuels.

As price received by the oil firm becomes less when the demand fall, the amount of resources that are worth extracting may become smaller. This is because the access to oil in different oil field may be different.

It is clear that some demand side policies may reduce the amount of fossil fuels that is worth extracting. Many of them will, however, fail in delaying the extraction of resources to later period. There are two countervailing effects on resource extraction over time. The first effect reduces the incentives to extract resources as prices fall. The countervailing effect increases the incentive to extraction as the supplier anticipate that demand is going to fall in future, which is going to reduce the opportunity cost of having fossil fuels in the ground. Unless the first effect is dominating the other it may not be reasonable to use demand side policies. (Sinn 2007). The permit programme controls the quantity of emission directly, which also means that the policy makers are controlling the extraction path directly.

8.2 Participation

A problem with the tax policy is that it is hard to harmonise a tax programme across countries, because the tax systems in different countries may be very different. Permits have proved better in being able to harmonise rules across border and it is able to send a price signal across borders.

Optimally all countries will be part of a world wide agreement to lower emission. There may, however, be countries that choose not to be a part of the agreement. This may have the consequence the overall demand for emission is going to fall as there is a lower demand for emission in participating countries. It follows that the price is going to fall in the non participating countries, which means that demand is going to increase. This means that the emission reduction of few countries may have limited effect on the overall emission, as non participating countries are going to increase their emission. (Martins & Burniaux 2000)

Another effect is that production prices are going to increase in the participating countries and the production price may fall or be stable in the non participating countries. The competitiveness of the participating countries with the non participating countries may fall, as the production costs of the participating countries increase relatively to the non participating countries. (Martins & Burniaux 2000). Another effect may be that participating countries may develop new technology, as production is becoming more expensive, which may in the long run lead to higher competitiveness.

Countries may also agree that they only sell products that are produced at a low carbon intensity, which will mean that if the non participating countries want to export to these countries they will have to produce at low carbon intensity. This will, however, not change the fact that it is important for a carbon reducing policy to be as wide as possible, to prevent that non participating increase their emission as the price of fossil fuel outside the participating countries is going to fall.

8.3 Allocation of Permits

When there are many firms the price of the permit is set by the market, which means that the firms will buy permits until the marginal abatement cost is equal to the price of the permit. This means that the amount of permits released is essential. It cannot be too high because then the supply is so big that the price becomes so low that it does not create any incentive to lower the emission. Firms have incentives to overstate their needs for permits. If the government measures the use of emission up to the implementation of a permit programme, then the firms will have incentives to increase emission artificially to look as if they need more permits

Permits can either be given away or sold on auction. In this way there is also raised revenue for the state. Another question that arises is who should be allowed to buy and sell permits. Of course the emitters and the government should be allowed to buy or sell.

Governments could buy permits and retire them, if they want to reduce emission. A question is if the government should allow third parties to buy and retire permits. This may mean that the population's actual preferences of emission gets revealed if everybody can buy and sell. Another way that the government can reduce emission is to make the permits yearly and then reduce the permits year after year. (B. C. Field & M. K. Field 2006)

It can be argued that if everybody is allowed to buy permits the cost will represent the people's preference for emission, because people can buy them and retire them. But third parties may not consider all effects, because lower supply of permits means that the price is going to be higher, as fewer permits increase the price of consumption goods. For example a higher fuel price means that it becomes more expensive to transport goods, which means that all consumption goods become more expensive. (Stern 2006)

There is no distorting effect from given the permits away. This is because firms even though they get the permits for free they still face the opportunity cost of selling them. Free permits are like a lump sum transfer from the government and it will have no effect on the firms' behaviour, as it is does not affect the firms' profit per unit. It is argued that there will be no distorting effects from one country auction its permits and if other countries distribute the permits for free. It will, however, have an equity effect as some firms receive a lump sum subsidy and others do not. This argument is assuming that there is free competition. If there are only a few firms and these enter into a price war, then the firm who has received the permit can hold longer than the firms who have to buy permits initially. As it is expected that many countries and firms are going to enter in a permit programme price war is less likely. (Woerdman 2000)

The free allocation of permits may build on the use of the emission in past periods. If this is the case firms will have the incentives to increase the emission until the base year from which the permit are distributed, to receive more free permit and thereby have it easier in reducing their emission. (Stern 2006)

Free permits may also reduce the incentives for new firms to enter the market. If incumbent firms have received their permits for free, while new entrants have to buy them when they enter the market, the new entrants have less incentive to enter the market.

There need to be established rules for new entrants. If the allocation of permits is given to new firm in proportion to the expected emission, they may reward carbon intensive technologies. The firm may go for polluting technology as this may raise the expected emission. There may also be a disincentive to exit the market, as firms lose the permits if they do not use it. A firm must stay open to receive free permits. (Stern 2006)

Under auction the firms' manager incentive to consider the cost efficient level of abatement, as there is an upfront cost of purchasing the permits. This may tend to lead to that the manager is going to make a cost efficient decision, while he under the free distribution just wanted as many permits as possible. Free allocation may delay the adjustment to a cost efficient abatement. (Stern 2006)

Auction reduces the administrative costs as the auction will reveal firms' MAC, as there are buying. Under free distribution the government have to find a genius way to distribute the permits. (Stern 2006)

Auction may lead to that major player's buy most of the permits and charge a mark up for reselling permits to smaller firms. To ensure efficient results the auction should promote competition and both large and small emitters should participate. Stern (2006) argues that small frequent auctions may be better at creating efficient result than larger infrequent auctions.

8.4 Double Dividends and Distorting Taxes

Economists argue that tax revenue raised from the pollution tax can be used to lower other distorting taxes. This means that the income tax may be lowered, which may lead to less distortion on the employment market. Distortion arises as the employee receives less than the employer pays, which means that the employee is going to work less. It is argued that a pollution tax will not only provide an efficient emission level, but it will also improve the revenue system reducing the dependence on income taxes and VAT. It may be claimed that a tax system will lead to both an efficient pollution level and a better tax system. Under Permit programme when permits are given away there is no revenue. (Oates 1995)

In the case where pollution taxes must exist alongside with other taxes it becomes more complicated. Let's consider a case where there is income tax, in this case there is distorting effect on the work leisure decision. An emission tax will raise the price and thereby aggravates the distortion of existing taxes and thereby reduce incentive to work, as the real wage falls. This is known as the tax interaction effect (Oates 1995).

This Criticism of tax interaction effect relies on that it assumes that the utility function is separable in environmental quality. This means that environmental quality will have no effect on the marginal rate of substitution between goods and leisure. Schwartz & Repetto (2000) argue that improved environmental quality is likely to raise labour supply, offsetting some of the interaction effects. There may be a health factor in improving the climate; for example abatement that reduces temperature increases may lower the risk of malaria. In the short run reduction of air pollution that improves overall health in connection with the pollution reduces the population sick days.

Empirical evidence is inconclusive. Beghin & Dessus (1999) find that there are gains from double dividends, as they find that reduction of pollution also leads to greater allocation efficiency. Parry (1995) finds that pollution double dividend does not exist. It is unclear if there exists double dividend.

8.5 Permits: Intertemporal trading

Intertemporal trading of permits may lower the cost of abatement. Intertemporal trading means that it is possible, when given a certain amount permits for a period, to bank some of the permits and use emission in a later period. Furthermore it also gives the firms the possibility of borrowing permits from the future and then emit more in the current period, while having to emit less in a later period. It is argued that the same emission cuts can be done at the lowest present value over time. Normally when implementing intertemporal trading it should only be allowed to borrow and loan emission over a short time period, to avoid that firms postpone emission forever, by keeping on borrowing from future periods. (Kling & Rubin 1997).

It may be argued that when there is uncertainty about abatement costs, intertemporal trading help to avoid unnecessary high abatement costs. This is because it postpones abatement until a later period, where it may be easier for firms to lower its emission, if abatement cost turns out to be higher in early periods and the technology improves faster than the government predicted.

Intertemporal trading may, however, not always lead to an efficient result, even when assuming perfect foresight. In many cases the private optimal abatement path will not correspond to the socially optimal solution. This is because the number of permits does not represent the true scarcity of emission, as they are artificial distributed.

When the government distributes the permits the firms are going to treat the permit as an exhaustible resource. This means they borrow and loan in such a way that the prices will rise with the discount rate according to the Hotelling rule cf. chapter 8.1 supply side. (Kling & Rubin 1997). If the discounted value of the abatement costs on the margin in a future period is less than current abatement costs of the last unit today, then it may be favourable for the firm to save emission for a later period. The emission will depend on the curvature of the MAC curve and the discount rate. A higher discount rate will encourage firms to borrow permits from future periods. A lower discount rate will encourage less borrowing. (Kling & Rubin 1997). If the MAC curve is very convex it will reduce the incentive to bring back emissions to an earlier period.

The socially optimal solution in this case may differ from the private, as the number of permits does not reflect the true scarcity of emission, because they are artificially distributed. Permits are distributed from the path of emission that the government thinks is optimal. But when they are distributed the firms treat them as a resource and discount them without any consideration of the damages of emission. This means that the path that the government has decided on is discounted by the firms. As the damages of emission depend on when it is emitted it will lead to higher damages (Kling & Rubin 1997). This means that although banking will generate the same accumulated emission over time, the social damages will not necessary be the same. (Kling & Rubin 1997)

Kling & Rubin (1997) suggests that the emission permits borrowed from future periods should be penalized with by the rate of discounting. Even though the discount rate may differ from firm to firm the government need to choose one. This will remove the extra incentive for the firms to increase they current emission.

8.6 Transaction Costs

A permit programme and tax programme will under perfect foresight lead to cost efficiency. But in the real world there are transaction costs as it is costly to find information and bargain. In this section I will mainly focus on permit programmes, but it is important to mention that there also are transaction costs under a tax programme. Although it may be argued that they are smaller than under a permit programme.

There are three sources for transaction costs. First there is the search for information. The market may not provide full information about firms pollution needs, due to the public good nature of pollution. Brokers may step in to provide firms with information about their pollution control options to reduce transaction costs. The brokers will, however, charge a fee. Secondly, there are the bargaining costs, as there are real fees involved in the bargaining process which include legal fees, broker fees and insurance fees. Thirdly, there are monitoring and enforcement costs. Enforcement costs and monitoring can be significant, but normally the government will take care of these costs. (Stavins 1995)

High transaction costs may eliminate potential gains of trade. There may be no ready means for buyers and sellers to identify each other and there are financial brokers that charges fees for administrating trade between firms. Hahn & Hester (1989) suggest that the Fox River water pollutant failed due to high transaction cost. Tripp & Dudek (1989) suggest that an important reason for the New Jersey pipelines development programme to be a success was that the government took on the responsibility of being a fee free broker. Empirical evidence shows that low transaction cost is essential for the success of a permit programme (Stavins 2000)

Stavins (1995) finds that if transaction costs are included a permit programme, it will not be cost efficient. Figure 13 assumes that the marginal transaction costs are constant and that these costs are paid directly by the seller. Firm 1 has a MAC curve 1 and firm 2 that has a MAC 2. If there is no transaction cost the final allocation after trade will be r no matter what the initial allocation is. If firm 1 has got fewer permits than is efficient it wants to buy permits from firm two. That is to say that the distribution of permits is on the right of r in the figure. That means the permit traded is going towards the origin. If firm 2 is awarded more permits than the efficient level, then permits traded will move us to the right.

Transaction costs increases the price for the buyer and decrease the price for the seller, which means that the price paid by the purchaser is driven upward. In a situation where firm 1 is awarded fewer, permits than what is optimal, then he will like to buy permits from firm 2 he permits until his MAC is equal to the MAC of firm 2 plus the transaction cost, which means that the trading of permits will lead to r_a instead of r. If the initial allocation is on the right side of r then the trading is going to be r_b. The equilibrium differs because the identity of buyer and seller switch.

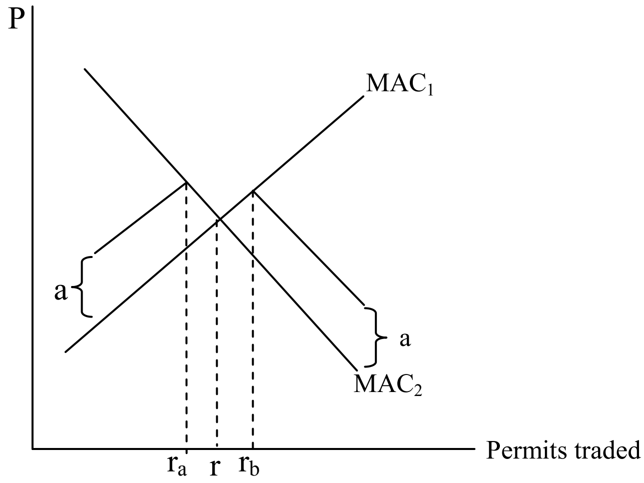

Figure 13: Permits traded considering transaction cost (Stavins 1995)

This leads to the question how transaction cost should be shared between the buyer and seller. The burden will fall mostly onto the firm that has the steepest MAC curve regardless of who is actually paying the broker's fee, as they have more to gain per unit of trade.

If the initial allocation of permits differs from the efficient level and transaction costs are significant then the efficiency will not be reach. Initial allocation will have an effect on the allocation of permits when there are transaction costs. As long as transaction cost are constant it will only have the effect that allocation ends up in r_a or r_b. But if the transaction costs were not constant, the initial allocation would affect the long run allocation. If transaction costs are increasing as more is traded, it will mean that fewer permits are going to be traded compared to the previous example. Decreasing Marginal transaction costs may occur when the broker gives a discount on the amount sold. In this case the equilibrium is going to be closer to the cost efficient equilibrium than otherwise. This means that the initial distribution has an effect not only in terms of equity but also in terms of efficiency. Transaction costs may lower the attractiveness of permits. (Stavins 2000).

Transaction costs increase the cost of using permits, as it reduces trading. Transaction cost may be reduced when there are many firms, as it will be easier for buyers and sellers to find each other. Frequent transactions may reduce transaction costs as frequent transactions create more information and reduce uncertainty. A tax programme also includes significant transaction costs, although they may be lower, as the price of carbon is known and buyers do not have to find sellers. An argument for tax is that the initial allocation of permits under a permit programme will affect the cost efficiency.

9.0 Discussion

Taxes and permits can be change over time. Taxes seem to perform better than permits in the short run, as it may be argued that the government can just change taxes many times in accordance with a long term goal, which will mean that the policy should be set according to a short term static model. The problem with this is that if the government changes the goals many times, it is impossible for the firms to plan their investments. This means that policy should at least focus on a model in the medium run. This will mean that slope of the MD curve be steeper and the MAC is going to be flatter than in the short run, which may favour a permit programme. The question is if this change the relative slope of the curves, so that permit becomes the favourable tool.

When making policy over time discounting becomes important, as it obliviously has a big effect on the right level of emission. The discount rate should reflect peoples time preferences, and as these are impossible to measure directly, the selection of the discount rate will necessarily reflects a scholar’s view. In the case of climate change the costs of emission are in the beginning of period and the benefits of reducing emission are in the long run. This means that a high discount rate put more weight on the costs than the benefits, which may mean that even severe costs far out in the future becomes insignificant in the present. On the other hand it is arguable that discounting is necessary as too many investments will become profitable at low or a zero discount rates, which lowers the consumption for the current generation. But what should the discount rate be and should it be declining? As it is a reasonable argued when there is uncertainty about the discount rate. There is no obvious answer to what the rate should be. This report has presented discount rates from 0 up to 3 %, but in principle it could be even higher. You can easily argue that one rate would be more appropriate than another rate and different scholars argues for different. It is unfortunate that a parameter that can completely change the result of an analysis relies so much on the individual scholar's judgement.

Hoel and Karp´s (2000) analysis includes multiplicative uncertainty. They find that taxes perform better than permits. They show that a tax system tends to put the uncertainty onto the future and under a permit programme the uncertainty is on the cost of the present. They select a relatively high discount rate of 3%, which may effect the result as the uncertainty in the future becomes less important as the future benefits of emission reduction is valued less. They also select the relatively short period of one year, which means that the policy can be changed every year. The high discount rate and the possibility of changing the rate so often will indeed favour a tax programme. The problem is that it may not be practical to change a policy that often and the decision of the appropriate discount rate is subjective matter.

There are a lot of arguments for taxes and permits. There seems to be higher transaction costs using permits than using tax, as fewer permits are going to be traded when transaction costs are included reducing the cost efficiency. Taxes raise revenue that may be used to lower distorting income taxes. Taxes do also perform better when the short run uncertainty is high, but it may be argued that most uncertainties in climate change are in the long run, as most of the damages are very uncertain and uncertainty increases as we look further out in the future. This may favour a permit programme, as it reducing the uncertainty about the damages.

The price of permits is likely to be highly volatile when the quantity of permits is totally fixed. The history of European trading prices for CO_2 shows that the price in 2006 ranged from \$44.47 to \$143.06 per ton of carbon. The price fell by more than 70% one month because of new regulatory information. Such high fluctuations are undesirable as fossil fuels are essential for production under the current technology. (Nordhaus 2008) A Hybrid model may be able to reduce price fluctuations.

Many of those who find that taxes perform remarkably better than permits focus on the demand side. But it is also shown that the tax rate is increasing over time to reach the result, as MD curve is increasing and technology improves. This may lead to that the suppliers are going to increase their supply, because they expect the price to fall. A permit programme will, however, set the quantity that makes it impossible for the oil sheiks to undermine the policy.

Even though other analyses show that a permit programme has a higher deadweight loss than a tax programme, it has the ability to work across borders and it does not lead to that oil sheiks increase their supply to undermine the policy. Furthermore a lower discount rate may lead to that a permit programme performs better. An important argument is that the permit programme may help lowering the uncertainty about the future as it directly sets the emission path in the future, which is considered to be higher than short run uncertainties about abatement costs. The downside of a permit programme is, however, that the transaction costs are higher and lead to higher abatement costs or high price fluctuation. If the government is very nervous about price fluctuation I may recommend the hybrid model, but I will set the fall back price relative high, such that the programme does not fall back to a continuously increasing tax.

10.0 The Price of Carbon over Time

This section will try to establish the price for emission, hence the tax level or the realised price of the supply of permits. To try to establish the level of tax we look at different models that try to project costs and benefits of different emission paths. Most of the literature focuses on risk rather than uncertainty. Schneider et al. (2002) argue that it is necessary to put subjective probabilities on in order to help the politicians to make a decision. There may be many different opinions on what are reasonable estimates for probabilities. This will, however, not uncover the uncertainties of the future, as the probabilities do only reflect the model, and human and politicians make there decisions facing an uncertain future. It may, however, help to establish what scientists' think it is reasonable to believe will be the likely consequences of different policies.

10.1 The Time Horizon of the Model

We need models that are able to forecast at least a 100 years. Some make models over even 200 or 300 years. The reason for this is that carbon emission now will affect future damages. This is an unusual problem, because forecasting becomes very difficult far out in the future. It would have been very hard for people before the 19th century to be able to foresee how the world looks in 2008. It is hard to imaging how the world would look in 2100. It is possible to discuss how long the time period of a model should be. It is clear that policies will not reach that far into the future, but it can also be argued that the consequence stretches far into the future. Does a shorter time horizon reflect the problems appropriately? It can be argued that under a business as usual policy the temperature is not going to reach the 3° C until 2100 and there is a lot uncertainty from this point. So 200 years may be an appropriate time horizon to reflect the problem appropriately. But there is probably infinity of possible imaginable futures. It is all depending on policy and peoples' action over a century, as there may be structural changes that are impossible to foresee.

A solution to this problem is to build different scenarios that show different possibility of future paths. These scenarios have to have different assumption about technology, growth, population growth and how people act. It is possible to come up with infinity of scenarios. (IPCC 2000). It may be possible to make policies all after which policy measures that over several scenarios perform best.

10.2 Distributional Effect in Weighing up Costs and Benefits

All the models are essentially weighing up costs and benefits. In practice models do not measure utility, they measure the result in money value, as it is impossible to measure utility. They measure the discounted costs and benefits, which results in a Net present value (NPV). Essentially a project that has a positive discount rate is a project that yields a positive yield and should be accepted. In practice the NPV normally be compared to the NPVs of other projects to make the best use resources, as there are limited resources. The discount factor is a significant player as it decides how to weigh present and future benefits.

Weighing up costs and benefits has some theoretical limitations, when talking about efficiency. This is because it is not possible to say that a project will be a Pareto improvement even though the NPV is positive. The explanation for this is that even though the aggregate welfare in a country is improved, some people may get to be worse off than they were before the implementation of the project. There may be a potential Pareto improvement in a project if the NPV is positive. This means that the beneficiaries should be able to compensate the people that suffer a loss and still be better of. This does not mean that the compensation is actually given, which then means that there still are people who suffer from the change. This means that a project may create inequality if the project benefits the rich and hurts the poor, even though it has a positive NPV. (Turner 2007)

In many cases it is possible to use the market value to estimate the cost benefits, but some costs and benefits are not sold at the market. This could be the value of scenery, the value people put on specific species or the value of life. If costs are intangible economists will try to reveal people's preferences. This could be done by asking people or finding another genius to reveal peoples preferences. There is maybe many reasonable ways of doing this, which may lead to many different reasonable results (Stavins 2000).

People's willingness to pay depend on their income and wealth, this means that the higher the income is the higher is the price that people are willing to pay. The reason is that when people get rich, they value the marginal increase of wealth less than when they were poorer. This means that if the costs are borne by the poor and the benefits are going to the rich, then the NPV is going to be much higher, due to that rich people are valuing the same cost and benefit at higher money value. This means that weighing up costs and benefits without trying to adjust for this may cause inequality.(Dolan & Aki Tsuchiya 2002)

When things in the future are unknown, we will value a project differently if an exogenous variable turns out to be certain value than if it is different. For example if we have a farmer who is considering building irrigation for his fields. In dry seasons he is going to value irrigation higher and in wet season's irrigation is not that important. The price that he is willing to pay is the option price when he does not know the outcome. Some may argue that the option price is just the simple average. Other may argue that he would be willing to pay more to insure that the irrigation was in place in dry seasons. The result depends on the preferences of people and how they are affected by uncertainty. (Graham 1981).

10.3 A General Equilibrium Model

Nordhaus (2008) uses a neo- classic general equilibrium growth model. Even though that it is unlikely that the world resembles an equilibrium economy, it may be argued as we do not know which structural changes there is going to be in the future, that we just as well assume that the structure of the economy is similar to the current economy. An argument against an equilibrium model is that in this model people know how the economy is going to evolve and can perfectly plan accordingly. This is, however, not the case, as adjustment to an unexpected change and cognitive limitations makes it impossible to use resources and plan optimally.

In the DICE model the current generation is investing in capital, technology and education. In this way they are reducing their consumption today in order to increase consumption in future. The Dice model maximises the present value of consumption. The Dice model includes natural capital, which means that GHG is considered as a negative natural capital and abatement, as an investment to raise natural capital. This means that by investing in emission reduction the current generation is trying to prevent harmful climate change and thereby trying to increase the consumption possibilities in future. (Nordhaus 2008)

The model has well defined preferences, which means that it is possible to rank different path of consumption. The importance of different generations is affected by the time preference and the diminishing utility of consumption. These two parameters interact in making the discount rate. In the model the parameters are set to be consistent with the interest and rates. (Nordhaus 2008). In the new version of the DICE model the discount rate has been lowered to 1.5 % instead of 3 % in the previous version.

Technology is assumed to exogenous, which is one of the limitations of the Dice model. However, it has proved very hard to model induced technical changes. It is assumed that carbon fuels are limited in supply. When carbon fuels become more expensive, substitution to non-carbon fuels takes place. Carbon fuels become more expensive either because of exhaustion or because of a policy which has been implemented to restrict carbon fuels. (Nordhaus 2008)

The climate change equation calculates the average temperature. The final issue is calculating the economic impact. Economic impact is very important in making economical sensible decision, but it has proven very hard to get reliable estimates of impacts of climate change in the long run. (Nordhaus 2008). The abatement cost is assumed to be highly convex, which indicates that the MAC rises more than linearly with the reduction rate.

I consider tree runs. The first run assumes that there is no policy over the next 250 years. The next run is the optimal, where the present value of the net benefits is maximised over the period. The third makes an optimal run using the Stern discounting (0.1%). Nordhaus (2008) optimal price of carbon starts as $27.28 in 2005 prices and rises to $98.01 in 2055, which reflects the social cost of carbon in his model. It rises further to a level of $217.02 in 2105. The Stern discounting has a price that far exceeds the optimal level of emission, as in 2005 the price of a permit or a tax has reached $298.98 and rises to $939.82 in 2105.

According to Nordhaus (2008) an efficient policy can avoid damages of $5 Trillion in 2005 prices in discounted value, while the abatement cost will be less than half of that. On the other hand an inefficient programme can have costs of up to $30 trillion more than the efficient programmes. (Nordhaus 2008). The Stern review measures costs to be 1% of total income, while efficient policy according to Nordhaus (2008) only has costs of 0.2-0.4 % of income and a more stringent policy may have costs of 0.6 % of total income. (Nordhaus 2008)

Emission will lead to that an increase of the concentration of GHG in the atmosphere. This increase leads to a certain temperature increase. I limit myself to only report the temperatures as these will reflect the increased concentration of GHG in the atmosphere. Table 5 reports the temperature increase under the different policies.

Policy	2005	2015	2025	2050	2100	2200
No policy	0.73	0.96	1.20	1.82	3.06	5.30
Optimal	0.73	0.95	1.17	1.68	2.61	3.45
Stern	0.73	0.89	1.03	1.31	1.52	1.27

Table 5: Global mean temperatures above 1900 level (Nordhaus 2008)

All policies, except the Stern discounting, leads to temperature increases of above 1.5° C in 2050 above 1900 level. In the Stern scenario the temperature increase is much less, as the temperature increase is only 1.52° C in 2100. In the Nordhaus optimal scenario temperature increase to world average temperature increases to well over 2 ° C, which to some scientists is threshold for more serious consequences cf. 11.6 A Precautious view.

10.4 Risk Implemented in the Model

Nordhaus (2008) treats risk by putting probabilities on his variables and parameters. The parameter probabilities build on subjective judgement and are not objectively calculated from historic trends. It is necessary to use judgemental probabilities as there is no or only limited historic observation to base the parameters on. For example, it is impossible to estimate the impact on society from a 3 ° C world average temperature increase, as society has never experienced such temperature increase. There is no single method in determining probabilities; modellers rely on their own judgement, surveys and results from other models and theories to get information about the distribution of the variables.

There may be many different risks that are possible to investigate. In this project I look at the risks that may affect the analysis the most. Nordhaus (2008) puts a distribution on the different variable and makes Monte Carlo estimation to try to reveal the distribution of climate change. Monte Carlo analysis may be appropriate to analyse risk. The idea is to assign distribution to all the variables and then make a large number of draws from these distributions to get a distribution of the cost and benefits (Stæhr 2006)

Table 6 shows how the risk of a couple of variables which affect the social cost of carbon the most. He looks at growth, temperature sensitivity, the asymptotic level of the population and the impact measured by the damages function. It shows how the social costs of carbon will change if the variable deviates from it expected value.

Standard deviation	**G(TFP)**	**Temperature Sensitivity**	**Population**	**Damage Coefficient**
0	28.10	28.10	28.10	28.10
1	36.07	38.07	32.14	40.99
2	48.08	46.44	35.91	53.89
3	51.21	53.49	39.44	66.80

Table 6 : Risk on key variables affect on the social cost of carbon, Nordhaus (2008).

The growth rate total factor productivity (Account for affect in total growth not caused by inputs) and has a mean of 0.0092 and has a standard deviation of 0.0040. The temperature sensitivity is measuring the doubling of the temperature in the atmosphere it assumed that the mean is a world average temperature increase is 3 ° C with a standard deviation of 1.11. The population is measuring the asymptotic level of the population. The mean is assumed to be 8.6 billion with a standard deviation of 1.9 billions. The damages coefficient is measuring the damages from climate change. It is measured by fraction of total output.

As the variables are normal distributed it means that 5 % of the distribution lies beyond 2 standard deviation. This means there is a 2.5 % chance, if uncertainty is only about growth the social cost of carbon is going to be above $48.08 in 2005. The table only shows risk concerning one variable, as there may be risks about more than one variable, the overall risk will be higher. (Nordhaus 2008). The risk that has the highest effect on social costs of carbon is the impact of the temperature increase (Damage Coefficient).

But also the risk surrounding growth and temperature sensitivity seems to have a big effect on the social costs of carbon

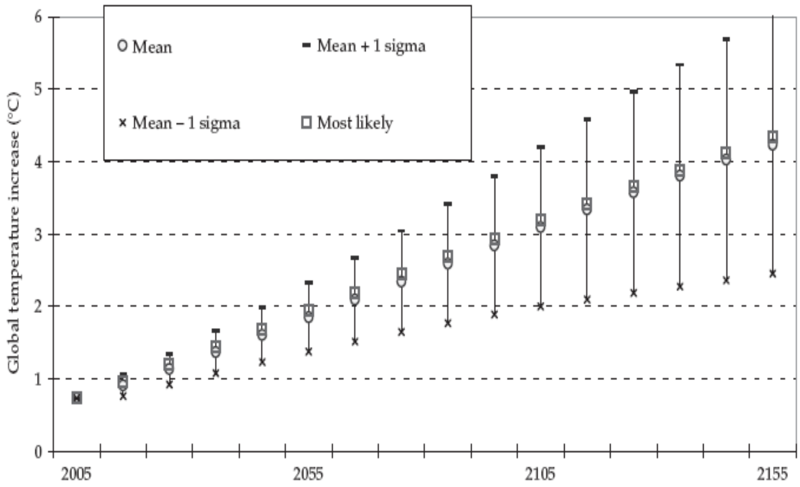

Figure 14. Risk of temperature increases, (Nordhaus 2008 p. 135)

Figure 14 shows the temperature increases from the 100 runs of Monte Carlo testing assuming that there is no active policy. It is clear to see that there is huge uncertainty about temperature increases, even inside one standard deviation, which means that 16% risk of temperature is being above the upper limit (68 % of all observation lies within one standard deviation as it is a normal distribution). In 2055 it is clear to see that temperature increase within one standard deviation has a risk of getting over 6 ° C. It is also clear that there is more risk about the temperature increase the further out in the future they are. A risk averse population will be concerned about the possible consequences as consequences may be much higher than the expected consequences.

Ackerman & Finlayson (2007) consider how model changes will affect the Dice model. They work in the original DICE model that has a 3% discount rate that falls to 1% over the 300 years. They argue that it underestimates the damages and that increases the damages. They make three changes. First, the way the model is build may underestimate the damages. The Dice model estimates the damages from the following formula.

$$D = -0.0045T + 0.0035T^2$$

This means that people are willing to pay for a warmer climate up until 1.3 ° C above the 1900 level. Ackerman & Finlayson (2007)) remove the first term, as statistics show that only a handful of the coldest countries are increasing their welfare from the temperature increase over the next 25 years. Furthermore they increase the impact of climate change so that it is in line with the IPCC estimates. They argue that even though that declining discount rate starting at 3% it falls too slow and it is still making the future damages insignificant. Ackerman & Finlayson (2007) makes a simulation with a 0 discount factor. He also includes a scenario where all the changes are included.

Assuming the original discount rate combined with the other scenarios they find that the social cost of carbon is between $6 and $16 in 1995 and rise to $138- $165 in 2195. If we assume a 0 discount rate and all the other modifications, the social cost of carbon will initially be $197 and rise to $579 in 2195. (Ackerman & Finlayson 2007). In this model social cost of carbon in 1995 may be between $6 and $197 depending on the assumption. The discount rate is the parameter that has far the largest effect on the result, even though increases in damages increase the social cost of carbon in 1995 from $6 to $16. A zero discount rate will increase the social cost of carbon to $197. It is paradoxical that a parameter that is based on personal judgement will have such a big effect on the appropriate price of carbon.

The RICE model is the regional model of the DICE model. The regions can be added up to world data. This means that technology, production growth and population growth are individually calculated for different regions. If technology spreads easy across borders, one may believe that technology shocks may be positively correlated. Developed and developing countries may have very different expectations for growth, technology and energy efficiency. Regional differences are part of the problem as uncertainty about how different regions evolve affects the results. Does China increase energy efficiency or do they continue developing in a carbon intensive way with low energy efficiency. (Below & Persson 2008)

Below & Persson (2008) find that the lower 95 % confidence interval is clearly above 2 ° C and may above 7 ° C in 2105. They argue that behind the severe risk there are socio economic factors, even though there is a great risk about sensitivity of the climate. A big part of the uncertainty is how USA and China develop, as these countries have an expected high productivity with low energy efficiency and dirty energy. Another reason could be higher expected population and production growth in populous regions, as the lower income countries host half of the population in the world. The most extreme outliers can have a temperature increase of up to 8.9 ° C. This result is primarily caused by high growth and lower energy efficiency in poorer regions. They find that if there is no policy, the average world temperature increase is going to be 4.5 ° C degrees higher than the 1900 level in 2105. A 99 % confidence level is ranged from 3.0 ° C to 6.9 ° C in 2105. They argue that many socio economic drivers play a significant part of the uncertainty. (Below & Persson 2008)

The variation of the temperature increase followed an emission path is severe and thereby there is also big variation of what is considered the appropriate price of carbon

10.5 Critique

Barker (2008) argues that General equilibrium models do not give an adequate picture of observed human behaviour both at individual level and on macro level. It is unsupported by empirical data. The continued use of equilibrium assumption in models and cost benefit analysis is that it makes mathematical computation easier. A severe failure is that models often are based on one year's data. He argues that analysis should not only build on cost and benefit, but should be an multidiscipline exercise using insights from other analyses such as social science, climate and geographical science, ethics, history, engineering and evolutional theory. He argues that intergenerational externality is an ethical question. Engineering history should be used in studying policies of GHG mitigation through studies of processes involving supply and demand. It should in particular study the possibilities of how to accelerate the decarbonisation of the economy. Economic history is important in understanding how emission policy effects economic development and technical change. This is because the policy evolves over the time scale that is longer than the life of most energy using capital. Politics of mitigation requires an unstable alliance between governments and political parties. It may be argued that policy is not made from governments looking objectively on a welfare function. Governments act in national interest and not in world interest. Economic geography and history may provide information of how economics grow and how technology diffuses and evolve.

Cost benefit analysis builds on that individual preferences can be fixed and utilities can be aggregated into a well-behaved mathematical welfare function that can be differentiated to give stable marginal properties, which climate policy can be build on. An assumption that is needed is that natural resource can be exchanged for money at any time and be change back at any time. That is to say that there are no irreversible effects. Uncertainty has been ignored and asymmetric risks of irreversible long-term damage are reduced to certainty equivalent[1] damages, which have been discounted and compared to the short term abatement cost. Barker (2008) argues that this makes cost benefit analysis inadequate in climate policy and may lead to misleading result.

A serious problem in the marginal analysis is that the marginal analysis is only concerned with small changes. The first problem lies in that future cost is not known in advance and that policy is not going to affect these costs and it may be argued that low cost policies can be expected to develop as price of emission becomes higher. A second problem is the non marginal nature of the economics. Technologies and innovation may change the economy non-marginally as we are moving from fossil fuel intensive economy to an economy based on renewable energy. This is because different mixes of technology are highly unlikely as there is economic of scales and technology lock in effects. (Barker 2008)

A problem is that most analyses are not concerned with equity. At the same time the politicians are concerned with wealth there are also concerned about distributional issues. Turner argues that the analysis should consider distributional matters. To include distribution matters. Kriström (2003) argues that distributional weighing should be included in the analysis, which means that there is going to be put a higher weight on costs and benefits that affect the below average income groups.

Paradoxically, it may be that the countries that have contributed least to Global warming and that the countries that least can afford it, are going suffer most from climate change, as these countries are located in warmer regions. Stavins (2000) is of the opinion that countries, that primarily have created the problems and the countries that best can afford it, should take on responsibility and most of the costs.

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[1] The certainty equilant is the fixed net benefit that will make the agent indifferent between getting the fixed net benefit and the random benefit. When people are risk adverse the certainty equilant will be below the expected benefit. The difference between the certainty equilant and the expected value is called the risk premium, e.g. the amount that people are willing to pay to avoid the risk of the project. (Stæhr 2006)

If people are precautionary they may want a higher abatement as the risk is associated with the damages are much greater due to the irreversibility of the damages and the non linearity of the damages than cost of abatement. (Barker 2008)

10.6 Extreme Events

Hallegatte et al. (2007) analyse extreme events in a model that allows disequilibrium in the short run, but has equilibrium in the long. This is because general equilibrium models cannot capture the effect of short run shocks. He argues that climate change will involve mainly short-term disequilibrium processes, as there may be sudden sharp consequences on production from flooding, hurricanes etc that may affect the production.

Hallegatte et al. (2007) modifies a neoclassic model by introducing shocks and delays into the adjustment of economic variables. All factors are rigid and cannot suddenly move to where it is most optimal to use resources if there is a shock in the economy. This means that there is not full employment all the time, as there may be institutional technical constraints that may delay full employment. Wages are rigid in the short term, but they will eventually increase to restore full employment if labour supply is below the demand. Investments cannot suddenly move to where they are most effective if there is a sudden surprise, because resources may be caught up in other projects at that time and cannot immediately be transferred. (Hallegatte et al. 2007)

Hallegatte (2007) analyses large-scale extreme weather events, which is defined as rare climate events causing significant capital destruction over a period. This can range from cyclones to several weeks of flooding. Research shows that in future extreme weather will become more frequent, because of temperature increases. The disaster primarily destroys productive capital. Consider the case where capital is immediately destroyed after the weather event. Normally an extreme weather event will affect capital randomly regardless of its effectivity. It may be argued that investments after the disaster will first go to replace destroyed capital rather than to building new capital, as it is more effective. But some empirics has shown that this is not always the case, as the damages after the flood in Germany in 2002, which would be compared to 10 days of Germany's investments, was reconstructed over 3 years. A source of friction is that consumers and insurance firms and public organisation need time and there may be a high amount of money and resources that has to be made free for the reconstruction. To simulate this Hallegatte et al. (2007) binds the amount of a countries investment that can go to reconstruction. Table 7 shows how the cost of different shock if an economy only can use certain part of its investment regenerating destroyed capital. In the case where 5% of the country's investments can go to reconstruction, a shock that has a direct cost of 5% of GDP will end up costing totally 7.86 % of GDP. If the country is only able to use 1% of its investment on the same event, it will cost 22.06% of GDP.

Shock	**10%**	**5%**	**3%**	**1%**
1.25	1.14	1.26	1.41	2.18
2.5	2.51	2.98	3.60	6.64
5.0	5.98	7.86	10.32	22.06

Table 7: (Hallegatte et al. 2007)

It is clear when the world is uncertain and people are not able to plan ahead, costs may be severe. In a model with perfect foresight people are able to plan their investment, but in this model resources are not around to reconstruct the economy, as resources are bound by other projects, which are less profitable than reconstructing the damaged capital. This is due to factors cannot be moved without a delay and planning of other project was made without considering the surprising disaster. As investment to reconstruction goes slowly and extreme weather events become more frequent, it may cause that the overall growth will be reduced. It is clear that the damages of climate change are going to be higher when resources cannot be moved immediate to suit a new situation after disaster. This means that the appropriate level of abatement is higher as the damages goes up. But as the world is uncertain and people have cognitive limitation resources will not be used optimally in the first place, which means that the cost of abatement goes up, hence the appropriate abatement goes down.

10.7 A precautious view

Baer & Mastrandrea (2006) are looking at climate change policy from precautionary view. Environmental scientist argue that if the temperature rise beyond 2 ° C above the pre industrial level then it would moves us beyond normal range of long term variations and should be avoided.

Even though that there are consequences up until 2 ° C such as increased flooding, droughts and malaria, the consequences become more severe if the temperature reach 2° C. This is because at 2 ° C there is an increased risk that the Greenland Ice sheet starts melting irreversibly, which will accelerate the rising of the sea level and will lead to that the sea level will rises 7m. There may be risks of abrupt changes in the atmospheric circulation (monsoon). There will be rising risks of the west Antarctic Ice sheet melting irreversibly, which combined with the melting of Greenland will lead to a 5-12 m increase in sea level. A substantial part of coastal areas will face flooding. Around 5% of the current population (270 million people) will be affected. Many major cities are likely to be abandoned unless flood defences are built. As temperature increases to 3° C and 4 ° C more people will die from malnutrition, malaria and more areas are going to be flooded and the ecosystem is going to weakening. There is risk of loosing the artic tundra and the Amazon. (Stern 2006).

Baer & Mastrandrea (2006) adapt this view and are trying to look at different emission paths and the likelihood that they may result in a temperature increase above 2 ° C. They argue that a precautious policy should secure 80-90% chance that the peak in the global mean temperature stays below the 2 ° C. They use Monte Carlo analysis to try to reveal the risk of the model. Then they calculate the number of runs when the temperature exceeds 2 ° C as percentage of all the runs.

Table 8 shows different emission reduction path risks of getting temperature increases above 2° C or 2.5 ° C. In all scenarios the policy starts in 2010 and when the maximum rate of emission reduction is 3% or 4% the world's emission will peak in 2014, except when the maximum decline is 5%, emission will peak in 2013. The fifth column shows the scenarios level of emission in 2050 compared to the 1990 level. The scenario where the emission will fall 5%, will have a carbon concentration at it highest point at 432 parts per million (ppm), which is measuring the concentration of carbon in the atmosphere. The preindustrial concentration of emission in the atmosphere is 280 pmm and currently the level is 430 ppm.

	Peak Co2	Pct > 2.0	Pct.>2.5	Emission in 2050
3%	441 ppm	20-49%	5-13%	52%
4%	435 ppm	16-43%	3-11%	25-43%
5%	432 ppm	12-32%	2-10%	19-29%

Table 8 (Baer & Mastrandrea 2006)

Table 8 shows when reduction of carbon is high there still is a significant risk of getting above 2° C. In the emission scenario where the maximum yearly emission reduction is 5%, the risk that the world average temperature is going to be higher 2.0° C, is 16-43% while the risk of getting over 2.5 ° C is 2-10%. To reach this goal the emission needs to be reduced to a level that is only 19-29% of the level in 2050, which means that the emission has to be reduced between 71 and 81 % below the 1990 level.

To many these reduction will seem political impossible, as they have high initial emission reduction. Table 9 below calculates some more gradual changes. This reflects the common stabilisation policies. Baer & Mastrandrea (2006) argue that the debate on stabilisation policies is misplaced. First they argue that the uncertainties about carbon sinks, which is ability of the earth to absorb carbon, make it very uncertain which level of emission leads to stabilisation. Secondly they argue if it was possible to achieve emission reduction adequate for stabilisation, there is no oblivious reason to stop reduction below the peak, because in this case the temperature may still continue to rise. Table 9 shows the risk of different temperature increases of different policy stabilisation goal in a simulation that runs over the next 200 years.

Stabilisation goal	Pct> 2,0	Pct>2.5	Pct>3.0	Pct>3.5
450 ppm	46-85%	21-55%	11-24%	4-11%
500 ppm	70-95%	36-77%	18-47%	11-24%
550 ppm	79-99%	55-88%	28-71%	17-19%

Table 9: (Baer & Mastrandrea 2006)

With these more sequential goals it seems less likely that world average temperature increases less than 2° C over preindustrial level in the next 200 years. If the stabilisation goal is 450 ppm then there is in the model a 46-85% risk of getting above 2 C. The higher stabilisation goals have a smaller cost, but it is also clear that the risk of higher damages increases.

10.8 Technology in a non-equilibrium model

This section considers model focuses on endogenous growth in a climate model. Barker et al. (2005) argue that the past 200 years have been characterized by ongoing fundamental changes rather than converging around equilibrium. Technology is important in climate change for two reasons. First, the technology has allowed climate change to happen. Secondly, it is argued that a low carbon society may require development and deployment of low carbon technology. (Barker et al. 2005)

In the model long run growth and technological change follow a historically led growth of cumulative causation and demand led growth, which focuses on investment and trade, and technology is a part of investment. Growth in this approach is dependent on the investment in new technologies. It tries to identify the endogenous technology effect on energy and export demand. This allows for further changes in technology can be induced by policies. In addition, substitution of fossil fuel energy by non fossil fuel energy is implemented in a non linear form trying to take account for investment, learning by doing and innovation. This measure allows for that induced technology can be modelled. The modelling explains how low carbon technologies are adopted as the cost of fossil fuel increases. A tax programme or a permit programme will then induce extra investment in low carbon technologies. Costs are declining relatively to investment and innovation. The process of substitution is considered to be highly non –lineary, as technology may take over faster and faster as it is developed.

There are three stabilisation goals of different emissions in the atmosphere in table 10. Table 10 shows the price of carbon that is necessary for reaching the stabilisation goal with or without induced technical change.

			Not ITC		ITC			
Scenario								
Pmm	**2020**	**2030**	**2040**	**2050-100**	**2020**	**2030**	**2040**	**2050-100**
550	27	74	110	147	16	32	49	65
500	59	119	178	238	27	54	81	108
450	184	368	551	735	108	216	324	432

Table 10: (Barker et al. 2005)

The table shows, if the technological change includes Induced technology change, then the price of carbon required in reaching the goal is around half in comparison with no induced technological change. Furthermore it is argued that 550 ppm and 500 pmm can be reached by relatively low costs, while a 450 pmm requires fast and very high costs. This is because the easier low abatement costs options have been exhausted and it has become costlier to lower of the carbon emission even further. In the power sector fossil fuels fall and the renewable energy increases. Increases in the price of carbon help to accelerate this effect. The growth rate is hardly affected by the decarbonisation partly because energy demand and supply is only is around 3-4 % of the rest of the economy. Induced technological change has a big effect on growth, as employment shift from traditional sectors to a modern sector, especially in the developing countries. (Barker et al. 2005). Induced technology change will reduce the abatement cost, which means that a higher abatement may be appropriate.

10.9 Discussion

Putting probability on the different parameters is not in line with the Keynesian uncertainty, as it is impossible to know the future. Even though there is many things about the future that are unknown, it may it may still be possible to say that one result is more likely than results subject to the current information available. Putting mathematical probability may make politicians blind to the uncertainties of reality. This is important because probabilities only apply to the model. It is a model result, which may help us to make a decision in the real world. The distribution of the model should build on what, according to the scientist, it is reasonable to expect and should rely on the current research and information. Because of the complexity of the system there are a wide number of reasonable distributions for climate sensitivity. Since different probabilities of distribution lead to different model outputs, there are also a range of reasonable estimates associated with any policy scenario.(Baer & Mastrandrea 2006).

There are two kinds of views when it comes to simulate people's time preferences. For ethical reasons scientist may select a discount rate close to zero. Neoclassic economists do, however, argue that the discount rate is significantly higher, about 1.5% or up to 3%. Nordhaus (2008) shows that different time preferences lead to a choice between prices of the permit of $28 – $298 in 2005. Ackerman & Finlayson (2007) find that different reasonable discount rates lead to a difference in the price of carbon between $16 and $197 in 1995. Assuming different time differences lead to very different result as the cost are in the present and the damages are in the future.

Different opinions about the discount rate lead to very different policy recommendations, as damages are out in future and costs of abatement are faced currently and a high discount rate puts less weight on future net benefits. As the discount rate reflects people's preference and the discount rate may change over time, it is impossible to come up with an objective measure for it, and there can be argued for very different discount rates. As it is impossible to set the discount rate, it may be argued that it is better to present the government with the consequences and the risks and uncertainties of different emission paths, and then let the government decide how they want to value the present and future, instead of presenting a net present value from a model that has an ambiguous discount rate. In this way the ambiguous subjective selected discount rate is not going to decide the climate policy.

Discounting is still necessary to model the individual behaviour over time and when there is uncertainty about the future, it may be argued for the use of a declining discount rate. Different discount rate can be used to produce model results as it is impossible to know peoples preferences and these may change in future. The different discount rates can be used to establishing different potential emission paths that may help the government to make decisions. But it is important not only to provide a single net present value to the government, which might make the government blind to the real damages and uncertainties that a policy may have.

Models try to estimate the best use of resources. General equilibrium models fail in doing this appropriately, as they assume that resources can be used optimally, as there is perfect foresight. Resources cannot be moved around and there will losses when economies are hit by surprising shocks. General equilibrium models do not take account for that there is something that we do not know. Furthermore it is argued that an equilibrium model does not reflect the real world as the economy changes over time, especially when it is over a long time period, as the economies structure is going to change many times over for example the next 100 years.

The models that do not include equilibrium seem to have higher costs than other models, as resources cannot be used optimally. Furthermore there may be structural changes that lead to lower energy use. The technology induced model shows how policy may help the induce low carbon technology that may help to restructure the economy towards a low carbon economy, as action now through low carbon technology may cause that it easier in future to follow this paths, as the future growth and technology is led by future cumulative causations. This means that future builds on current and future actions and you may get lock in a certain policy or technology path.

In setting a reasonable price of carbon there are two sets of thoughts. The one is the risk averse thought which leads to big immediate cuts in emission in the battle to avoid the uncertainty that follows from the global average temperature getting above 2 ° C. It is argued that the risk averse policy may require emission cuts by 2050 that are 80% lower than the 1990 emission level. The other view is that the policy makers should make a sequential reduction and reach a goal around 450 ppm and 500 ppm. There is, however, the risk of the average world temperature increasing above 2° C or even 3 ° C. But they argue that the abatement costs are higher than the benefits of avoiding the consequences and the uncertainties. It may be a reasonable to chose a risk averse policy and start to reduce the emission, as Stern (2006) argues that it will cost around 1 % of GDP, while the cost in the future may be up to 20% of GDP and irreversible.

In a risk averse policy the cost of carbon is well above a policy that of smaller more sequential reductions. It may not be plausible to make a policy that is risk averse, as it seems easier politically to get a goal through that cost less now but cost more in future.

Induced technology growth may lower the cost of a risk averse policy, as firms are starting to improve the technology and thereby lowering costs significantly, which means that the risk averse cost of carbon may not be so high. The question is if the government is willing to introduce a permit programme that leads to a price of carbon let us say of a $100 in the near future in order to secure the relative risk averse policy. The G8 are, however, starting to talk about a reduction that keeps world average temperature below 2□ C. The question is if they are able to follow this up when they start to talk about emission reduction and abatement costs for the individual countries. When considering that there is uncertainty of irreversible big consequences, it seems sensible to accept high abatement costs in order to try to lower the uncertainties about the future. It is, however, important to say that both lines of thoughts do although argue that action beyond the current Kyoto Protocol is necessary.

11. Conclusion

It is clear that there is a high degree of uncertainty about climate change in future. It may be argued that policy makers should take a risk averse position towards climate change, as there may be big irreversible consequences, and the public good nature of climate change makes it impossible to reduce the risk by dividing the risk on many individuals. It is also being argued that damages due to that they are irreversible should not be discounted, because it makes the irreversible damages insignificant as they are in far out in future.

It is clear that using incentives based policies will reduce the costs of the policy, but should the policy makers rely on a tax programme or a permit programme? Simulations shows that a tax programme will perform better than a permit programme. This reflects a high discount rate that reduces the weight of the uncertainty in future. When looking at it from an uncertainty point of view, taxes will perform better when the uncertainty is on the costs of abatement, while a permit programme will perform better when uncertainty is on the damages. It may be reasonable to argue that uncertainty about the damages is higher than the uncertainty about the abatement costs, as damages are in the future and we still have limited knowledge about how climate change works. When there is uncertainty about the costs and benefits, the discount rate may increase, which may favour a tax programme. But when the discount rate is uncertain the discount rate may be declining over time, which may favour permit programmes. Permit programmes seem to perform better when there is uncertainty about future. The choice of discount decides if uncertainty in future is important. A high discount rate means that the uncertainty about future is not important.

Supporters of a tax programme argue that the relevant policy period is relatively short and that a tax would perform better, which means that the marginal abatement cost curve is steep and the marginal damage curve is flat. They argue that there is a double dividend, which may help to reduce the income tax distortion. A higher discount rate may favour a tax programme as the uncertainty of the future weighs very little. They argue that people do in fact value present consumption higher than future consumption and low or zero discount rates may increase the investment for the future and pillage the current generation. But the model shows that the tax has to be increasing, as the social cost of carbon increases with the concentration of carbon emission in the atmosphere. This may lead to faster extraction paths of fossil fuels which may undermine the policy, as the suppliers expect to receive a lower price in future. In a permit programme the quantity of emission is locked, which means that suppliers cannot increase the emission.

A permit programme also performs better if the policy cannot be changed over long periods, as the marginal abatement curve is flat over long periods and the marginal damages curve is steep. It may be argued that the price of carbon has to be effective for a longer period, as it makes it easier for firms to plan their investments. The drawback of a permit programme is that all the expected trade gains will not be fulfilled when there are transaction costs, and a tax programme will have better costs efficiency than a permit programme.

It may be argued that a risk averse government will be prefer a permit programme rather than a tax programme, as a permit programme reduces the uncertainty about the damages, which, as it is argued, are higher and are in the future. If the initial stock of green house gases in the atmosphere is high, it will favour a permit programme, as the damages and the uncertainty about damage increases. A permit programme will also work better across borders, as it is hard to harmonise taxes across borders, as countries has different tax systems. A hybrid model may be recommended if the governments are concerned with price fluctuation. Furthermore auction over the permits reduces the uncertainty about the right initial allocation of permits, as the firms that are willing to pay the most for having the highest abatement cost.

Policy makers cannot just make a policy in a model, as a model is not able to reveal all uncertainties and it relies on different assumptions. The probabilities of a model only apply to the model, as it is impossible to put probabilities on uncertain events in future. A model cannot include all uncertainties or surprises, as there are unknown conditions, and it cannot give an accurate picture of the uncertainties. Models should, however, build on what is reasonable to believe with the information that is available. There may, however, be many reasonable estimates for the different emission scenarios.

This means that risk averse policy makers need to make the precautions that they feel necessary. The damages in future are big and irreversible and the policy makers may want to adapt a policy that is more cautious and adapt an emission reduction that is higher than risk neutral models tell them, as the models cannot cover all the uncertainties and uncertainties are bigger regarding the future damages than regarding the present abatement cost. It is important that the policy makers take action, even though there is limited information. If policy makers decide to wait, they will lose the net benefits from the policy in the period where no action was taken.

It is argue that a risk averse policy is a policy that keeps the average policy below 2° C. It is argued that sharp cuts in emission is needed to reach this goal and it may be necessary to reduce emission by 50 – 80% below the 1990 level by 2050 depending on how risk averse the government is. This will of course reduce the damages, but it will also increase the abatement costs. Other economists focus on the costs and argue that strict emission cuts makes abatement costs higher than the avoided damages. This is primarily because they assume a high discount rate that makes future damages insignificant and because they have risk neutral view.

12. References

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