On the optimal allocation of green-technology under climate change agreements

David Schüller

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Preface

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All remaining errors are my own.

David Schüller

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Abstract

This thesis investigates if a technology transfer mechanism can help to reach a cooperative outcome, in a game on a climate change treaty that involves emission caps for both developed and developing country. A climate change treaty without the inclusion of developing countries and their acceptance of emission limits is likely to be ineffective. Too little research and development of green-technology is currently undertaken, considering its potentially global impact especially in developing countries. Analysing a simple game with two asymmetric players, a tentative result is that the technology transfer mechanism considered here cannot help to establish the cooperative outcome as a Nash-equilibrium. However, the inclusion of secondary benefits in the payoff function, which are likely to occur when such a transfer takes place, could change this result.

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1. Introduction

> *"Two neighbours may agree to drain a meadow, which they possess in common; because it is easy for them to know each others mind; and each must perceive, that the immediate consequence of his failing in his part, is the abandoning the whole project. But it is very difficult, and indeed impossible, that a thousand persons shou'd agree in any such action; it being difficult for them to concert so complicated a design, and still more difficult for them to execute it; while each seeks a pretext to free himself of the trouble and expence, and wou'd lay the whole burden on others" (Hume 1740, p.538)*

The problem of organization of cooperative effort among a large number of people described above by the great philosopher David Hume is a most basic one which has re-occurred countless times throughout human history. Tribes needed to organize their daily activities so that everyone is fed in the evening without being able to control the effort of all members at all times. During the First World War, soldiers stuck in trench warfare who were opposing each other for extended periods found a mutual agreement, finally without tacit cooperation, which allowed both sides to survive for some time (Ashworth 1980; Axelrod 1984). Though cooperation got initially started verbally, this was quickly suppressed by superiors. Without this mean to establish cooperation, each battalion would fire at the same spot at the same time each day so that the other side could prepare and eventually reciprocate. This system was later broken-up by raids, which made it impossible to leave the enemy unharmed. In modern day large scale companies the employer must find ways to induce workers to exert their best effort even if the employer does not possess the information, what level this is and has no legal way of obtaining such information.

What about cooperation on an aggregate level such as cooperation among nations? Whereas such cooperation on an international scale in the past was often limited to a few nations with a clear goal, for example the defeat of Nazi Germany or lowering trade barriers simultaneously; issues that require international cooperation today tend to be inherently more complex rendering cooperation often difficult to achieve. In the case of the depletion of the Ozone layer cooperation succeeded via the Montreal Protocol on Substances that Deplete the Ozone Layer and later amendments.

The problem that arguably currently looms darkest on humanity's horizon is the issue of global climate change. Scientific consensus today points towards human activity as one of the main drivers of this change (Stern 2007; IPCC 2007a). To be clear, the science is still riddled with uncertainties. But though it is sound, science does not always translate well into action. In his book "Predictably Irrational - the hidden forces that shape our decisions" Dan Ariely (2008) describes a series of experiments where people, when giving the opportunity tend to cheat, at least a little. More importantly, they tend to cheat a lot when money is not involved directly. Even if the tokens that they receive for the outcome of an experiment where exchanged seconds later into money, the rate of cheating increased dramatically compared to receiving money directly. Concerning the issue of international climate change negotiations this insight from psychology is a saddening one. States are sovereign and cannot be forced by others to adhere to an agreement or to pay fees for non-compliance, offering room to "cheat". A cap-and-trade system of green-house gas emissions is seen by many as the vital component of any such international agreement. But such a system, by removing money as a direct medium of exchange, may then drastically increase the chances of states cheating one another, or not engaging in any sort of cooperation at all. Within the issue of climate change this incentive is even more pertinent as one state might profit more from cooperating than not if all others cooperate, but the benefits are even higher if all but him cooperate, creating a powerful incentive to free-ride.

There are, however, some silver linings on the horizon. The Montreal Protocol succeeded after all and many have looked to it for guidance. Nations tend to stick to agreements if they are "self-enforcing" (Barrett 1994), providing an overall benefit to a country. Furthermore, whereas many games of cooperation assume players to be symmetric, they certainly are asymmetric when it comes to climate change. These asymmetries boost the impact that side-payments, monetary or non-monetary, can have on cooperation.

Many argue that technology should play a more important role than it does today to combat human induced climate change. More specifically, technology transfer to countries that do not possess the technical skills to develop them locally but will be responsible for much of the increase in emissions in the future will be important.

The first question this thesis seeks to address is if such a technology transfer scheme is already in place. A tentative result is that there is no such mechanism in place. The logical question to ask is then what such a mechanism could look like. Finally, this thesis will address the issue if such a transfer can increase cooperation as a side-payment in a new climate change treaty.

The next section will lay the theoretic foundations for the following analysis. It will offer an introduction of environmental-, resource-, development economic literature that is related to the issue of technology transfer, research and development of technology, and climate change. One part will also be concerned with literature on international cooperation and game theory. All parts together should constitute a theoretic basis on which to build an effective climate change agreement.

In the third section the Kyoto protocol will be analyzed based on the economic foundations from chapter one in order to see if it was effective to address the issue of climate change. The three mechanisms of the protocol will receive special attention, as they are the only part of the protocol that addresses technology transfer in some fashion. Section four contains an analysis of the Asian Pacific Partnership on Clean Development, especially with respect to recent literature in resource economics.

In section five the main contribution of this thesis will be introduced, a largely self-conceived technology transfer mechanism under a new climate change agreement with abatement requirement for both developed and developing countries. The mechanism will be analyzed in section six with a simple game with asymmetric players to explore the most important frictions it will face when trying to increase cooperation in a climate change agreement. Chapter seven concludes.

2. Theory and Background

2.1 Public goods, a global stable climate and R&D

A pure public good is commonly defined by two properties: Non-excludability and non-rivalry (Perman et al., 2003). Non-excludability means that no one can be excluded from the consumption of a good. Non-rivalry implies that consumption by one agent does not come at the expense of the consumption by another agent. The classical example of such a good is national defense. No resident of a country can be excluded from its consumption, as in being protected from foreign and domestic foes. Furthermore, consumption by one resident however defined in the context of defense, does not preclude others from being defended. In the case of defense, all agents have an incentive not to contribute to its provision since once it is available they do not have to pay any additional fee to enjoy the consumption of it. States can overcome this behavior by levying taxes on its citizens and punishing tax evasion severely.

All public goods have inherent externalities that would lead to their under provision, if left to market outcomes without a regulation agency. Externalities can also occur in the case of private goods. In general: “An external effect, or externality, is said to occur when the production or consumption decisions of one agent have an impact on the utility or profit of another agent in an unintended way” (Perman et al. 2003, p.134).

This thesis is mainly concerned with the global public good nature of a stable climate. Consumption of a stable climate has been non-rivalrous for most of human history as consumption of stable weather by, for example, an American farmer does not preclude their European counterparts to enjoy a largely predictable season that allows them to plan their harvest and planting cycles. This line of argumentation implies that a stable climate can be seen as natural capital in the process of production (Perman et al. 2003). Without a stable climate humanity would find it hard to exist and production of any goods would be difficult. Also, non-excludability is given as it is up until now technically impossible to “restrict” the usage of a stable climate in a specific region in the world.

With the advent of the industrial revolution humanity started to emit massive amounts of climate relevant gases into the atmosphere, notably CO_2. This happened without taking into account the negative effects that this might have on a global stable climate. The first to mention that human activity might have an impact on the climate was Baron Jean-Baptiste Fourier in 1827 (Fourier 1827). A first estimate of the exact magnitude of this impact was published by Svante Arrenhenius in 1896 (Arrhenius 1896). “The first official recognition came from the US President’s Science Advisory Committee in 1965 when, amongst other things, it noted that climate change could be caused by human activities and could have important consequences” (Agrawal 1998, p.606). In the second half of the 1970s the argument was advanced that more CO_2 emissions would actually lead to a cooling (IPCC 2007a). This was later refuted and it was found that it were in fact aerosols that were emitted alongside CO_2 that were responsible for this phenomenon. “95% of all the climate change science literature since 1834 was published after 1951” (IPCC 2007a, p.98). Climate gases once emitted, stay in the atmosphere for a long-time, about 25% is likely to stay in the atmosphere indefinitely (Archer 2005). This makes climate relevant emissions a stock pollution problem in that if more emissions are released than naturally decay, the stock of emissions increases. Emissions by one country do not only impact its own climate but have a global effect, since it is the accumulation of greenhouse gases worldwide that changes the climate. This makes the problem of human induced climate change a transboundary environmental problem. There is current scientific consensus that if the emission concentration surpasses 550ppm CO_2 the increase in global temperatures will be beyond the critical level of 2 degrees by the middle of the century (Stern 2007). Costs in terms of forgone economic growth and damages would in this case most likely be substantial. Optimally then, to preserve a stable climate and to avoid the loss of economic growth in the future, emission levels should not reach this level taking the natural rate of decay into account.

As the negative stock externality that climate gases have has not been sufficiently taken into account so far by polluting agents, a variety of interventions can be applied to internalize this effect. For example, by levying a tax on the usage of fossil energy, the cutting of rain forests and other climate gases related activities. The optimal level of greenhouse gas emission can be fine-tuned by the tax, as this makes emissions more expensive. Market mechanisms should then lead to a substitution away from production inputs that emit greenhouse gases. Allocating emission permits to all countries at a level that would avoid drastic climate change is the second common solution offered by environmental economic theory. This would establish a shadow-price on the usage of fossil fuels in terms of abatement cost. By allowing permit trade to take place, the marginal cost of abatement would be equalized globally rendering this an efficient solution (Perman et al. 2003). But for most of the time since the industrial revolution began these options have been safely ignored, either due to non-awareness of the stock nature of the problem or the absence of international cooperation which will be discussed in more detail below.

The second important externality issue related to climate change concerns the research and development (R&D) of technologies that help to adapt or mitigate climate change. The output of R&D is knowledge. Knowledge in economic theory is commonly classified as a pure public good. Once produced, no one can be excluded from acquiring it without further protective measures such as patents that credit the inventor. Usage of knowledge by one person does not preclude others from using it, making it non-rivalarous. Knowledge is then produced at a socially sub-optimal level as producers cannot recover their investment as no one is willing to pay for something that is available for free (Jaffe et al. 2005). To overcome this problem, producers of knowledge are granted patents that allow them to restrict access to knowledge and thus recover their investment.

Concerning the issue of R&D related to global environmental problems, Hoel (2005) shows that if countries only consider the impact that R&D has on their own economy whereas the real effect is global, R&D levels on climate technology are sub-optimal. Without an international agreement, countries will only equate the marginal benefit of R&D with the marginal environmental costs within their own borders. But R&D can lower abatement costs globally. Climate technology might still reach other countries due to spill-over effects, but this is a second best outcome as countries will not take this into account when considering on their level of R&D expenditure.

Technological spill-overs can also reduce the “leakage” effect which occurs when not all countries are part to an international agreement that specifies binding emission reductions (Golombek and Hoel 2005). Reduced demand for inputs that emit greenhouse gases when used in a country or sector lowers the international price of these production inputs. The reduced price will then create the incentives for those countries or sectors affected by the agreement to increase their use of the good, increasing emission levels and lowering thereby the effectiveness of any such agreement. Addressing the two issues of global public goods described can only be achieved via international cooperation. Reasons for the absence of cooperation and ways to improve the likelihood of it are discussed in the next section.

2.2 International cooperation

Solving transboundary issues of pollution requires cooperation from at least two states, in the case of climate change cooperation from most of the world (Stern 2007). In contrast to pollution issues that happen within the borders of a state, there is no agency that can force states to adhere to agreements made between them unless they delegate that role to an international agency and decide to give up sovereignty. In the case of human induced climate change this has not happened so far. Agreements must then be “self-enforcing” if they are to be effective (Barrett 1994; Wagner 2001). Agreements are self-enforcing when two conditions are fulfilled. First of all, the payoff for a country must not be driven below the non-cooperative level. Secondly: “… the agreement (must) not be vulnerable to free-riding and deviant behavior by individual countries or sub-coalitions of countries.” (Wagner 2001, p.384). It is then said to be a stable agreement as participation is the best alternative for the member.

However, the incentive to cooperation may decrease the more countries are part to an agreement. It usually pays for countries to cooperate as compared to non-cooperation, but it pays even more if everybody else continues to cooperate and one country leaves the agreement: “The larger are the potential gains to cooperation, the greater are the benefits of free-riding and so the larger are the incentives to defect” (Perman et al. 2003, p.310).

This is similar to the outcome of a prisoner’s dilemma game. In this one-shot game, the payoff for cooperation to both players is higher than the payoff for defection by both parties, but the highest payoff is obtained when one player defects and the other cooperates, the defecting one receiving the larger payoff. As both have an incentive to defect, none of them can be assured of cooperation in a non-cooperative setting. The Nash-equilibrium is then defection by both players. A more formal analysis of this will be given in chapter five. Assuming that countries act as rational players in the case of an international agreement on climate change this will lead to a low number of signatories as they expect defection which in turn decreases their benefit from cooperation. The problem of human induced climate change is a good example of this scenario with some special properties. Since it is a global stock problem, the benefits of one country abating are spread to all countries, which implies that one country is not able to appropriate completely the benefits of its own abatement. Furthermore, the benefits are only occurring in the future which reduces the benefit of abating today even further when taking discounting into account.

Free-riding can also be a problem in treaties even if they have a high level of participation. A consensus treaty is self-enforcing and has a high level participation, but the abatement level that signatories have to fulfill is below the cooperative outcome (Barrett 1999). A treaty of this kind is designed to get as many countries on board as possible, but comes at the price of lowering abatement levels to a point that everyone can agree on. In this scenario all signatories are collectively free-riding. In order to move from this impasse the benefits of cooperation must increase while the cost of defecting must to do so as well.

The economic development of all rich economies today has been heavily reliant on the use of fossil fuels without the before mentioned externality priced into their usage. In 1994 the United Nations Framework Convention on Climate Change (UNFCCC) entered into force when more than 50 parties had ratified it, which was agreed upon at the Earth Summit in Rio in 1992. To this date 192 countries have ratified the convention. By signing, countries took on a "non-binding aim to reduce atmospheric concentrations of greenhouse gases with the goal of "preventing dangerous anthropogenic interference with Earth's climate system." [1] The convention also specified that developing countries would not have to re-structure their economies away from reliance on fossil fuels unless developed countries would provide sufficient funds and technology. This concept has also been embedded in the Kyoto Protocol which entered into force in February 2005.In it, member parties endorse the “common but differentiated” approach which puts the burden of financing mitigation and adaptation on industrialized countries [2]Most of the increase in emissions in the future will be coming from developing countries. The effort of developed countries alone, as specified in the Kyoto Protocol, will not be sufficient to stabilize emissions at a non-critical level or only does so at a prohibitively high cost (Stern 2007).

Another way of increasing the benefits of accession to an agreement is via side-payments, commonly referred to as “carrots”. Side-payments have been shown to be particularly powerful if there is asymmetry between nations: “The conventional wisdom that self-enforcing IEAs (International Environmental Agreements) can not achieve substantial gains when the gains to cooperation are large does not hold when nations are asymmetric” (McGinty 2006, p.4). Intuitively, asymmetry allows for larger transfers of wealth than symmetric conditions. These transfers can help to increase cooperation.

Asymmetry in the context of climate change can be linked to at least three dimensions. Firstly, the marginal costs of abatement differ substantially among countries with developed countries having relatively high costs and developing countries having relatively low costs (Ellerman et al. 1998; Nordhaus 1998). Secondly, the level of R&D activity related to green-technology. This issue will be discussed at length in the next section, but the main result that emerges is that green technology is largely developed in rich democracies. Finally, developing nations are likely to suffer more from damages than developed ones (Stern 2007; IPCC 2007b).

[1] http://en.wikipedia.org/wiki/United_Nations_Framework_Convention_on_Climate_Change

McGinty (2006) focuses on the first asymmetry and suggests that transfers should be implemented "through a system of tradable pollution permits which will equate the marginal abatement costs…" (p.8). When carrying out simulations for 20 nations he finds that exploiting asymmetry under the aforementioned transfer scheme can reduce the free-rider incentive significantly as compared to the symmetric case. Barrett (2003) puts the asymmetry into the Ozone depletion context. He assumes that nations further away from the equator have more to gain from the treaty as they will suffer more due to lighter skin color, and depletion being more pronounced the further away a country is from the equator. His findings are similar in that asymmetry combined with side-payments substantially increases the number of signatories to an agreement compared to the non-cooperative symmetric situation.

In the case of the Montreal Protocol on the protection of the ozone layer, developing countries are reimbursed the incremental cost of accession to the treaty. Incremental costs are those that occur once a party accedes to an agreement. For developing countries, acceding to the agreement then came at no cost. This mechanism was instrumental in increasing the number of participants. But there was also a cost to non-accession: trade sanctions. Non-acceding parties could suffer from trade sanctions as trade between parties and non-parties on chlorofluorocarbons (CFC) substances or goods including them should be restricted. The power of this "stick" is increasing in the number of parties to the agreements as this means larger restrictions. Trade-restriction in this case had the advantage that by not trading CFC containing substances, parties effectively shielded them from the problem of leakage (Barrett 2007). Relocating to a location that allowed CFC containing production was not profitable since with a high rate of participation there was no market to sell the products to. The cumulative impact of this "stick" and "carrot" was to increase cooperation significantly. The incremental cost clause was added to the agreement in 1990 and soon after important developing countries such as India and China joined the agreement (Barrett 2003).

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[2] http://unfccc.int/kyoto_protocol/items/2830.php

Technology transfer as side-payment mechanism in a new climate change agreement seems to have potential to increase cooperation, as it did in the Montreal protocol. But how should a transfer pattern look like? Where is green-technology actually developed? What institutions are essential in its development? These questions are addressed in the next section.

2.3 On the development and distribution of green technology

The development of advanced technology takes largely place in rich democratic countries (Acemoglu et al. 2006; Aghion et al. 2007). For example, about 70% of the technology that is currently transferred under the Clean Development Mechanism (CDM) under the Kyoto Protocol comes from Japan, Germany, the USA, France, and Great Britain (Seres 2007). Certain factors that are common to most democracies seem to be instrumental for the development of these technologies. First, democracies are better at providing public goods such as good quality infrastructure and funding for public research which are vital ingredients to technological advancement (Mesquita et al., 2003; Aghion et al. 2007). Secondly, they provide a more competitive environment than autocratic states by keeping the cost of entry for companies which want to enter a sector at a lower level (Aghion et al. 2007). Finally, they provide a more secure legal environment which allows companies to appropriate the profits from their research (Mesquita et al., 2003).

What are the driving factors that lead to a superior performance of democracies in the field of green-technology? Kuznets (1955) made the prediction that income inequality would increase in the early stages of economic development and then later decrease again, thus follow an inverted U-shape. In the beginning of the 1990’s when environmental data became more readily available a similar argument was made with respect to the quality of the environment. It was argued that in the early stages of economic development, environmental pollution tended to increase and in later stages this development would be reversed, thus following a similar pattern as the income -inequality development relationship (Grossman and Krueger 1991*;* Shafik and Bandyopadhyay, 1992; Panayotou 1993). One of the basic arguments made as to why this phenomenon is observed is that in the early stages green technology is not available or is prohibitively expensive, thus abatement does not take place. Another line of reasoning argues that in the early stages agriculture and resource intensive industry are the pre-dominant economic activities, whereas in later stages it is informational and services industries that dominate which are less natural resource intensive and produce less waste (Dinda 2004). Furthermore, a common observed phenomenon when it comes to increasing material wealth is that people start to attach more value to things that go beyond the basics needs, such as environmental quality. Finally, countries with higher incomes tend to invest more into R&D which often leads to the replacement of dirty technologies with greener options (Komen et al. 1997).

There are four important qualifications to the basic arguments (Arrow et al. 1995). First, the relationship holds mostly for pollutants that have local short-term costs but not for pollutants that involve long-term costs and dispersed effects. Second, the relationship seems only to hold for flow pollutants whereas stock pollutants do not seem to fit the pattern. Third, there might be a leakage effect in that the reduction of a pollutant in one country or sector can lead to the increase in another country or sector. This is essentially the leakage argument as discussed above. Finally, reduction in pollutants usually goes hand in hand with better environmental regulation that stems from institutional change. The argument is then that it is not first and foremost the increases in preference for environmental quality that is the driving factor behind the environmental Kuznets curve, but the ability of a society to translate these preferences into better environmental institutions that drive the development. As with respect to the effect of democracy on this phenomenon it is argued that “Institutional changes triggered by citizens’ demand for cleaner environments are more likely to occur in democratic countries” (Dinda 2004, p.444).

Mesquita et al. (2003) argue that in stable democracies it is by far easier to win election with policies aimed towards the public, then by pleasing a small circle of cronies. In autocracies, a small circle might be enough to ensure the survival of the government, such as high ranking officials in vital military positions. But in democracies where power is less concentrated in the hands of a few the relevant electoral is not the small circle of cronies but a large part of the citizens. Bribing every citizen is then prohibitively expensive and it pays to embark on visible public policies. Polluting companies certainly benefit from not having to pay for the externality they cause to the neighbourhood or to the global climate, at least in the short-term. The cost are then borne by the public and a regulator is needed to enforce the property rights of the public to a clean environment, dismissing the case of the company claiming that it has the right to pollute and citizens are to pay for not suffering from it. Such enforcement of property rights usually necessitates a functioning legal system and low levels of corruption. Mesquita et al. (2003) argue that an independent legal system is only in the interest of the government if the size of the electorate is large enough to switch its focus towards public policies. Also, the scientific expertise necessary to detect environmental pollution and create sufficient documentation to bring the case before courts necessitates expertise that is usually obtained at the tertiary level of education. Mesquita et al. (2003) present statistic evidence that it is the tertiary level of education that represents the gravest risk to autocratic regimes.

Autocratic regimes are often characterized by high endemic levels of corruption. Besides raising the cost of doing business and making the judicial process less reliable, corruption requires a certain level of secrecy which means that the less people that are involved the better. This will reduce the number of firms active in a market and even more so the number of foreign firms entering (Shleifer and Vishny 1993). Since they are often drivers of innovation, the secrecy necessary to carry out corruption is a further factor inhibiting innovation and the development of new technologies. In technologically advanced sectors, having superior technology is often the decisive competitive advantage (Aghion et al. 2007). By ensuring competition in these sectors, companies are then more likely to develop better technology in order to keep or acquire an advantage.

Cohen and Levinthal (1989) argue that a firm's ability to appropriate research depends on its own R&D activity and that publicly available knowledge can increase a firm's ability to do so. Additionally, the more complex technology becomes the more R&D activity is required to adopt it. Then if democracies ensure competition in an environment that has reached a high level of technology, firms will continue to invest in R&D in order to be able to adopt advances in technology.

Another important issue in this context is spill-overs. As argued above, spill-overs discourage investment into R&D as a company is not able to appropriate all of the benefits of its R&D. But if R&D helps to catch the spill-over from other companies, then spill-overs might actually encourage R&D in order to be able to appropriate the research of others.

Rich and democratic countries are the main developers of green-technology (Komen et al. 1997; Aghion et al. 2007). This is not likely to change soon as changes in political institutions as well as changes in wealth necessary to promote R&D for green-technology at a sufficient level often takes decades. In sum, the empirical phenomenon of the environmental Kuznets curve seems largely driven by institutional factors and does not hold for all pollutants, most importantly not the main pollutants driving human induced climate change. Nevertheless, countries with democratic institutions seem better equipped to master the problems related to this global problem as they can translate environmental preferences of their citizens better into effective policies than autocracies. As most of the increase in emissions will be coming from developing nations, technology transfer will be a vital component of any effort to avoid or mitigate drastic climate change. But since it is a vital component of any strategy that seeks to avoid or mitigate climate change and as most of the increase in emissions will come from developing countries, technology transfer will have to take place. What criteria can be applied in order to evaluate the success chances of technology transfer? What are the benefits besides the reduction in emissions? These questions are dealt with in the following section

2.4 Success conditions for technology transfer and benefits

The Green Revolution in agriculture that started in the 1930's with research conducted by Norman Borlaug reaching Asia and Africa in the 60's and 70's, serves as an illustrative example concerning the success conditions for technology transfer. It was by far more successful in Asia than in Africa and a substantial part of the divergence in results can be attributed to the different educational levels in the two continents (Kapur and Crowley 2008). Local universities and research institutions played a decisive role in adopting the technologies to local circumstances: "Thus, in the absence of domestic skills, even global public goods (embodied in this case in the green revolution technologies) have very limited payoffs." (Kapur and Crowley 2008, p.13)

As argued above, tertiary education poses a significant threat to a regime. Therefore, a high level of tertiary education among the population is more likely to be observed in countries with democratic institutions. What drives this result? University education generates externalities for society at large that are hard to quantify (Kapur and Crowley 2008).For example, a stronger belief in freedom and universality. The presence of externalities would lead to an underprovision of tertiary education if no intervention by the state takes place. In addition, these values challenge the foundation of any oppressive regime which makes sub-optimal provision even more likely. A look at the current scale of public funding when it comes to tertiary education reveals that this problem has been recognized (OECD 2007).

Another variable that plays an important role when it comes to the success of technology transfer is the level of corruption. Vishny and Shleifer (1993) argue that in countries with high levels of corruption there is an unusually high demand for technology that is too advanced given the technological level and skills present. However, it is much easier to collect bribes on too advanced expensive technology than on technology that can be supplied by several producers. Especially if aid money is used in the process which would require several potential suppliers biding for the contract, choosing a technology that is only supplied by one company and much more expensive is the more attractive option. Empirical studies have shown that corruption and other institutional variables are highly correlated with tertiary education and vice versa (Mesquita 2003, Kaufmann et al.2005). For example, low levels of corruption are often found in countries with a high level of education and a reliable rule of law. How exactly these variables influence each other and how the causality runs is still subject to research. However, this indicates that the before mentioned institutional variables can serve as indicators of the success chances of technology transfer. On a more general level, the International Environmental Technology Transfer Board established several criteria that can help to determine the success of technology transfer (MacDonald 1992). First of all, there should be local demand for the technology. Secondly, local entities must be informed about the availability of technology which requires a good informational network. Thirdly, a supporting infrastructure must be in place both in terms of capital and trained labour. Fourthly, the transfer must be economically viable in that it strengthens the local economy. Fifthly, there must be sufficient financing, especially in the initial stages of the project. Finally, the technology must be appropriate to the context which can be facilitated by cooperation with local research institutions.

What are the potential benefits of technology transfer? Developing economies often experience increasing returns to scale in the initial stages of development (Murphy et al. 1989). In the model that Murphy et al. (1989) present, there are several industrial producers, none of which can produce profitably unless others use and pay for public infrastructure as well. Furthermore, one industrial producer creates demand for the others' products by paying a wage above the agricultural wage level which allows for spending on more industrial goods. This is a variant of the Big-Push argument introduced first by Rostein-Roda (1943) that coordinated investment can help to jump-start industrialization when for each producer individually it is rational to not embark on this path.

A relevant question is what kind of energy infrastructure will be erected to support the process of industrialization. To this day most developing countries and especially the larger ones such as China, India and Brazil have predominately based their energy infrastructure on fossil fuels (IEA 2008). This can partially be attributed to considerable subsidies for fossil fuels, missing development of green-technology locally and missing information about the availability of such technology from developed countries (MacDonald 1992; Darmstadter 2002). Technology transfer can help to turn resolve the issue of missing information and locally missing development. Subsidies are however a political issue and face potentially the largest obstacle to a green-energy infrastructure.

In conclusion, technology transfer can have a substantial positive impact on the development of a poor country. But often in the past it has failed to achieve its full-potential due to lack of consideration of institutional factors that play an important role in determining its success and the lack of understanding of how to change these institutions over time.

2.5 Resource markets and green technology

One of the most important results in the resource economics literature is the Hotelling rule (Hotelling 1931). It derives the optimal development of the price of a non-renewable resource over time depending on certain assumption. Assuming zero extraction costs, the price of a non-renewable resource should increase at the social rate of discount. This is the intertemporal efficiency condition for an efficient extraction path. One implication of this is that the discounted price of the natural resource is constant over time, which is a reformulation of the general asset-efficiency condition. The Hotelling rule is then a necessary dynamic efficiency condition, but sufficiency is only achieved when one also considers the static efficiency requirements. Static efficiency in this context requires that whatever use a resource is put to, its marginal value should be equal to the marginal value of the resource stock in situ (Perman et al. 2003). In situ means resources left in the ground. Resource owners are then indifferent between extracting the resource in order to invest the proceeds and leaving the resource in the ground.

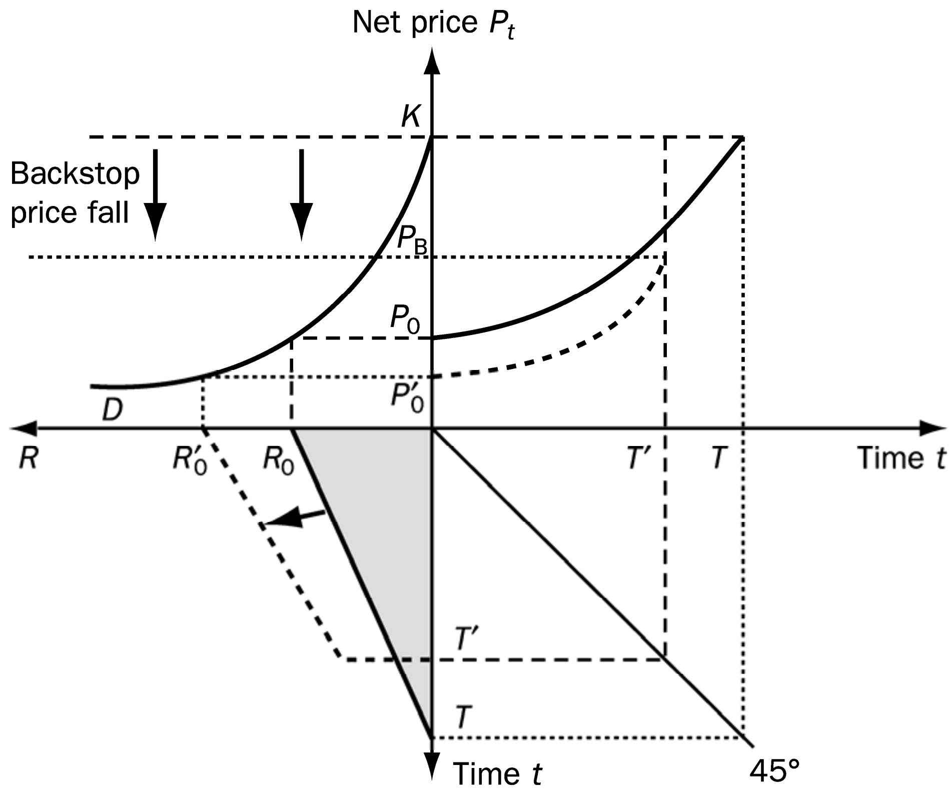
There are four main complications that run counter to the assumptions made when deriving the Hotelling rule when confronting it with actual properties of non-renewable resource stocks. Firstly, the total stock of a resource is usually not known with certainty *(*Perman et al. 2003). Secondly, over time there will be new discoveries. Thirdly, there is a difference between the total stock available and that which is economically viable to extract. Finally, R&D can change extraction costs, replace the non-renewable resource by a renewable one and can give a clearer image of the damages expected from extraction.

The Hotelling rule is of significant relevance concerning the issue of human induced climate change since the emissions causing it come from non-renewable resources. By considering the Hotelling rule and the four mentioned complications one can arrive at an extraction pattern which corresponds to different emission scenarios. Since we are considering a stock problem, the goal should be to flatten the extraction path of non-renewable resources that emit greenhouse relevant gases and thereby lowering the amount of emissions at every point in time (Sinn 2007). Sinn considers several policy measures that are available to achieve this outcome. By announcing a decrease in the ad-valorem tax today, governments would provide producers with an incentive to extract at a later point in time. The problem of this policy lies in fact that governments would have to commit to reducing taxes in the future, which is problematic at best. A second measure is a constant unit tax on carbon extraction. In order to be effective it should be constant over time and it should be applied uniformly world wide in order to avoid leakage effects. Another solution would be to subsidize the in situ stock, in effect paying resource owners to not extract. The political infeasibility of paying quasi-regimes that already derive large resource rents renders this option unfeasible. Taxing capital income would slow down the rate of extraction as investment of resource derived income becomes less attractive. This could however lead to a sub-optimal accumulation of capital in the world economy. A more viable step would be to close tax havens in order to ensure equal taxation of resource owners.

Sinn also makes the argument that if resource owners feel unsafe about their property rights, they will increase the speed of extraction as they cannot be sure that they will be able to derive income from the resource in the future. Finally, binding emission constraints reduce the price of the resource because they lower the demand for emission related products by increasing the price of the final product. By setting an upper limit to allowed emissions and by sufficiently broad participation a ceiling would be established that ensures that critical limits will not be reached. Since the Kyoto protocol currently only restraints a minority of worldwide emissions a more inclusive climate change agreement is necessary to render this strategy effective. Without broad participation lower prices for fossil fuels in one region will increase the demand for them in others, the leakage effect.

What is the impact of better green-technology development and dispersion? Abatement costs will be lowered and the incentives to switch from fossil to renewable fuels will increase. The effects are illustrated in the following figure adopted from Perman et al. (2003)

Figure 1: Effect of a fall in the price of a renewable energy technology on the consumption of a non-renewable energy source



Source: Perman et al. 2003

More R&D and better dispersion of green-technology are likely to reduce the cost of abatement and encourage the usage of clean fuels as compared to fossil fuels as their price decreases, the backstop price in the figure. With a lower backstop price P_B , given the demand curve D, the resource owner can only charge P_B at the end of the extraction period since above this price all consumers will switch to the backstop technology. Two important assumptions underlying this figure are that all of the resource will be extracted and that the backstop technology is available in amounts that can satisfy any level of demand for it. The curvature of the curve that describes the development of the net price over time is determined by the social discount rate, following Hotelling's rule. The fall in the backstop price does not change the social discount rate. Therefore, the curvature or increase over time does not change. Given the same increase of price over time, the initial price P_0 has to drop to P'_0 , in order to reach P_B at a point when all of the resource is extracted. The lower price of the non-renewable resource at all points in time as compared to before encourages more consumption. As the total stock of the resource has not changed, this implies that the resource will be extracted at an earlier point in time. The extraction schedule is described in the quadrant R/T, where R stand for the amount extracted at a certain point in time.

A consequence of this result when we consider fossil fuels is more greenhouse gas emission in a shorter period of time. But demand for fossil fuels in general will decline due to the lower price of renewable options. Depending which of these effects dominates the time to total extraction of the non-renewable resource may eventually be longer or shorter (Hoel 2008). Without an international agreement in place that puts a ceiling on the maximum amount emissions, better technology policy by itself is unlikely to help avoiding drastic climate change (Sinn 2007; Hoel 2008).

Combating human induced climate change in order to avoid excessive economic costs will necessitate a substantial increase in technology transfer compared to the level we observe at the moment due to the expected increase in emissions from developing countries and the pattern of development of green technology. This transfer will have to be part of an international agreement that also includes emission limits, most likely for developing and developed countries. Such an agreement should include as many countries as possible in order to strengthen the overall effectiveness in terms of avoidance of excessive costs. The next two chapters will analyze the two currently most important international treaties on international climate change, showing their shortcomings and potential for synergies, based on the pre-ceding discussion.

3. The Kyoto Protocol

3.1 Introduction

Adopted on December 11th 1997, the Kyoto protocol is an international environmental agreement that seeks to limit global greenhouse gas emissions in the face of human induced climate change. It came into force on the 16th February 2005 when at least 55 parties covering 55% of the industrialized countries' green house gas emission of 1990 had ratified, accepted, approved and acceded to it. Whereas countries member to the convention are only encouraged to reduce their emission, the protocol commits them to do so. The first phase of emission reductions is scheduled to run for 5 years from 2008 to 2012. In this phase the overall goal is to reduce global greenhouse gas emissions of industrialized countries, or Annex I countries, by 5.2%. As historical emission levels are quite diverse, different reduction obligations have been assigned to countries. For example, whereas the EU is expected to reduce its emissions by 8% and Japan by 6%, Russia is allowed to stay emit at his 1990 level. Developing or Annex II countries are exempted from emission reduction. This exemption is embedded in the protocol under the "common but differentiated approach" which takes into account historical emission patters. Under this approach, the burden of financing the mitigation and adaptation falls on the industrialized countries. As of January 2009 the Kyoto Protocol covers 63.7% of industrialized countries' emission in 1990[3].

In order to lower the cost of compliance to the protocol in absence of developing countries which would provide a large amount of emission permits, two flexible mechanisms are part of the protocol. The first is the Clean Development Mechanism (CDM), where agents from industrialized countries can engage in projects in developing countries that help to reduce emission, thereby gaining emission credits at a lower cost than in their domestic market. An important requirement for a CDM project to be approved is the "additionality" requirement in

[3] http://unfccc.int/files/kyoto_protocol/status_of_ratification/application/pdf/kp_ratification.pdf

that it reduces emissions of the project over what would have occurred without the CDM. The second flexible mechanism is the Joint Implementation mechanism (JI). Projects under this mechanism have to fulfill similar requirements as the CDM. Whereas CDM projects can be carried out between Annex I and Annex II parties, countries with emission restrictions and without emission restrictions, JI can only be carried out between Annex I countries.

3.2 Analysis

The protocol in its current form does not have a favorable cost-benefit ratio for Annex I countries when contrasting the costs that they have to incur in order to fulfill their abatement obligations, in comparison to the probable benefits they derive from damages avoided in the future. Whereas this cost-benefit ratio was 1:11 for the Montreal Protocol for the participating industrialized countries, this ratio stands at 1:0.5 for the Kyoto Protocol for Annex I parties (Barrett 2007). These numbers rely on results from estimations carried out by Nordhaus and Boyer (2000). They recently revised their numbers and the ratio now stands at 1:1.7 (Nordhaus 2008). Even though this renders overall action profitable, it does so only marginally compared to the Montreal Protocol. An aspect that made the Montreal protocol so effective was that all its parties profited considerably from it (Barrett 2003). One important factor that makes the Kyoto Protocol so expensive for Annex I countries is that developing countries have no abatement obligations and are therefore not participating in the emission market. Abatement in developing countries is generally cheaper than in developed countries (Ellerman et al. 1998; Nordhaus and Boyer 1998). If these countries were bound by emission limits and offered their permits on the international permit market it would be considerably cheaper for actors in developed countries to abate. Nordhaus and Boyer (1998), using the RICE-98 model in order to determine the costs of the protocol, find that the US would have to pay two thirds of the total cost of the implementation of the Kyoto Protocol. They also find that without the inclusion of developing countries and effective enforcement, the cost of permit per ton of CO_2 is likely to rise over 250$ throughout this century. Finally, the further mitigation and adaptation measures are postponed in the future the more will cost increase, likely so at an increasing rate (Stern 2007).

As mentioned above, the world does not only suffer a global externality from climate changing emissions but also a lack of environmental related R&D that deals with climate change relevant emissions. That externality is not sufficiently addressed in the Kyoto protocol. There is no mechanism that would allow countries to take into account the global effect that their environmental related R&D has which will lead to an underprovision (Hoel 2005). Countries will only consider the reduction in abatement costs that their R&D has at home if there is an international agreement regulating emissions without R&D provisions. If there is no international agreement regulating emissions they will consider the benefit that environmental R&D, has on indicators such as companies' profits or on locally relevant pollutants within national jurisdiction. The optimal provision of knowledge at home is already negatively influenced by the knowledge externality discussed above. The effect of R&D is a reduction in marginal abatement cost. As long as this is only set equal to the countries' marginal abatement cost whereas a new technology has a truly global potential, the effort exerted will be sub-optimal. Even if the permit trade that takes place under the Kyoto Protocol equalizes marginal abatement costs in participating regions and induces more environmental R&D as a market "pull" effect (Jaffe et al. 2005; Lawrence 2007), the level is still likely to be insufficient:"… there will be too little R&D expenditure in the Kyoto type agreement even if total emissions are set equal to what they are in the first-best optimum" (Hoel 2005, p.59). Furthermore, the permit trade does not have any provisions in itself addressing the issue of technology transfer between Annex I and Annex II parties. Technology transfer may take place through technological spill-overs, but most likely at levels that are insufficient.

The only way in which technology transfer is somehow addressed in the protocol is via its two other mechanisms, the CDM and JI. Yet technology transfer is not a necessary condition for projects under these mechanisms to take place. The mechanism has only been operating fairly recently. A study by Seres (2007) finds that about 39% of CDM projects claim to involve technology transfer. What exactly is meant by technology transfer is not specified under CDM regulations. These projects are responsible for 64% of all emission reductions achieved under CDM, which points to the fact that it is often large projects that involve technology transfer. About 56% of projects that involve technology transfer claim to transfer equipment and knowledge, 32% involve only knowledge. Projects with knowledge transfer alone account for about 11% of all technology transfer projects.

Even if technology transfer is involved, the mechanisms themselves suffer from several inefficiencies that make them unsuitable for achieving a reduction in abatement costs that does not change the global amount of emission permits. As long as there are no emission limits in place in developing countries, CDM projects lowering the demand for fossil fuels in one sector of the economy can cause an increase of demand in another, the leakage effect mentioned before (Hagem 2009).The mechanisms also increase the incentive to reduce the profitability of projects artificially. Projects under CDM and JI are only carried out if they fulfill the additionality criterion, which requires that they would not have been carried out without the investment via one of the two mechanisms. This can lead to too many projects being actually carried out which may in turn then increase total emissions (Wara 2008; Hagem and Holtsmark 2009) Investors receive emission credits for the estimated avoided emissions. By increasing the estimated emissions of a project, developing country entrepreneurs can increase the profitability of the projects for foreign investors which will then receive too many emission permits with respect to actually avoided emissions. With human induced climate change being a stock pollution problem, the overall impact of CDM and JI is inconclusive at best. A possible fix to these problems would be better enforcement. But enforcement comes at the price of higher transaction costs and many worthwhile projects especially at a smaller scale are then unlikely to be carried out (Hagem 2009).

Estimates regarding how much developing countries will need in order to finance mitigation and adaptation efforts vary between 10-100 billion US$ per year: World Bank US$10-40 billion, UNFCCC US$ 28-67 billion, UNDP US$ 86 billion, Oxfam International US$ 50 billion, Christian Aid US$ 100 billion (Hægstand and Skjærseth 2009).

The large variation in the estimated cost is due to the uncertainties inherent in such a theme as climate change, which makes adequate predictions of where the damages will take place difficult. Under the Kyoto Protocol the Adaption Fund (AF) has been established which derives money from a 2% charge on all CDM projects. At the time of writing the fund has just become operational and no projects have been supported yet (Hægstand and Skjærseth 2009). Financing from other international funds focused on the issue amount to 133.4 million US$ represents a substantial gap from what is needed. World Bank and UNDP estimates indicate that the financial basis of the AF can grow rapidly over the next years and might even reach US$ 950 million by 2012. But those figures depend on the continued and better functioning of the CDM mechanism. What a post-Kyoto agreement will look like can only be guessed at this time. Considering the drawbacks of CDM and JI described above the question if the fund will survive in this form the next round of negotiations should be asked.

Most of the funds described in the previous section represent public finance efforts to deal with the problem of poor-country adaptation. In the area of technological development and diffusion it is the private sector that is of utmost importance and as long as there are not sufficient incentives in place to get it sufficiently engaged it is unlikely that enough funds will be provided by public sources (Lawrence 2007). Also, with much of the funding for new technologies coming from public funds there is always the risk of lobbying, or winners picking themselves.

Another incentive issue concerning technological development when it comes to the Kyoto protocol is its relatively short time horizon when considering the scale of the problem and uncertainties with regard to the outcome of the following negotiations. If private investors are to commit to substantial investments they need a longer time horizon (Wagner 2001). Strategic underinvestment might actually be an outcome of this. Countries could claim to have excessive abatement costs, therefore being in need of large amounts of permits or little abatement requirements imposed on them. Those high costs could be achieved by under-investment into environmental R&D (Wagner 2001). Finally, as already noted above the Kyoto Protocol has the characteristic of a consensus protocol. The emission cuts are not substantial enough to really put a dent to the climate change issue since developing countries are not subject to emission limits, the cooperative outcome, but they are set at a level that was able to include as many parties as possible resulting in collective free-riding. (Wagner 2001).

3.3 Conclusion

The Kyoto protocol represents the first serious global effort to curb greenhouse gases in order to avoid drastic climate change. As such it was likely that several short-comings would be discovered in its design and there were in fact several significant ones. Firstly, while taking into account the negative externality of greenhouse gases and addressing this via binding emission limits, it fails to take into account the knowledge and adaptation externalities. Too little research R&D in green technology is carried out on a global scale since countries and entrepreneurs do not have incentives for taking into account the global effects of their efforts. Secondly, the mechanisms that are addressing these issues, the CDM and JI, suffer from bad incentives and it is questionable if they will still exist in their current form when the time comes to instate a new agreement. Yet one of the funds that is supposed to increase investment into mitigation and adaptation in developing countries, the AF, relies on funding from CDM. This is far from optimal when considering the long-term nature that is inherent to many of these investments. Thirdly, since only industrialized countries are subject to emission limits the cost-benefit ratio is unfavorable. It is largely accepted that developed countries are likely to finance most of the adaptation measures necessary in developing countries. Developing countries will be responsible for most of the increase in emissions in the future (IEA 2008). Coupled with the leakage issue it will be necessary to impose some sort of emission limits on developing countries as otherwise efforts by industrialized countries are unlikely to have any effect (Stern 2007). Also, without such limits in place Annex II countries will have insufficient incentives to adopt green technology. It is important to realize these short-comings since the mechanisms employed in the Kyoto Protocol are likely to exert a strong influence on future climate change agreements.

4. The Asian-Pacific Partnership on Clean Development and Climate

4.1 Introduction

First announced at the 38th ASEAN Ministerial in Vientiane, Laos in 2005 the Asian-Pacific Partnership on Clean Development and Climate (APP) was officially launched in July 2006. One of the purposes of the partnership is to, “Create a voluntary, non-legally binding framework for international cooperation to facilitate the development, diffusion, deployment, and transfer of existing, emerging and longer term cost- effective, cleaner, more efficient technologies and practices among the Partners through concrete and substantial cooperation so as to achieve practical results.”[4] Eight public-private task forces have been created in order to achieve this purpose in different sectors. These are: Aluminum, building and appliances, cement, cleaner fossil energy, coal mining, power generation and transmission, renewable energy and distributed generation and finally steel. Currently the US, Australia, Canada, Japan, South Korea, India and China are members to the APP. Together, they account for more than 50% of global climate change relevant emissions.

4.2 Analysis

What can an agreement like the APP achieve theoretically? And what has it achieved until now? As mentioned above, pure technology agreements are unlikely to achieve much when it comes to emission reductions due to the impact that new technologies have on resource markets. A lower choke price for non-renewable resources might actually speed up extraction (Perman 2003; Hoel 2008). Without binding emission limits that are enforced, this may lead to more climate change relevant emission over a shorter period of time which will result in worsening the climate change problem as argued above. Even if the lower price of green

[4] http://www.asiapacificpartnership.org/english/about.aspx

technology leads to a replacement of fossil fuels and actually lower emissions in that country, the global effect may still not be positive. This is due to the leakage effect that will encourage consumption of fossil fuels since reduction of demand in countries regulated by emission caps or taxes will depress the global price.

This effect is similar to the problem described above concerning the CDM since developing countries are not subject to any emission limits. Two important sectors that are globally responsible for a large part of emission have no task force assigned to them in the APP. The two sectors are agriculture and transportation, responsible for 13.5% and 13.1% respectively of global greenhouse gas emissions. (IPCC, 2007c). With improvements occurring in the other sectors, those sectors are likely to benefit from lower energy prices. Even though some of the members are also part to the Kyoto Protocol and subject to binding emission limits, Japan, Australia and Canada all of them are currently far away from fulfilling their emission reduction obligations it is unlikely that they will achieve them before 2012[5].

Spending public money on R&D also comes with a series of problems. Governments are in general not good at picking winners, markets often do better (Jaffe et al. 2005). Public spending gives politicians the opportunity to claim that spending and use it as an argument when elections come up. Slashing taxes or quantity restriction on industry is less likely to be used as an argument for re-election even though it offers the better long-term solution (Jaffe et al. 2005). However, there are certain situations under which the argument for government intervention in this field can be advanced. As the global climate is a global good, public spending on technological improvements can be justified on similar grounds as spending on national defense. Secondly, as some major players are still not governed by environmental policy such as emission caps that is by many considered the most effective way to encourage development of new technology, public spending in this area can fill part of the gap (Jaffe et al. 2005).

In order to stimulate adaptation of new green technologies, two kinds of incentives are required. A “push” incentive that can come in the form of research,

[5] http://unfccc.int/files/press/backgrounders/application/pdf/ghg_fact_sheet.pdf

better information or subsidies and a “pull” incentive that can come from increasing taxes on the undesirable economic good, fossil fuels in this case (Lawrence 2007). The APP scores only well on the push side of the issue, whereas the pull issue is markedly absent. As the agreement is voluntary in nature, there is no real incentive for countries to adopt costly technologies, especially if they are aware of the leakage issue. Public information might not be able to reach all relevant companies that might actually have an incentive to adopt a technology. However, higher prices eventually reach all those companies.

What about the financial base of the APP? The US has promised US$ 50 million for its first year of operation (Lawrence 2007). Australia has promised US$ 150 million over the next 5 years (Lawrence 2007). Compared to the actual need for investment of US$ 10-100 billion annually this sum seems meager (Skjaerseth 2009). Even more so when considering that the members of the APP are responsible for more than 50% of global emissions. In the Montreal protocol developed countries had an obligation via a certain formula to pay for the incremental cost of developing countries for acceding to the agreement. In the case of the APP this is voluntary and the outcome seems to be disappointing.

4.3 Conclusion

Members to the APP agree that “The Partnership will be consistent with and contribute to Partners’ efforts under the UNFCCC and will complement, but not replace, the Kyoto Protocol.”[6] Most of the member countries that are also bound by the Kyoto protocol are currently failing their emission reduction obligations[7]. Furthermore, the economics of APP suggest that its complementarity with the Kyoto protocol is ambiguous at best.

To date the APP has largely relied on public finance measures. It has the potential to bring the private sector into the picture as it has adopted a sectoral

[6] http://www.asiapacificpartnership.org/english/about.aspx

[7] http://unfccc.int/files/press/backgrounders/application/pdf/ghg_fact_sheet.pdf

approach that specifically wants to spread best-practice examples from the different sectors. But so far it has achieved little in this respect which could have been a major positive distinction in comparison to the Kyoto Protocol (Lawrence 2007). The voluntary nature of funding has not led to levels of funding that are in line with what is needed, as could be expected. But most importantly, the APP neglects the power of the “pull” incentive. This could come from a system of binding emission limits and trading and is likely to be far more effective than the policy of picking winners as it seems to be practiced at the moment. There is room for public spending in the field of environmental R&D, but this is generally more effective at the basic research level and not when bringing products to the market.

The APP can certainly help to bring information about new technologies to the market, which is an important part in any technological diffusion policy. But as long as APP members are not willing to act upon the negligence described, the partnership cannot be regarded as viable option for combating human-induced climate change and is unlikely to be an effective complement to the Kyoto protocol. Taking into account some of the failures described in the last two chapters concerning technology transfer as well as the theoretical background in chapter one, a largely self-conceived technology transfer mechanism will now be introduced in the next chapter.

5. Green Technology Banks

5.1 Introduction

The preceding section showed that the currently two most important international agreements trying to address the issue of human induced climate change lack several relevant dimensions in order to be effective. The Kyoto Protocol, while limiting emissions in industrialized countries, fails to take into account the problem of insufficient R&D in green technology and addresses technology transfer only superficially. Furthermore, developing countries do presently not face emission limits, which led to an increase of the compliance cost for developed countries as they could not take advantage of the lower abatement cost in developing countries via emission permit trade. Without developing country participation in a climate change agreement, developed countries had an incentive not to agree on substantial emission cuts then, due to the associated costs.

An important actor concerning the provision and dispersion of green-technology is the private sector. On a global scale they have little incentive to increase their efforts in environmental R&D and to take into account the effect that this could have in developing countries. Also, without the willingness of developing countries to accept binding emission limits the efforts of developed countries are unlikely to have a significant effect due to the issue of leakage.

The APP is a purely technology-orientated partnership based on voluntary participation and contributions. In its founding statement the claim is made that it complements the Kyoto Protocol. As argued above, it is unlikely to do so. First of all, it is likely to lead to increases in emissions due to the working of resource markets. Secondly, its funding so far is meager as can be expected from a voluntary agreement that tries to address a problem riddled with externality issues. Thirdly, without a technological “pull” incentive for India and China, by for example binding emissions limits, adoption of green technology will be limited.

A conceivable first-best solution to the problem of the sub-optimal provision of R&D could be to stipulate commitments in a new climate change agreement. Monitoring R&D expenditures of other countries and developing global guidelines to do so involve substantial transaction costs. Hoel (2005) notes “Policies aimed at influencing R&D investments by private firms will be an integrated part of a country’s tax system and to some extent other domestic policies. As tax systems and other policies vary significantly across countries, it will in practice hardly be feasible for a country (or some international agency) to verify all aspects of R&D policies of other countries” (p.53).

5.2 GTB

5.2.1 The Basic Idea

In order to address some of the previously mentioned shortcomings I will now introduce the concept Green Technology Banks (GTB). It is based on the idea advanced by Barrett (2001) and Benedick (2001;2007) that a more technology-centred approach is necessary to address the issue of human induced climate change. The operational details are however quite different. The overriding goal of the proposal is to develop an incentive compatible mechanism to transfer green-technology to developing countries. This transfer, intended as a side-payment in a new agreement, might be one aspect that can help to increase cooperation in a new climate change agreement that includes emission limits for all countries. To analyse its potential to do so, game theoretical tools will be used in chapter six. As this proposal is largely self-conceived and given the time limitations of a Master’s thesis, the proposal should be seen as a first step that will not be able to address all concerns in the pages ahead. The goal of this section is then to offer an introduction to the economic mechanisms that should induce developed and developing countries to participate.

5.2.2 Assumptions

Several assumptions are vital for the GTB to be workable. First of all, the assumption is made that technology is a private good that has a range of positive externalities as discussed in the theory and background chapter. Technology here is first and foremost considered to be a technical apparatus. The soft-skills that come with it, such as better technical knowledge, fall under the category of externalities. Secondly, it is assumed that in the foreseeable future there will be no global permit market but rather several regional permit markets that are imperfectly linked. Furthermore, these regional permit markets will not be perfect in the sense that not all sectors of the economy will be regulated by emission caps or taxes, especially in developing countries. One implication of this is different abatement cost levels in different regions of the world. Finally, as the GTB is to operate under a climate change agreement that imposes emission limits on developed as well as developing countries, any permit transfers that takes place will be a zero sum game in terms of global total emissions. If a transfer takes place, one country will have to give up emission permits in order for the transacting partner to acquire them.

5.2.3 Informational basis and governance

Three major obstacles hinder the spreading of already existing green-technology and environmental R&D at sufficient levels taking into account its global effects. First of all, it is largely produced by private companies in developed countries and it is protected by patents that make it often unaffordable for governments and entrepreneurs in developing countries. Secondly, developed for condition prevalent in developed countries, it cannot easily be used in developing countries. In addition to this developing countries often do not have the capacity to adapt the technology to local circumstances. Finally, there is no common and easily accessible database or information source that gives a concise overview about the developments in the field of green-technology and environmental R&D: “Technology infrastructure such as data collection and dissemination, and training of scientists and engineers is likely to be seriously underprovided by market incentives alone.” (Jaffe et al. 2005, p.173). This lack of information combined with the two previous hindrances results in a less than optimal adoption of green-technology with respect to better known polluting technologies.

Under the GTB, developed countries are to establish a database with information about green-technologies available from the public and the private sector in developed and developing countries. Information about the availability of green-technology would become accessible essentially for free but the actual construction plans would still be protected by patents. The database would be a sales catalogue and users would still have to pay for acquiring the actual technology. The goal of the database is to create a common platform that is widely known and accepted in order to provide up-to-date technological information in the field of green-technologies to reduce the search costs for the private and public sector in both developed and developing countries. Developed countries should bear the financial responsibility for setting up the operation. Public and private research institutes as well as firms and governments from both developing and developed countries can contribute to the database. As argued above, most of the green-technology is developed in the private sector of rich democratic countries. Most of the input to the database will come from there but it can be expected that technology from developing countries will play an increasingly important role over time.

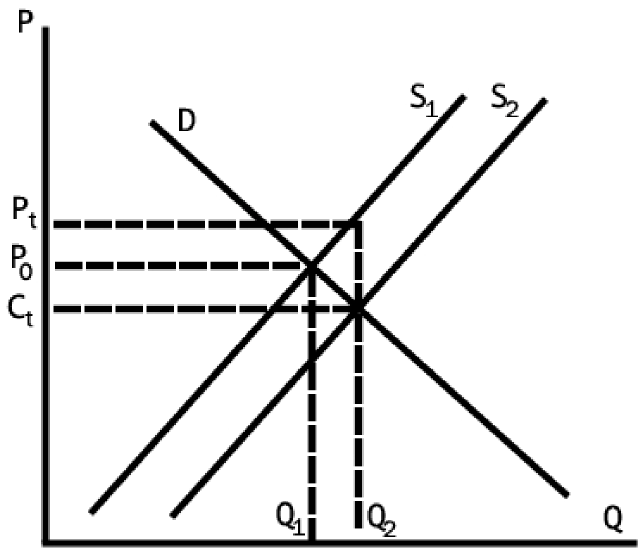
As this will be an international body both developed and developing countries should be part of the governance structure with influence not attached to financial commitments but rather as equals. Experts from developing and developed countries should be responsible for keeping the database up to date and approaching both the public and the private sector for contributions. Developing country expertise will be crucial to identify technology that has the potential to be successfully transferred to developing countries or that has the potential to be adopted to local conditions (MacDonald 1992).

5.2.4 The incentive mechanism to focus more on green-technology R&D

Under the GTB, developed country firms would receive extra emission permits if a transfer of technology takes place. How many emission credits are transferred depends on the evaluation of the amount of emissions that have been avoided compared to the Business-As-Usual case (BAU). An exact determination of how many emissions were avoided could be carried out by similar institutions as the ones that are currently responsible for this task under the CDM. The emission permits could be sold in the regional market where the developed country company operates or be used to lower the required abatement effort. The opportunity to sell emission credits in the regional permit market is crucial as it allows developed country companies that are not regulated by emission caps to gain from increasing R&D into green-technology. Both types of companies receive then effectively a subsidy for technology transfer. The overall goal of this in-kind reward is to increase R&D in green-technology that is also applicable in developing countries.

The developed country government would buy emission credits from the government of the company that receives the technology. The former then transfers these emission credits to the developed country company involved in the project. The developing country government either buys the emission rights from the participating company if it is subject to emission caps, or buys them in the regional emission market if a company is not subject to emission caps. Companies in developing countries subject to tradable emission caps do not receive a direct subsidy but can now obtain technology at a lower price than before. This is due to the standard tax/subsidy incidence as shown in the figure below adopted from Schotter (2001):

Figure 5.1: Effect of a subsidy for developed country firms on the price and quantity of green-technology



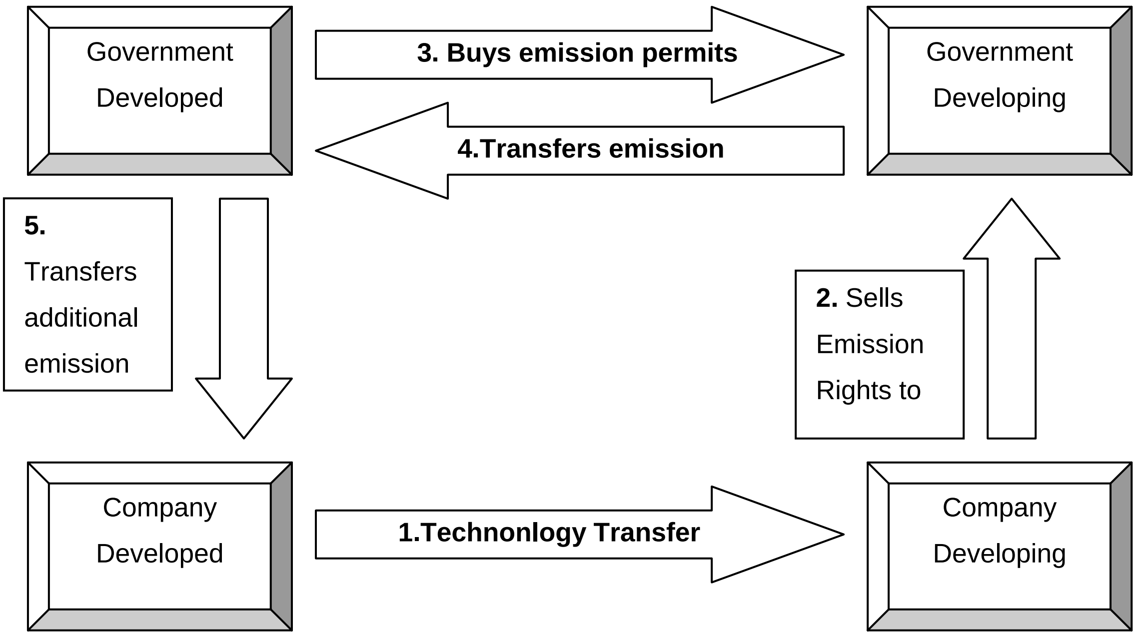
Source: Schotter 2001

The initial market price, $P_{0,}$ is defined by the intersection of the curves labelled D and S_1 .The subsidy to the developed country firm shifts the supply curve of technology down to the right. This increases the quantity of technology supplied, from Q_1 to $Q_{2,}$ and decreases the price consumers of technology have to pay, in this case developing country firms. As in the standard analysis, how much of the subsidy accrues to consumers and how much to suppliers depends on the elasticity of the two curves. In the figure above, the area from C_t to P_0 below the demand curve accrues to the consumer, developing country firms. The area P_0-P_t above the supply curve S_2 accrues to developed country firms supplying the technology. Due to the permit transfer the price of permits in the regional market in developing countries will increase, since supply is reduced. However, the assumption is made here that the level of the price increase will not be substantial enough to offset the benefit of a decreased price of green-technology.

Companies in developing countries that are not subject to emission caps receive an actual subsidy besides the decrease in the price of technology. The money paid by the developed country government for the emission credits obtained by the developing country government will be transferred to them. Since non-regulated companies do not have the same “pull” incentive (Lawrence 2007) to adopt green-technology as their regulated peers, an additional incentive to do so is important.

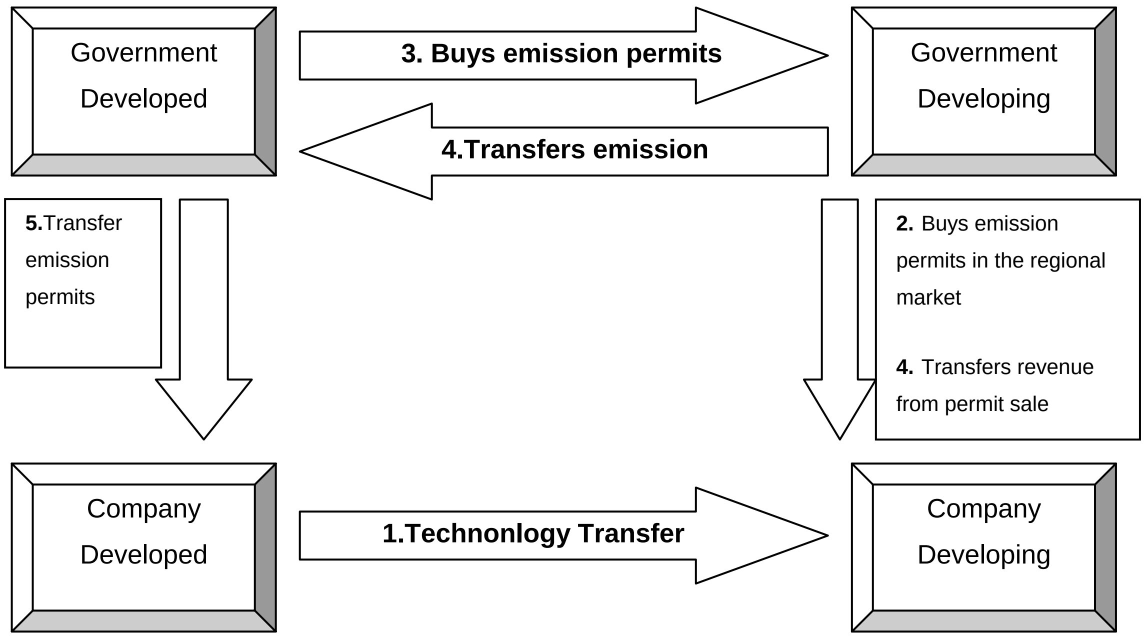
Under this transfer scheme the global amount of emissions does not change. The two figures below illustrate the working of the mechanism for companies that are regulated by emission caps and companies that are not regulated by emission caps.

Figure 5.2: Technology Transfer among companies subject to emission caps



Source: Self-conceived

Figure 5.3: Technology Transfer among companies not subject to emission caps



Source: Self-conceived

The assumption is made here that if regional permit markets were established in developing countries, the market price of permits would be substantially lower than in a developed country market.. This is based on the assessment of various studies that abatement costs are lower in developing countries (Ellerman et al. 1998; Nordhaus and Boyer 1998; Barrett 2007). The technology-transfer mechanism would then lead to more equal marginal abatement costs in the two regions.

The eligibility of firms in developing countries to receive a technology-transfer subsidy should be based on the chances of success for advanced technology in that country. Such success criteria could for example be based on the level of corruption, higher education, rule of law and similar institutional indicators as argued above

Finally, a regular evaluation should take place if the emission credit transfer alone is enough to induce sufficient R&D in green-technology. If this is not the case, then the developed country government should evaluate to provide subsidies in addition to emission credits.

5.2.5 Access to the database and incentives for developing country actors

The information provided in the database can be accessed by firms, research institutions and governments from both developed and developing countries for free. These actors can use the information to identify technologies that are suitable for projects they are about to undertake. If entrepreneurs of developing countries who are members to a new climate change agreement have identified a technology that they would like to use, they and the providing company from the developed country engage in the transfer described in the previous section. Mostly developed countries will be responsible for financing the transfer mechanism based on the pattern of green-technology development discussed in chapter two.

The transfer scheme does not extend to technology outside the GTB database. Green technologies under the GTB are evaluated by experts for their potential effectiveness and stand for a certain quality which cannot be assured for technologies outside the agreement. Actors in non-participating countries to the new climate change agreement will still have access to the database, but will not receive subsidies for technologies acquired via the GTB. Entrepreneurs in developing countries should therefore have an interest in pressuring their respective government to join the agreement in order to gain access to green-technology via GTB, as it reduces their cost of operation and offers them technology that might otherwise be hard to come by. An important consideration in this context pertains to secondary benefits derived from technology transfer. Some of them, such as higher economic growth and more reliable energy infrastructure, were laid out in chapter two. Additional benefits are usually the reduction of other pollutants with a local impact (Ekin 1996), better health (Künzli 2001), and increased technical skill of employees. These secondary benefits represent then an additional incentive for developing countries and firms to participate in the GTB. The relative costliness of abstention for developing countries in terms of potential access to subsidized green-technology should increase the more developed countries are part to a new treaty as the likelihood increases that developing country actors could find a feasible technology for their projects without having to incur higher costs.

5.2.6 Incentives for developed country actors to join and provide R&D

In order to increase the involvement of the private sector in developed countries in green technology R&D and dispersion private firms receive subsidies in form of emission credits from their governments for technology transferred under the GTB. These can then be sold on the regional permit market or used to reduce obligatory abatement effort. This represents a “push” and “pull” incentive (Jaffe et al. 2005) for private firms and research institutions in developed countries to take into account the effect that their technology can have in developing countries. Firms from developed countries can comply with emission limits imposed on them at a lower cost. The abatement that they undertake in developing countries via their technology transfer is likely to be cheaper than it would have been at home. If they are not subject to emission caps, they can sell the emission permits in the marketplace. An extensive analysis if these incentives are sufficient is not part of this thesis but would be a valuable extension if data is available.

The setup of the GTB is similar to the one that drives the CDM and transactions occurring under this mechanism are rapidly increasing. But any mechanism that has the goal of transferring technology from developed and developing countries and aims to be incentive compatible will run into these costs Once again, a definitive analysis of the transaction costs of the CDM and GTB mechanism are not part of this thesis but would be valuable extensions.

An additional incentive is dependent on the level of usage and popularity of the GTB. The more known the GTB is in developing countries, the more beneficial will participating in it be as developing and developed country entrepreneurs will use it as a standard tool to find technologies that are necessary for their projects. This has the potential to reduce marketing costs for developed country firms.

5.2.7 Technical assistance

In addition to financial assistance, technical assistance will be needed as well in order to train personnel to maintain the technology and to further its distribution in the economy from a local basis. This can be part of the GTB transfer if the company providing the technology also has experts available that can help to implement technology locally. Otherwise, auctions should be held to find the best offer for technical assistance. Many development agencies around the world have technical departments that would be well equipped to cater to this need.

5.2.8 Green-Technology and Non-Members to a new climate change agreement

Should countries part to a new climate change agreement actively hamper the access to green-technology to non-participants? Trying to block usage of green technology by countries not part to a new climate change agreement is potentially harmful to them. Golombek and Hoel (2005) investigate a situation where there is a “clean” country that is concerned with the environment and performs R&D and a “dirty” country that is little concerned with the environment and performs no R&D. There is no agreement concerning limiting emissions between the two actors. Technological spillovers occur in a linear fashion. It is shown that if abatement is increased in the clean country via more R&D that lowers abatement costs, technological spillovers lead to more abatement in the dirty country as well if the damage function is linear, otherwise the effect is not clear. One could argue that it is important to have a threat in place in order to encourage countries to join a new climate change agreement. But since it would be beneficial for the developer of a technology to allow for spillovers to take place freely given that technology is already developed, it is unlikely that this will be a useful tool.

5.2.9 GTB in comparison to CDM

The GTB mechanism is in some respects similar to the CDM mechanism in place now. It offers governments or firms from developed countries an opportunity to achieve abatement at a lower cost in developing countries. Emission reductions must be certified which implies similar transactions cost issues as for the CDM. Yet any mechanism that wants to promote transfers of this kind will be subject to these issues.

As mentioned before, a definite comparison of transaction costs between CDM and GTB is not part of this thesis. However, compared to CDM the GTB offers a different incentive structure to resolve the disparity of worldwide green-technology distribution. First of all, it establishes an informational base that was previously not available. Secondly, where technology transfer came more as a by-product in the CDM case, it is the overriding goal in the GTB case. Finally, developed countries subsidize green-technology transfer to developing country companies by buying emission permits from their respective government which then transfers the money back to them. The CDM mechanism does not have a similar provision (Seres 2007).

5.3 Summary

The GTB is a side-payment mechanism that has the goal to increase cooperation in a new climate change agreement that entails emission limits for both developed and developing countries. The assumption of an encompassing climate change agreement is a substantial but necessary one for the GTB to work. Otherwise, the working of resource markets described above would probably lead to more emissions globally. More importantly, the emission credit transfer mechanism developed above would not work. Another crucial assumption is the non-existence of a global permit market. Furthermore, within the regional permit markets not all sectors are regulated by emission caps.

The GTB is designed to offer benefits to both developed and developing countries while raising the cost of non-participation in a new climate change agreement. First and foremost it addresses the problem of information flow between the developed and developing world on the issue of green-technologies. Too little information about what technology is available in the developed world and too little interest in adopting this technology to circumstances in the developing world are present today. The private sector plays an important role in this context, but global mechanisms reflect this only to a minor degree. To rectify this, firms in developed countries are offered several incentives. They receive extra emission permits depending on how many emissions have been avoided in a developing country due to their technology. These permits can then be sold in the regional market or be used to reduce their obligatory abatement effort. This should be an incentive for both regulated and un-regulated companies to participate. If this incentive turns out to be insufficient to induce environmental R&D at a high enough level, developed country governments should consider direct subsidies in addition to the transfer of emission permits.

Firms in developing countries have an interest in pressuring their governments to gain access to the GTB, as they profit from lower market prices from technology and potential secondary benefits from technology transfer, if they are regulated by emission caps. Unregulated companies receive a direct monetary subsidy in addition to a lower price for technology. This subsidy is equivalent to the amount of emissions avoided compared to the BAU-case times the price of permits in the regional market. The underlying reason for the extra subsidy for unregulated companies is that they do not have a similar “pull” incentive to adopt cleaner technology as regulated companies. Developed country governments would shoulder most of the financial burden of the GTB since companies from developed countries are by and large responsible for the R&D of green-technologies.

In conclusion, by establishing GTB developed country governments can potentially increase the likelihood of developing country participation in global abatement efforts, which is a pre-requisite for avoiding drastic climate change based on current emission projections. In order to assess the viability of the GTB to do so, the next section will employ non-cooperative game theory to see if it can strengthen the self-enforcing nature that a global climate change agreement must have.

6. The GTB Game

6.1 The asymmetric Prisoner's dilemma game

To analyze whether the GTB idea has the potential to increase cooperation in a post-Kyoto climate change agreement this section will draw on results from non-cooperative game theory. The choice to use non-cooperative theory is based on the discussion in section 2.2 about self-enforcing agreements. Countries are unlikely to reach an agreement in a cooperative setting as long as it is not in their self-interest, considering the actions of other participants out of their control. They will then only adhere to agreements if they derive a positive payoff from doing so, while taking the actions of others as given. The analysis will start out by setting the prisoner's dilemma (PD) situation into the context of climate change negotiations. It will then proceed by including the technology transfer scheme described above as a strategy in order to see if this can help to reach and sustain the cooperative outcome. A further adjustment will be the introduction of asymmetries between the two players.

6.1.1 Players and bargaining

There are 2 players, a coalition of developed countries C and a coalition of developing countries A. This is a simplification as compared to the situation in chapter five were at least four parties were involved, an aggregate of firms and the government in developed and developing countries. Coalition members will adhere to the policy decided upon for the whole coalition. Internal bargaining problems due to an uneven distribution of benefits which might require compensatory transfers are assumed away.

6.1.2 The payoff function and the business as usual case

The payoff function presented in this section adopted from Wagner (2001) will be modeled in terms of abatement only. This is assumed to be the only action variable for both players. All strategies lead to different levels of abatement. The payoff function for player C is then defined as follows:

$$\Pi_C(q_C, q_A) = B_C(q) - c(q_C) \tag{1}$$

$q = q_A + q_C$, stands for abatement effort and subscripts C and A for the abatement effort of the respective player. $B(q)$ is the benefit function for each individual player with the following properties: $\partial B_i(q_i + q_j)/\partial q_i > 0, \partial^2 B_i(q_i + q_j)/\partial q_i{}^2 < 0 \quad i = C, A$. The benefit function is concave and increasing in abatement of any of the two players. The benefit of abatement is the avoidance of damages that would occur otherwise. $c(q_C)$ is the cost function of abatement with the following properties: $\partial c(q_C)/\partial q_C > 0, \partial^2 c(q_C)/\partial q_C{}^2$ In other words, the cost function is increasing and convex in own abatement effort. Both functions start at the origin, $B(0) = 0, c(0) = 0$. Maximizing (1) with respect to the variable that the players control, their own abatement effort, yields the individual country's' optimality condition:

$$\frac{\partial \Pi_C(q_C, q_A)}{\partial q_C} = \frac{\partial B_C(q)}{\partial q_C} - \frac{\partial c(q_C)}{\partial q_C} = 0 \tag{2}$$

$$\frac{\partial B_C(q)}{\partial q_C} = \frac{\partial c(q_C)}{\partial q_C} \tag{3}$$

$$\frac{\partial B_A(q_A, q_C)}{\partial q_A} = \frac{\partial c(q_A)}{\partial q_A} \tag{4}$$

Marginal benefits of abatement for each country should equal marginal cost of abatement for each country in absence of any agreement specifying abatement levels, provided the other coalition's strategy is considered fixed. This case will be referred to as the business-as-usual case, representing the fully non-cooperative case in the PD-game below since both coalitions optimize their abatement only according to their own benefit.

6.1.3 Asymmetries

The two players in the PD-game are assumed to be asymmetric. Two factors define the asymmetry in this game. First of all, given a total level of abatement $q=q_A+q_C$, $B_A(q)$ will always be higher than $B_C(q)$ .This asymmetry is introduced since the most recent reports on the impact of human induced climate change indicate that developing countries will suffer most from climate change and especially so since they have less financial means to adapt (Stern 2007; IPCC 2008a). Secondly, the level of abatement to be undertaken if one of the players or both cooperate is unequal. Player C, if cooperating, will be obliged to abate considerably more than player A. This assumption is based on the notion that developed countries are responsible for most of the emissions in the atmosphere today and therefore should carry most of the burden to achieve world-wide abatement. If a player decides to cooperate his abatement choice becomes discrete, as he will be bound by treaty obligations. If he chooses not to cooperate his decision will still be based on equations (3) and (4)

6.1.4 Strategy space and the game in normal form

The strategy space for player C is $S_C = \{CP, NC\}$ and the strategy space for player A is $S_A = \{CP, NC\}$. If the cooperative strategy CP is played, a player has to abate an exogenously given amount which is assumed to be larger as compared to what each player would have abated without an agreement. Specifying abatement obligations in this fashion allows for the usage of the continuous benefit function to analyze the payoff from strategies, even if they represent discrete choices since the interest lies in the overall payoff which is defined by equation (2). Under strategy NC, both players choose their abatement levels according to equations (3) and (4). Situations where one player cooperates while the other defect can be considered as a situation with partial climate change agreements where only one region abates. The full cooperative situation {CP,CP} is equivalent to a global climate change agreement being in place where both developed and developing countries decrease their emissions. The game then looks as follows:

Figure 6.1: The PD-Game

	A	
C	CP	NC
CP	4,7	-3,8
NC	6,-1	0,0

6.1.5 Payoff analysis and the Nash-equilibrium

Payoffs on the left accrue to player C, payoffs on the right to player A. Payoffs here are modeled to be consistent with the assumptions made above. The result would not change with different numbers, as long as the relative difference between them is maintained. The Nash-Equilibrium in the one-shot situation considered here is {NC,NC} as in the standard PD-game since both players have an incentive to deviate from the cooperative outcome as they can gain as long as the other player continues to cooperate. Knowing this, rational players will choose not to abate as they cannot rely on the cooperation of the other. The payoff in this situation for both players is {0,0}. Payoffs for both players are zero as this case represents the BAU-scenario and no benefits or losses accrue to the players beyond what they would have done when strictly maximizing their own benefit. Due to the asymmetries the payoffs differ from the standard symmetric PD-situation. The following cell by cell analysis should give an overview of how they affect the payoffs.

{NC,NC} to {NC,CP}

Player A has now specific abatement obligations, which are assumed to be higher than what he would have abated without an agreement. This implies an increase in cost, but also increased benefits. Overall however, the increase in cost should outweigh the increase in benefits as he has to deviate from his non-cooperative optimal choice and no abatement from C takes place. Benefits for C increase as he profits from A's abatement while he does not have to incur extra cost.

{NC,NC} to {CP,NC}

Costs for C are substantially higher due to the obligatory abatement which is large relative to A's obligations. Benefits for C increase as well, but he has to deviate from the optimality condition which leads to an overall negative outcome. Benefits for player A increase likewise considerably due to player C's abatement while he bears no extra costs since he does not cooperate.

{NC,NC} to {CP,CP}

Benefits increase for both players due to the abatement that takes place, relatively more for player A due to the asymmetry of the benefit functions. Costs increase for both players as well since both have to carry-out obligatory abatement above what they would do in the absence of an international agreement. For player C the costs increase relatively more since he has more abatement to carry out. Therefore, C's overall benefit is less than that of player A.

The outcome in real world terms is that no global or partial climate change agreement is in place that would lead to abatement. As the strategy space available is similar to the one that was up for negotiation when the Kyoto Protocol was agreed upon, the outcome of the negotiations may seem similar to the situation where player C cooperates and A defects. Why would developed countries still cooperate? As described above some developed countries did in fact not join the protocol, most prominently the US. In many cases it is uncertain if abatement obligations under the protocol will be fulfilled. The tendency of countries since the Protocol has been active seems to have been a move towards the non-cooperative Nash-Equilibrium. It seems therefore likely that the Kyoto Protocol did not provide sufficient incentives to sustain cooperation among developed players or offer sufficient incentives for developing countries to join. In the following section a game with the GTB offering new strategic choices will be considered to find out if this mechanism could provide incentives to sustain a cooperative outcome.

6.2 The GTB Game

6.2.1 Cost/Benefit functions and the GTB

The benefit function and the conditions that apply to it are still the same as in the PD-game, but changes occur to the cost function once the GTB is introduced. A general benefit that is assumed to accrue to both players when the GTB mechanism is setup is lower marginal abatement costs. The GTB encourages environmental R&D and the simplifying assumption is made here that more R&D leads to lower abatement costs thus:

$$\frac{\partial c_{C/GTB}(q_C)}{\partial q_C} < \frac{\partial c_C(q_C)}{\partial q_C} \text{ and } \frac{\partial c_{A/GTB}(q_A)}{\partial q_A} < \frac{\partial c_A(q_A)}{\partial q_A},$$

where C/GTB and A/GTB stand for the marginal cost for developed and developing countries respectively with GTB. Player C gains additionally if the GTB is set up since he obtains emission permits from player A for transferring technology which means that he has to carry out less abatement. Abatement cost for player A increase since the overall allocation of permits does not change and a reduction in his emission permits leads to more abatement obligations and higher cost. Transactions costs that would most certainly occur under any such emission permit transfer mechanism are assumed away here. However, as player C has to abate substantially more than player A when cooperating, a decrease in cost is an important channel through which his willingness to cooperate can be furthered.

6.2.2 Players and strategy space

The players taking part in the GTB game are the same as before, a coalition of developed countries C and a coalition of developing countries A. The strategy space for player C is $S_C = \{CP-TS, NC, CP\}$ and $S_A = \{CP, NC\}$ for A. CP-TS for player C implies that he faces obligatory abatement requirements as in the CP case described above and that the GTB mechanism will be setup by player C. CP-TS is only a strategic option for player C as the assumption is made that green-technology is pre-dominantly researched and developed in the countries that are assumed to be part to such a collation, Germany, US, Japan and France for example. CP for both

C and A implies that both have to carry out obligatory abatement but no GTB mechanism is setup. NC implies that both players will abate according to (3) and (4). The payoffs for the strategy combinations from the PD-game are unchanged. The normal form of the game then looks as follows

Figure 6.2: The GTB-Game

	A	
C	CP	NC
CP-TS	C11,A11	C21,A21
CP	4,7	-2,8
NC	6,1	0,0

6.2.3 Payoffs, GTB and Nash-Equilibrium

The goal of the following analysis is to find out what payoffs in cells {CP-TS,CP} and {CP-TS,NC} would have to be to constitute a Nash-Equilibrium. For {CP-TS,CP} to be a Nash-equilibrium, deviation has to yield a lower payoff for both players than cooperation. This implies that C11>6, the payoff from cooperation for player C including GTB has to be higher than the payoff from playing NC while A continues to cooperate. Furthermore, A11>A21, the payoff for player A has to be higher than the payoff from defecting while C continues to cooperate.

Does the GTB offer sufficient incentives to fulfill these conditions? The following discussion is kept at an informal level due to the time limits of the Master Thesis. A definitive conclusion can only be reached with further specification of the cost and benefit functions. The results obtained below should serve as an indication for the reader where the most crucial frictions are.

The GTB reduces compliance cost for player C as his marginal abatement costs are lowered due to more environmental R&D. In addition he receives some of A's emission permits for the technology transfer. Therefore, he has to carry out less abatement and his costs are lowered. Compared to {CP,CP} player C should then have a higher payoff as his costs are reduced while benefits stay at the same level since global abatement does not change under the GTB. If the reduction in cost is sufficiently large, the GTB has the potential to make CP-TS the dominant strategy for player C when A plays CP.

Concerning player A, a first step is to analyze how his payoff changes when moving from {CP,CP} to {CP-TS, CP}. Compliance costs are lowered as player A profits from more environmental R&D. However, costs also increase as player A transfers emission permits to player C which increase compliance cost. Whether his payoff increases overall is therefore ambiguous. What about {CP,NC} in comparison to {CP-TS,NC}? {CP-TS,NC} should have the exact same payoffs for A as {CP,NC} since the GTB cannot work without obligatory abatement effort for player A. Thus A21=8.

In summary, the discussion for player A seems to indicate that NC is the dominant strategy when C plays CP-TS. Since the payoff to player C when A does not cooperate is equal with or without the GTB, -2 in the matrix above, his dominant strategy if A plays NC is NC. The Nash-equilibrium would then be {NC,NC}.

6.2.4 Secondary benefits

The main market failure that the GTB tries to address is the lack of environmental R&D worldwide. More R&D, and the following transfer from developed to developing countries, will most likely not only replace brown technology; it will also lead to some potentially substantial secondary benefits. As mentioned in chapter one and five, these can include higher economic growth, a more reliable energy infrastructure, the reduction of other pollutants with a local impact, better health and the increased technical skills of employees. These potential benefits are not part of the simple payoff function above since they do not easily translate into abatement. If they would be modelled, the payoff to player A is likely to increase which might establish the fully cooperative solution as a new Nash-Equilibrium {CP-TS,CP}. But a caveat is in order here since this result depends crucially on the exact modelling of the secondary benefits, which is not done here.

6.3 Conclusion

The results obtained in this section are tentative and should be confirmed with a formal analysis which was not feasible given the time limits of this thesis. However, an important result is that with the asymmetries assumed here, a difference in benefits of abatement and a difference in abatement obligations, the GTB mechanism as introduced in this game is not likely to help establish a Nash-equilibrium in a game of international cooperation on a new climate change agreement. The GTB lowers the cost of compliance for the developed country coalition while the result for the developing country coalition is ambiguous. Important factors left out in the previous analysis are secondary benefits. Their potential positive impact could lead to the establishment of the fully cooperative outcome as a new Nash-equilibrium. Further issues that should be considered in a more elaborate model, indicating the need for further research, will now be addressed in the concluding section.

7. Summary

This thesis has investigated if a technology transfer mechanism, different from currently operating ones, could help to increase cooperation under a new climate change agreement. A new agreement should be as globally encompassing as possible to avoid emission leakage via the working of resource markets and would therefore include emission limits for both developed and developing countries. The motivation for evaluating the issue from this perspective stems from the insight that the problem of human induced climate change faces two separate market failures: A largely unincorporated externality from greenhouse gases on the one hand and a lack of environmental R&D due to inconsideration of its global effects on the other hand. A priori, a technology transfer scheme under a global climate change agreement seems to have the potential to address both problems.

The analysis started out by evaluating current mechanisms to transfer technology, operating under the Kyoto Protocol and the APP. A result that emerged in the case of the Kyoto Protocol was that its mechanisms address technology transfer between developed and developing countries in a rather indirect fashion. Additionally, they do not fulfill optimality conditions when considering the two market failures mentioned above. The CDM suffers from bad incentives that lead to too high avoided emission claims from participating parties. Permit trading might lead to more R&D but probably not at a sufficient level and more importantly it does not address the issue of technology transfer. Since the Kyoto Protocol does not encompass all countries and furthermore does not cover all sectors in Annex I countries, emission reductions in one sector may lead to an increase in emissions elsewhere in the economy. The time-frame of the Protocol is most likely too short to induce long-term investment needed for some essential green-technologies to reach a marketable status. Emission cuts for Annex I countries are also far from sufficient to avoid a high probability of drastic climate change, which has been attributed to the consensus-treaty nature of the agreement. However, one should not forget that the Kyoto Protocol represents the first serious effort to address the issue of human induced climate change and that it was clear from the outset that the result would not be perfect. It is nevertheless crucial to realize these short-comings when designing a new agreement.

By employing recent results from resource economic theory concerning the influence of the price of green-technologies on the extraction path of non-renewable resource relevant for the green-house effect, the argument was made that the APP does not address the issue of human induced climate change effectively. Without binding emission limits for its members it may actually worsen the situation and incentives to actually apply new green-technology are low. This is due to the likely price development of non-renewable resources when green-technologies are introduced which might actually lead to more greenhouse gas emissions. The sectoral approach concerning the development and transfer of technologies deserves credit and can serve as an input for the development of a more effective technology transfer scheme. A vital actor that both the Kyoto Protocol and the APP fail to include through economic incentives at a sufficient scale is the private sector. Without including this sector and its R&D capacity in an effective manner, it is unlikely that sufficient transfer of technology will ever take place.

To address the short-comings with respect to technology transfer that both agreements have, the GTB concept was introduced. The first goal of the scheme is to address the lack of information about the availability of green-technologies. For the GTB to be workable certain assumptions are vital: First of all, the overall amount of emission permits world-wide should not change under this arrangement. Secondly, I assume that there is a global permit market, but an imperfect one. The GTB offers incentives for both developed and developing country actors to engage in the transfer of technology, with technology suitable to conditions in developing countries. Realizing that the directionality of the transfer runs from North to South is crucial. The underlying reason for this pattern of R&D concerning green-technologies has been established in chapter two. There, the conclusion was reached that environmental R&D takes by and large place in rich and democratic countries. Developed country actors can gain since they receive emission permits, which can be sold in the local permit market or used to reduce abatement obligations. Developing country actors not regulated by emission caps receive benefits in monetary form since their governments would buy emission credits according to the amount of emissions avoided in the local permit market. These will then be bought by the developed country government and the funds would be transferred to the developing country entrepreneur. A benefit that accrues to both regulated and non-regulated actors in the developing country is a decrease in the price of green-technology. This follows from the working of market mechanisms if a subsidy is paid to developed country actors in the form of emission permits. Finally, there are potentially significant secondary benefits that accrue to the developing country actors such as higher economic growth, a more reliable energy infrastructure, the reduction of other pollutants with a local impact, better health and the increased technical skills of employees. Since I discovered no prior evaluation of exactly such a proposal during my research, the goal of the analysis carried out here was to introduce the reader to the basic incentives that underlie the GTB and show were the most important frictions lay. Undoubtedly, there are still a variety of issues that need further investigation. For example the issue of product piracy, potential negative effects of technology, the political feasibility of such a scheme and how to integrate such an approach with official development aid efforts.

Finally, a simple game theoretic analysis was carried out to determine if the GTB could potentially increase cooperation in a new climate change agreement. In the games analyzed two players participated, a coalition of developed countries, player C, and a coalition of developing countries, player A. A further assumption was the asymmetry of players. They are assumed to derive different benefits from abatement as well as receiving differing amounts of emission permits. The latter assumption leads to different abatement costs and makes side-payments a viable option from which both sides can profit. The analysis started with the asymmetric PD-situation where payoffs were modeled and based on the assumptions made. As in the standard one-shot PD-game the non-cooperative outcome was the Nash-equilibrium. In the following game, the GTB strategy was added to the developed country coalition's strategy space. In order to determine if this could help to achieve and sustain a cooperative solution between the two players, an informal discussion about the requirements of the payoffs in order to make cooperation a dominant strategy was presented. For player C the result emerged that a sufficient reduction in costs due to the GTB could make cooperation with the GTB mechanism in place the dominant strategy. For player A the result was ambiguous since costs decrease on the one hand due to more environmental R&D, but increase on the other hand due to transfer of emissions permits to player C. Since benefits do not change for player A when he moves from the non-cooperative strategy without the GTB to the one that includes it, the discussion pointed towards dominance of the non-cooperative strategy for player A. Given A's strategic choice, a rational response from player C would be to not cooperate, re-establishing the non-cooperative outcome as a Nash-Equilibrium as in the PD-game. In conclusion, the GTB game as modeled in chapter six was unlikely to help establishing a cooperative solution under a new climate change treaty with obligatory abatement for developing and developed countries.

Future research on this issue could address several concerns. First of all, the secondary benefits that could potentially accrue to player A when a technology transfer takes place are not part of the payoff function. It solely depends on abatement effort of the two players. Taking secondary effects into account could substantially increase the likelihood of player A to cooperate. Secondly, bargaining between firms and governments could be introduced before the negotiations between governments take place. This would make it a two-level game. Introducing this aspect might be more in line what can be expected in actual negotiations since companies are likely to do what they can to reduce abatement effort, exerting strong lobbying pressure at the national and international level. Thirdly, a numerical analysis specifying cost and benefit functions might be carried out. In this analysis the number of players should be increased, specifying individual countries and their characteristics. This should help determine the size of the cooperating coalition. Finally, further asymmetries could be introduced such as the ability of different developing countries to adopt green-technologies, which can have an impact on their benefit function

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