Climate Change, Water Scarcity, and the Depletion of Non-renewable Resources

A theoretical microeconomic analysis of contemporary topics in environmental economics

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Abstract

Wie schon der Titel dieser Dissertation nahelegt, werden im Zuge dieser Arbeit drei verschiedene Themengebiete bearbeitet. Dabei werden verschiedene mikroökonomische Modelle entwickelt, welche einige der wichtigsten umweltökonomischen Fragestellungen aufgreifen. Dabei wird eine detaillierte und stringente Analyse der Effekte und Auswirkungen von Politik- und Regulierungsinstrumenten innerhalb gegebener Marktstrukturen durchgeführt. Jedes der drei Kapitel behandelt und umfaßt die folgenden Aspekte:

- Überblick und Diskussion ausgewählter Literatur welche zum jeweiligen Thema veröffentlicht wurde
- Analyse von Marktstrukturen sowie relevanter Marktakteure und Variablen
- Die Erstellung eigener ökonomischer Modelle
- Herleitung von Ergebnissen und graphische Interpretation
- Kritische Würdigung und Fazit

Die Struktur der Arbeit ist wie folgt: Das erste Kapitel gibt einen präzisen Überblick über Inhalt und Intention der Arbeit. Kapitel zwei behandelt das erste der drei Hauptthemen, den Klimawandel. Insbesondere wird die Frage behandelt, wie sich nachfrageseitige Regulierungsinstrumente in einem bereits stark regulierten Energiemarkt auswirken. Kapitel drei befaßt sich mit der Regulierung von Wassernutzung bzw. -verschmutzung von Fließgewässern. Kapitel vier behandelt die Thematik der nicht-erneuerbaren Ressourcen, insbesondere die der fossilen Brennstoffe und der inländischen Preispolitik Erdöl exportierender Nationen. Kapitel fünf schließt die Arbeit mit einem kritischen Fazit ab. Insgesamt kann die Essenz der Arbeit wie folgt umschrieben werden:

- Die Regulierung ökonomischer Aktivität muß mit Bedacht erfolgen
- Eine einfache mikroökonomische Analyse kann hilfreiche Einblicke in die Auswirkungen von Regulierungsinstrumenten bieten
- Eine genaue und detaillierte Analyse der Marktstruktur sowie der relevanten Marktakteure ist entscheidend für die Qualität und Bedeutsamkeit der Ergebnisse

Alles in allem ist die Arbeit dazu gedacht, die Bedeutung und vielfältige Anwendbarkeit ökonomischer Theorie und ökonomischer Modelle aufzuzeigen. Sie zeigt zudem, daß viele Bereiche der Umweltökonomie mittels der Anwendung grundlegender mikroökonomischer Theorien analysiert werden können. Selbstverständlich ist die Realität selbst äußerst komplex und kein Modell wird daher je in der Lage sein, diese in Ihrer Gesamtheit zu erfassen. Daher konzentrieren sich die Modelle auf die wichtigsten und relevantesten Aspekte der Wirklichkeit.

Abstract

As the title of this PhD thesis suggests, there are three different topics discussed in the course of this work. The intuition behind this is to construct several microeconomic models dealing with some of the most pressing issues in today's environmental economics. Thereby, a thorough and straightforward analysis of the effects and the impact of policy measures or regulatory instruments within a given market structure is conducted. Each of the three chapters is concerned with and comprises the following aspects:

- Reviewing and discussing the ideas presented in selected pieces of literature which have been published on the respective topic
- Identifying and analyzing market settings and structure, as well as relevant actors and variables
- Creating own microeconomic models
- Calculating and deducting results and presenting graphical interpretations
- Critical summary and conclusion

The structure of the work is as follows: Chapter 1 gives a concise overview over both content of and intention behind this work, while Chapter 2 deals with the first of the three main topics, namely Climate Change. In particular, the analysis deals with identifying the impact of implementing a demand side oriented policy measure in an energy market, whose supply side is already highly regulated. Chapter 3 will deal with a model of a river basin that is exposed to water consumption or manmade effluents. The special aspect incorporated in this model is the location-specific nature of the problem, as upstream action triggers downstream effects. Chapter 4 is dedicated to special topics in the field of non-renewable resources with special reference to the effects of pricing policies in oil exporting nations. Chapter 5 is comprised of some concluding remarks. The essence of this work can be characterized as follows:

- Any regulation of economic activity is an instrument that has to be applies with caution.
- A simple microeconomic analysis can yield helpful information on the nature and intensity of effects that a specific regulatory tool will inflict on the regulated market and its parties involved.
- Identifying the market structure and its relevant economic agents and other aspects is crucial to setting up a model that will render useful and meaningful results.

This work is supposed to shed some light onto the value as well as the vast applicability of economic theory and theoretical modeling. It shows that many fields of interest in environmental economics can be analyzed applying basic microeconomic theory. Naturally, reality is complex and complicated and no model will ever be able to fathom and comprise all of it. Hence, models never reveal the entire scope of the real setting but focus on the most important characteristics of reality.

Acknowledgements

"*Two roads diverged in a wood, and I-*
I took the one less traveled by,
And that has made all the difference. "[1]

From time to time, through the last couple of years, the words of this poem by Robert Frost, *The Road Not Taken*, have crossed my mind. Mainly on several occasions of my professional life, may it be presentations, colloquia, or workshops, I felt somewhat isolated, certainly not socially, i.e. for personal reasons, but solely on a professional level, as my work and analysis seemed to differ from what appeared – and still appears - to be en vogue. However, I was lucky to have enough support and inspiration in both my personal live and my professional surroundings, to work through these sometimes frustrating moments. Especially, I would like to thank Prof. Meran for his guidance and unconditional support along the way, as well as Prof. Schwalbe, a brilliant lecturer, without whom I would have never thought about pursuing this path in the first place. Moreover, I would like to thank Prof. Bogart, whose inspiring teaching sparked and sustained my interest in economics during my year abroad at CWRU, Cleveland, OH. Next, I have to thank Prof. Rauscher for his constructive remarks and enlightening discussions. Moreover, I want to thank Prof. Jörg Naeve, Priv. Doz. Tone Arnold, and Isabel Reichhold for their support and helpful discussions.

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Berlin, Germany Nadine Wittmann
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[1] Frost, Robert. *Mountain Interval.* New York: Henry Holt and Company, 1920; Bartleby.com, 1999. www.bartleby.com/119/. [Date of Printout].

Table of Contents

Tables, Charts, and Figures

Abbreviations

APS……………………………………….……….Ambient Permit System
AT………………………………………………..Abatement Technology
BE…………………………………………………….….…Brow Energy
E…………………………………………………………………..Energy
EE…………………………………………..………..Energy Efficiency
EEM………………………………………Energy Efficiency Measure(s)
EUETS………………………………...European Emission Trading System
F…………………………………………..Energy Efficiency Measure(s)
FOC…………………………………………….……..First Order Condition(s)
GE…………………………..………………………………Green Energy
GHG……………………………………………….....Greenhouse Gas
HH…………………………………………………………..Households
IFN…………………………………………………Instream Flow Needs
IM…………………………………...………………Incentive Mechanism
MAC…………………………………………...Marginal Abatement Cost
MC……………………………………………………….Marginal Cost
MPV…………………..……………………………Marginal Production Value
MWQI……………………..………..Marginal Water Quality Improvement
MR……………………………………………..………Marginal Revenue
PEM………………………………………………Physical Externality Model
POS……………………………………………….……..Pollution Offset System
OPEC…………..………………Organization of Petrol Exporting Countries
TDP……………………………………………..…Tradable Discharge Permit
TRS………………………………………………..Trading Ratio System
WC…………………………………………...………White Certificates
WCTS…………………………………….…White Certificate Trading Scheme
WIP……………………………….....Work in progress (Publication pending)
WTP……………………………………………………Willingness to Pay

1 Introduction

As the title of this work implies, there is not just a single subject in question but rather three different topics, which will be dealt with in the following. The idea behind creating this work is to construct several microeconomic models dealing with some of the most pressing issues in today's environmental economics. In doing so, it is intended to conduct a thorough and straightforward analysis of the effects and the impact of policy measures or regulatory instruments within a given market structure.

There are two main points that are discussed in the course of this introduction. First, the reasons behind the choice of topics for this work are given. Second, the intuition behind the choice of economic methods to conduct the analysis will be rendered.

Regarding the first point in question, one does not have to be an expert on environmental economics to understand why the three issues, namely climate change, water scarcity and the depletion of non-renewable resources, have been chosen to become the central topics of this work. Watching the News on TV or taking a peek in a newspaper will suffice to clarify the importance of these topics for mankind regarding its present and future alike. An increasing number of devastating storms and floods in some areas of the world are ascribed to the beginning climate change caused by an increasing level of Co2 in the atmosphere.[2]

With respect to the topic of climate change, the economic analysis in this work deals with the effects and impact of European policy measures meant to decrease Co_2 emissions by fostering the production of renewable energy on the one hand and by increasing efficiency in both energy production and consumption on the other.[3]

Regarding the topic of water scarcity, the analysis can be divided into two aspects regarding the availability of drinking water. While an increasing number of areas suffer from long periods of live-threatening droughts, industries in water-abundant areas dispense with wastewater treatment and emit effluents into river basins, which are likely to cause both health threats to living-beings and ecological damage to the eco system.[4]

With respect to these issues, the second part of this work deals with modeling a market for water certificates regarding the water of rivers basins.

Last but not least, especially after the oil crises of the 70's and 80's, economists around the world took increased notice of theories on exhaustible resources. Many experts approve of and favor Hotelling's approach and model dealing with the depletion of non-renewable

[2] IPCC, see http://www.ipcc.ch/publications_and_data/publications_and_data_reports.htm
[3] The political basis is the ratification of the Kyoto Protocol by the EU as well as the resulting European 20/20/20 or, since the beginning of 2010, 30/20/20 vision.
[4] E.g. http://water.org/ or the National Drought Mitigation Centre: http://www.drought.unl.edu/whatis/cchange.htm

resources. However, there is a small group of economists, let me call them *Hotelling-defiant*, opposing the idea, that resources can be defined as being exhaustible. Probably the most renowned amongst them is M.A. Adelman. His work is also dedicated to the analysis of the price and cost of world oil supply. Over all, the market for fossil fuel is vast and of such importance to most industrialized nations that many of the issues involved and actions taken in that segment are not only based on economic but also political reasoning.[5] These circumstances certainly do not serve to facilitate economic modeling.
Regarding the state of affairs, the third part of this work models and analyzes the effects of price differences in export and in-country oil prices of oil producing countries. This becomes especially important if such countries - e.g. some of OPEC's members like Saudi Arabia - plan to increase the deployment of renewable resources in their in-country energy production.[6]

After having displayed the motivation behind the choice of topics, the second point in question needs to be dealt with. Each of the three chapters is concerned with and comprises the following aspects:

- Reviewing and discussing the ideas presented in selected pieces of literature which have been published on the respective topic
- Analyzing these literature sources as well as identifying the differences in comparison to the starting point of the author's own model
- Identifying and analyzing market settings and structure, as well as relevant actors and variables
- Creating own microeconomic models
- Calculating and deducting results and presenting graphical interpretations
- Critical summary and conclusion

In constructing and analyzing the microeconomics models, both mathematical methods and graphical illustrations are applied. However, all of them have one common denominator: there will be no empirical data analysis or econometric methods applied. Nonetheless, the author is of the strong belief that the results of her work render valuable information about the nature and direction of effects caused by certain policy measures or by the actions of other market participants, even without the help of databases or CGE modeling. Nowadays, it sometimes appears as though several economists might cling to the belief that, if there is no data analysis involved in their modeling, they might as well not model at all. However, the

[5] Watkins, G.C. (2006)
[6] Said, S.A.M., El-Amin, I.M., Al-Shehri, A.M. (2004)

author of this work prefers to swim against the econometric tide, which, to her, seems rather prevalent in current environmental economics. Paul Krugman's view on the value of simple theoretic models appears to deliver a sophisticated justification for this approach:

"Let me also say something else. Anyone who has ever made the effort to understand a really useful economic model (like the simple models on which economists base their argument for free trade) learns something important: The model is often smarter than you are. […] by the act of putting your thoughts together into a coherent model forces you into conclusion you never intended […]. The result is, that people who have understood even the simplest, most trivial-sounding economic models are often far more sophisticated than people who know thousands of facts […], who can use plenty of big words, but have no coherent framework to organize their thoughts."[7]

Now that the necessary preliminaries have been dealt with, a short outline of the structure of the work is given in the following. As chapter one has already given a concise overview over both content of and intention behind this work, chapter two deals with the first of the three main topics, i.e. Climate Change. In particular, the analysis deals with identifying the impact of implementing a demand side oriented policy measure in an energy market, whose supply side is already highly regulated. In Chapter three a model of a river basin that is exposed to water consumption or manmade effluents is discussed. The special aspect incorporated in this model is the location-specific nature of the problem, as upstream action triggers downstream effects. A comparison between first and second best regulation is undertaken after the model has been constructed. Chapter four is dedicated to special topics in the field of non-renewable resources with special reference to the effects of pricing policies in oil exporting nations. Chapter five is comprised of some concluding remarks.

[7] Krugman, P. (1999), p. 113

2 The European Effort to Fight Climate Change: What's cooking in the policy kitchen; do too many cooks spoil the broth?

The Kyoto Protocol was the first step toward an international effort to reduce so called green house gas (GHG) emissions, which are said to be the main cause of climate change. The countries which ratified the Kyoto Protocol agreed to reduce their Co_2 emissions by a certain percentage until 2012, with respect to their emission levels of 1990 (baseline).[8] The European Union (EU), being one of those who ratified the protocol instantaneously, agreed to reduce their emissions by at least 8 percent. However, until 2007, the EU has only managed to achieve a reduction of 4.3 percent.[9] Nonetheless, the EU set up even more ambitious goals beyond 2012, called the 20/20/20, i.e. 30/20/20,[10] vision. This vision implies a 20 (30) percent cut in GHG emissions, an increase of renewable energy to 20 percent of total energy consumption, and a 20 percent increase in energy efficiency.[11] Due to these demanding goals, various policy measures have been employed in order to ensure that the goals can be met. Regarding the reduction of emission levels, a cap-and-trade system (Brown Certificates) has been established. In case of fostering so called renewable, i.e. Green, energy, member states chose different policy measures, such as direct subsidies, feed-in tariffs (Germany), or a Green Certificate trading scheme based on a quota system (Denmark).[12] These measures are directed at the supply side of the energy market. However, the third part of the EU's vision refers to an increase in overall energy efficiency, which includes the demand side of the energy market as well. This goal has been formulated in the EU Directive on Energy End-Use Efficiency and Energy Services as follows: "*Improved energy end-use efficiency will also contribute to the reduction of primary energy consumption, to the mitigation of Co2 and other green house gas emissions […]*."[13] Once such a political aim is set, the question arises what measures can be chosen to achieve it. As the implementation of market-based instruments has gained popularity in recent years[14], experts came up with the idea of implementing a market for tradable energy efficiency certificates, so called White Certificates. The proposed system works as follows: if end-users fail to fulfill a minimum requirement of energy efficiency measures set by authorities they need to buy White Certificates. If they surpass their requirements they thereby generate White Certificates and are able to sell these excess White Certificates to end-users, who

[8] Kyoto protocol: http://www.bmu.de/files/pdfs/allgemein/application/pdf/protodt.pdf

[9] Excluding emission/ removals from land-use, land-use change, and forestry. United Nations: National Greenhouse Gas Inventory data 1990-2007: http://unfccc.int/resource/docs/2009/sbi/eng/12.pdf

[10] The numbers have been changed slightly to a 30/20/20 vision ("if the conditions are right"). See source referred to in footnote 11.

[11] Europe 2020: A European strategy for smart, sustainable, and inclusive growth: http://ec.europa.eu/eu2020/pdf/COMPLET%20EN%20BARROSO%20%20%20007%20-%20Europe%202020%20-%20EN%20version.pdf

[12] Meran, G., Wittmann, N. (2008).

[13] EU Directive 2006/32/EC

[14] E.g. http://www.grist.org/article/the-making-of-a-conventional-wisdom/

have not increased their energy efficiency sufficiently. In reality, in order to achieve a reduction in costs and complexity, distributors or suppliers of energy take on the role of end-users in the market for White Certificates.[15] In this case, end-users are only indirectly affected by the new market-system through an incentive mechanism set up by their distributors. In a few European countries a White Certificate Trading scheme (WCTS) has already been implemented, e.g. Great Britain, France, Italy, and parts of Belgium (Flanders).[16] An overview over the respective WCTS systems is given by a working paper of the Öko-Institut e.V. (Institute for applied Ecology)[17]:

2-1 WCTS in Europe

	Great Britain (EEC2)	Italy	France	Flanders (Belgium)
Liable parties	Electricity and Gas suppliers. Threshold: More than 15,000 customers	Electricity and Gas grid operators. Threshold: More than 100,000 customers	Energy suppliers including fuel traders. Threshold: Sales volume of more than 40 TWh	Electricity distributors. Threshold: below 70kV
Energy Efficiency Goal	130.2 TWh Fuel-Standardized Energy (End-Use) per Period (3 years: 2005-2008)	2.9 MtOE/a (primary energy) in the 5th year after the regulation has been issued	54 TWh over the course of three years (End-Use energy)	0.58 TWh p.a. (primary energy, not just energy production)
Accountability	Ex-ante, once for the entire life-cycle of the implemented energy efficiency measures (EEM)	Ex-ante, once regarding standardized EEM. Otherwise, ex-post, periodically	Ex-ante, once for the entire life-cycle of the implemented EEM	Ex-ante, once for the entire life-cycle of the implemented EEM
Recipients of Measures	ONLY households	All	All (including Transportation sector) except for facilities taking part in Brown Certificate Trading	Households and non-energy intensive industries, sale & services sectors
Sanction on Non-compliance	Depending on the level of defection (fine can be up to 10% of companies' revenues) Buy-out: no	Depending on the reason of defection and the price of certificates Buy-out: no	Buy-out: 2ct/kWh	Buy-out: 10ct/kWh, must not be passed on to consumer prices
Certificate Trade	Yes, but only bilateral with approval of regulation authority	Yes	Yes	No

Source: Bürger, V., Wiegmann, K., (2007), p. 37. Translation: Author

[15] Oikonomou et al. (2008)
[16] Child et al. (2008)
[17] Bürger, V., Wiegmann, K. (2007)

Other EU member states have also taken the implementation of WCTS into consideration. The following section deals with a review of the literature, which deals with an analysis of the effects of introducing WCTS into the energy market, either verbally or in different model settings.

2.1 Literature Review

There are various papers that have dealt with the effects of WCTS. Each of them has taken on a different approach; some have chosen a purely verbal analysis while others have worked with graphical or mathematical techniques to get to the point. Approaches which are most important with respect to the model presented in section 2.2 will be dealt with separately in greater detail in subsections 2.1.1 to 2.1.3. Compared to the findings presented in section 2.2 these approaches can be differentiated as shown by the following table:

2-2 Literature and Research Overview Chapter 2

Relevant Author(s)	Research Topics
Oikonomou et al.	WCTS combined with Emission Tax or/and Energy Tax (Section 2.1.1)
Sorrell et al.	WCTS combined with EU ETS (Section 2.1.2)
Meran/ Wittmann	WCTS combined with Green (Quota) and Brown (EU ETS) Certificates. Distributors operate under perfect competition. (Section 2.1.3)
Wittmann	I. Novelty: Re-setup of Sorrell et al.'s Model (section 2.1.2.1 to 2.1.2.4) II. Novelty (in comparison to Meran/ Wittmann) (section 2.2): 1. Distributors operate as regional monopolists. 2. Price caps (including incentive mechanism) regarding retail energy price. 3. Cost recovery scheme on behalf of distributors regarding cost of WCTS.

Source: Author's design

Nonetheless, there are several other papers whose authors have busied themselves with the concept of WCTS, which are presented in the following.

The working paper *Energieeinsparquote und Weisse Zertifikate*[18] by Bürger and Wiegmann of the Öko-Institut (Institute for Applied Ecology) is an elaborate analysis of the potential and limitations of WCTS. WCTS is defined as a quota based market mechanism meant to increase the market penetration of demand side EEM (energy efficiency measures). Their

[18] Translation (by the author): Energy savings quota and White Certificates

work gives a detailed overview over the actions that need to be taken to set up a WCTS. The reason why a market based instrument is of great interest to policy makers is based on the assumption that it will be less of a burden to regulation authority's budget.

Langniss and Praetorius published a paper dealing with the question: *How much market do market-based instruments create? An analysis for the case of "white" certificates*[19]. They discuss the problems of how to design WCTS in order to reach an efficient outcome. Moreover, the question arises how it can be combined with the EU emission trading system. Also, defining the target group that has to take part in WCTS and measuring the energy savings, proof to be important issues to the authors that are discussed in the course of their paper. Langniss and Praetorius also give a short overview over the international experience with WCTS.

Regarding Great Britain, an interesting feature which has not been mentioned in the table of section 2.1 is that 50 percent of all energy savings have to take place in low-income households. Energy suppliers are obliged to take part in WCTS on behalf of their customers, which are separated into two groups, low-income households and others.

The Italian WCTS includes a guarantied recovery cost rate of 0.017€ for every kWh saved. If the cost of EEM exceeds this rate, it has to be borne by the companies' profits.

In general, Langniss and Praetorius propose that a regulated market reduces the risk of investments in EEM significantly. Therefore, in equilibrium, an unregulated market renders an inefficiently low level of EEM. This problem can, presumably, be solved by the implementation of WCTS. Langniss and Praetorius cite several papers to undermine this proposition, however, those, unfortunately, do not refer to WCTS in particular, but to investment in energy efficiency in general. Afterwards, they concern themselves with the issue of transaction costs which have to be incurred in case of WCTS. It is assumed that trade will occur as long as marginal cost for EEM differs among obliged parties. Therefore, certificate trading will ensure that marginal cost becomes equal across obliged parties. This is certainly quite in line with basic theory on permit trading under perfect information and perfect competition. Then they consider the potential for economies of scale by bundling demand for EEM, but do not specify what exactly is meant by *bundling demand* and whose demand will be bundled. Pricing in opportunity costs in the marginal cost of EEM is mentioned next. This leads to the statement, that "*As long as the marginal income from energy sales is larger than the difference between the price of certificates […] and the costs of generating certificate with own energy customers so long will it be more favorable to purchase certificates […]*"[20].

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[19] Langniss, O., Praetorious, B. (2004)
[20] Langniss, O., Praetorius, B. (2004)

Unfortunately, the paper does not present a formal model to ascertain this proposition. Moreover, it is quite likely that the relevant figure is the price of certificates minus the *marginal* cost of generating one certificate. Also, it is quite likely, that marginal cost of creating one certificate is not equal across EEM but increases the more EEM have already been conducted. Hence, it should be the marginal cost of the last, i.e. most costly[21], EEM implemented that matters.

According to Langniss and Praetorius, "*tradable certificate schemes have thereby the advantage that market prices of certificates will reveal the low total costs of EE[M] policy*"[22]. However, this statement appears to be imprecise. The equilibrium price of tradable certificates reveals – again under the assumption of perfect information and perfect competition – the marginal cost of the last, i.e. marginal unit of EEM chosen. Thereby, the pattern of trade identifies who will be net-seller/net-buyer of certificates, thereby displaying who can provide a certain amount of EEM at a lower/higher cost.

When it comes to the question of who should have to take part in WCTS energy suppliers should be obliged, according to Langniss and Praetorius. This results from the fact that energy generators are assumed to have no insight into the demand side, and that energy distribution remains a natural monopoly and lacks competition. Moreover, suppliers have better information on the kind of EEM available and are supposed to face the lowest transaction costs. Why all of this should hold true is neither proven by sources nor by a model. In the end, it is suggested that the trade of White Certificates and Brown Certificates should be combined due to otherwise higher transaction costs. This is another fairly questionable statement, as there is no clarification on how exactly this combination of two certificate schemes targeting two completely different issues should be conducted.

Giraud and Quirion focus on *Efficiency and Distributional Impacts of Tradable White Certificates Compared to Taxes, Subsidies and Regulations*[23]. They set up a partial equilibrium model where suppliers are obliged to take part in WCTS on behalf of their costumers (end-users). They assume an endogenous level of energy service and analyze the substitutability of energy and energy saving. Moreover, they take a look at the effects of the elasticity of demand. In their model WCTS and an energy tax are equally efficient, but with respect to creating incentives to reduce overall energy service consumption WCTS performance is poor. However, when it comes to measuring price effects, they conclude, that WCTS will result in a lower increase in consumers' energy price than any of the other policy measures. They implement a data base to arrive at numerical results. The results of their optimization model coded in Scilab vary according to the elasticity of substitution between energy and energy saving. They arrive at three major conclusions. First, it is important

[21] It is assumed that there is a linear but increasing marginal cost of EEM.
[22] Langniss, O., Praetorius, B. (2004)
[23] Giraud, L-G., Quirion, P. (2008)

whether the target given to suppliers is based on their previous energy sales or whether it is arbitrary and disconnected from historical data. Second, WCTS produces higher costs than an energy tax but less than a subsidy on energy savings products. Third, WCTS "*may be politically easier to implement than an energy tax, because it entails less wealth transfers*"[24].

Last but not least, Mundaca and Neij examine the experiences of WCTS gathered in countries where it has already been implemented, in order to explore its potential for Sweden[25]. Therefore, the central point of their report is whether WCTS is an appropriate policy measure for Sweden. They analyze its (cost) effectiveness as well as administrative burden, transaction costs, distributional effects, and political feasibility. Also, the measurement and verification of EEM and the question of cost recovery plays a central role in their analysis. Moreover, they try to identify the level of interaction between WCTS and other policy instruments. In their concluding discussion they arrive at the following results: In their opinion, the reasons why WCTS should be preferred over other policy instruments are "*vague and not well understood*"; that seems to be the case in all of the countries where it has already been implemented. The design of WCTS differs significantly in all of the respective countries. The administrative burden rises with the number of parties involved and the variety of EEM available. Although a market-based measure is supposed to be political more feasible than a tax, obliged groups might oppose the system, due to various reasons, e.g. "*The obliged parties (distributors of gas and electricity) strongly opposed to the obligation, claiming that their core business was far from reaching end-users and thus they were unable to implement measures to meet the obligation*"[26]. Overall, Mundaca and Neij conclude that, although there might exist benefits from implementing WCTS, in a theoretical context, the challenges that arise in order to ensure that such a scheme works properly in reality must not be underestimated.

2.1.1 The Model of Oikonomou et al.

In the paper *White Certificates for energy efficiency improvement with energy taxes: A theoretical economic model* Oikonomou et al. examine the interaction of WCTS and energy taxes[27]. The model is set up as follows: producers of energy face perfect competition and a carbon tax. Suppliers of energy also face perfect competition as well an electricity tax.[28] Moreover, they are also obliged to take part in WCTS. Demand for electricity is determined

[24] Giraud, L-G., Quirion, P. (2008)
[25] Mundaca, L., Neij, L. (2006)
[26] Mundaca, L., Neij, L. (2006)
[27] Oikonomou et al. (2008)
[28] Oikonomou et al. (2008) admit that, in reality, the assumption of perfect competition in electricity supply does often not hold true.

by a utility function depending on households' income (Y), stock of household appliances (K), and the quantity of electricity demanded. Distributors are exempted from the analysis as Oikonomou et al. want to focus on competitive market segments and electricity distributors, in reality, constitute a natural monopoly. As can already be detected by this summary, the model setting involves various policy instruments, i.e. both taxes and market-based instruments alike. In general, looking at the situation in countries where WCTS has already been implemented, all of them are subject to the European Emission trading system (EUETS). Moreover, policy measures which foster renewable energy are also in place in all of these countries. Hence, it appears quite unusual to assume that producers of electricity do not have alternative, i.e. Green, resources and production technology available. Besides, only producers and suppliers are endogenous market segments of the model. End-users and their choices, as well as tax levels and WCTS price and penalty are exogenously given. This certainly poses a substantial simplification within the model setting. The following graph depicts the model structure:

2-3 Market structure design of Oikonomou et al.

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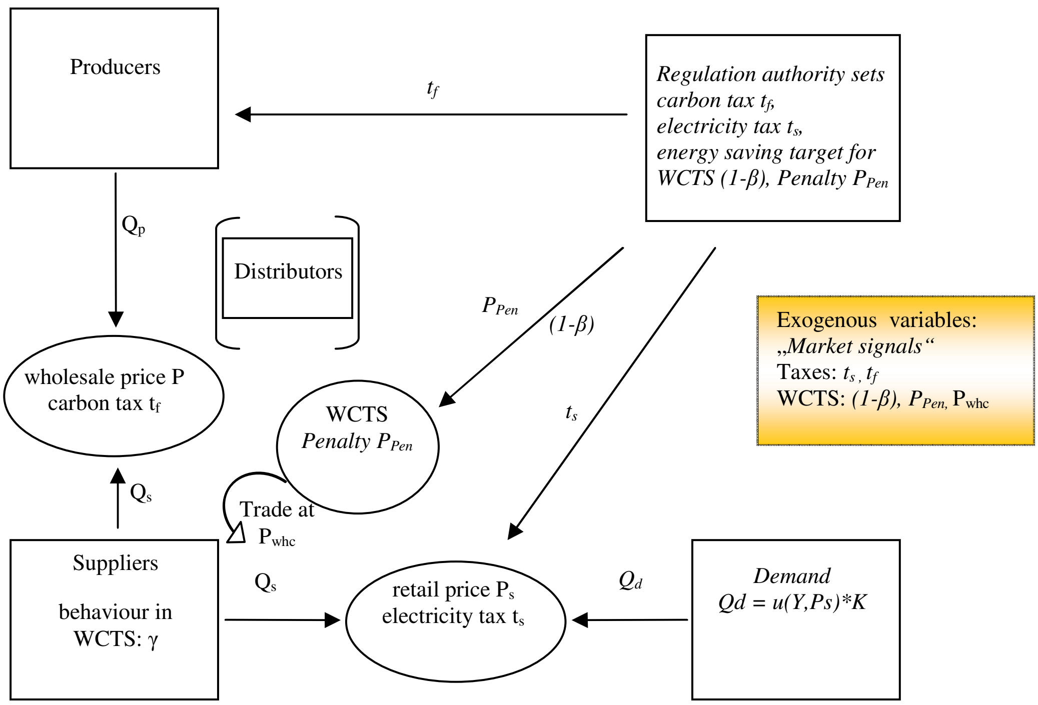


Source: N. Wittmann
(drawn from information given by Oikonomou et al. (2008))

Electricity and carbon tax are both unit quantity taxes. As all of the market segments operate under perfect competition, a pass through rate of 100% is assumed. Therefore, the sales price after taxes has to be equal to the sales price before taxes plus taxes, i.e.

$P_{buy} = P_{sale} + t_i \; \forall i = f, s$.[29] The change in consumer sales price with respect to tax, in this case, is therefore equal to $\frac{\partial P_{buy}}{\partial t_i} = 1$.[30] Regarding the model of Oikonomou et al., they assume quadratic cost functions of production and supply, which is quite common. The carbon tax (t_f) enters the model as a production cost as fossil fuel is assumed to be an input factor. Hence, it appears in the quadratic section of the cost function, which results in the following FOC: [31]

$$P = (C_f + t_f)Q_p + C_v \tag{2.1}$$

Once they inlcude WCTS into their model, Oikonomou et al. explicitly take the penalty of defecting into account. This means that they also differentiate between target (1-β) and actual behavior (γ) of suppliers in WCTS. In general, findings like "*if demand raises supply price rises" or "the level of electricity tax can determine the final price of electricity"* (Oikinomou et al. 2008) are in line with basic microeconomic theory. In the end, a data application is undertaken in order to undermine theoretical findings. To sum it up, Oikonomou et al. arrive at the following conclusions: "*According to a general evaluation of […] WhC with carbon and electricity taxes, various positive and negative effects […] are present, which can lead to an added value […], although uncertainties of outcomes are quite high."* (Oikinomou et al. 2008).

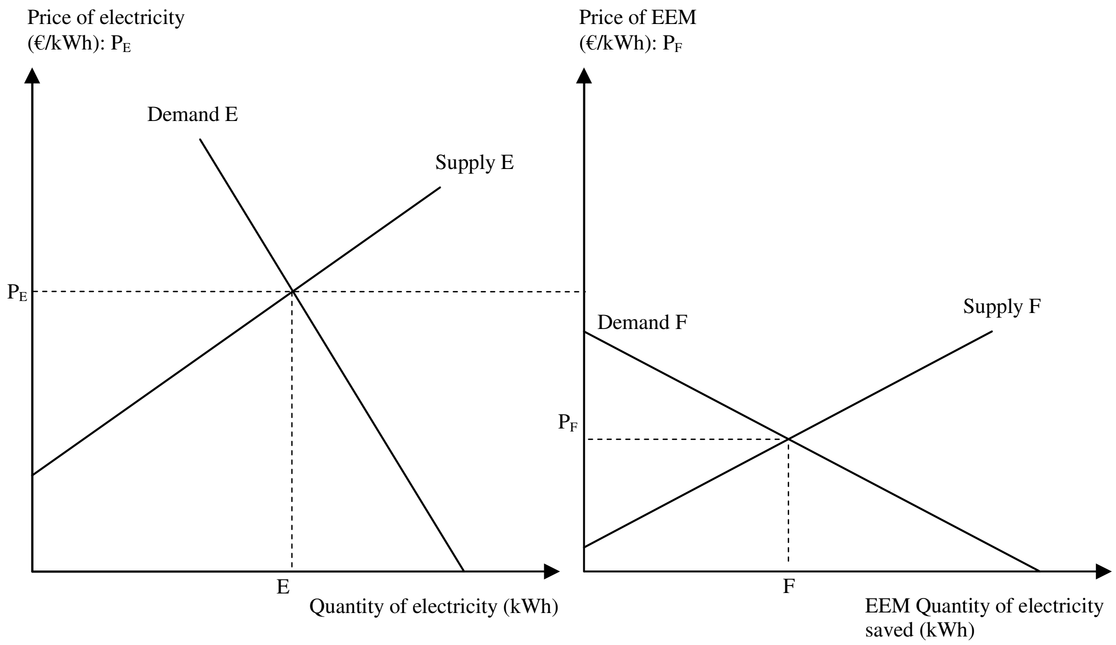
2.1.2 The Model of Sorrell et al.

The paper by Sorrell et al. *White certificate schemes: Economic analysis and interaction with the EU ETS* implements graphical techniques to analyze the interplay of WCTS and EUETS[32]. While EUETS is meant to restrict Co_2 emissions in Europe, WCTS is perceived as a cost-effective measure to foster demand-side investment in EEM. The market structure and the relevant market groups are identical to those of Oikonomou et al. (2008)[33]. In the beginning, Sorrell et al. also concern themselves with the question of how to measure additionality when it comes to EEM. Sorrell et al. cite Baumert (1998) who defined two possible interpretations, financial and environmental additionality. Financial additionality refers to the question whether the EEM would have taken place in the absence of financial incentives, like WCTS. Environmental additionality refers to the amount of EEM that is undertaken in the course of a project. The latter also demands that a project-baseline is defined on historical data or forecast in order to measure the performance of the EEM in

[29] Varian, H.R. (1994), p.228
[30] A pass through rate of 100% is therefore satisfied.
[31] C_f and C_v are both cost parameters.
[32] Sorrell et al. (2008)
[33] Section 2.1.1

question. After having introduced the relevant variables, Sorrell et al. present a graphical model of the electricity market and the market for EEM, which is presented in the in the following graph:

2-4 Electricity and EEM markets



Source: Sorrell et al (2009)

This presents the ex-ante WCTS situation within the electricity market of Sorrell et al.. According to the latter, they have incorporated both renewable (GE) and non-renewable (BE) energy generation in their model. However, it is not made clear how and where these two are differentiated. In general, the two products are assumed to have different cost structures[34]. Does the supply curve of electricity, which reflects marginal cost of production (MC), represent a weighted average of the two? How does one know, how much of E (electricity) is GE or BE? These questions remain unanswered, although, after the introduction of WCTS, Sorrell et al. infer its effects on both GE and BE. How this is done by looking at the graphs remains questionable.

Moreover, there is another issue that needs to be dealt with. E and F[35] are implicitly defined as perfect substitutes as every unit of F saves exactly one unit of E. There is no restriction mentioned that there is a minimum requirement of E needed. In case of the two graphs presented by Sorrell et al. it seems as though supply of E, i.e. MC_E, is always above supply of F, i.e. MC_F. If that were the case, depending on the underlying utility function, it seems as

[34] E.g.: Amundsen, E.S., Mortensen, J.B. (2001), or Meran, G., Wittmann, N. (2008)
[35] F being equal to EEM according to Sorrell et al.s' notation.

though a corner solution, i.e. E* = 0 and F* > 0, appears possible.[36] Also, the way the two graphs are presented gives the impression that the two demand curves are not correlated. However, as the two goods are (perfect) substitutes this impression is certainly a misconception. Therefore, a different approach is used in the following section in order to clarify the circumstances prevalent in the market that has been constructed by Sorrell et al. (2008).

2.1.2.1 A Modification of the Model of Sorrell et al.

Let's assume that a representative end-user of electricity face a utility function (U) with respect to electricity that is defined as follows:

$$U(e,f) = \alpha e + \beta f \quad \forall \alpha, \beta > 0 \tag{2.2}$$

This function implies that the two goods, electricity (e) and EEM (f) are perfect substitutes. Now, given the prices of the two goods, p(e) and p(f), end-users maximize their welfare according to

$$\max_{e,f} \quad U(e,f) \tag{2.3}$$

If there are welfare implications to be inferred, a fixed income I of end-users can be assumed and an income (I) restriction has to be incorporated in the maximization problem, i.e.

$$s.t. \quad I = p(e) \times e + p(f) \times f \tag{2.4}$$

Using the method of Lagrange, we arrive at the necessary FOC. Eliminating the Lagrange multiplier, this renders the common microeconomic result that, in case of perfect substitutes, the slope of the indifference curve has to equal the price ratio of the two goods:

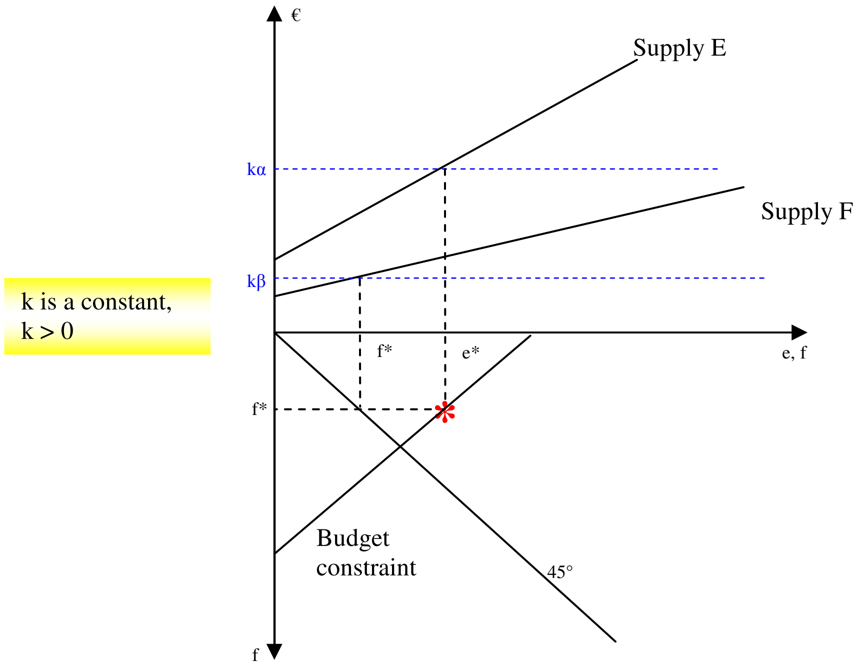
$$\frac{p_f}{p_e} = \frac{U_f}{U_e} = \frac{\alpha}{\beta} \tag{2.5}$$

In most cases, as not only I but also marginal prices p_e, p_f are given and constant[37], a corner solution is reached in equilibrium, i.e. only one of the goods is consumed, while demand for the other equals nil. In our case, prices are not constant but a function of quantity supplied. Therefore, in equilibrium, it can be the case that both e > 0 and f > 0, which is exemplified in the following graph:

[36] If there is no minimum Quantity of E defined, in theory, customers could substitute E completely through F.

[37] This implies that the marginal rate of substitution (MRS) is constant, as well, i.e. $\frac{p_f}{p_e} = \text{constant}$.

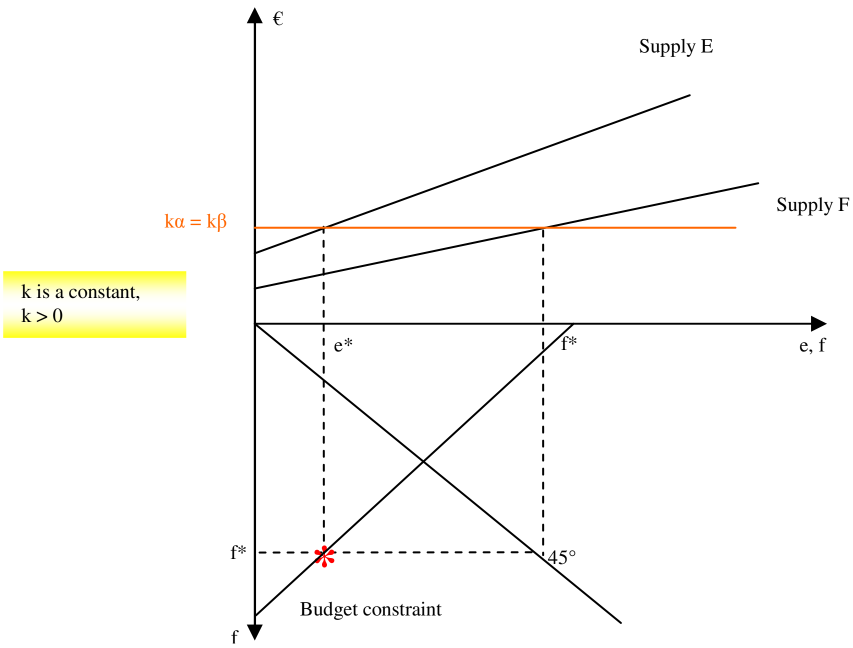
2-5 Perfect Substitutes I



Source: Author's design

In this case, it is assumed that $\alpha \neq \beta$. The constant k only enters the picture to ensure that the intersections can be drawn correctly, i.e. the ration is just multiplied by $1 = \frac{k}{k}$, hence, we have $\frac{\beta}{\alpha} = \frac{k \cdot \beta}{k \cdot \alpha}$ If the two coefficients α, β were equal, i.e. α = β, the graph changes slightly as shown in the following:

2-6 Perfect Substitutes Part II



Source: Author's design

In general, the two parameters, α and β, could be a way to discern different consumer groups and display their environmental preferences (awareness). For example, if $\alpha < \beta$ consumers value EEM higher, i.e. gain a higher utility from one unit of EEM than from electricity, maybe because it soothes their environmental conscience.
In general, the interdependency of the two market segments, the market for E and the market for F, becomes much clearer, if the two are combined in one graph.

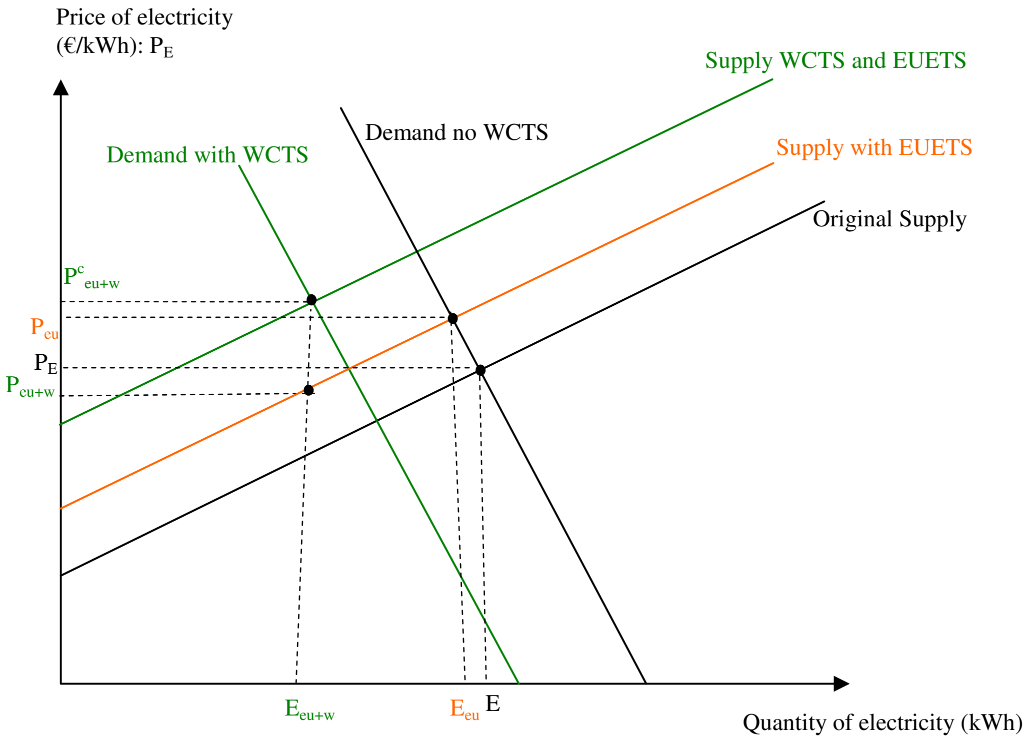
2.1.2.2 Introduction of WCTS

As has been mentioned before, the introduction of WCTS leads to a restriction placed on electricity consumption. Once Sorrell et al. include WCTS in their analysis, they translate the restriction on electricity consumption set by WCTS into an outward shift of the demand curve for EEM[38], since this leads to an increase in EEM consumption and a decrease in electricity demand. Afterwards they discuss an increase in energy prices and its effects. Also, the unresponsiveness of supply of EEM with respect to price, as well as the cost recovery of EEM enters the focus of their attention. Each of these additional aspects is depicted by a different graph.

In the end, they return to their initial model setting, including WCTS and EUETS. They compare the initial and final equilibrium in the electricity market with a WCTS and use a table to present suggestions on the effect of WCTS on various variables, e.g. Prices, demand, Co_2 emissions, as well as producer and consumer surplus. The results remain vague, e.g. *"Producer Surplus* [EEM]*: Could be small, since supply curve is likely to be flat.", "Consumer Surplus - overall: Likely to be reduced if supply curves are flat."* (Sorrell et al. 2009). This does not present a clear picture of results. Of course, any result of any model depends on the assumptions made in the beginning or along the way, but given these assumption, a clear outcome should be portrayed in the end. However, Sorrell et al. merely continue their analysis by introducing another market section, the EUETS into their graphical analysis. The overall findings are presented in a final graph including the effects of both WCTS and EUETS. However, the graph only shows the effects on the market for electricity (E), while the effect on the market for EEM (F) is only implicitly included in the final graph, through a shift in the electricity demand curve:

[38] These EEM are defined as *additional,* meaning that they would not have taken place in the absence of WCTS.

2-7 Electricity and EEM Market - WCTS and EEM



Source: Sorrell et al. (2008)

According to Sorrell et al., the introduction of EUETS leads to a rise in cost of electricity production. This is a straightforward assumption which is in line with basic microeconomic theory, due to the fact that emissions are restricted and, therefore, become a scarce resource. According to Sorrell et al., the introduction of WCTS leads to a shift in both demand and supply of E and lead to the following effects: *"The retail price* [with WCTS] *may either be higher or lower than with the EU ETS alone [P^c_{eu+w} < > P_{eu}]. While the reduction in demand following energy efficiency investment lowers the retail price, the recovery of costs increases the retail price […] the [WCTS] is likely to increase retail prices compared to the EU ETS alone."* (Sorrell et al. 2009).

Again, the effects are ambiguous and no definite result emerges, e.g. with respect to consumers surplus Sorrell et al. state that it is "*likely to be lower than with EU ETS alone"* (Sorrell et al. 2009). Therefore, the following section intends to incorporate WCTS and EUETS in the analysis presented in section 2.1.2.1, in order to clarify possible effects.

2.1.2.3 WCTS and EUETS in the Modified Model of Sorrell et al.

Again, e and f are perfect substitutes just as in equation (2.2). In addition, however, there is a restriction on the maximum amount of e, i.e. $\overline{e} \geq e*$. End-users maximize their welfare according to equation (2.3), (2.4), and the additional restriction on e. If all end-users face the same utility function, i.e. they are identical,[39] the restriction on e boils down to $\overline{e} = e*$, for each of them. Overall, the effects of WCTS and EUETS can be summarized as follows: The implementation of EUETS simply leads to a parallel upward shift of supply E, depending on the price of emission certificates (z), i.e. $MC_E + z$.

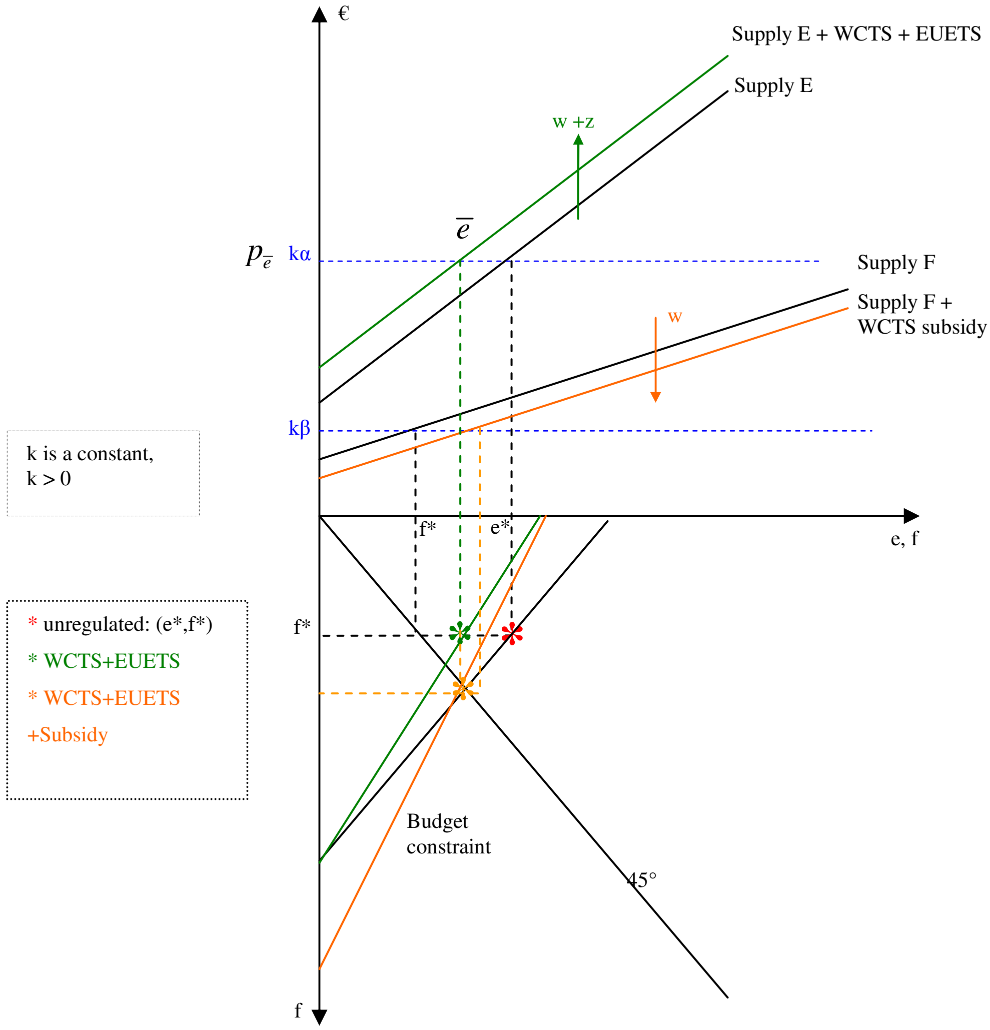
As suppliers are obliged to take part in WCTS on behalf their customers, supply changes again, depending on the price of White certificates (w), i.e. $MC_{WCTS+EUETS} = MC_E + z + w$.[40] Prior to WCTS, α and β were given and the amount of e* and f* were chosen according to equations (2.5). After introducing WCTS, the price of the quantity $\overline{e}$ is given by $MC_{\overline{e}}(\overline{e}) = \overline{p}_{\overline{e}}$. [41] Therefore, three out of four relevant variables are fixed. In case of WCTS, Sorrell et al. also suggest that suppliers of electricity subsidies end-users with w in order to increase the demand for EEM and reduce the demand of electricity, so that the target set by WCTS can be met. The following graph shows an example of possible market equilibria regarding the different model settings:

[39] This is a simplifying assumption that reduces complexity within the model but not the relevance of results. Also, each group of the initial Sorrell et al. model, e.g. producers of electricity and EEM, is also assumed to be homogenous.

[40] According to basic microeconomic theory, he price of the two certificates displays the marginal cost of the "last", i.e. marginal, abatement (z) or energy efficiency (p_w) measure undertaken in equilibrium.

[41] In this case, all end-users are identical regarding their Utility function. Therefore, there will be no trade in equilibrium and each of them demands exactly $\overline{e}$.

2-8 Introduction of WCTS and EUETS



Source: Author's design

The supply of EEM (F) shifts downward due to the assumption of Sorrell et al. that suppliers of E subsidize consumption of EEM with w in order to ensure that $\overline{e}$ can be met. This implies that the price of White Certificates reflects the marginal cost of the EEM that is necessary to achieve the necessary reduction of electricity consumption, i.e. compliance with $\overline{e}$.

Regarding the analysis of effects of introducing WCTS and EUETS several conclusions can be inferred. First of all, with respect to producers, due to perfect competition, profits will always be equal to zero.[42] Second, regarding end-users, two changes have to be taken into account: Supply of e becomes more costly as it is shifted upward by (w + z). Supply of f becomes cheaper as it is shifted downward by (w). As both goods are perfect substitutes, the combined effect on consumers' welfare depends solely on the price of Brown Certificates (z).

[42] It is assumed, that there are no windfall profits from issuing Brown Certificates via Grandfathering. This implies that these certificates are auctioned off by the government.

As it is assumed that z > 0, consumers will arrive at a lower indifference curve, as their income (I) remains unchanged (as shown in the graph on p. - 28 -). As the regulation authority is assumed to auction off Brown Certificates, it receives $z \times \overline{e}$. If this revenue was used to provide consumers with public services, *overall*, i.e. across-markets, the level of consumer welfare would remain unchanged.

2.1.2.4 Conclusion

Overall, the model of Sorrell et al. intends to present a graphical analysis of the effects that arise once EUETS and WCTS are included into the electricity market. However, although the implicit simplifying assumption that the two goods, electricity and EEM, are perfect substitutes is certainly justifiable, the graphs shown in their paper do not appear to picture the effects correctly. Moreover, the market for electricity is presented by one supply curve only, but is supposed to include two products, i.e. GE and BE. There is not hint at how the effects on the two can be differentiated or whether the price of electricity is a weighted average of the two different cost structures. The analysis of effects remains relatively vague and does not render clear results, given the assumptions that have been made. Therefore, although the approach of using graphical techniques to analyze the market is quite sensible, the practical application remains unsatisfactory from a reader's point of view.

2.1.3 Green, Brown, and now White Certificates – are three one too many?

Besides the work of Amundsen and Mortensen[43] on the interaction of Brown and Green Certificates, the paper by Meran and Wittmann, *Green, Brown, and now White Certificates – are three one too many?*[44], has formed the foundation of the model that will be presented in section 2.2. Meran and Wittmann strive to identify the interdependencies between and effects of Green, Brown, and White Certificate markets. Therefore, a model is constructed in which there are producers (Green and Brown), distributors, and end-users of energy/electricity, as well as a market for EEM of end-users and for abatement technology (AT) of Brown Energy producers. The only exogenous variables[45] are the price of EEM and of AT. In order to focus on the interplay of the policy instruments implemented, all relevant market segments are assumed to function under perfect competition.[46] The model is structured as follows: The supply side of the energy market includes producers of Green (y)

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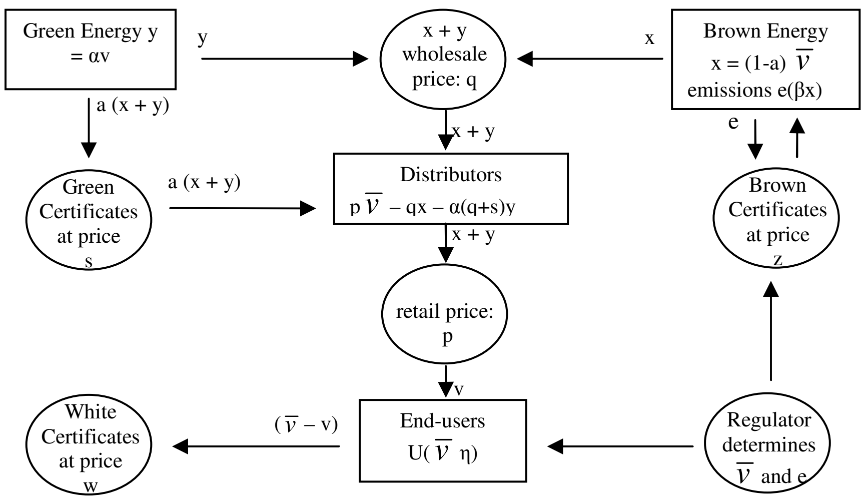
[43] Mortensen, E.S., Amundsen, J.B., (2001)
[44] DIW Berlin, discussion paper 809, (2008)
[45] Exception: Policy measures, i.e. Green Energy Quota α, Co_2 emission restriction E, and WCTS energy consumption restriction $\overline{v}$.
[46] Meran and Wittmann admit that the energy market is characterized by imperfect competition, in reality.

and Brown Energy (x). In the initial model setting, i.e. ex-ante WCTS, Green Energy has to be supplied according to a minimum quota requirement (α). On the one hand, there is a market-based subsidy, called Green Certificates, which have to be bought by distributors of energy at price s, in order to foster the production of Green Energy. On the other hand, producers of Brown Energy have to take part in EUETS, which implies that emission certificates have to be bought at price z. Also, AT can be implemented in order to reduce emissions per level of energy produced. Distributors and End-users of energy represent the demand side of the market. End-users can choose between the consumption of energy or EEM.[47] Also, consumption is based upon a strictly concave utility function (U), which depends on energy services (σ) which can either be provided by energy (v) or EEM. In each market segment, demand and supply side measures of energy efficiency can be defined. With respect to Brown Energy the level of emissions (e) per level of energy output (x) is represented by the emission factor β. With respect to energy consumption energy efficiency is measured by η,[48] as

$$\sigma = v\eta \, . \tag{2.6}$$

In this model, end-users of energy are directly affected by WCTS. If their energy consumption exceeds the standard $\bar{v}$, which is set by regulation authorities, they have to buy White Certificates at price w. If they surpass energy savings requirements, i.e. consume less than $\bar{v}$, they are able to sell the certificates, which have thereby been generated. The market structure, as well as all relevant variables, is sketched the following graph:

2-9 Market Structure



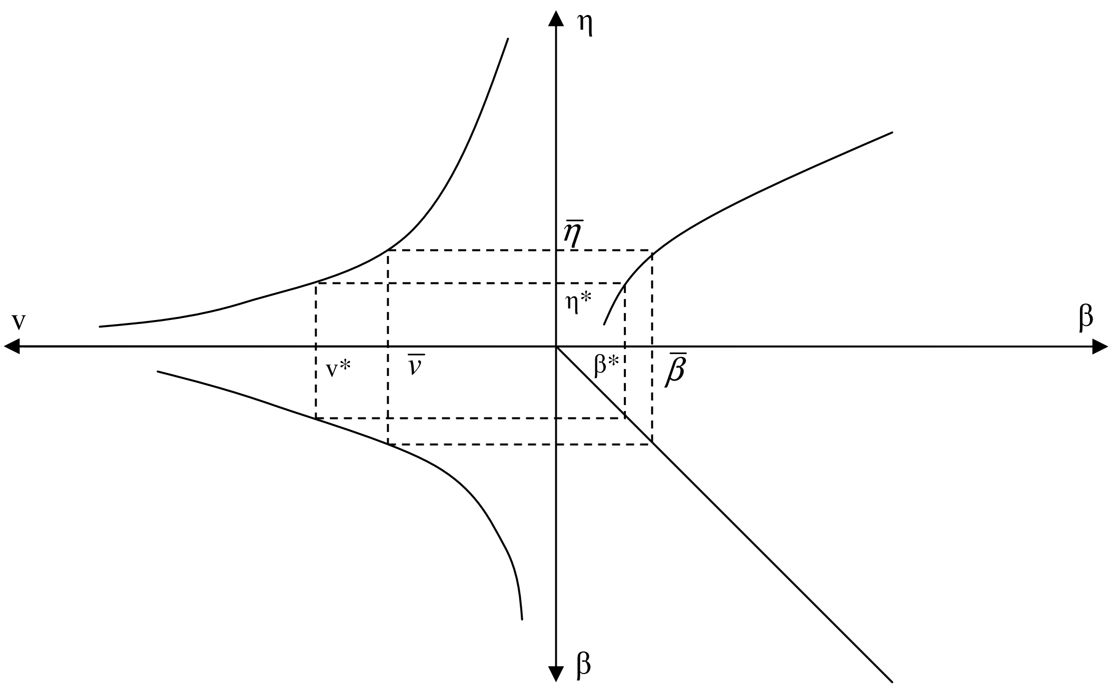
Source: Meran, G., Wittmann, N. (2008)

[47] It is assumed that the two goods are substitutes, as the rebound effects, in this case, is valued at less than 100%, i.e. approximately 20-30%, according to Greening, L.A., Green, D.L., and Difiglio, C. (2000).

[48] These variables have been introduced in a revised version of the paper submitted to the Journal of Environmental and Resource Economics in 2010.

After having introduced the structure of the model, Meran and Wittmann set up the equilibrium conditions of the market without WCTS. Afterwards, WCTS is introduced into the model and changes in the equilibrium outcome are calculated implementing comparative static. In this model setting WCTS into the model leads to the following result:
"*The introduction of WCTS leads to an increase in end-users' energy efficiency measures, i.e.* $\hat{\eta}$[49] *increases, whereas environmental efficiency in the production of Brown Energy is reduced, i.e.* $\hat{\beta}$[50] *increases*."
The proof of this proposition is also illustrated by a graph illustrating the relationship between energy consumption (v) and the efficiency measures of both demand (η) and supply (β) side.

2-10 Effect of introducing WCTS



Source: Meran, G., Wittmann, N. (2008)

A restriction of demand (v* → $\bar{v}$) always leads to an increase in both EEM (η) *and* the emission factor (β). Of course, in case of EEM, this is the intended result. However, with respect to the emission factor, this is an unwanted deterioration which stifles the first of the three EU vision's goals. Therefore, these findings show, that the regulation of the demand side leads to a trade-off regarding the performance of the emission factor of the supply side, i.e. Brown Energy production. Moreover, as overall energy consumption declines, the quota

[49] $\hat{\eta}$ denotes the optimal amount of η.

[50] $\hat{\beta}$ denotes the optimal amount of β

system with respect to the amount of Green Energy leads to reduction in the overall quantity of Green Energy demanded and, hence, supplied. Therefore, by introducing WCTS in order to foster the third of the three goals of the EU's 20/20/20 vision[51], the other two goals are hampered. Therefore, there is a significant catch to implementing WCTS, which has to be taken into consideration. Others have also hinted at possible difficulties[52]. However, the paper by Meran and Wittmann manages to dissect the chain of cause and effect and to illustrate it in a mathematical and graphical manner alike. It is also shown that the situation does not improve, if WTS is implemented only for a group of end-users. Switching the policy instrument also does not resolve the trade-off either, as long as both supply and demand side are regulated. Meran and Wittmann show, that, only if regulation authorities confine themselves to regulating just one side of the market, in this case the supply side, can this trade-off be overcome. Therefore, they propose that tightening the cap of emissions will render a better outcome than the introduction of a demand-side oriented policy measure. Therefore, the message of these findings is that, in some cases, less is definitely more.

2.2 White Certificates Revisited – Extending the Basic Model

In this section, a model is introduced which includes the same relevant supply and demand side market groups as the model by Meran and Wittmann. However, the market structure differs. On behalf of distributors, it is assumed that those operate under a monopoly setting, each of them supplying electricity to a specific region in which it does not have to fear competition[53]. Moreover, the issues of cost recovery and price caps as well as an incentive mechanism for fostering EEM are analyzed in detail.

2.2.1 Introduction

As has already been shown by Montgomery[54], establishing markets for certificates can result in achieving a certain level of environmental quality efficiently, since social costs of pollution, assuming that they are feasibly calculable, have been accounted for, and hence, internalized. These findings are certainly one of the reasons why certificate schemes have become increasingly popular in environmental policy. However, as has been hinted at in the previous sections, the question is not whether a stand-alone certificate scheme renders an

[51] Or, respectively, 30/20/20 vision, for details see footnote 11 .
[52] Oikonomou et al. (2008), see sections 2.1.1 and 2.1.2.
[53] This fact might stem from various reasons, e.g. geographical, historical, or political reason. Or it might be due to collusion and the presence of a functioning cartel.
[54] Montgomery, W.D. (1972)

efficient outcome but whether a combination of more than one certificate scheme targeting both demand *and* supply side of the same market leads to undesired results.

Therefore, despite several arguments in favor of WCTS stated in some of the current literature[55], the effects of introducing WCTS into a market system, which is already regulated through a cap-and-trade system for GHG emissions and a quota system meant to improve competitiveness of Green Energy, need to be analyzed thoroughly. The model developed in the following sections shows that results are less favorable than it might appear at first glance. It is shown that regulating energy demand achieves an increase in EEM solely at the expense of other goals such as the environmental efficiency of energy production, an effect described as pincers policy[56]. Moreover, in case of assuming a regular, i.e. falling, demand curve for energy, a monopoly distributor will always prefer a price-induced reduction of demand for energy, combined with buying white certificates over implementing incentive mechanisms to enforce consumers' investment in energy efficiency. Only if the properties of the model are varied, distributors will set an incentive greater than zero. However, in any case, without a reduction of the cap on emissions and an increase of the minimum quota of renewable energy, the introduction of WCTS will result in negative side effects on the environmental goals set regarding energy production and the amount of Green Energy produced. Therefore, implementing WCTS into a market which is already highly regulated cannot be considered the icing on the cake of environmental policy. Actually, quite the contrary turns out to be the case: the amount and intensity of interdependencies and, hence, the countervailing effects of the various policy measures are intensified. Rather than proposing the introduction of yet another policy instrument, the findings of the model call for the use of existing policy measures in a more effective way, in order to achieve the ambitious goals of European environmental policy.

The following analysis is structured as follows: Before dealing with the implementation of WCTS the outline of the model is presented in section 2.2.2. In section 2.2.3, a total integration of end-users into WCTS is modeled. In Section 2.2.4 an incentive mechanism, implemented by distributors to foster EEM, is introduced. The issue of possible measures of cost recovery by distributors is dealt with in section 2.2.5. Section 2.2.6 deals with setting a price cap on the price of energy. Section 2.2.7 is dedicated to relaxing the assumption that all distributors need to take part in WCTS. Section 2.2.8 deals with alternative policy measures, which can be used instead of WCTS, such as the reduction of the cap on emissions and the increase in the quota of renewable energy. Section 2.2.9 is comprised of some concluding remarks.

[55] Bertoldi et al. (2005)
[56] Meran, G., Wittmann, N. (2008)

2.2.2 Model Setting

First of all, in many countries, parts of the energy market are characterized by imperfect competition, as it has already been stated in other papers[57]. However, in order to isolate the effects of WCTS, imperfect competition is assumed only on behalf of distributors of energy, which are perceived as regional monopolists[58], who are able to set the price of energy sold to their consumers. Producers of energy are supposed to operate under perfect competition. Hence, the setting can be described as follows: There are four groups that are involved in the market for energy: producers of Brown Energy, producers of Green Energy, as well as distributors and end-users of energy. In the absence of WCTS, markets for Green and Brown Certificates are already in place and assumed to be working properly. Sanctions for non-compliance with regulations, quotas or standards are assumed to be effective as well, so that there is no incentive to defect. Whereas the market for Brown Certificates is designed as a cap-and-trade market with maximum emissions set at level $\overline{e}$, the market for Green Certificates is based on a minimum quota (α) system, i.e. $\alpha \in [0; 1]$, of Green Energy in relation to total energy consumed as shown in the paper by Amundsen and Mortensen[59]. Now, properties and equations for each set of actors need to be defined.

2.2.2.1 Supply Side[60]

This side of the market consists of producers of Brown Energy and producers Green Energy. The market is assumed to be perfectly competitive. Hence, all of them are assumed to be price-takers without market power.

2.2.2.1.1 Green Energy

The producers of Green Energy receive wholesale price q for each unit of Green Energy (y) produced as well as price s of Green Certificates, which can be perceived as a market-based subsidy which has to be paid by distributors. The costs of production K(y), where $K_y > 0, \text{ and } K_{yy} > 0$, are assumed to be relatively high. Hence, without subsidies and quota α, Green Energy would not be able to compete successfully with Brown Energy. Profits are maximized according to

$$\max_y \quad [(q+s)y - K(y)]$$

which results in the following first order condition (FOC):

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[57] Sorrell et al. (2009), see 2.1.2, Oikonomou et al. (2008), see 2.1.1, or Fadeeva, O. (2003)
[58] Section 2.1
[59] Amundsen, E.S., Mortensen, J.B. (2001)
[60] Modelling the supply side of energy is based on Meran, G., Wittmann, N. (2008)

$$K_y(y) = (q+s) \quad (2.7)$$

As a result, the amount of Green Energy produced can be expressed [61] by the following supply function:

$$\hat{y} = \hat{y}(q+s), \quad \hat{y}_q > 0 \quad (2.8)$$

2.2.2.1.2 Brown Energy

The producers of Brown Energy face production costs $C(x)$, $C_x > 0, C_{xx} > 0$ as a function of units of energy produced x, which are assumed to be relatively low, compared to the costs of producing Green Energy. However, the production of Brown Energy is assumed to result in emissions of Greenhouse Gases, e.g. CO_2. Therefore, producers of Brown Energy incur additional costs as they need to comply with emission cap $\overline{e}$ set by regulation authorities and need to buy a certificate at price z for each unit e of CO_2 emitted. Additionally, they could also invest in abatement technologies I at price D which reduces the amount of emission per unit of energy produced[62]. Emission can, thereby, be expressed as a function of amount of energy produced and investment in AT:

$$e = e(x, I), \quad e_x > 0 \quad \text{and} \quad e_I < 0 \quad (2.9)$$

It is assumed that emissions rise as x rises and fall as I rises. In both cases, diminishing marginal effects exist, i.e. $e_x > 0, e_{xx} > 0$, $e_I < 0, e_{II} > 0$. Moreover, it is assumed that the marginal impact on emissions through an increase in output is reduced as I rises, i.e. $e_{xI} = e_{Ix} < 0$. Finally, $e(x, I)$ is convex and, hence, producers' resulting profit function is concave. Profits are maximized according to

$$\max_{x,I} \, [qx - C(x) - ze(x,I) - ID]$$

which results in the following FOC:

$$q = C_x(x) + ze_x(x, I) \quad (2.10)$$

$$D = -z\,e_I(x, I) \quad (2.11)$$

As a result, the amount of Brown Energy produced and the amount of investment made can be expressed as a function of prices q, z, i.e.

$$\hat{x} = \hat{x}(q, z) \quad \hat{I} = \hat{I}(q, z) \quad (2.12)$$

since $D = \overline{D}$ is held constant. In order to analyze the effects on $\hat{x}$ and $\hat{I}$ with respect to changes in prices q and z, equations (2.10) and (2.11) are used. Changes in q render the following results: As shown in the appendix, both $\hat{x}$ and $\hat{I}$ rise in q, i.e. $\hat{x}_q > 0$ and $\hat{I}_q > 0$.

[61] Appendix 2.4.1.1
[62] Montgomery, W.D. (1972)

Changes in z result in the subsequent effects: while $\hat{x}$ is negatively correlated to z, $\hat{I}$ increases if z rises, i.e. $\hat{x}_z < 0$ and $\hat{I}_z > 0$. To summarize

$$\hat{x}_q > 0, \quad \hat{I}_q > 0, \quad \hat{x}_z < 0, \quad \hat{I}_z > 0 \tag{2.13}$$

Subsequently, we need to determine the reaction of the emission function, i.e. $\hat{e}(q,z) = e(\hat{x},\hat{I})$, to possible changes in q and z:

$$\hat{e}(q,z) = e(\hat{x}(q,z),\hat{I}(q,z)) \tag{2.14}$$

From equations (2.13) and (2.14) it follows that

$$\hat{e}_z = e_x\hat{x}_z + e_I\hat{I}_z < 0 \tag{2.15}$$

The reaction of $\hat{e}$ to an increase in q is ambiguous. This follows from

$$\hat{e}_q = e_x\hat{x}_q + e_I\hat{I}_q \tag{2.16}$$

and equation (2.13) and (2.14). In the following, it is assumed that $\hat{e}_q > 0$, since, as energy wholesale price increases, production rises and, therefore, emissions increase, as well. The countervailing effect of an increase in abatement investment (I) does not compensate for an increase in emissions due to an increase in the production of Brown Energy x.

2.2.2.2 Demand Side

This side of the market consists of distributors and end-users of energy.

2.2.2.2.1 End-users

A concave utility function (U) is assumed, which depends on the amount of energy consumed v at price p and the amount of investment i in energy efficiency at price d. The utility function (U) can be perceived as a reduced form of a traditional utility function and a household production function[63]. In the absence of White Certificates, the utility of a representative household of region j is maximized according to

$$\max_{v_j,i_j} [U(v_j,i_j) - p_j v_j - i_j d]$$

which results in the following FOC:

$$p_j = U_{v_j}(v_j,i_j) \quad \text{and} \quad d = U_{i_j}(v_j,i_j) \tag{2.17}$$

The equilibrium amount of energy demanded $\hat{v}_j$ and the amount of investment chosen $\hat{i}_j$ can be expressed as a function of market price p_j

[63] Wirl, F. (1991)

$$\hat{v}_j = \hat{v}(p_j), \quad \hat{i}_j = \hat{i}(p_j)$$

as $d = \overline{d}$ is assumed to be constant. Results regarding changes in p_j are as follows: While $\hat{v}_j$ is always negatively correlated regarding changes in p_j, $\hat{i}_j$ is positively (negatively) related to p_j, if $\hat{i}_j$ and $\hat{v}_j$ are substitutes (complements). Considering changes in d, we obtain the following results as shown in appendix
I.2: While $\hat{i}_j$ is always negatively correlated regarding changes in d, $\hat{v}_j$ is positively (negatively) related to d, if $\hat{i}_j$ and $\hat{v}_j$ are substitutes (complements). In the following it is assumed that energy consumption and investment in energy efficiency are substitutes.[64]

2.2.2.2.2 Distributors

The distributors buy energy from producers at wholesale price q and sell it at market price p, where p > q. They are not able to influence wholesale prices, as they are relatively small regional monopolists. Nonetheless, distributor j, $\forall j = 1,...,n$, is able to set the market price p_j of its region j and to maximize its profits accordingly. Distributors need to ensure that the amount of Green Energy satisfies quota α and, hence, are forced to buy the respective amount of Green Certificates at price s. As Brown Energy is assumed to be relatively cheaper, distributors demand the minimum amount of Green Energy, $y = \alpha(x+y)$ (minimum quota system), to satisfy the demand in their respective region j. The total amount of energy demanded is denoted by $\hat{v} = \hat{x} + \hat{y}$ (market equilibrium), whereas $\hat{v} = \Sigma_{i=1}^{n} \hat{v}_j$. Also, distributors incur network costs $c^n(v)$, with $c_v^n(v) > 0, c_{vv}^n(v) > 0$, which depend on the amount of energy distributed. Hence, each distributor j maximizes its profits according to

$$\max_{p_j} \; (p_j - q - \alpha s)\hat{v}_j(p_j) - c^n(\hat{v}_j) \tag{2.18}$$

Utilizing the market equilibrium condition $\hat{v}_j = \hat{x}_j + \hat{y}_j$ leads to

$$\hat{v}_j + (p_j - q - \alpha s - c^n_{v_j})\frac{\partial \hat{v}_j}{\partial p_j} = 0 \tag{2.19}$$

which yields

[64] As in section 2.1.3

$$p_j + \frac{\hat{v}(p_j)}{\frac{\partial \hat{v}(p_j)}{\partial p_j}} = q + \alpha s + c^n_{v_j}, \forall j = 1,..,n. \tag{2.20}$$

Distributors will set marginal revenue equal to marginal cost and choose prices p_j accordingly.

2.2.3 WCTS for All Distributors

Taking all assumptions and previously stated settings into account, we can determine the equilibrium conditions for the energy markets through the following equations (2.21) to (2.23):

$$(1-\alpha)\,\Sigma_{j=1}^{n} \hat{v}_j(p_j) - \hat{x}(q,z) = 0 \tag{2.21}$$

$$\alpha\,\Sigma_{j=1}^{n} \hat{v}_j(p_j) - \hat{y}(q+s) = 0 \tag{2.22}$$

$$\overline{e} - \hat{e}(q,z) = 0 \tag{2.23}$$

and equations (2.20) determining equilibrium prices p_j for every region j. Solving these equations, results in a set of equilibrium prices in the absence of WCTS, i.e. $q^o, z^o, s^o > 0$, and $p_j^o > 0$.

The introduction of an effective WCTS into the market system by establishing a maximum quantity of energy demanded $\overline{v}_j$ for every region j, results in the following equations, taking into account that $\overline{v}_j < \hat{v}_j(p_j^o)$:

$$(1-\alpha)\,\Sigma_{j=1}^{n} \hat{v}_j(p_j) - \hat{x}(q,z) = 0 \tag{2.24}$$

$$\alpha\,\Sigma_{j=1}^{n} \hat{v}_j(p_j) - \hat{y}(q+s) = 0 \tag{2.25}$$

$$\overline{e} - \hat{e}(q,z) = 0 \tag{2.26}$$

$$\overline{v}_j - \hat{v}_j(p_j) = 0 \;\; \forall j \in n \tag{2.27}$$

Equilibrium market prices p_j are now determined through a slight modification of equation (2.18) taking into account that for every unit of energy consumed more (less) than $\overline{v}_j$ a White Certificate w has to be bought (is generated)

$$\max_{p_j} \,(p_j - q - \alpha s)\hat{v}_j(p_j) - c^n(\hat{v}_j) + w(\overline{v}_j - \hat{v}_j(p_j)) \tag{2.28}$$

which results in the following equilibrium condition for market prices p_j

$$p_j + \frac{\hat{v}(p_j)}{\frac{\partial \hat{v}(p_j)}{\partial p_j}} = q + \alpha s + c^n_{v_j} + w \tag{2.29}$$

Price w of white certificates is thereby perceived as an additional marginal cost of energy production. Through the introduction of WCTS energy producers are forced to adapt the goal of forcing demand to become equal to or less than $\bar{v}_j$. Naturally, they do not have to buy w for every unit of energy distributed, however, every unit of energy distributed less (more) than $\bar{v}_j$ would generate (cost) w but they would also forgo (gain) p_j. Hence, w can be seen as a real cost for every unit of energy distributed, where $\hat{v}_j > \bar{v}_j$, and as an opportunity cost for every unit of energy distributed, where $\hat{v}_j < \bar{v}_j$.

The solution obtained by these equations leads to equilibrium prices defined as $p^w_j, q^w, s^w, z^w > 0$, and w > 0.

Proposition 2.1: *The introduction of a WCTS leads to an increase of $\hat{i}_j$ and a decrease of $\hat{I}$ and of the amount renewable energy supplied $\hat{y}$.*

Proof: Let us begin with the latter statement. Since, by equation (2.14) $\bar{e} = \hat{e}(q,z) = e((1-\alpha)\bar{v}, \hat{I}(q,z))$, where $\bar{v} = \Sigma^n_{j=1}\bar{v}_j$, it follows that $\hat{I}_{\bar{v}} > 0$:

$$\hat{I}_{\bar{v}} = \frac{-(1-\alpha)e_x}{e_I} > 0 \tag{2.30}$$

The equilibrium amount of renewable energy supplied is characterized by equation (2.8), i.e. $\hat{y}(q+s)$. Therefore, this results in $\hat{y}_{\bar{v}} = y_1(\frac{\partial \hat{q}}{\partial \bar{v}} + \frac{\partial \hat{s}}{\partial \bar{v}}) > 0$ [65]. As the amount of energy consumed is reduced, i.e. $\bar{v} = \Sigma^n_{j=1}\bar{v}_j = \Sigma^n_{j=1}\hat{v}(p^w_j) < \Sigma^n_{j=1}\hat{v}(p^o_j)$, the amount of renewable energy supplied is reduced as well. In order to prove the former assertion, we differentiate equation (2.17) with respect to $\bar{v}$ which yields

$$\frac{\partial \hat{i}}{\partial \bar{v}} = -\frac{U_{iv}}{U_{ii}} < 0$$

Applying some comparative static to equations (2.24) to (2.29)[66] results in

[65] Appendix 2.4.1.1
[66] Appendix 2.4.2

$$p_{\bar{v}}^{w} < 0,\ q_{\bar{v}}^{w} > 0,\ s_{\bar{v}}^{w} \gtrless 0,\ (q_{\bar{v}}^{w} + \alpha s_{\bar{v}}^{w}) > 0,\ z_{\bar{v}}^{w} > 0, \text{ and } w_{\bar{v}} < 0.$$

Now, all of the effects of implementing WCTS can be inferred. In order to increase end-users' energy savings and energy efficiency regulation authorities set $\bar{v} = \Sigma_{j=1}^{n} \bar{v}_j < \Sigma_{j=1}^{n} \hat{v}(p_j^o)$. As sanctions are supposed to be working properly, distributors will force end-users to comply with $\bar{v}$ through a price-induced reduction of demand in energy. Depending on region j households' utility function, the reduction in demand will determine whether distributor j becomes a net seller or a net buyer of White Certificates, or simply meets $\bar{v}_j = \hat{v}_j(p_j^w)$. Moreover, consumers will substitute energy consumption with investment in energy efficiency as its price as also become relatively cheaper compared to the price of energy, i.e. $\frac{\bar{d}}{p_j^w} < \frac{\bar{d}}{p_j^o}$. But that is not the end of the story. The production of renewable energy $\hat{y}$ decreases. Moreover, the production of Brown Energy $\hat{x}$ and the price of Brown Certificates z decreases, along with the amount of investment in abatement technology $\hat{I}$. Hence, the reduced amount of Brown Energy $\hat{x}$ is produced using less AT, i.e. $\hat{I}\downarrow$, and at a lower price for Brown Certificates $z\downarrow$, which results in an increase in emissions per unit of energy $[\frac{\hat{e}(q,z)\uparrow}{\hat{x}(q,z)\downarrow}]\Uparrow$. As a result, the environmental efficiency in energy production is reduced. From an environmental point of view, this is clearly a negative effect.

2.2.4 Implementing an Incentive Mechanism

It has also been suggested, that distributors design an incentive mechanism to further stimulate households' investment in energy efficiency, e.g. wall insulation or improvement of heating control[67]. This incentive can be perceived as a market-based subsidy of energy efficiency measures. Instead of having to pay $\bar{d}$ for every unit of i_j, households of region j now only pay $(1-\sigma_j)\bar{d}$, where $0 \le \sigma_j \le 1$ while the respective distributor j provides $\sigma_j \bar{d}$ for every unit of i_j acquired. In this case, distributors are assumed to have perfect information about households' utility function and their utility maximizing FOC. Therefore, they are able to predict households' reaction to energy prices p_j and incentive σ_j. Like a Stackelberg leader, distributor j now chooses the profit maximizing level of p_j and σ_j, given $\bar{v}_j$

[67] Fadeeva, O. (2003)

accordingly. End-users' utility maximizing conditions, equations (2.17) are therefore modified as follows.

$$\max_{v_j,i_j} [U(v_j,i_j) - p_j v_j - (1-\sigma_j) i_j \overline{d}]$$

which results in the following FOC:

$$p_j = U_{v_j}(v_j,i_j) \quad and \quad (1-\sigma_j)\overline{d} = U_{i_j}(v_j,i_j) \tag{2.31}$$

The equilibrium amount of energy demanded $\widehat{v_j}$ and the amount of investment chosen $\hat{i}_j$ can be expressed as a function of market prices p_j and σ_j which results in

$$\hat{v}_j = \hat{v}_j(p_j,\sigma_j) \qquad \hat{i}_j = \hat{i}_j(p_j,\sigma_j)$$

While equations (2.24) to (2.27) remain unchanged, equations (2.28) are modified. The incentive mechanism (IM) is a cost to distributors. If they do not regulate demand through this measure, they either have to buy white certificates at price w or pay sanction t for every unit of energy which exceeds $\overline{v}_j$.

$$\begin{aligned} \max_{p_j,\sigma_j} \; & (p_j - q - \alpha s)\hat{v}_j(p_j,\sigma_j) - c^n(\hat{v}_j(p_j,\sigma_j)) \\ & + w(\overline{v}_j - \hat{v}_j(p_j,\sigma_j)) - \sigma_j \, \overline{d} \, \hat{i}(p_j,\sigma_j) \end{aligned} \tag{2.32}$$

Proposition 2.2: Maximizing profits is equal to minimizing costs. Hence distributors will set $\hat{\sigma}_j = 0$ as long as no additional constraints, e.g. a price cap, enter the picture.

Proof: FOC with respect to σ_j yields $(p_j - q - \alpha s - c^n_{v_j} - w)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \overline{d}\,\hat{i} - \overline{d}\,\sigma_j \frac{\partial \hat{i}}{\partial \sigma_j} < 0$ which means that

$$0 \neq (p_j - q - \alpha s - c^n_{v_j} - w)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \overline{d}\,\hat{i} - \overline{d}\,\sigma_j \frac{\partial \hat{i}}{\partial \sigma_j}. \tag{2.33}$$

Hence the necessary condition $\sigma_j[(p_j - q - \alpha s - c^n_{v_j} - w)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \overline{d}\,\hat{i} - \overline{d}\,\sigma_j \frac{\partial \hat{i}}{\partial \sigma_j}] = 0$ can only hold true if $\sigma_j = 0$.

Hence, in this setting a distributor will never implement an IM as a market-based subsidy to increase households' investment in energy efficiency. After distributor j has set $\hat{\sigma}_j = 0$, the remaining set of equations equals the model depicted in the previous section, i.e. (2.24) to (2.27), including both positive and negative effects resulting from the implementation of

WCTS. However, these results imply that, aside from the assumption of perfect information, energy demand correlates negatively to energy prices and that there are no goals or regulations regarding the level of energy prices. As will be seen in section seven of this paper, if the latter condition is changed, results differ.

2.2.5 Cost Recovery

Another issue that needs to be looked at is the question of cost recovery on behalf of distributors. In reality, distributors are eligible to redeem costs of WCTS by increasing the price of energy - with or without limits - or, as known from the Italian WCTS, there exists a fund out of which distributors receive redemption for co
sts incurred through their efforts in reducing households' demand in energy and increase in energy efficiency. Assuming that for every White Certificate generated distributor j receives a given level of compensation b, i.e. b > 0, it follows that[68]:

$$\begin{cases} \text{with } b: p_j(1+ 1/\varepsilon_j) + w + b = MC_j \quad \forall \hat{v}_j < \bar{v}_j & (2.34) \\ \text{without } b: p_j(1+ 1/\varepsilon_j) + w = MC_j \quad \forall \hat{v}_j < \bar{v}_j & (2.35) \end{cases}$$

with $MC_j = q + \alpha s + c^n_{v_j}$ and $1/\varepsilon_j = \frac{\hat{v}(p_j)}{p_j}\frac{\partial p_j}{\partial \hat{v}(p_j)}$.

Corollary 2.1: *Every increase in b is offset by an equivalent decrease of the price in White Certificates w, i.e.* $\frac{\partial w}{\partial b} = -1$.

Proof: Both instruments, White Certificates through price w and the redemption fund through payment b, target the same section of the market. Distributor j maximizes its profit according to equation (2.34), while the remaining equilibrium conditions, i.e. equations (2.24) to (2.27) are unchanged. Equilibrium conditions render prices p^b_j, s^b, q^b, z^b, and $w > 0$. As b>0, changes in the price of White Certificates are $\frac{\partial w}{\partial b} = -1$, whereas $\frac{\partial p_j}{\partial b}, \frac{\partial q}{\partial b}, \frac{\partial s}{\partial b}, \frac{\partial z}{\partial b} = 0$. [69] This kind of offsetting effect of two policy instruments, which simultaneously target an identical

[68] Naturally, we have b, w=0 $\forall \bar{v}_j \le \hat{v}_j(p^w)$.

[69] Appendix 2.4.4

section of the market, has already been referred to by Heilmann.[70] The remaining results are therefore identical to those witnessed in section 2.2.3.

2.2.6 Price Cap

So far, it has been the case, that there is no upper limit on the price set by distributor j. If it were the case that, after having introduced WCTS, distributors were only allowed increase price by a certain percentage μ, i.e. $0 \leq \mu < 1$, such that $p_j^w = (1+\mu)\ p_j^o$, the price-induced reduction of demand might not suffice to meet the requirement of $\overline{v}_j \geq \hat{v}_j(p_j^w)$. Market equilibrium is defined by the following equations

$$(1-\alpha)\,\Sigma_{j=1}^{n}\hat{v}_j(p_j) - \hat{x}(q,z) = 0 \tag{2.36}$$

$$\alpha\Sigma_{j=1}^{n}\hat{v}_j(p_j) - \hat{y}(q+s) = 0 \tag{2.37}$$

$$\overline{e} - \hat{e}(q,z) = 0 \tag{2.38}$$

$$\overline{v}_j - \hat{v}_j(p_j) = 0 \quad \forall j \in n \tag{2.39}$$

and the cost minimizing condition regarding distributor j

$$\min\left\{t(\hat{v}_j(p_j^w,\sigma_j) - \overline{v}_j), \sigma_j \overline{d}\hat{i}_j(p_j^w,\sigma_j)\right\} \quad \forall(\hat{v}_j > \overline{v}_j) \tag{2.40}$$

Proposition 2.3: The capped energy price does not suffice to make HHs' comply with restriction on energy demand (WCTS). As no one is able to generate White certificates (WC) price of WC will become very high, i.e. w → ∞. Hence, distributors can either pay fine t or use IM and will choose the least cost combination in order to maximize their profits.

Proof: The maximum possible price is $p_j^{\overline{w}} = (1+\mu)\ p_j^o$ which results in $\overline{v}_j < \hat{v}_j(p_j^w)$. This results in the following situation with respect to distributors choice of σ_j, given the exogenous values for t and $\overline{d}$:

[70] Heilmann, S. (2005)

$$\begin{cases} t > \sigma_j \bar{d} \longrightarrow \sigma_j > 0 \quad \forall \bar{v}_j < \hat{v}_j & (2.41) \\ t = \sigma_j \bar{d} \longrightarrow \sigma_j \geq 0 \quad \forall \bar{v}_j < \hat{v}_j & (2.42) \\ t < \sigma_j \bar{d} \longrightarrow \sigma_j = 0 \quad \forall \bar{v}_j < \hat{v}_j & (2.43) \\ t, \sigma_j = 0 \, \forall \bar{v}_j \geq \hat{v}_j & (2.44) \end{cases}$$

Distributors j will utilize an IM to improve energy efficiency, and thereby reduce the amount of energy demanded, if its costs are less or equal to per unit sanctions of non-compliance with $\bar{v}_j$, as shown in the case of (2.41) and (2.42). If sanction are low, then IM will not be used, as in the case of (2.43).

Hence, given certain assumption, such as a binding price cap, distributors might utilize IM to increase end-users energy efficiency. In any of the above cases, however, end-users' investment in energy efficiency measures rises[71]. Nonetheless, the negative effects of introducing WCTS into the market regarding investment in abatement ($\hat{I}$) and the amount of Green Energy produced ($\hat{y}$) are still present. Hence, even if IM is implemented, without a increase in the minimum quota of Green Energy demanded, α, and a decrease in the cap on emissions, $\bar{e}$, WCTS has a negative impact on the other goals of environmental policy, which have been stated previously.

2.2.7 WCTS for a Group of Distributors

In reality, not all distributors of energy are forced to take part if WCTS is implemented. Only distributors whose number of clients, i.e. number of households supplied, surpasses a certain threshold set by regulation authorities have to comply. Therefore, it is assumed that only a number of K distributors, i.e. $K \subset N, k \in K, K \neq \emptyset$ are large enough to take part in WCTS while the remaining N\K distributors do not meet the threshold requirement. Before introducing WCTS all distributors were faced with identical profit maximizing conditions. Now, a representative distributor k of group K sets his profit maximizing price p_k according to equation (2.29) while a representative distributor j of group N\K, i.e. $j \in N \backslash K$, utilizes equation (2.20) to set price p_j. Hence, market equilibrium is defined by the following equations:

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[71] As $\frac{\partial \hat{i}_j}{\partial p_j}, \frac{\partial \hat{i}_j}{\partial \sigma_j} > 0.$

$$(1-\alpha)\left[\sum_{k\in K}\hat{v}_k + \sum_{j\in N\setminus K}\hat{v}_j\right] - \hat{x} = 0 \tag{2.45}$$

$$\alpha\left[\sum_{k\in K}\hat{v}_k + \sum_{j\in N\setminus K}\hat{v}_j\right] - \hat{y} = 0 \tag{2.46}$$

$$\overline{e} - \hat{e}(q,z) = 0 \tag{2.47}$$

$$\overline{v}_k - \hat{v}_k(p_k) = 0 \quad \forall k \in K \tag{2.48}$$

Proposition 2.4: *In the absence of limits for energy prices, prices p_k is always higher than p_j[72], as distributor k has to account for the opportunity cost w of every unit of energy supplied, whereas distributor j does not.*

Proof: Distributor k will set price p_k according to

$$p_k + \frac{\hat{v}_k}{\frac{\partial \hat{v}_k}{\partial p_k}} = q + \alpha s + c^n_{v_j} + w \tag{2.49}$$

While distributor j will set price p_j according to

$$p_j + \frac{\hat{v}_j}{\frac{\partial \hat{v}_j}{\partial p_j}} = q + \alpha s + c^n_{v_j}. \tag{2.50}$$

Representative households j and k are characterized by equation (2.17). Applying some comparative static to equations (2.45) to (2.48), (2.49), and (2.50) renders

$p^w_{k\,\overline{v}} < 0$, $q^w_{\overline{v}} > 0$, $s^w_{\overline{v}} \gtrless 0$, $(q^w_{\overline{v}} + \alpha s^w_{\overline{v}}) > 0$, $z^w_{\overline{v}} > 0$, $w_{\overline{v}} < 0$, and $p^w_{j\,\overline{v}} > 0$.

As price p_k, set by the regulated distributor, rises, demand of household k will decrease. However, as wholesale prices decrease, the effect on the price set by distributor j is exactly opposite to that. As p_j decreases, demand of household j increases.

The question that remains is, how large the relative changes in demand are and whether the two contrary effects offset each other or not.

Lemma 2.1: The increase in demand in $\hat{v}_j(p^w_j)$ does not completely offset the decrease in demand, i.e.[73]

[72] It is assumed that households are bound to be supplied by their regional supplier.

$$\frac{\partial V}{\partial \overline{v}_k} = \frac{\partial \hat{v}_k}{\partial p_k}\frac{\partial p_k}{\partial \overline{v}_k} + \frac{\partial \hat{v}_j}{\partial p_j}\frac{\partial p_j}{\partial \overline{v}_k} > -1. \tag{2.51}$$

Proof: Appendix 2.4.7

The effects of implementing WCTS in case of partial integration can certainly be considered ambiguous. Energy demand of households which are supplied by regulated distributors will decrease and cause investment in energy efficiency to increase, as its relative price is reduced. However, energy demand of households supplied by unregulated distributors will increase, and cause investment in energy efficiency to decrease, as its relative price is raised. The combined effect on wholesale prices and amount of energy produced depends on which effect is larger. In case of this model setting no complete but a partial offset occurs. Nonetheless, implementing WCTS renders results which are far from what can be considered a satisfying second-best solution, at least from an environmental point of view.

2.2.8 Is Less Still More?

As the implementation of WCTS results in a negative impact on environmental policy measures present in this model, an alternative is proposed. Instead of introducing yet another policy measure, regulation authorities might achieve a better outcome by using the policy instruments already prevalent in the market, such as the cap on emissions $\overline{e}$. In equilibrium, equations (2.20), and (2.21) to (2.23) remain unchanged, i.e.

$$(1-\alpha)\,\Sigma_{j=1}^{n}\hat{v}_j(p_j) - \hat{x}(q,z) = 0 \tag{2.52}$$

$$\alpha\,\Sigma_{j=1}^{n}\hat{v}_j(p_j) - \hat{y}(q+s) = 0 \tag{2.53}$$

$$\overline{e} - \hat{e}(q,z) = 0 \tag{2.54}$$

and

$$p_j + \frac{\hat{v}_j(p_j)}{\frac{\partial \hat{v}_j(p_j)}{\partial p_j}} = q + \alpha s + c^n_{v_j},\ \forall j = 1,..,n. \tag{2.55}$$

Proposition 2.5: *As $\overline{e}$ is reduced, emissions become more costly due to an increase in scarcity. Therefore, investment in abatement will increase. Households' investment in energy*

[73] Define V as $V = \left[\sum_{k\in K}\hat{v}_k + \sum_{j\in N\setminus K}\hat{v}_j\right]$

efficiency increases as well, as the wholesale price, and along with it the market price, of energy increases.

Proof: [74] Firstly, households' reaction to a reduction in the cap of emission needs to be analyzed, as well as the effect of the latter on BE producers' investment in abatement. Comparative static with respect to $\overline{e}$ yields, that households' investment in energy efficiency increases, i.e. $\hat{i}_{j_{\overline{e}}} < 0$. Secondly, BE producers' investment in abatement increases as $\overline{e}$ is reduced, i.e. $\hat{I}_{\overline{e}} < 0$.

Hence, the results of a reduction in the cap of emissions are clearly favorable. The only negative effect is the reduction in production of renewable energy, due to an overall decrease in energy demanded, i.e. $\frac{\partial \hat{v}_j}{\partial \overline{e}} > 0$. There are two remedies to dispense with this problem. First, regulation authorities could increase the minimum quota of renewable energy demanded, i.e. α[75]. Second, the problem is solved by the market itself, if the cap on emissions raises the price of Brown Energy to such a level that the price of Green Energy is equal or even less than that. In that case, distributors would be either indifferent between the two types of energy or even prefer Green Energy over Brown Energy, as is has become relatively cheaper. If there are no relevant restrictions on the capacity of production of Green Energy, both alternatives present a possible and, which is even more important, a environmentally favorable solution to the problem in question.

2.2.9 Conclusion

In general, assuming distributors to be monopolists can be considered a realistic model setting, looking at the history of various European countries[76]. Other problems of environmental policy such as negative direct and indirect effects between policy instruments[77] are displayed in this model, as well. Some experts assume energy demand to be relatively inelastic to price changes[78] and propose WCTS as a possible solution to successfully deal with this problem. However, in the setting without price caps, WCTS is just another way to increase the relative price of energy. As a result, the effect of a possible increase in energy prices due to the implementation of WCTS will have no effect regarding

[74] Appendix 2.4.7
[75] Appendix 2.4.7
[76] E.g.: Langniss, O., Praetorius, B. (2004)
[77] Heilmann, S. (2005)
[78] Bertoldi et al. (2005)

end-users' energy efficiency or energy consumption, if the latter really reacted inelastic to price. If there are restrictions on energy prices, e.g. price caps, an incentive mechanism created by distributors to increase energy efficiency of end-users will pose an effective measure to reduce energy demand, as long as the per unit sanctions of non-compliance on behalf of distributors are greater or equal to the cost of the incentive mechanism. However, the negative effects of the introduction of WCTS, regarding the amount of Green Energy produced and the level of investment in AT, remain prevalent and have to be dealt with. Therefore, even in this particular case the implementation of WCTS creates additional problems through its effect on the environmental policy measures already in place. To sum it up, in this model, a very sensible and effective way to achieve all of the environmental goals mentioned above is to keep things simple. Instead of introducing yet another certificate system the policy measures which are already in place need to be used to accomplish additional goals. Through a reduction in the cap of emissions - and, if necessary, a raise in the quota for renewable energy - all goals can successfully, efficiently, and effectively be achieved without having to incur any negative side-effects or additional costs on behalf of regulation authorities. Therefore, even in the case of trying to accomplish one more object through environmental policy, regarding the given circumstances, implementing fewer measures really seems to be the better deal.

2.3 Summary

Overall, looking at the analysis presented in this chapter, the question posed in the headline should be answered with "yes", given the assumption, that different policy measures are defined as "cooks", which are spoiling the "broth", i.e. the goals of environmental policy, in this case. Each of the "cooks" might - at first glance - make sense and serves its cause: Metaphorically speaking, one chops the vegetables, another fillets the meat, another fillets fish, and the last one creates the final dish out of the ingredients. However, if the first three have to share one "cutting board", i.e. market, the meat and vegetables will soon smell like fish and the three cooks will soon start thinking about stabbing each other rather than about cutting the ingredients correctly, due to the psychological stress caused by confined spaces. Eventually, the fourth cook becomes so confused due to the chaos and bickering around him that he will use the wrong ingredients to spice the dishes. This will cause guests to complain and soon the restaurant will be out of business. The same happens if one market (cutting board) is targeted by all kinds of policy measures (cooks). None will remain unaffected by the other and one will have a hard time to dissect the various interdependencies and to identify and forecast all of their effects.

It is certainly true that action must be taken to fight climate change through cutting down on emissions and energy consumption and through an increase in the use of Green Energy. However, this has to be done deliberately and thoughtfully and the analysis presented in this chapter has certainly shown that - always keeping in mind the given assumptions - a *larger quantity* of policy instruments applied does *not* necessarily lead to a *higher quality* outcome.

2.4 Appendix

2.4.1 Basics of the Model

2.4.1.1 Supply Side

Green Energy

$$K_y(y) = q + s, \quad K_{yy}\hat{y}_q = 1, \quad \hat{y}_q = \frac{1}{K_{yy}} > 0 \tag{2.56}$$

Brown Energy

Changes in q:

$$\Delta \begin{pmatrix} \hat{x}_q \\ \hat{I}_q \end{pmatrix} = \begin{pmatrix} -1 \\ 0 \end{pmatrix} \tag{2.57}$$

where $\Delta = \begin{pmatrix} -(C_{xx} + ze_{xx}) & -ze_{xI} \\ -ze_{Ix} & -ze_{II} \end{pmatrix}$.

Assuming concavity it follows that

$$|\Delta| = z(e_{II}(ze_{xx} + K_{xx}) - ze_{xI}^2) > 0. \tag{2.58}$$

From (2.57) it follows

$$\Delta = \begin{pmatrix} -(C_{xx} + ze_{xx}) & -ze_{xI} \\ -ze_{Ix} & -ze_{II} \end{pmatrix}. \tag{2.59}$$

Changes in z:

$$\Delta \begin{pmatrix} \hat{x}_z \\ \hat{I}_z \end{pmatrix} = \begin{pmatrix} e_x \\ e_I \end{pmatrix} \tag{2.60}$$

From (2.58) and (2.60) it follows

$$\hat{x}_z = \frac{z(e_I e_{xI} - e_x e_{II})}{|\Delta|} < 0 \quad \hat{I}_z = \frac{z(e_x e_{Ix} - e_I(\frac{C_{xx}}{z} + e_{xx}))}{|\Delta|} > 0. \tag{2.61}$$

2.4.1.2 Demand Side

Changes in p:

$$\Omega\begin{pmatrix}\hat{v}_p\\ \hat{i}_p\end{pmatrix}=\begin{pmatrix}1\\0\end{pmatrix} \tag{2.62}$$

where $\Omega=\begin{pmatrix}U_{vv} & U_{vi}\\ U_{iv} & U_{ii}\end{pmatrix}$.

By the assumption of concavity it follows that

$$|\Omega| = U_{vv}U_{ii} - U_{vi}^2 > 0. \tag{2.63}$$

From (2.62) and (2.63) it follows that

$$\hat{v}_p = \frac{U_{ii}}{|\Omega|} < 0 \tag{2.64}$$

$$\begin{aligned}\hat{i}_p &= -\frac{U_{iv}}{|\Omega|} > 0, \textit{if i and v are substitutes. And}\\ \hat{i}_p &= -\frac{U_{iv}}{|\Omega|} < 0, \textit{if i and v are complements.}\end{aligned} \tag{2.65}$$

Changes in d:

$$\Omega\begin{pmatrix}\hat{v}_d\\ \hat{i}_d\end{pmatrix}=\begin{pmatrix}0\\1\end{pmatrix} \tag{2.66}$$

$$\hat{i}_d = \frac{U_{vv}}{|\Omega|} < 0 \tag{2.67}$$

$$\hat{v}_d = -\frac{U_{iv}}{|\Omega|} < 0 \ \textit{if i and v are complements. And} \tag{2.68}$$

$$\hat{v}_d = -\frac{U_{iv}}{|\Omega|} > 0, \textit{if i and v are substitutes.} \tag{2.69}$$

In the following, it is assumed that EEM and energy consumption are substitutes. This is in line with empirical findings regarding a rebound effect of about 20% or less[79].

2.4.2 WCTS for All Distributors

Changes in prices p_j with respect to $\overline{v}_j$ are derived according to equation (2.27):

$$1-\hat{v}_{j p_j}\frac{\partial p_j}{\partial \overline{v}_j}=0 \ \forall j \in n$$

which results in

[79] Greening, L.A., Green, D.L., Defiglio, C. (2000)

$$\frac{\partial p_j}{\partial \bar{v}_j} = \frac{1}{\hat{v}_{jp_j}} < 0. \quad (2.70)$$

From (2.24) to (2.26) we can derive the effects of changes in $\bar{v}$ on prices q, s, and z :

$$\Theta \begin{pmatrix} q_{\bar{v}}^w \\ s_{\bar{v}}^w \\ z_{\bar{v}}^w \end{pmatrix} = \begin{pmatrix} \alpha \hat{v}_{jp_j} \frac{\partial p_j}{\partial \bar{v}_j} \\ (1-\alpha)\hat{v}_{jp_j} \frac{\partial p_j}{\partial \bar{v}_j} \\ 0 \end{pmatrix} \quad (2.71)$$

where $\Theta = \begin{pmatrix} \hat{y}_q & \hat{y}_q & 0 \\ \hat{x}_q & 0 & \hat{x}_z \\ \hat{e}_q & 0 & \hat{e}_z \end{pmatrix}$.

Due to assumption of concavity and due to equations (2.9), (2.13), and (2.56) it can be inferred that

$$|\Theta| = -\hat{y}_q(\hat{x}_q \hat{e}_z - \hat{x}_z \hat{e}_q) > 0. \quad (2.72)$$

From (2.71) and (2.72) it follows that

$$q_{\bar{v}}^w = \frac{-(1-\alpha)\Sigma_{j=1}^n \hat{v}_{jp_j} \frac{\partial p_j}{\partial \bar{v}_j} \hat{x}_q \hat{e}_z}{|\Theta|} > 0$$

$$s_{\bar{v}}^w = \frac{\Sigma_{j=1}^n \hat{v}_{jp_j} \frac{\partial p_j}{\partial \bar{v}_j} [\hat{e}_z((1-\alpha)\hat{y}_q - \alpha \hat{x}_q) - \hat{x}_z \hat{e}_q]}{|\Theta|} > 0$$ [80]

$$z_{\bar{v}}^w = \frac{(1-\alpha)\Sigma_{j=1}^n \hat{v}_{jp_j} \frac{\partial p_j}{\partial \bar{v}_j} \hat{y}_q \hat{e}_q}{|\Theta|} > 0$$

and from equation (2.70) it follows that $p_{j_{\bar{v}}}^w > 0$. Changes in w are derived regarding equation (2.29):

$$\frac{\partial w}{\partial \bar{v}_j} = \frac{\partial p_j}{\partial \bar{v}_j} - [\frac{\partial q}{\partial \bar{v}_j} + \alpha \frac{\partial s}{\partial \bar{v}_j}] - c_{v_j v_j}^n \hat{v}_{j_{p_j}} \frac{\partial p_j}{\partial \bar{v}_j} + \frac{\hat{v}_{j_{p_j}}^2 \frac{\partial p_j}{\partial \bar{v}_j} - \hat{v}_j \hat{v}_{j_{p_j p_j}} \frac{\partial p_j}{\partial \bar{v}_j}}{\hat{v}_{j_{p_j}}^2}$$

[80] Due to the assumption that $(1-\alpha)\hat{y}_q < \alpha \hat{x}_q$.

$$\frac{\partial w}{\partial \overline{v}_j} = \frac{\partial p_j}{\partial \overline{v}_j}\beta - [\frac{\partial q}{\partial \overline{v}_j} + \alpha \frac{\partial s}{\partial \overline{v}_j}] < 0$$

Assuming that $\beta = [1 - c^n_{v_j v_j}\hat{v}_{j_{p_j}} + \frac{\hat{v}^2_{j_{p_j}} - \hat{v}_j \hat{v}_{j_{p_j p_j}}}{\hat{v}^2_{j_{p_j}}}] > 0$.

2.4.3 Incentive Mechanism

Due to his Stackelberg leader position distributor j takes into account equations (2.31) and, hence, maximizes equation (2.32) which results in

$$0 = \widehat{v_j}(p_j, \sigma_j) + (p_j - q - \alpha s - c^n_{v_j} - w)\frac{\partial p_j}{\partial \overline{v}_j} - \overline{d}\sigma_j \frac{\partial \hat{i}_j}{\partial p_j}$$

and $0 \neq (p_j - q - \alpha s - c^n_{v_j} - w)\frac{\partial \hat{v}_j}{\partial \sigma_j} - \overline{d}\,\hat{i} - \overline{d}\,\sigma_j \frac{\partial \hat{i}}{\partial \sigma_j}$.

2.4.4 Cost Recovery

Distributor j acts according to equations (2.34). Changes in prices p, q, s, and z with respect to b are defined through equations (2.24) to (2.26) and changes in w are defined through equations (2.27) which leads to

$$\Sigma^n_{j=1}\frac{\partial p_j}{\partial \overline{v}_j} = \Sigma^n_{j=1}\frac{0}{\hat{v}_{j p_j}} = 0 \tag{2.73}$$

From (2.24) to (2.26) we can derive the effects of changes in $\overline{v}$ on prices q, s, and z:

$$\Theta \begin{pmatrix} q^w_b \\ s^w_b \\ z^w_b \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \end{pmatrix} \tag{2.74}$$

where $\Theta = \begin{pmatrix} \hat{y}_q & \hat{y}_q & 0 \\ \hat{x}_q & 0 & \hat{x}_z \\ \hat{e}_q & 0 & \hat{e}_z \end{pmatrix} > 0$ according to equations (2.72). From (2.72) and (2.74) it follows that

$q^w_b = \frac{0}{|\Theta|} = 0, \quad s^w_b = \frac{0}{|\Theta|} = 0, \quad z^w_b = \frac{0}{|\Theta|} = 0,$ and from equations (2.73) it follows that $p^w_{j_b} = 0$.

Changes in w are derived regarding equations (2.34): $\frac{\partial w}{\partial b} = -1$.

2.4.5 Price Caps

Households act according to equations (2.31) which results in changes in p:

$$\Omega \begin{pmatrix} \hat{v}_{j_{\sigma_j}} \\ \hat{i}_{j_{\sigma_j}} \end{pmatrix} = \begin{pmatrix} 0 \\ -\bar{d} \end{pmatrix} \tag{2.75}$$

where $\Omega = \begin{pmatrix} U_{vv} & U_{vi} \\ U_{iv} & U_{ii} \end{pmatrix}$. According to equations (2.63) it follows that $|\Omega| > 0$. From (2.63) and (2.75) it follows that

$$\hat{v}_{j_{\sigma_j}} = \frac{\bar{d}U_{vi}}{|\Omega|} < 0, \; and \tag{2.76}$$

$$\hat{i}_{j_{\sigma_j}} = -\frac{\bar{d}U_{vv}}{|\Omega|} > 0. \tag{2.77}$$

2.4.6 WCTS for a Group of Distributors

From equations (2.45) to (2.50) the effects on prices q, s, z, w, p_k and p_j can be inferred. With respect to changes in prices p_k equations (2.48) render

$$\frac{\partial p_k}{\partial \bar{v}_k} = \frac{1}{\hat{v}_{k\,p_k}} < 0 \quad \forall k \in K \tag{2.78}$$

With respect to changes in q, s, and z equations (2.45) to (2.47) render

$$\Gamma \begin{pmatrix} q_{\bar{v}}^{w} \\ s_{\bar{v}}^{w} \\ z_{\bar{v}}^{w} \end{pmatrix} = \begin{pmatrix} \alpha \partial V / \partial \bar{v}_k \\ (1-\alpha) \partial V / \partial \bar{v}_k \\ 0 \end{pmatrix} \tag{2.79}$$

where $\Gamma = \begin{pmatrix} \hat{y}_q & \hat{y}_q & 0 \\ \hat{x}_q & 0 & \hat{x}_z \\ \hat{e}_q & 0 & \hat{e}_z \end{pmatrix} < 0,$ and $V = \left[\sum_{k \in K} \hat{v}_k + \sum_{j \in N \setminus K} \hat{v}_j \right]$. From (2.79) it follows, that

$$q_{\bar{v}}^{w} = \frac{(1-\alpha)\, y_q\, e_z\, V_{\bar{v}}}{|\Gamma|}, \; s_{\bar{v}}^{w} = \frac{-V_{\bar{v}}\,[\,\hat{y}_q \hat{e}_z (1-\alpha) - \alpha(\hat{x}_q \hat{e}_z - \hat{e}_q \hat{x}_z)]}{|\Gamma|}, \; z_{\bar{v}}^{w} = \frac{(1-\alpha)\,\hat{y}_q \hat{e}_q\, V_{\bar{v}}}{|\Gamma|}. \tag{2.80}$$

Also, we have

$$\partial V / \partial \bar{v}_k = v_{k_{pk}} \frac{\partial p_k}{\partial \bar{v}_k} + v_{j_{pj}} \frac{\partial p_j}{\partial \bar{v}_k}. \tag{2.81}$$

From (2.64) and (2.78) it follows, that $v_{k_{pk}} \frac{\partial p_k}{\partial \bar{v}_k} > 0$. With respect to the sign of $v_{j_{pj}} \frac{\partial p_j}{\partial \bar{v}_k}$ it follows from (2.64) that $v_{j_{pj}} < 0$, and from (2.50), that

$$\frac{\partial p_j}{\partial \overline{v}_k} = (q_{\bar{v}} + \alpha s_{\bar{v}}) - \frac{1}{\left[c_{vv} v_{p_j} - 1 + \frac{v_{pp}}{v_{p_j}} \right]} \tag{2.82}$$

Utilizing results for $q_{\bar{v}}, s_{\bar{v}}$ from (2.80), as well as information given by (2.81) in (2.82) and solving for $\frac{\partial p_j}{\partial \overline{v}_k}$, renders

$$\frac{\partial p_j}{\partial \overline{v}_k} > 0. \tag{2.83}$$

Using all of the above results in equation (2.81) yields $\partial V / \partial \overline{v}_k > -1$.

2.4.7 Is Less Still More?

From (2.52) to (2.55) we can derive the effects of changes in e:

$$\Gamma \begin{pmatrix} q^l_{\bar{e}} \\ s^l_{\bar{e}} \\ z^l_{\bar{e}} \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 1 \end{pmatrix} \tag{2.84}$$

where $|\Gamma| > 0$ as shown in section 2.4.6. From (2.52) to (2.55) and (2.84) it follows that

$$q^l_{\bar{e}} = \frac{(\hat{y}_q - \alpha^2 \Sigma^n_{j=1} \widehat{v_{j\,p_j}})\hat{x}_z}{|\Gamma|} < 0$$

$$s^l_{\bar{e}} = \frac{\hat{x}_z(-(\hat{y}_q - \alpha \Sigma^n_{j=1} \widehat{v_{j\,p_j}})\hat{x}_z}{|\Gamma|} > 0$$

$$z^l_{\bar{e}} = \frac{\hat{x}_q(\alpha^2 \Sigma^n_{j=1} \widehat{v_{j\,p_j}} - \hat{y}_q) + (1-\alpha)^2 \hat{y}_q \Sigma^n_{j=1} \widehat{v_{j\,p_j}}}{|\Gamma|} < 0$$

and according to equations (2.55) it follows that $p^l_{\bar{e}} < 0$. Regarding I: It follows from (2.12) and (2.13) that

$$\hat{I}_{\bar{e}} = \hat{I}_q \frac{\partial q}{\partial \overline{e}} + \hat{I}_z \frac{\partial z}{\partial \overline{e}} < 0 \tag{2.85}$$

$$\Omega \begin{pmatrix} \hat{v}_{\bar{e}} \\ \hat{i}_{\bar{e}} \end{pmatrix} = \begin{pmatrix} p^d_{\bar{e}} \\ 0 \end{pmatrix} \tag{2.86}$$

Regarding i: It follows from equations (2.63) and (2.86) that

$v_{\bar{e}} = \frac{U_{ii} p^l_{\bar{e}}}{|\Omega|} > 0$

$i_{\bar{e}} = -\frac{U_{iv} p^l_{\bar{e}}}{|\Omega|} < 0$ as i and v are substitutes.

$$|\varepsilon| \begin{pmatrix} p^l_{\bar{\alpha}} \\ s^l_{\bar{\alpha}} \\ z^l_{\bar{\alpha}} \end{pmatrix} = \begin{pmatrix} -y(p+(1-\alpha)s \\ x(p-\alpha s, z) \\ 0 \end{pmatrix} \tag{2.87}$$

Changes in α: It follows from (2.87) and (2.58) that

$p^l_\alpha = \frac{-y(p+(1-\alpha)s)(1-\alpha)y_q e_q + \alpha x(p-\alpha s,z)(x_q e_z - e_q x_z)}{|\Delta|} > 0$[81]

$s^l_\alpha = \frac{x(p-\alpha s,z)((x_q-(1-\alpha)v_p)e_z - e_q x_z) + y(p+(1-\alpha)s)e_z(y_q - \alpha v_p)}{|\Delta|} \lesseqgtr 0$

$z^l_\alpha = \frac{y(p+(1-\alpha)s)(y_q e_q - \alpha^2 e_q v_p) - x(p-\alpha s,z)\alpha e_q (1-\alpha)}{|\Delta|} < 0$

$$\Delta \begin{pmatrix} \hat{x}_\alpha \\ \hat{I}_\alpha \end{pmatrix} = \begin{pmatrix} q^d_\alpha - z^d_\alpha \\ z_\alpha \end{pmatrix} \tag{2.88}$$

Regarding I: It follows from (2.58) and (2.88) that

$x_\alpha = \frac{-z_{e_I I}(q^d_\alpha - z^d_\alpha) - z^d_\alpha e_{xI} z^d}{|\Delta|} < 0$

$I_\alpha = \frac{(K_{xx} + z^d e_{xx}) z^d_\alpha + z e_{Ix}(q^d_\alpha - z^d_\alpha))}{|\Delta|} < 0$

$$\Omega \begin{pmatrix} \hat{v}_\alpha \\ \hat{i}_\alpha \end{pmatrix} = \begin{pmatrix} p^d_\alpha \\ 0 \end{pmatrix} \tag{2.89}$$

Regarding i: It follows from (2.58) and (2.89) that $v_\alpha = \frac{U_{ii} p^d_\alpha}{|\Delta|} < 0$ and $i_\alpha = -\frac{U_{iv} p^d_\alpha}{|\Delta|} > 0$, as i and v are substitutes.

[81] As renewable energy is supposed to be more expensive, price of energy is to increase in α.

3 Water Scarcity: Is the Blue Planet running out of Blue Gold?

"If the wars of this century were fought over oil, the wars of the next century will be fought over water." (Serageldin, I., 1995)

This prediction by a former vice president of the World Bank has been quoted quite often in recent years. The book on *Water wars: privatization, pollution, and profit* by Shiva Vandana is only one of the various writings that deal with social, economic, and political problems that cause or are caused by water scarcity or water pollution. There are many examples of areas where drinking water is or will become a dangerously scarce resource not only in economic terms but also in terms of human health and social and political stability: *"Stories of water shortages in Israel, India, China, Bolivia, Canada, Mexico, Ghana, and the United Stated make headlines in major newspaper, magazines, and academic journals."*[82] Various economic activities, e.g. mining or forestry, are in need of vast amounts of water. An increase in awareness across the globe was accompanied by the introduction of the so called water footprint concept of products or entire nations by Haekstra in 2002[83].
Several countries try to solve water scarcity by energy-intensive, high-cost technologies, e.g. sea-water desalination in the Middle East, the Hoover Dam or water pipelines in the United States (Nevada). However, even experts fear that it will not take long until even these expensive and seemingly elaborate measures will not suffice to satisfy the insatiable need for water, may it be of the growing human population itself or of the industrial and agricultural sector.
Therefore, the question arises what policy measures are available to regulate water use or water pollution in order to avoid an aggravation of present or a development of future water scarcity.

3.1 Literature Review

Several books and papers have dealt with the problems of and possible solutions to excess water consumption or water pollution. Various policy measures are available, e.g. the traditional centralized regulation or modern market-based permit approaches. However, before a policy measure can be chosen, the problem or market failure that has to be regulated needs to be identified. In case of water consumption or pollution, different

[82] Vandana, S. (2002)
[83] http://www.waterfootprint.org/?page=files/home

circumstances call for different approaches. First, the origin and nature of the water consumed or polluted has to be defined. Options are:

- ground water or surface water
- flowing (river basin) or standing (lake) water

With respect to water pollution, several kinds exist:

- Non-point and point source pollution: This refers to how well the source of pollution can be determined. Point sources are industrial facilities or sewage treatment plants. [84] *As water from rainfall and snowmelt flows over and through the landscape, it picks up and carries contaminants from many different sources. This is called Non-Point Source pollution.*[85]
- Assimilative and accumulative pollutants: [86] While the former is absorbed by the medium it has been put into, the latter cannot be absorbed and a stock of pollutant accumulates within the medium over time.
- Uniformly or non-uniformly mixed pollutants: This refers to how the pollutant spreads within the medium. The former disperses quickly, while the latter does not and, hence, its effects are mostly confined to the local area of the pollution site. [87] Examples for the various kinds of pollutants are:

3-1 Pollutants

Substances	Uniformly mixed	Non-uniformly mixed
Accumulative	Co2 (air) Sewage overflow (water)[88]	Heavy metals (water)
Assimilative	GHG (air)	Nutrients, salt (water)

Source: Keudel, M. (2006)

Once all of the relevant characteristics are identified, regulation authorities can concern themselves with choosing the appropriate policy measure to tackle the problem in question. According to Griffin's book *Water Resource Economics*, public policy is responsible for signaling water's opportunity cost to all relevant agents.[89] Otherwise, water consumption and water pollution is prone to cause non-internalized negative externalities. The following table presents a general overview over the structure and content of this chapter, regarding both relevant literature and the author's research focus:

[84] Keudel, M. (2006)
[85] http://protectingwater.com/
[86] Tietenberg (1985) in Keudel, M. (2006)
[87] Keudel, M. (2006)
[88] Bakker, K., Wiggers, J.B.M. (1978)
[89] Griffin, R.C. (2006)

3-2 Literature and Research Overview Chapter 3

Relevant section and author(s)	Research Topic
Hwang/Shaw	Modelling a Discharge Permit Scheme along a river basin. (Section 3.1.1)
Antrobus/ Mbhata	Analysing economic, sociological, and political implications of unregulated/ regulated water consumption along the Kat River water basin without using economic modelling techniques. (Section 3.1.3)
Weber	Modelling optimal water consumption and pollution along a river basin (discrete model). Two Alternatives: optimal regulation (planner's program) vs. Certificate Scheme. (Section 3.1.6)
Wittmann	I. Novelty: Hwang/Shaw's Critical Zone approach has significant implications on companies located in a critical zone (exemnplified in a n=2 location setup) (Section 3.1.2) II. Novelty: Translating Antrobus/Mbhata's approach into a useful economic model and comparing status quo to the effects of regulating water consumption. (Section 3.1.4) III. Novelty: Incorporating land rents into a model setup similar to that of Weber. (Section 3.2)

Source: Author's design

Regarding section 3.2, which deals with a modified Version of Weber's Model, the relevant setting can be characterized as follows:

- surface water
- flowing (river basin)
- point source water consumption/pollution
- accumulative
- uniformly mixed

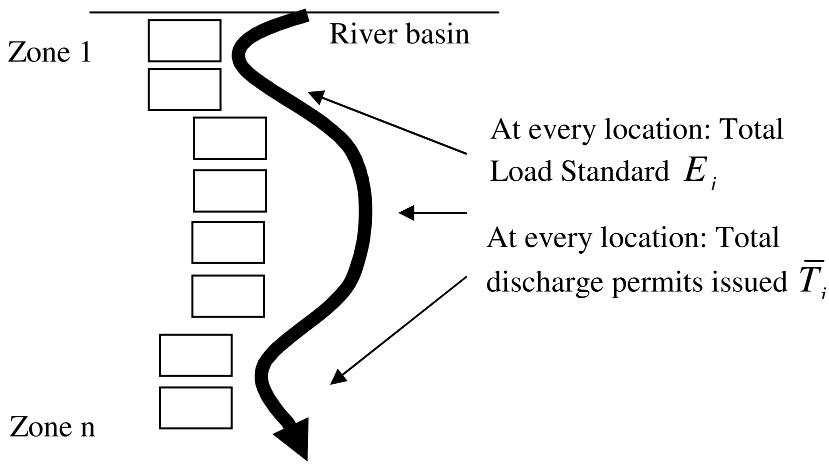
In advance, however, several other approaches are presented and analyzed in order to attain a broad grasp of current research. The IWP Discussion Paper by Keudel (2006), for example, made a serious attempt to give a concise review on theoretical and practical approaches to water quality trading. Montgomery (1972) and his permit trading system regarding non-uniformly mixed assimilative pollutant was the first of its kind. He proved that a competitive equilibrium does exist and that it equals the cost minimum result. However, Hung and Shaw (2005) found critical aspects of Mongomery's findings, set up a different model and proposed that additional restrictions are needed to arrive at the least-cost result. The model of Hung and Shaw deals with tradable-permit systems.

3.1.1 The Model of Hung and Shaw

The model of Hung and Shaw (2005) develops a so called Trading Ratio System (TRS). There are three important characteristics to their approach. First, it is designed as a zonal approach in which the river basin is divided into n zones, where $n \in N$. Second, trading ratios between zones are assumed to be exogenously given. Third, permits are tradable freely according to the given trading ratios. Hung and Shaw propose that their approach (TRS) can achieve a given standard of environmental quality efficiently, i.e. with minimum abatement costs. Also, transaction costs appear to be relatively low. Hung and Shaw compare their model to the most commonly known TDPs, i.e. tradable discharge permit systems, namely APS, i.e. ambient-permit system, POS, i.e. pollution offset system, and ERS, i.e. exchange-rate emission trading system. Regarding APS, Montgomery showed that a competitive, cost-minimal equilibrium exists. However, as every discharger has to buy permits from the so called pollution receptor points which are affected by him, Hung and Shaw criticize the resulting high level of transaction costs. With respect to POS, any trade among dischargers has to be simulated in advance to ensure that no environmental standards are violated. Hung and Shaw criticize both high transaction costs and uncertainties ingrained in this method. In case of ERS, trading ratios have to be set in advance by regulation authorities by calculating dischargers' marginal abatement costs in *least-cost equilibrium.* Hung and Shaw argue that information requirements as well as transaction costs are too high.[90]

Contrary to these disadvantages, TRS is supposed to reduce transaction costs and information requirements and to facilitate trading among dischargers. Hung and Shaw construct the following scenario:

3-3 Hung and Shaw's River Basin



Source: Author's design,based on verbal description by Hung and Shaw (2005)

[90] For further details on the details and characteristics of the different permit schemes, please refer to Hwang/Shaw (2005).

E_j denotes the Total Load Standard defined by regulation authority for each zone. $\overline{T}_j$ is the number of discharge permits issued for each zone, which implicitly contains the water quality standard set by regulation authority. In accordance with basic microeconomic theory, Hung and Shaw (2005) demand that marginal abatement cost equals marginal emission damage in equilibrium. In every zone, the cost-minimal solution for n dischargers is reached by minimizing

$$\min_{e_1, e_2, \ldots, e_n} \sum_{i=1}^{n} c_i(e_i^0 - e_i) \tag{3.1}$$

s.t.

$$\sum_{i=1}^{n} t_{ij} e_i \leq E_j, \quad j = 1, \ldots, n \tag{3.2}$$

where $e_i \in \left[0, e_i^0\right]$ and $c_i(\cdot)$ represents abatement cost of discharger i.[91] Also, Hung and Shaw define a transfer/trading coefficient t_{ij} which represents the effect of one effluent emitted in zone i on zone j, i.e. $0 \leq t_{ij} \leq 1$. Therefore, an additional necessary condition is

$$c_i^{'}(e_i^0 - e_i^{eff}) = \sum_{j=1}^{n} \mu_j t_{ij}, \quad \forall i. \tag{3.3}$$

It simply states that given the marginal abatement cost of discharger i, the cost effective effluent level has to equal the total marginal damage of all zones affected by i's effluent. This marginal damage is represented by the shadow price of water quality μ weighted by the relevant transfer coefficient.

Implementing TRS, the first zone receives a total of $\overline{T}_j$ discharge permits which equals the Total Load Standard, i.e. $\overline{T}_1 = E_1$. Downstream zones receive permits depending on E_j and on the weighted upstream pollution transferred:

$$\overline{T}_j = E_j - \sum_{k=1}^{j-1} t_{kj} \overline{T}_k \tag{3.4}$$

t_{kj} is a coefficient indicating the level of dispersion of one unit of discharge from zone k to zone j, $\forall\, k < j$.

A critical zone s can be defined as $t_{(s-1)} E_{s-1} > E_s$: This means that the water quality deterioration has reached such a high level, that the impact of the effluent from zone s-1 suffices to result in a violation of the quality standard of zone s, given the environmental

[91] Cost functions are assumed to be increasing and strictly convex.

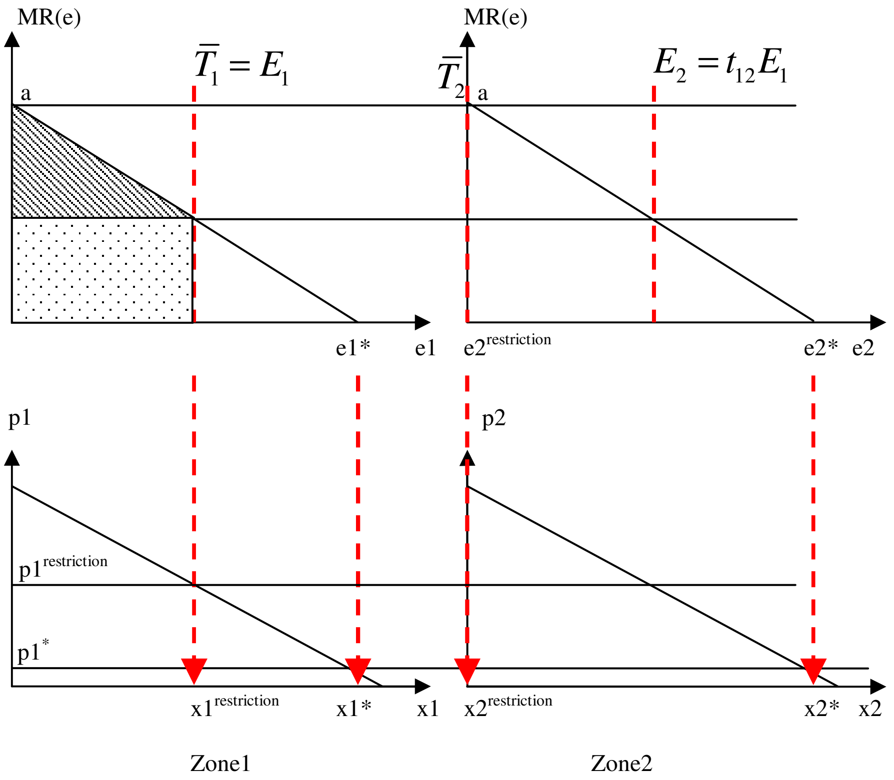
quality standards of and transfer coefficient between zone s-1 and s. In this case, Hung and Shaw suggest that regulation authorities issue zero discharge permits to dischargers at zone s, i.e. $\overline{T}_s = 0$ and set discharge permits at zone s-1 at $\overline{T}_{s-1} = \frac{E_s}{t_{(s-1)s}} - \sum_{k=1}^{s-2} t_{ks}\overline{T}_k$, $\forall k < s-1 < s$. Thereby, Hung and Shaw propose that the problem is dissolved and that the quality standard in zone s can be met, i.e. $t_{(s-1)}E_{s-1} = E_s$. What effects does this approach render with respect to dischargers?

3.1.2 An Analysis of Hung and Shaw's Critical Zone Approach

It is assumed that there are only two zones at the river basin and there is only one discharger d_i located in every zone i, i = 1, 2. Discharge is a negative externality which stems from the production of a good x which is supplied at marginal cost. It is assumed that the two dischargers, i.e. companies, have identical production processes. Profits can be expressed in terms of units of discharge e_i, and there is a clear relationship between good x and externality e, i.e. $e_i(x) = x$. Both face a downward sloping marginal profit function with respect to discharge, i.e. $MR = a - be_i$ with $x_i^* = e_i^* = \frac{a}{b}$. In this case, abatement costs are zero and as all other marginal costs mc_i are constant and equal across dischargers, we arrive at $p^* = mc_i$, which is equal at every location, given the assumptions mentioned above.

Now, regulation authorities restrict the amount of effluent, however, the transfer coefficient is $t_{12} = 1$. Zone one receives total discharge permits $\overline{T}_1 = E_1$. Zone two, however, appears to be a critical zone, as $t_{12}E_1 = E_2$. Therefore, regulation authorities set $\overline{T}_2 = 0$. In the absence of trade, the following situation emerges:

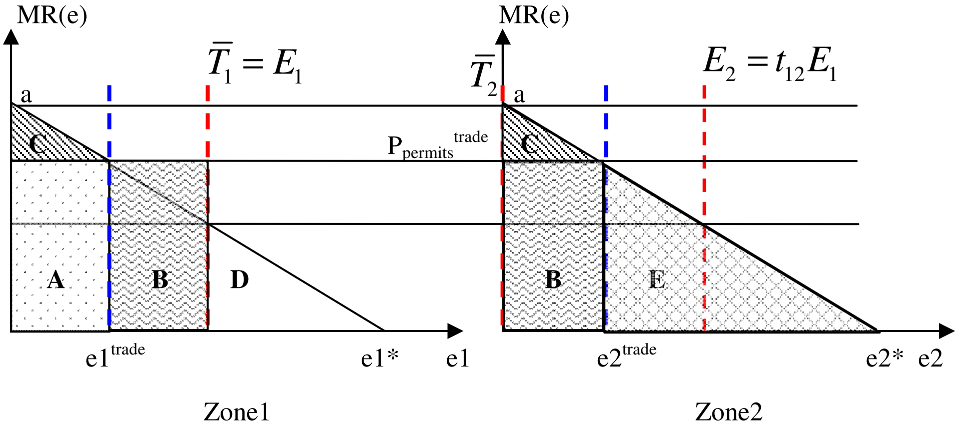
3-4 Discharge Permit Allocation



Source: Author's design

In the absence of trade, the two companies would arrive at $x_1^{restriction} = e_1^{restriction} > 0$ and $x_2^{restriction} = e_2^{restriction} = 0$. Marginal revenues are MR($e_1^{restriction}$) > 0 and MR($e_2^{restriction}$) = 0, which are marked by the shaded/dotted[92] areas. In case of a market for permits being established, companies of Zone 1 and Zone 2 are able to trade permits until their Marginal Costs of emissions are equal, as shown in the following graph.

3-5 Discharge Permit Trade



Source: Author's design

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92 The dotted area of Zone 1 represents so called Windfall Profits, for explanation see e.g. http://dipbt.bundestag.de/dip21/btd/16/107/1610715.pdf.

This results in an unequal distribution of profits as well as unequal cost structures among companies:

- Total Revenue $_{Zone\ 1}$ = C (Revenue) + B (Gains from Permit Sale) + A (Windfall Profits[93]).
- Total Revenue $_{Zone\ 2}$ = C (Revenue)
- Total Cost $_{Zone\ 1}$ = D (Abatement Cost)
- Total Cost $_{Zone\ 2}$ = E (Abatement Cost, where E > D) + B (Cost of Permit Purchase)

Thereby, company in Zone 2 incurs higher costs and lower production profits. This means that company in Zone 1 receives a location-advantage over company in Zone 2. The effect could be prevented by setting $\overline{T}_1 = \overline{T}_2 = \frac{1}{2}E_2$. The desired final discharge level, in this case E_2, is set by regulation authorities and the resulting amount of permits is equally divided amongst dischargers. Thereby, distributional effects through location (dis-)advantages are avoided. In case of negative downstream externalities resulting from upstream water discharges/consumption, regulatory approaches have to keep these special circumstances in mind when adopting a zonal approach as suggested by Hung and Shaw.

Over all, Hung and Shaw (2005) perceive their approach as being cost-effective and propose that it renders an efficient market equilibrium in which all externalities are internalized. However, not only the analysis undergone in this section suggests that there are certain parts of the model which cause assailable results. Keudel (2006) also argues that the classification and ranking of different permit scheme approaches constructed by Hung and Shaw lacks specific information. Hung and Shaw base their evaluation of TRS in comparison to other permit scheme approaches on the level of Transaction Costs (TC). In Keudel's opinion, TC alone are not a sufficient criterion to rate the efficiency of a permit system.

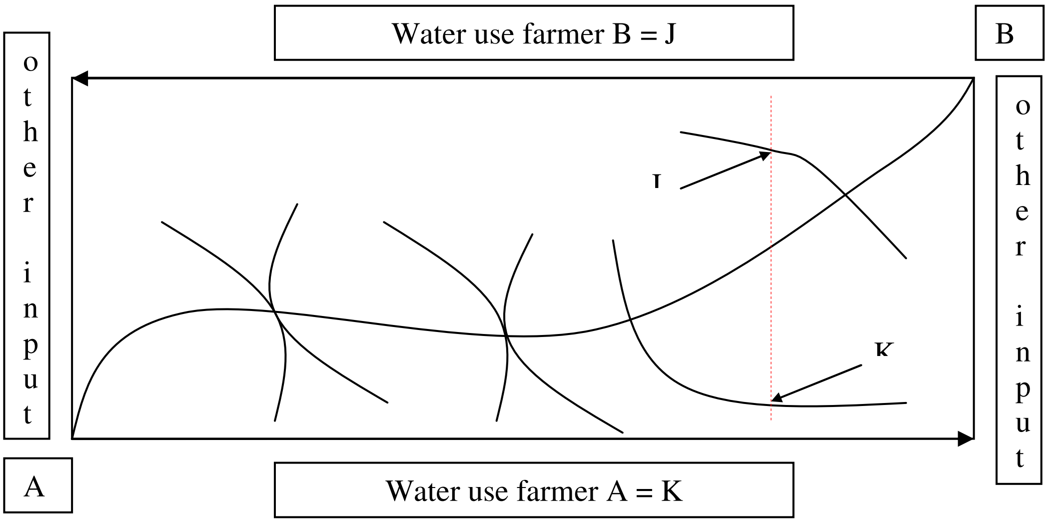
3.1.3 The Kat River Basin

Mbatha and Antrobus[94] published an article called *a case of location externalities on agricultural resource allocation in the Kat River basin, South Africa*. They propose that the physical location of a farmer along a river where water is diverted individually causes economic inefficiencies due to input misallocations, ceteris paribus. Their model is based on the Physical Externality Model (PEM) by Bromley. In particular they are concerned with

[93] See footnote 92
[94] Antrobus, G.G., Mbatha, C.N. (2008)

empirical data on commercial citrus farmers located along the Kat River Basin. In general, empirical data shows that upstream farm units are far more influential. According to Vatn and Bromley[95] previous case studies showed that economic disadvantages nearly always result in political disadvantages. Mbatha and Antrobus use Bromley's method of depicting *inefficient resource allocation in agricultural production* through an Edgeworth box.

3-6 Inefficient Resource Allocation



Source: Bromley (1982) in Mbatha and Antrobus

According to Mbatha and Antrobus (2008) various "*inefficient decision making factors*", i.e. physical location, uncertainty, and risk averseness, cause farmers to produce outside the contract line, i.e. (K, J). It is obvious that there is potential for pareto efficient actions. However, Mbatha and Antrobus do not present a immediate solution to this problem. Instead, they collected data to analyze the usefulness and accuracy of Bromley's PEM with respect to citrus farming along the Kat River. After having analyzed the data, they arrive at the conclusion that the PEM is a *"useful initial framework for interrogating the Kat river Valley (KRC) system"*. However, they complain that is does not present sufficient explanation for production patterns of Middle and Lower Kat River citrus farmers: *"The KRV makes a useful empirical case that a tool box of economic models is not always sufficient in providing meaningful answers to economic investigations."* (Antrobus, Mbhata 2008). Well, according to Krugman (1999) the problem with economic models is that one has to understand them first, before they can draw meaningful answers from them. Bromley's model shows a static result, which is based upon certain assumptions. If these are not adapted or modified according to the situation in question, the analysis has to fail. Therefore, the setting discussed in the paper by Mbata and Antrobus (2008) is analyzed implementing an appropriate economic model.

[95] In Mbaha, C.N., Antrobus, G.G. (2008)

3.1.4 Economic Analysis of Location Externalities

According to the paper by Mbata and Antrobus (2008), the farmers located along the Kat River Basin are occupied with citrus production. The River Basin is geographically divided in three sections i, namely Upper (i=1), Middle (i=2) and Lower (i=3) Kat. The most important input factors to producing citrus (z_i) are Kat River water (w_i), which is diverted individually, and land (l_i). All agents are supposed to be risk averse. In the Middle Kat section there is a water dam, which is operated and controlled by Middle Kat farmers. Kat River water and land are substitutes, to a certain extent[96]. However, as they are not perfect substitutes, there is a certain minimum amount of both land and water required to engage in citrus production, i.e. $w_i \geq \underline{w}_i$ and $l_i \geq \underline{l}_i$. Moreover, there is also an upper bound to both input factors, i.e. $\overline{w}_i$ and $\overline{l}_i$, which varies from section to section. These bounds result from historical, institutional, and political factors and are given exogenously. With respect to land, settlement patterns result in high land development restrictions for Upper Kat farmers, less severe but still fairly restrictive development opportunities in the Middle Kat, and large land development opportunities for Lower Kat farmers. In case of Kat River water, the restriction pattern works exactly the other way around, as Kat River water is most restricted in the Lower Kat section, less scarce in the Middle Kat section due to farmers' control over the Kat Dam, and relatively unrestricted in the Upper Kat section, due to farmers' location advantage of being closest to the Kat River's source. What becomes clear from this setting is that there is actually not just one externality but actually two externalities involved. Each of them affects one of the two citrus production input factors. On the one hand Kat River water consumption *down*stream is *negatively* affected by *up*stream water consumption. On the other hand, a location specific "externality" with respect to farm land development due to historic settlement patterns is present which causes the availability of farm land to *increase* from *up*stream to *down*stream.[97]

Overall, it becomes quite clear, that, in order to analyze the situation described above, some microeconomic theory other than an Edgeworth box has to be applied in the following.[98]

[96] Mbatha and Antrobus explain that if additional land is developed for farming, new wells and other rivers running through these lands can be used by the farmers to water their plants. Hence, the more land, the more Non-Kat River water is available to farmers. Therefore, land can actually be perceived as a substitute for Kat River water, to a certain extent.

[97] Of course, these circumstances are not caused by the agents involved in citrus production. Therefore, the term "externality" might appear a little awkward or even false. However, the author intends to convey the fact that the availability of both input factors is affected by location-specific aspects.

[98] Surely, an Edgeworth box can be used to describe the allocation of two input factors among two producers. However, first of all, Mbatha and Antrobus differentiate between *three* different River sections and not just two. Moreover, Edgeworth's box is all about showing possible potential of gains from trade, resulting from inefficient initial allocation of resources. However, although Kat River water might be tradable, downstream farmers cannot trade land to upstream farmers given the assumption that those do not want to move or at least diversify their location pattern. Overall, the economic model chosen and the explanation given by Mbatha and Antrobus do not suffice to present a clear economic result.

3.1.4.1 Mathematical and Graphical Analysis

All farmers, i.e. Upper, Middle and Lower Kat farmers, produce citrus using the two input factors land and water, as has been mentioned above. In order to simplify the analysis, let's assume that there is one representative farmer located in each of the three regions. Moreover, in order to confine the analysis to the supply side, it is assumed that all farmers produce a given amount of citrus $\overline{z}$, which are sold at a given price $\overline{p}$, using location specific amounts of the two input factors, w_i and l_i. The prices of the input factors, p_w and p_l, are assumed to be constant and given as well. As a maximization problem this setting appears as follows:

$$\max_{w_i, l_i} \quad \overline{p}\,\overline{z}(w_i, l_i) - p_w w_i - p_l l_i \tag{3.5}$$

s.t.

$$\underline{w}_i \le w_i \le \overline{w}_i \text{ and } \underline{l}_i \le l_i \le \overline{l}_i \quad \forall i, i = 1,2,3. \tag{3.6}$$

Given the fact that the two input factors are assumed to be perfect substitutes[99] and that output level and price are given, input demand will depend on the input's prices and the restrictions on availability as well as the fact that the farmers are assumed to be risk averse. On the one hand, the price of Kat River water is expected to be very low, i.e. close to zero, as water can be diverted individually and there are no further costs associated with water diversion, i.e. $p_w \to 0$.[100] On the other hand, the price of developing land for citrus production is a more costly, long- investment, i.e. $p_l > p_w$. Therefore, equation (3.5) can be changed to a cost (C_i) minimization problem including the restrictions specified in equation (3.6):

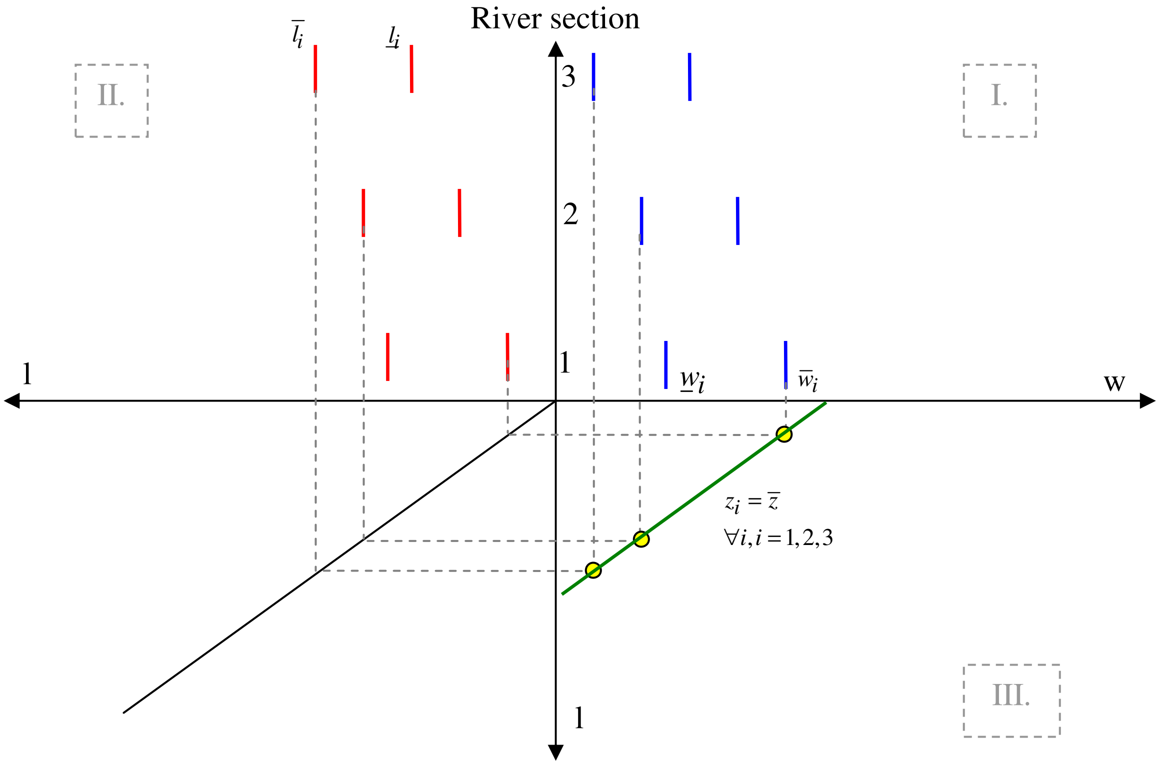
$$\min_{w_i, l_i} \quad C_i(w_i, l_i, p_w, p_l) \tag{3.7}$$

s.t. equation (3.6).

In equilibrium, the maximum amount of Kat River water will be demanded in each section, and then minimum amount of land, needed to produce $\overline{z}$. Thereby, the following graph emerges, given demand of and restrictions on the input factors and all of the other assumptions made in advance:

[99] Within the boundaries of minimum/maximum input requirements/availability.
[100] The costs of building the Kat River Dam are not comprised in the analysis, for reasons of simplicity and clarification. Mbatha and Antrobus have neglected them as well.

3-7 Input factor combination



Source: Author's design

Both Middle and Lower Kat River farmers only expect the minimum water flow to reach their area ($\underline{w}_2, \underline{w}_3$), because all participants are assumed to be risk averse. Therefore, they use the maximum amount of land available ($\overline{l}_2, \overline{l}_3$), which is needed to produce the given output level of citrus $\overline{z}$. Upstream Kat River farmers know that there is no one above them to divert water which causes them to expect and use the maximum amount of water available and the minimum amount of land needed, i.e. $\overline{w}_1$ and $\underline{l}_1$. Thereby, Middle and Lower Kat farmers manage to offset the negative location specific externality with respect to water supply, due to the presence of the positive location specific "externality" with respect to less restricted land availability. Nonetheless, as land development is supposed to be a more costly input factor, it becomes clear that the costs of production vary across locations, i.e.

$$C_1^*(\overline{w}_1, \underline{l}_1, p_1, p_1) < C_2^*(\underline{w}_2, \overline{l}_2, p_2, p_2) < C_3^*(\underline{w}_3, \overline{l}_3, p_3, p_3) \qquad (3.8)$$

This implies that, given a fixed market price $\overline{p}$ for citrus output, Upper, Middle, and Lower Kat farmers achieve different profit levels. The resulting distributional effect, might, in the long run, lead to a different market structure, depending on the level of difference in profits and on whether farmers actually manage to avoid negative profits. Higher profits might also result in higher both economic and social influence of Upper Kat Farmers, which has been hinted at by Mbatha and Antrobus (2008) in their analysis.

Of course, this is a very confined model of the citrus market. It is, among others, a simplifying assumption that there is a given equal amount of citrus produced in each section. However, the article by Mbatha and Antrobus (2008) also concerns itself solely with the supply, i.e. production, side of the market and does not provide the reader with any information on output levels. Thereby, given the information about the region and agents involved, this economic model manages to explain the status quo in the market of citrus production, although some additional simplifying assumptions with respect to production costs and citrus demand have been made.

3.1.4.2 The Effect of Kat River Water Allocation Related Regulation

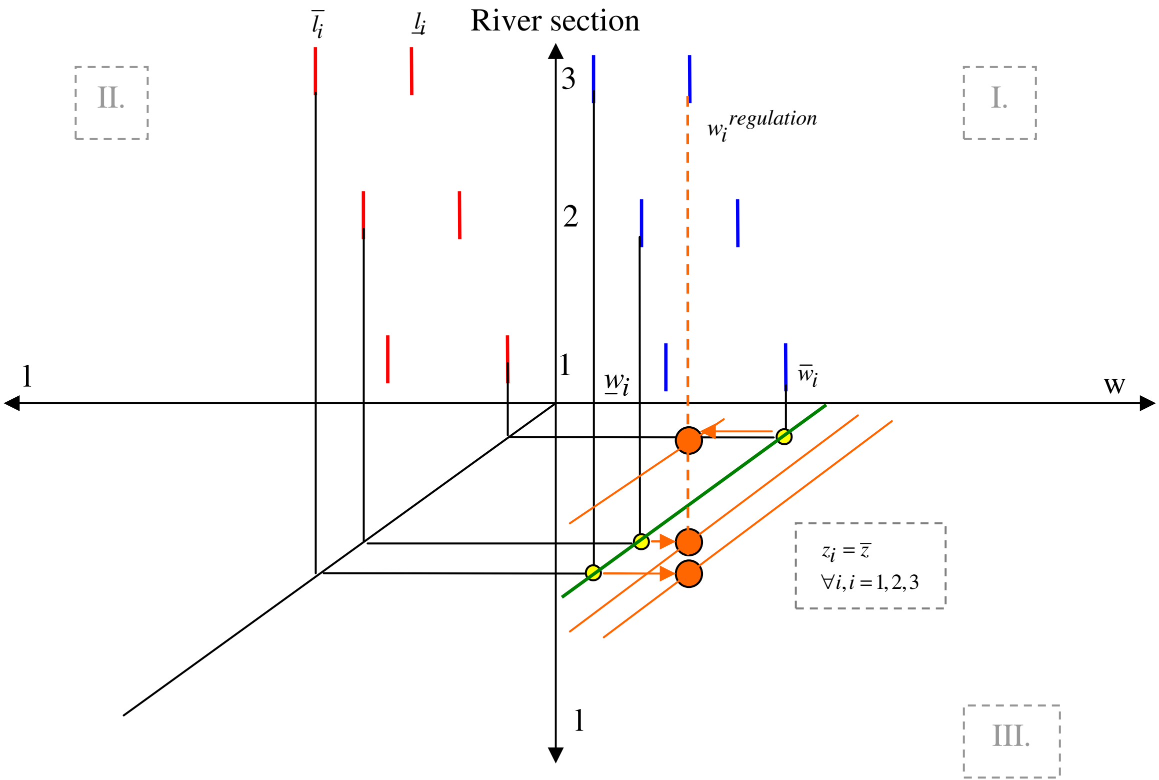
In the course of their article, Mbatha and Antrobus argue that *"the mere physical location of farmers along a given watercourse, where water resources are diverted individually, contributes to economic inefficiencies due to production input misallocations, ceteris paribus."* (Antrobus, Mbhata 2008). Their critique is, therefore, not concerned with ecological effects of water flow levels but simply with the perceived disadvantages of different production units that can be distinguished by location.

As shown in the previous section, it is true that the location specific input availability leads to distributional effects, due to different input prices for Kat River water and land. If regulation authorities now want to dispense with these inequalities by introducing water rights for each section of the Kat River, the following situation could occur: Each of the sections is ascribed to an equal amount of water rights. Total Kat River water is thereby divided into three equal shares, as there are three identical representative farmers. If the water rights are not tradable, each of the farmers, i.e. Upper, Middle, and Lower Kat River, will use their water rights for citrus production.

However, as land development can be perceived as a long term investment, Middle and Lower Kat farmer now have more input factors at their disposal as they need to produce $\overline{z}$ while Upper Kat farmers suffer from too little land available to retain the previous level of citrus production $\overline{z}$. Thereby, the following situation emerges:

All farmers use the same amount of water in their citrus production ($w_i^{regulation}$). However, as Middle and Lower Kat River farmers hold a higher level of land than needed to produce $\overline{z}$. Upper Kat farmers are not able to produce $\overline{z}$ unless they increase their input level of land in citrus production. These production levels prior to changes in land development investment are depicted by the orange points in the graph below:

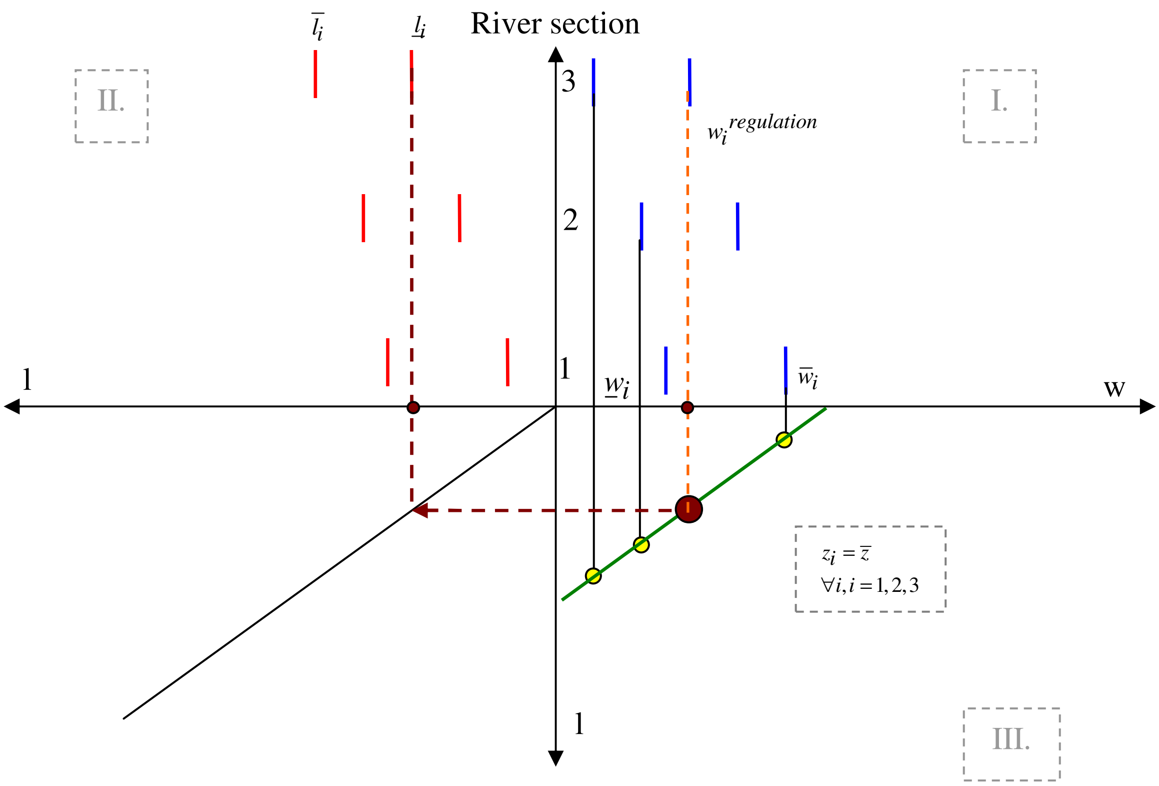
3-8 Regulated input factor combination



Source: Author's design

In the long run, the use of the input factor land can be adjusted according to the new setting, which will lead to an increase in land development in the Upper Kat region, i.e. $l_1 > \underline{l}_i$, and a reduction in the Middle and Lower Kat river sections, i.e. $l_2 < \overline{l}_2$ and $l_3 < \overline{l}_3$. This will lead to an increase in production cost of Upper Kat Farmers and a decrease in production costs for Middle and Lower Kat farmers. Thereby, distributional effects and the difference in profit levels will be eliminated. This results from the fact, that each of the three representative farmers will use the given amount of water, i.e. $w^{regulation}$. As all of them face the same production function and given output level, they will also use equal amounts of land, as shown in the graph below:

3-9 Regulated input factor combination II



Source: Author's design

This example shows that, oftentimes, it is quite likely that there are two sides to every story about regulating economic activities. Hence, if regulation takes place solely for economic and no other, e.g. environmental, reasons, one has to bear in mind the effects on the investment in land development in Upper, Middle, and Lower Kat River sections – and eventually has to decide whether they are desirable or not.

In general, the analysis shows, that, if regulation authorities attempt to regulate a market a careful analysis of all relevant parameters and aspects is necessary. Therefore, it is certainly true and of high importance, that economic or regulatory tools are not implemented without analyzing possible effects according to a carefully constructed model setting. If done so, however, valuable results can be achieved. On the contrary, Mbatha and Antrobus (2008) end their paper arriving at the following conclusion: *"A word of caution for economic research […] would be […] to discard any belief that economic models can provide enough or even suitable tools for explaining socio-economic systems […]"*[101]

Overall, there is not much to say about this statement, as everybody is certainly entitled to their own opinion. However, looking back at the analysis and the results of the previous

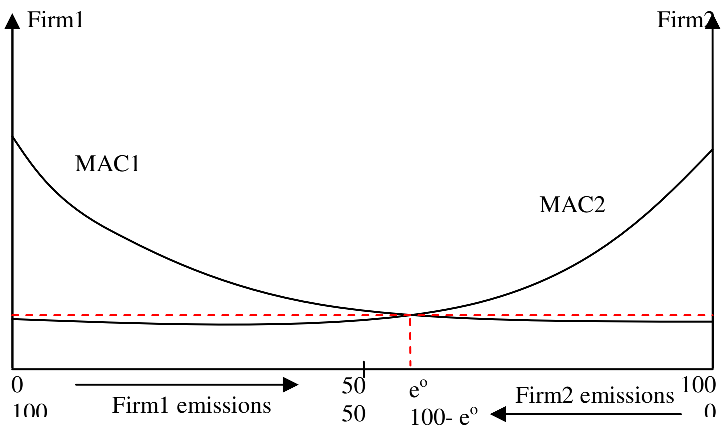
[101] Mbatha, C.N., Antrobus, G.G. (2008)

sections, it might become clear, that one can only get meaningful answers if they are asking the question in a way that it can be understood. Let me put it this way: Asking for directions to get from Berlin to Alaska will not get you a route to reach the Sahara as a result - especially not if you are asking an expert, e.g. a geographer.

3.1.5 Effluent Trading to Improve Water Quality

This section is a short review of Rousseau's identically named paper[102], which starts with an overview over the basic microeconomic theory on permit trading. She implements the analysis of Tietenberg, to show how permit trading can lead to an efficient, i.e. least costly, outcome, due to the fact that, in equilibrium, the marginal abatement costs (MAC) of all participants of the permit trading scheme become are equal.

3-10 Marginal Abatement Cost



Source: Kolstad (2000) in Rousseau, S. (2006)

The most interesting part of this paper is the section in which Rousseau (2006) presents a detailed table of effluent permit systems, most of them implemented in the US since 1995 during the Clinton era. However, in recent years, other nations, like EU member states, have also been concerned with establishing such permit systems. Therefore, the European Council Directive on water (2000/60/EC) set up an ideal framework for evaluating the possibility of establishing tradable emission permit systems within the EU in order to improve water quality. Rousseau argues that the reason why permit systems should be implemented on an EU level is that many river basins across Europe are transboundary flows. Even in the case of a fairly small region like Belgium/Flanders, this proves to be the case, at least according to Rousseau (2005). These circumstances might otherwise lead to conflicts over

102 Rousseau, S. (2005)

water resources between EU nations. In the following there is an excerpt of Rousseau's table in order to provide the reader with an idea of the different areas in which such permit systems are applicable:

3-11 Water Pollution Permit Programs

Project	Water Body	Country	Activity description	Focus	Obstacles	Estimated Savings
Minnesota River nutrient trading study	Minnesota River	US	Watershed Trading study	Phosphor (P)	Difficult to target	13-14$/lb P reduced
Neuse River nutrient sensitive water management strategy	Neuse River Estuary	US	Watershed trading program	Nitrogen (N)	Trading between point sources and agriculture was not authorized	14-19$/lb N for each lb over association's allocation
Tar-Pamlico nutrient reduction trading program	Pamlico River Estuary	US	Watershed trading program	P,N	Very complex to quantify impacts of runoff from animal feeding operations/imprecise language in trading rules	25-35$/kg N and P over association's allocation
Rhine River Basin nitrate reduction study	Rhine	EU	Study	N		
Tampa Bay cooperative nitrogen management	Tampa Bay	US	Regional cooperation	N	Goals could be reached without trading	
Passaic Valley sewerage commission effluent trading program	Hudson River	US	Pretreatment Program	Metals	Firms apprehensive about sharing info and uncertain about appropriate pricing/ Time consuming negotiations/ Trading rules developed after compliance investment of most firms	
Tradable discharge permit system for water pollution of the upper Nanpan River	Nanpan River	China	Potential for trading study		No efficient compliance incentive and enforcement mechanism	190.000$ p.a.
Long Island Sound trading program	Long Island Sound	US	Large watershed trading program	N	Trading association must find ways to encourage trading	200 Mio$ over 15 years
Hawkesbury-Nepean River nutrient trading	Hawkesbury-Nepean River	Australia	Bubble license regime for sewage treatment plants	P,N		10-20% compared to uniform discharge concentration limits

Source: Rousseau, S. (2005)

Another key issue of Rousseau's paper is the development of a list of crucial recommendations to political authorities who intend to set up a water pollution permit system: First, before designing the permit system, a detailed study of the river basin and the nature of the pollutant have to be conducted.

Second, the water quality targets have to be defined carefully. In order to receive cooperation of affected parties, Rousseau gives the advice that permits need to be grandfathered rather than auctioned off. Also, if the permits can be traded, trading rules need to be established. Setting up a functioning, i.e. effective, monitoring system is also a crucial aspect of the permit system. Naturally, Rousseau demands that the system has to be enforceable. This implies that trade and AT need to be promoted. Also, sanctions for non-compliance need to be defined which reflect *the nature of the violations*[103]. Last but not least Rousseau emphasizes the importance of a periodical evaluation of the working and the effectiveness of the permit system, once it has been established. Overall, although not concerned with the analysis of theoretic economic models, Rousseau's work presents a valuable insight into the nature and the complexity of the problem in question. The overview over water pollution permit systems, which have already been implemented, presents political decision makers with additional and valuable information.

3.1.6 The Model of M. Weber

The paper *"Markets for water rights under environmental constraints"* by Weber[104] seeks to comprise both ecological and economic aspects of water flows and allocation along a river site. While minimum instream and endpoint flow and pollution constraints are implemented to ensure that the river's eco system remains intact, an efficient allocation of water resources along the river can be seen as the goal of her economic analysis. Her model intends to show that implementing a tradable permit system for water consumption and pollution rights will render the optimal solution as location specific permit prices will emerge.

3.1.6.1 Optimal Allocation

Before a market for tradable permits is introduced, Weber introduces the assumptions relevant to her analysis and calculates the first best solution to the maximization problem where a benevolent regulator maximizes total benefits from allocating water consumption and pollution rights.[105] First, the river basin is divided into n locations. Each location is occupied by one user i, i.e. $i \in n$. Second, the difference in water quality, q(i), between

[103] Rousseau, S. (2005)
[104] Weber, M.L. (2001)
[105] In the following only the part of Weber's paper dealing with pollution rights will be discussed. This is done for the following reasons. First, except for the name of the variables and the return flow parameter, the two aspects are identical. Second, the externalities inflicted on downstream locations have the same direction. Third, the analysis remains more concise and compact without the slightest loss of generality and applicability.

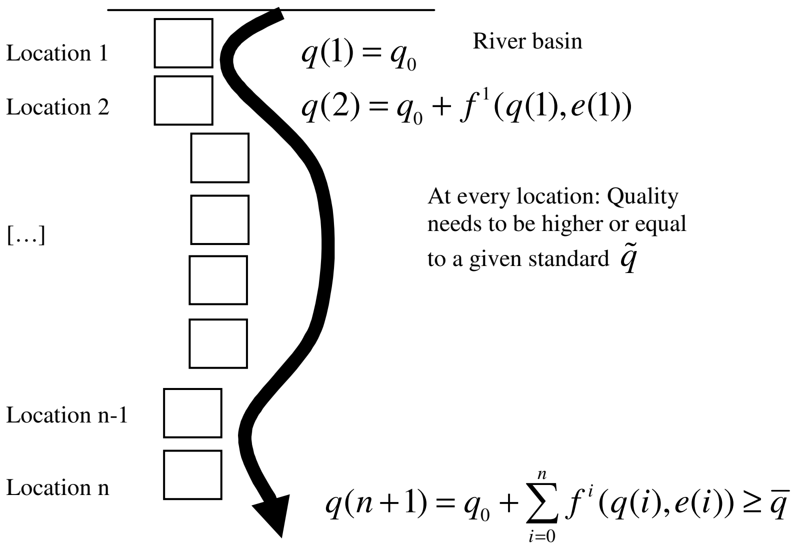
locations, i and i+1, is expressed through a site specific function, f^i, where e(i) denotes pollution discharge, i.e.

$$q(i+1)-q(i)=f^i(e(i),q(i)) \tag{3.9}$$

given the assumption that $f^i(\cdot)$ is decreasing and strictly concave in e and increasing and strictly concave in q.

Endpoint constraint with respect to water quality are denoted by $\overline{q}$, while so called instream flow needs (IFN)[106] are defined by $\tilde{q}$. Weber defines so called *third party effects* which appear if this IFN becomes binding due to a transfer of pollution rights from downstream to upstream users. This effect is similar to that discussed in sections 3.1.1 and 3.1.2. Now, the following graph is meant to illustrate the given model settings:

3-12 Water Quality Evolvement



Source: Author's design given the verbal descriptions in Weber (2001)

Weber's *users of water*, which are located along the river, possess a benefit function which is increasing and strictly concave in both water pollution and quality:

$$B^i=B^i(e(i),q(i)) \tag{3.10}$$

Therefore, the regulator now maximizes total benefits from allocation pollution rights along the river, given the constraints mentioned above:

[106] Weber, M. L. (2001)

$$\max_{e(i)} \quad \sum_{i=1}^{n} B^i(e(i), q(i)) \tag{3.11}$$

s.t.

Quality (μ(i)): $q(i+1) - q(i) = f^i(q(i), e(i))$

IFN (λ(i)): $q(i) + f^i(q(i), e(i)) - \tilde{q}(i) \geq 0$

Starting and Endpoint constraints:
$q(1) = q_0, q(n+1) = \overline{q}, e(i) \geq 0$

This is a so-called general and discrete constrained control problem with one control variable, i.e. e(i), one state variable, i.e. q(i), and one inequality constraint. Setting up the Hamiltonian and the Langragian renders the necessary condition for an optimal solution. In this case, the value and the change in the co-state variable, $\mu(i)$, take the centre of attention:

$$\mu(i) = -\frac{B_e^i}{f_e^i} - \lambda(i) \tag{3.12}$$

$$\Delta\mu(i) = -[B_q^i + \lambda(i) - \frac{B_e^i}{f_e^i} f_q^i] < 0 \tag{3.13}$$

Equation (3.12) shows that, in equilibrium, the marginal cost and benefit of an extra unit of pollution right to user i have to be equal. Equation (3.13) proves that the cost of pollution declines from upstream to downstream river sites, due to the fact that fewer users are affected by the resulting externality. Therefore, Weber proposes that a permit market in which, in equilibrium, permit values decline from upstream to downstream users renders the optimal solution.

3.1.6.2 Implementing a Tradable Permit System

Weber now introduces a *decentralized* market for pollution rights which is designed as a market for tradable permits, d(i), whose initial allocation d_0^i is grandfathered. The regulator grandfathers a total of $\overline{D}$ permits, i.e. $\overline{D} = \sum_{i=1}^{n} d_0^i = q_0 - \overline{q}$. Users are able to generate additional certificates if $f^i(i) > 0$. The permit price that holds between location k (seller) and i (buyer), i.e. $i \neq k, \forall i, k \in n$, is denoted by p_{di}^k. Now users are able to control the water quality at their location through the sale and purchase of pollution permits. Weber defines the market to be in equilibrium if there is no more incentive *"for any pair of users to trade"*[107]. Naturally, each of them intends to maximize their gains from trade given the constraints on water quality:

$$\max_{e,d} \quad B^i(e(i), q(i)) - \sum_{k \neq i} p_{di}^k d_i^k \tag{3.14}$$

s.t.

$$\text{Quality } (\gamma(\text{i})): \quad \sum_{i \neq k} d_i^k + d_i^0 + f^i(q(i), e(i)) = 0$$

$$\text{IFN } (\vartheta(\text{i})): \quad q(i) + f^i(q(i), e(i)) - \tilde{q}(i) \geq 0$$

$$\text{Starting and Endpoint constraints:}$$
$$q(1) = q_0, q(n+1) = \overline{q}, e(i) \geq 0$$

Now, the difference equation with respect to quality has changed into an equality constraint. The value of permits and its change along the river, which has to have the same sign as the change in value of the co-state in section 3.1.6.1 is identified through defining the payoffs from possible permit trade.

3.1.6.3 Is there a Nash Equilibrium in Permit Trade?

The payoff for user i from buying an upstream right is divided in an increase in water quality and an additional right to pollute:

$$\text{Marginal improvement in quality:} \quad \mathrm{B}_q^i - \frac{B_e^i}{f_e^i}[1 + f_q^i] - p_{di}^k \tag{3.15}$$

$$\text{Additional right to pollute:} \quad -\frac{B_e^i}{f_e^i} - \vartheta(i) - p_{di}^k \tag{3.16}$$

The payoff from buying a downstream right is confined to equation (3.16) as there is no improvement in water quality included. In her paper, Weber states the following: It will never be a Nash Equilibrium for user i to buy a right from a downstream user k for the following reasons[108]: One the one hand, there will always be a user j located further down the river willing to pay more for the same right, i.e. i < k < j. On the other hand, user k will never want

[107] Weber, M.L. (2001)
[108] Weber, M.L. (2001)

to sell a right to an upstream user i, as he wants to be compensated for his deterioration in water quality, i.e. $-(\mathrm{B}_q^i - \frac{B_e^i}{f_e^i}[1+f_q^i])$, in addition to the loss the benefit from pollution, i.e. $(-\frac{B_e^i}{f_e^i} - \vartheta(i))$, and i will only be willing to pay for the latter part. Now, the question arises from which of the various upstream locations user i will choose to buy certificates from. According to Weber, a Nash Equilibrium in trade results in the "*socially optimal outcome"* and requires that

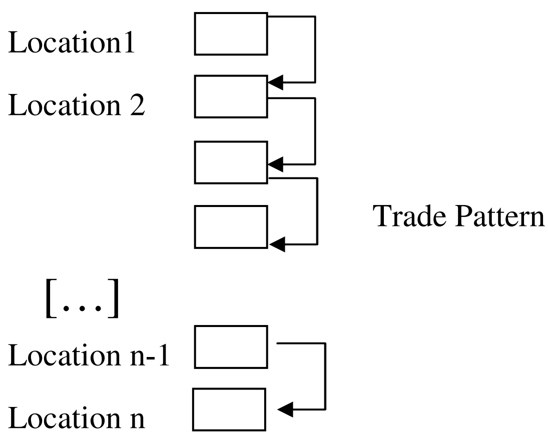
$$-\frac{B_e^i}{f_e^i} - \vartheta(i) = \mathrm{B}_q^{i+1} - \frac{B_e^{i+1}}{f_e^{i+1}}[1+f_q^{i+1}]. \tag{3.17}$$

The left hand side of this equation obviously represents the marginal cost of user i selling a permit to user i+1. The right hand side represents the net marginal benefit of user i+1 from buying a permit from i. Weber states that equation (3.17) , in order to be a sufficient condition for a Nash Equilibrium, implies that

$$p_{di}^{i-1} > p_{di}^{i+1}. \tag{3.18}$$

Moreover, regarding equation (3.18) Weber (2001) suggests that *"downstream users are never willing to pay the opportunity cost for non-adjacent upstream permits at the margin […] there is no price which i-1 is willing to pay to i+1 that will not be matched by i." (Weber 2001).* According to Weber this is proven by the fact that the reservation price at any site i for selling a pollution permit downstream equals the marginal social cost of water pollution at site i. To Weber, this implies that, as the marginal social cost of pollution declines from upstream to downstream since fewer users a negatively affected, reservation price for selling a right downstream must also decline. Thereby, Weber identifies the following equilibrium trade pattern:

<u>3-13 Weber's Trade Pattern</u>



Source: Author's design given the description in Weber, M.L. (2001)

For a critical analysis dealing with the results of Weber (2001) with respect to a Nash equilibrium one may turn to Rauscher, M., and Wittmann, N.[109]. In their paper, they show, that a Nash Equilibrium only exists if regulation authorities restrict trade options. The trade pattern identified by Weber is a Nash Equilibrium only in the case where no other than adjacent trade is allowed. Once this assumption, which has been implicitly made by Weber (2001), is relaxed, Weber's findings no longer hold true.

3.2 Modifying the Model of M. Weber

In the following, the model setup of Weber is used to describe the change in quality and effluent emission along a river basin. In sections 3.1.3 to 3.1.4.2 not only water but also land as an input factor in companies' production function, which are located along a river, played an important role in the analysis. Now, the approach is slightly changed and adapted. There is no difference in the size of the land available for development along the river, but companies located along the river basin demand land spots of identical size. However, they have to pay rent to occupy these spots. In the long run, if production is negatively affected by decreasing water quality from upstream to downstream locations, this should have an effect on the value of the different land spots along the river. Therefore, land rents appear to be affected by location specific water quality.[110] A detailed analysis is conducted in the model presented in the following sections. Also, different approaches to water quality regulation are examined and compared. There are three different settings which are taken into account in the course of the following analysis: Laissez-faire (i.e. absence of regulation), centralized regulation, and market-based regulation through tradable certificates. In the first setting, the market remains unregulated. In the following setting a regulator controls the market for effluents. Afterwards, a market for certificates is introduced, followed by some further analysis and concluding remarks.

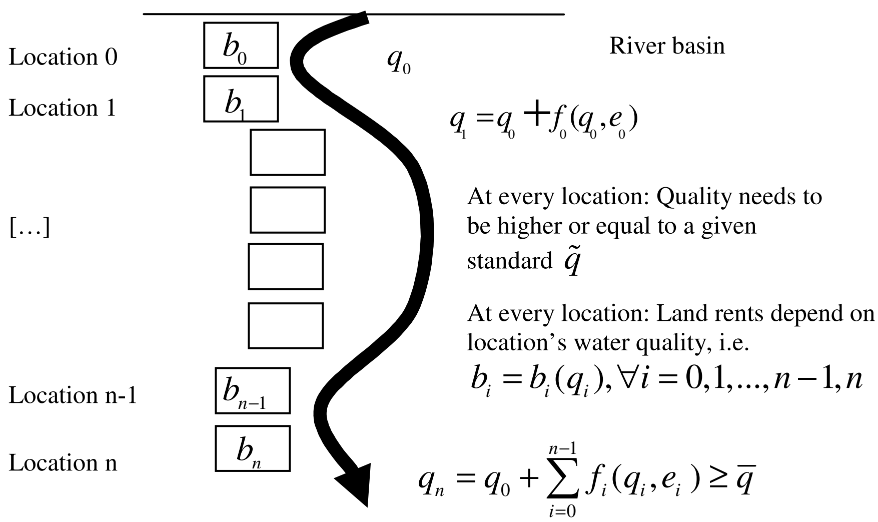
3.2.1 Model Setting

In this model, a number of n identical companies are located along a river site. Each of them, denoted with i, i.e. $i \in n$, emits an amount of effluent e_i in the process of their economic activity. The operating profit of every company G_i depends on the amount of effluent emitted

[109] Rauscher, M., Wittmann, N. (2011)
[110] The model presented in the following only takes a look at a very confined section of the market. Land owners or the companies' production output demand are not part of the analysis. These market segments have been omitted in order to narrow the analysis down to the aspects that have also been the focus of sections 3.1.3 to 3.1.4.2 and 3.1.6.

and the quality q_i of the water at their location i, i.e. $G_i = G_i(e_i, q_i)$, as long as land rents are omitted. Profits increase both with the amount of effluent emitted and the water quality at site i, i.e. $G_{i_e}, G_{i_q} > 0$. In order to facilitate the analysis, it is assumed that optimal output prices are constant along the river. Equilibrium amount of production, i.e. output, is assumed to be constant, as well. The water quality at location (i+1) depends on the amount of effluent emitted and the quality prevalent at site (i) and is described by a difference equation[111] $f_i(e_i, q_i) = q_{(i+1)} - q_i$. It is assumed that water quality decreases in effluents e_i, $f_{i_e} < 0$, while the assimilative capacity increases in water quality q_i, $f_{i_q} > 0$[112]. At the initial site $i = 0$ water quality q_0 is given. Additionally, it is assumed that regulation authorities set a lower bound regarding the water quality along the river flow, i.e. $q_i \geq \tilde{q}, \forall\, i \in n$, and beyond the last location n, i.e. $q_{n+1} \geq \overline{q}$. If land rents are introduced in the model, companies have to pay a rent, b_i[113], at each of the n sites along the river. This rent is part of the operating profit function, and is determined endogenously in the model, i.e. $G_i^{rent} = G_i^{rent}(e_i, q_i, b_i)$, where $G_{i_b} < 0$. The following graph illustrates the general model setting:

3-14 Water Quality



Source: Author's design

[111] This is done as described in the Model of Weber.

[112] As done by Weber, this allows for water quality to improve, i.e. $f_i(e_i, q_i) > 0$, even though $e_i > 0$.

[113] Regarding b_i, it is assumed that there is a minimum level of land rent $b_i \geq \overline{b},\ with\ \overline{b} \geq 0$, at which land owners are willing to rent the land. For reasons of simplicity it is also assumed that there is no alternative land use available.

3.2.2 Laissez-faire (short run)

In order to get an insight into the market, the situation in the absence of regulation has to be evaluated. Each company i will maximize its operating profits

$$\max_{e_i} G_i = G_i(e_i, q_i) \tag{3.19}$$

which results in $G_{i_e}(e_i, q_i) = 0$. The value of negative externalities inflicted on downstream locations j by upstream locations i can be summarized as follows

$$\sum_{j=i+1}^{n} \frac{\partial G_j}{\partial e_i} = \sum_{j=i+1}^{n} G_{jqj} \frac{\partial q_j}{\partial e_i} < 0 \tag{3.20}$$

since operating profits at any location j correlate negatively with the amount of effluents which are emitted at any upstream location i. The fewer upstream locations i there are, the higher j's operating profit will be. Therefore, in the short run, highest operating profits will occur at location 1, and lowest at location n. Furthermore, in the short run, land rents can be considered as fixed. In the long run, however, they can be considered as negotiable, and are therefore endogenously determined in the following setting. Therefore, companies now maximize operating profits according to

$$\max_{e_i, b_i} G_i^{rent} = G_i^{rent}(e_i, q_i, b_i) \tag{3.21}$$

which results in $G_{i_e}^{rent}(e_i, q_i, b_i) = 0$ and $b_i = \bar{b}$[114]. Hence, negative externalities, which are displayed by equation (3.20), remain non-internalized in the short run, even if land rents enter the picture. This stems from the fact, that, in the short run, locations are considered fixed. Therefore, companies do not have to take into account the effects of their activities on downstream locations.

3.2.3 Laissez-faire (long run)

In the long run, every company will still maximize its profits as in the case of short run, i.e. equation (3.19) still holds. However, in the long run, companies are able to change, or rather switch, locations along the river. Hence, in equilibrium, land rents at each location i will reflect the level of negative externalities inflicted on downstream locations j, as represented by equation (3.20). This results in the following location-specific land rents' pattern:

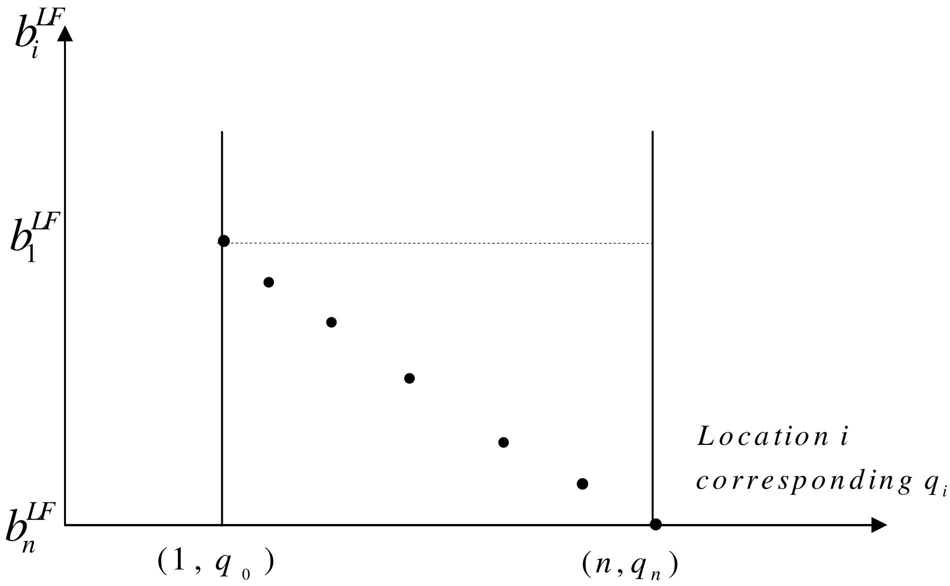
---

[114] This results from the fact that G_i is decreasing in b_i as it is a cost. Hence, ceteris paribus, profit maximization implies cost minimization, and companies will only pay the minimum rent.

$$b_n = \bar{b},$$
$$b_i = \bar{b} + \sum_{j=i+1}^{n} G_{jqj} \frac{\partial q_j}{\partial e_i} \;\; \forall i = 0,...,(n-1). \tag{3.22}$$

Thus, the evolution of land rents can also be graphically illustrated as follows:

3-15 Long run location-specific land rents



Source: Author's design

Hence, in the long run, due to the assumption of spatial mobility, negative externalities, displayed by equation (3.20), are internalized through decreasing levels of location-specific land rents. Thereby, operating profits become equal across locations in the long run.

3.2.4 Regulation

It is assumed that there exists a regulation authority, deciding on the equilibrium amount of effluents and water quality levels, through maximizing aggregate operating profits. In order to find our more about the effects, resulting from the operating profit equality constraint, the constraint is omitted in this section. Therefore, aggregate operating profits $\sum_{i=1}^{n} \Pi_i$ are maximized according to the following set of equations:

$$\max_{e_i, b_i} \sum_{i=1}^{n} \Pi_i = \sum_{i=1}^{n} G_i(e_i, q_i, b_i) \tag{3.23}$$

s.t.

$$\mathrm{f}_i(\mathrm{e}_i,\ \mathrm{q}_i) = \mathrm{q}_{i+1} - \mathrm{q}_i. \tag{3.24}$$

$$0 \le -\tilde{q} + q_i + f_i(e_i, q_i) \tag{3.25}$$

$\forall i \in n.$

This is a constrained control problem with two control variables, one state variable, and one inequality constraint. An interior solution to the problem is guaranteed similar to the assumptions made by Weber[115]. The Hamiltonian is

$$\mathbb{H}_i = G_i(e_i, q_i, b_i) + \mu_i f_i(e_i, q_i) \tag{3.26}$$

and the Lagrangian

$$\mathbb{L}_i = \mathbb{H}_i + \lambda_i(-\tilde{q} + q_i + f_i(e_i, q_i)). \tag{3.27}$$

The relevant initial and endpoint constraints and consumption constraints are

$$q_1 = q(0),\ q_{(n+1)} = \overline{q},\ e_i \ge 0 \tag{3.28}$$

The necessary conditions which will maximize (3.23) are therefore

$$\frac{\partial \mathbb{L}}{\partial e_i} \le 0, \frac{\partial \mathbb{L}}{\partial b_i} \le 0 \text{ [116]} \tag{3.29}$$

$$\Delta\mu_i = -\frac{\partial \mathbb{L}}{\partial q_i} \tag{3.30}$$

and the complementary slackness conditions are[117]

$$\lambda_i \ge 0, \frac{\partial \mathbb{L}}{\partial \lambda_i}\lambda_i = 0 \tag{3.31}$$

---

[115] Firstly, $f_i(e_i, q_i)$ has to be strictly concave and increasing in q_i and strictly concave and decreasing in e_i. Secondly, the operating profit function is strictly concave in q_i and e_i. Thirdly, input consumption has to be strictly positive, $e_i > 0$.

[116] According to Kuhn-Tucker conditions, we have $e_i \ge 0$, $\frac{\partial \mathbb{L}}{\partial e_i} e_i = 0$ and $b_i \ge \overline{b} \ge 0$, $\frac{\partial \mathbb{L}}{\partial b_i} b_i = 0$.

[117] Leonard, D., van Long, N. (1992), p. 199

Taking the necessary derivatives and solving for G_{i_e}, μ_i, and $\Delta\mu_i$, renders[118]

$$G_{i_e} = -(\mu_i + \lambda_i) f_{i_e} > 0, G_{n_e} = 0 \tag{3.32}$$

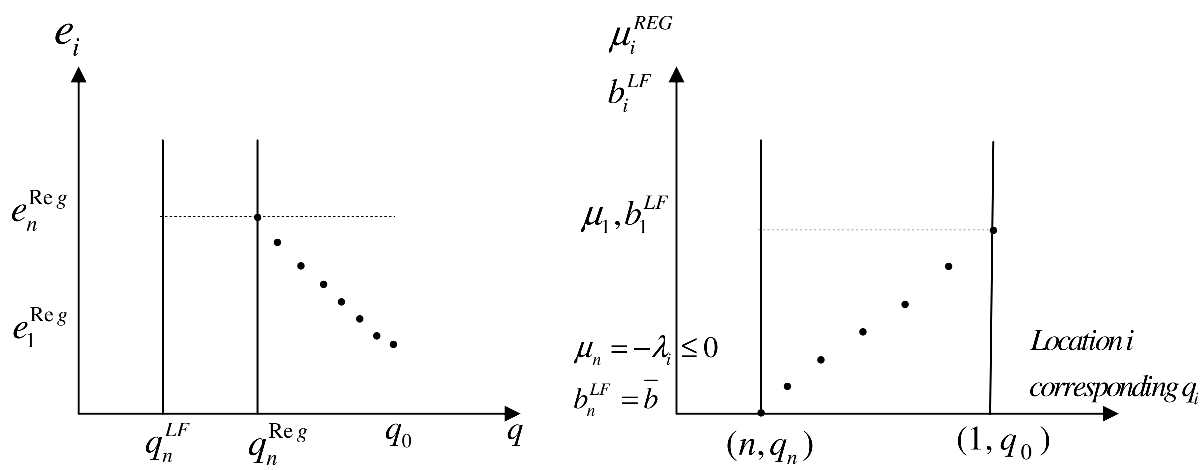
$$\mu_i = -\frac{G_{i_e}}{f_{i_e}} - \lambda_i > 0, \mu_n = -\lambda_n \leq 0 \tag{3.33}$$

$$\Delta\mu_i = -[G_{i_q} - \frac{G_{i_e}}{f_{i_e}} f_{i_q} + \lambda_i] < 0 \tag{3.34}$$

$$G_{i_{bi}} \leq 0, b_i = \bar{b} \, \forall i \tag{3.35}$$

This clearly shows that in the case of regulation, negative externalities are internalized through different location specific production, and hence emission output, levels. The very last location n is allowed to emit the highest level of effluent as there are no more downstream locations. If the IFN is not binding at location n, then $\lambda_n = 0$ and therefore, we have both $G_{n_e} = 0$ and $\mu_n = 0$. If compared to the case of laissez-faire where externalities are internalized through land rents, regulation leads to a smaller level of effluents, ceteris paribus, μ_i can be perceived as the marginal value, or socially optimal price, of one unit of effluent at location i, which is greater than zero. Results can be graphically illustrated as follows:

<u>3-16 Illustration and comparison of results</u>



Source: Author's design

[118] Making the assumptions stated in Leonard, van Long, Corollary 6.5.1. p. 214. These ensure concavity of the Lagrangian, i.e. $\mu_i \geq 0$. Intuitively speaking, as the multipliers and costate variables represent the shadow value of relaxing the relevant constraint by one unit their value has to be positive as relaxing rent or assimilative constraints results in higher operating profits.

In case of the socially optimal price path for effluent e, $\Delta\mu_i$, represented by equation (3.34), is decreasing as we move down the river, which means that, the further downstream a unit of effluent is emitted, the less damage it causes and, hence, its socially optimal price decreases as well. The so-called recursive nature[119] of the problem allows the application of Bellman's functional recurrence equation. Hence, along with the relevant constraints and equations (3.24), (3.25), and (3.28) to (3.35), optimal values for $\hat{e}_i(q_i)$, $\hat{\mu}_i$, and $\hat{\lambda}_i$ can be deducted through backward induction.

3.2.5 A Market-Based Certificate Trading Scheme

Many people propose a market-based regulation as they believe that it is the more efficient measure when it comes to environmental policy. As has already been shown by Montgomery[120], the cost-minimizing solution can thereby be obtained. A certificate scheme for effluents emitted along a river site can be designed as follows: companies along the river receive a certain initial allocation of certificates, d_i^0, where $\sum_{i=1}^{n} d_i^0 = q(0) - \overline{q}$, but are also able to trade certificates amongst each other, as shown by Weber. The price of certificates is denoted with $p_{d_i}^k$, assuming that company i and k, $\forall\, i$, $k \in n$, $i \neq k$, are trading.

3.2.5.1 Effluent Certificates

In this market setting every company maximizes operating profits according to the following set of equations:

$$\max_{e_i, d_i^k} (G_i(e_i, q_i, b_i) - p_{d_i}^k d_i^k) \qquad (3.36)$$

s.t.

$$\begin{aligned} 0 &\leq -\tilde{q} + q_i + f_i(e_i, q_i) \\ 0 &= d_i^k + d_i^0 + f_i(e_i, q_i) \end{aligned} \qquad (3.37)$$

Taking the necessary derivatives with respect to e_i, b_i, and d_i^k yields

$$G_{i_e} = -(\lambda_i + \chi_i) f_{i_e} > 0 \qquad (3.38)$$

---

[119] Leonard, D., van Long, N. (1992), p. 174

[120] Montgomery, W.D. (1972)

$$\chi_i = p_{d_i}^k. \tag{3.39}$$

In the short run, land rents will, again, equal $b_i = \bar{b}$. In the long run, land rents will internalize the cost of certificate trade. The latter case is exemplified in section 3.2.6.

In order to identify equilibrium certificate prices, each locations' WTP (willingness to pay) for both upstream and downstream certificates has to be identified. Combining equation (3.38) and (3.39) yields

$$WTP^{down} = p_{d_i}^{k\ down} = -\frac{G_{i_e}}{f_{i_e}} - \lambda_i > 0. \tag{3.40}$$

Hence, equation (3.40) reflects the marginal production value (MPV) of one certificate. However, regarding the total location-specific value of a certificate one has to take into account both the MPV as well as its marginal water quality improvement (MWQI) which occurs if a downstream location i buys a certificate from an upstream location k. The latter accounts for the otherwise negative external effect from upstream emission on downstream water quality, which can be expressed by $MWQI_i = \frac{\partial \mathbb{L}_i}{\partial q_i} = G_{i_q} - \frac{G_{i_e}}{f_{i_e}} f_{i_q} + \lambda_i$.

The combined value of MVP and MWQI then renders the total WTP of a downstream location i regarding an upstream certificate of location k, which renders

$$WTP^{up} = p_{d_i}^{k\ up} = G_{i_q} - (1 + f_{i_q}) \frac{G_{i_e}}{f_{i_e}}. \tag{3.41}$$

In equilibrium, the price of certificates will reflect the marginal value, i.e. the social cost, of emitting effluent. Hence, the results of section 3.2.4 and 3.2.5 will be identical, i.e. $p_{d_i}^{k_{up}} = \mu_i$ given that the total number if emissions issued equals the first-best level of aggregate water quality deterioration.

3.2.6 A simple Setup: The n=2 location case and its Nash Equilibrium in Certificate Trade

In a simplified setting where there are only 2 locations along the river, results are easier to fathom and, under certain assumptions, can even be graphically illustrated. Aside from there being only 2 locations, further simplifying assumptions, which, however, do not cause a loss of generality, are made as follows:

First, it is assumed that water quality evolves according to $f(e_i, q_i) = f(e_i) = -e_i$. Initial grandfathered endowments with certificates are equal, i.e. $d_0 \; \forall i = 1,2$. Emissions have to be matched by certificates, i.e. $e_i = d_0 + d_i^k \; \forall i \neq k, with\, i,k \in n = 1,2,$ and there is no internal flow constraint. Second, as there are only 2 locations, the number of certificates traded has to be equal at each of them, i.e. $|d_1^2| = |d_2^1| = \hat{d}$. This renders the following market setting:

3-17 Market setting in the n=2 location case

	N=2
Certificate: (short run) MPV:marginal production value MWQI: Marginal Water Quality improvement	$G_{iei} = -\lambda(i) = p_i^k$ $WTP^1 = p_1^2 = G_{1e1} \Rightarrow MPV\; of\; one\; certificate$ $WTP^2 = p_2^1 + \lvert -G_{2q2} \rvert = G_{2e2} + \lvert -G_{2q2} \rvert$ $\Rightarrow MPV + [MWQI\;] of\; one\; certificate. \quad b_1, b_2 = \overline{b}$

Source: Author's design

Results of this setup can be summarized as follows:

3-18 Table of Results

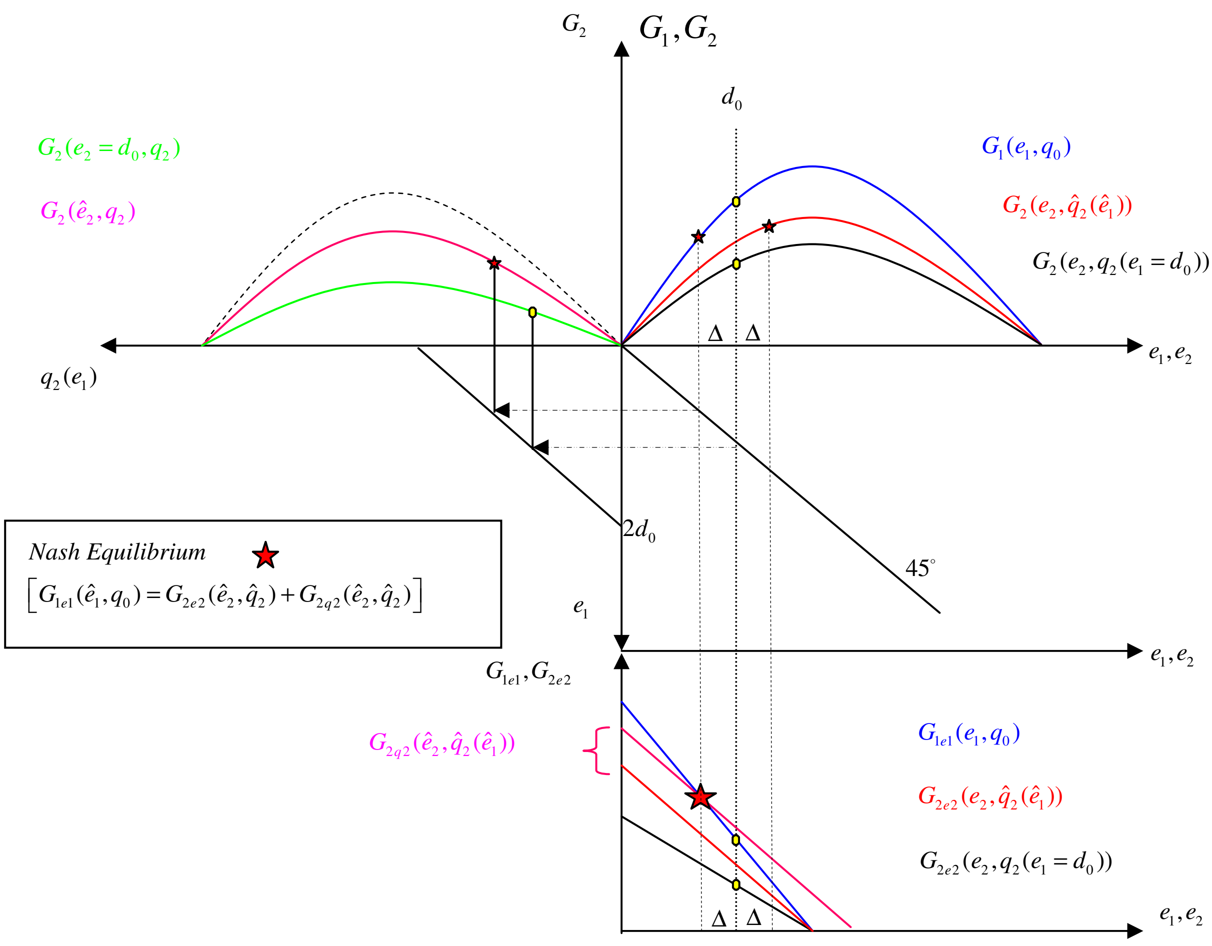
Trade $WTP^1 = G_{1e1}(e_1 = d_0, q_0)$ $WTP^2 = G_{2e2}(d_0, q_2(e_1 = d_0))$ $+\lvert -G_{2q2}(d_0, q_2(e_1 = d_0)) \rvert$	$Case\; I \quad : \widetilde{WTP}^1 < \widetilde{WTP}^2 \Rightarrow \hat{e}_1 < \hat{e}_2, \hat{d} > 0$ $Case\; II \;\; : \widetilde{WTP}^1 = \widetilde{WTP}^2 \Rightarrow \hat{e}_1 = \hat{e}_2 = d_0, \hat{d} = 0$ $Case\; III : \widetilde{WTP}^1 > \widetilde{WTP}^2 \Rightarrow \hat{e}_1 > \hat{e}_2, \hat{d} > 0$
Nash Equilibrium	***Intervall*** *[WTP^i,WTP^k] is non-empty.* ***Intervall*** *is compact and konvex with borders being continuous functions (Case II special, Intervall is only one point).*
Long run land rents	$Case\; I \quad : b_2 = \overline{b}, b_1 = \overline{b} + \left[\hat{d} \cdot \left(G_{2\hat{e}2} + G_{2\hat{q}2} \right) \right]$ $Case\; II \;\; : b_2 = \overline{b}, b_1 = \overline{b} + G_{2\hat{q}2}$ $Case\; III : b_2 = \overline{b} + \left[\hat{d} \cdot G_{1\hat{e}1} - G_{2\hat{q}2} \right], b_1 = \overline{b}$

Source: Author's design

There are three possible initial pre-certificate-trade cases, displayed by Case I to Case III in row one of the above table. In any case, however, the respective WTP's comprise an intervall. Given its characteristics – as shown in row two, column two – as well as the fact that the underlying functions are well-behaved, this leads to the conclusion that a fixpoint and, hence, a Nash Equilibrium in certificate trade, does exist.

With respect to equilibrium location-specific land rents, as has already been mentioned in section 3.2.5.1, these will reflect the cost of certificate trade. The three possible cases are shown in row three of the above table. Given certain assumption regarding the connection between the relevant variables e_i and q_i in the operating profit function $G_i = G_i(e_i, q_i, b_i)$, results can be graphically illustrated as follows[121]:

3-19 Graphical Illustration of a Nash Equilibrium in Permit Trade



Source: Author's design

The graph represents a special version of Case I described in table 3-18. The initial setting is displayed by the initial allocation of certificates d_0 (vertical lines, intersections with relevant curves are denoted by yellow dots). As quality at location 1 remains fixed and does not

[121] The underlying assumption is, that a change in e_i only leads to a shift of G_{i_q} and vice versa.

change, permit trade only influences emission levels, i.e. e_1, e_2, as well as water quality at location 2, i.e. $q_2 = q_0 - e_1$. That is also the reason why there is only a movement along the G_1, G_{1e1} curve (line), while, with respect to location 2, a shift in relevant $G_2, G_{2e2}, and\ G_{2q2}$ curves (line) occurs. There is a unique Nash equilibrium (denoted by the red star(s)) in which the relevant necessary condition holds, which states that no more gains from permit trade are feasible, i.e.

$$\left[G_{1e1}(\hat{e}_1, q_0) = G_{2e2}(\hat{e}_2, \hat{q}_2) + G_{2q2}(\hat{e}_2, \hat{q}_2)\right]. \tag{3.42}$$

Now, the question remains whether such a Nash Equilibrium can also exist in the case of n>2 locations.

3.2.7 Is there a Nash Equilibrium in case of n>2 locations?

Water quality is location-specific along the river. In order to get an idea of how the site-specific WTPs evolve, the results displayed by equations (3.40) and (3.41) could be analyzed with respect to changes in q_i, which renders

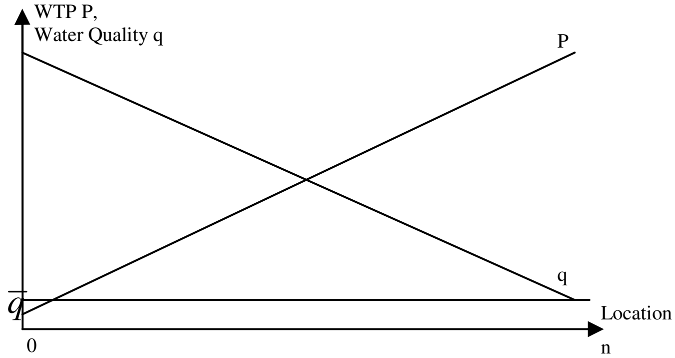
$$\frac{\partial p_{d_i}^{k_{up}}}{\partial q_i} = -\frac{1}{f_{i_e}^2}((G_{i_{e_q}} + G_{i_{e_b}} b_{i_q}) f_{i_e} - f_{e_q} G_{i_e}) - \lambda_{i_q} < 0 \tag{3.43}$$

$$\frac{\partial p_{d_i}^{k_{down}}}{\partial q_i} = -\frac{1}{f_{i_e}}((1 - f_q)(G_{i_{e_q}} + G_{i_{e_b}} b_{i_q}) - f_{q_q} G_{i_e}) + G_{i_{q_q}} < 0 \tag{3.44}$$

Equations (3.43) and (3.44) show that in this setup, the higher the water quality, the lower the value of an additional certificate.[122] Intuitively speaking, the company at location 1 values certificates the lowest, while the company at location n values certificates the highest. This results from the assumption of a concave operative profit function $G(e, q, b)$ with a positive but decreasing slope regarding both e and q. The evolvement of WTP with respect to water quality along the river site is illustrated in the following graph:

[122] If the internal flow constraint is not binding, then $\lambda_i = 0$ and hence $-\lambda_{i_q} = 0$. If the flow constraint becomes binding, then the bidding price will be zero, as location i is not allowed to hold the certificate, i.e. $-\frac{1}{f_{i_e}^2}((G_{i_{e_q}} + G_{i_{e_b}} b_{i_q}) f_{i_e} - f_{e_q} G_{i_e}) = \lambda_{i_q}$.

3-20 Evolvement of WTP with respect to changes in water quality



Source: Author's design

However, this does not imply that a Nash Equilibrium in permit trade does exist. A detailed analysis of Weber's Nash Equilibrium has been conducted by Rauscher and Wittmann[123] and shows, that, in the case of n>2 locations, a Nash Equilibrium *does not* exist, unless trade is restricted in some way or another. Therefore, the trade pattern identified by Weber (2001) does represent a Nash Equilibrium *if* trade is restricted to *adjacent locations* only.

3.2.8 Comparison of Results

The results of the previous section are summarized in the following table. We look at land rents, b_i, the amount of effluents emitted, which is indirectly referred to by G_{i_e}, and the marginal value of one unit of effluent, μ_i:

3-21 Comparison of Results I

	G_{i_e}	b_i
Laissez Faire, no land rent	0	$\bar{b}$
Laissez Faire + land rent	0	$b_i = \sum_{j=i+1}^{n} G_j q_j \frac{\partial q_j}{\partial e_i} \ \forall i = 1,...,(n-1),$ $b_n = \bar{b}$
Centralized regulation	$-(\mu_i + \lambda_i) f_{i_e}$	$b_i = \bar{b}$
Certificates	$-(p_{d_i}^{k_{up}} + \lambda_i) f_{i_e}$	$b_i = \bar{b} + [\text{cost of certificate purchase}]$

Source: Author's design

[123] Rauscher, M., Wittmann, N. (2011)

Therefore, as has been mentioned as well as illustrated before in graphs 3-15 (p. - 82 -) and 3-16 (p. - 84 -), land rents serve to internalize costs of deteriorated water quality in the case of long-run laissez-faire and costs of certificate purchases in case of market-based regulation. Hence, locational mobility causes profits to even out across locations in the lung run. When it comes to comparing the two regulatory options with each other, there is no difference in $G_{i_{\hat{e}}}$, given that $p_{d_i}^{k_{up}} = \hat{\mu}_i$, which would be the case if the aggregate amount of certificates duplicates the optimal deterioration of water quality in case of centralized regulation, i.e. the benevolent dictator case.

3.2.9 Conclusion

In general, the reason for regulating water allocation rights along a river site, may it be market-based or not[124], is, that there exist negative external effects from upstream companies' effluents[125] regarding downstream locations. In this simple case with perfect information and identical companies and locations, long run laissez faire internalizes negative location-specific externalities through land rents while regulation internalizes the latter by restricting output of effluents. A market-based solution can only render optimal results if trade patterns are restricted in some way, e.g. adjacent trade as – though only implicitly – assumed by Weber (2001). Overall, several articles have dealt with these issues, many of them empirically or verbally. The model presented in this chapter has taken a different approach in combining common microeconomic and urban economic theory.

3.3 Summary

Looking at the models presented in this chapter the answer to the question posed in the headline is twofold: At first glance, the problem of water scarcity appears to be a location specific issue. However, although some regions might not be directly affected by a lack of water, they might be indirectly affected through a threat of political, social, economic and ecological instabilities that arise from regions suffering from water scarcity. Therefore, this regional issue has a significant potential to turn into a global issue, if it is not ascribed to the necessary attention. Second, man-made pollution of water puts additional strain on the availability of drinking water and threatens the health of humans and ecosystems alike, especially in so-called developing or third-world countries. However, the problem is certainly

[124] Keeping in mind, however, that in case of market-based regulation and n>2 locations, additional restrictions regarding possible trade patterns, are needed, as mentioned in section 3.2.7.
[125] The same holds true for water consumption, as shown by Weber (2001).

not confined to these regions. The sea suffers from all kinds of polluting remainders of maritime traffic, such as tanker accidents, or illegal offshore tanker washing: “Nearly half of the pollution at sea caused by crude oil, and other refined products results from international maritime traffic”.[126] And industrialized nations are confronted with tackling rising levels of hormones through enhanced wastewater treatment.[127] Overall, if “Blue Gold” is defined as clean drinking water, which is free from any artificial remainders caused by mankind having indulged in the countless blessings of modern industrialized life, the answer tends to be “yes”. At least, one has to admit that both rising population levels and striving for never-ending economic growth add additional stress on providing everyone with a sufficient amount of water, which cannot be denied and needs to be dealt with accordingly.

[126] http://na.oceana.org/sites/default/files/o/fileadmin/oceana/uploads/europe/reports/oil-report-english.pdf
[127] Tabak, H.H., Bloomhuff, R.N., Bunch, R.L. (1981)

4 Depletion of Non-renewable Resources: Nothing but a new version of Andersen's tale of the emperor's new clothes?

"Oil shortages have been predicted over the past 30 years.
In fact, oil is more plentiful now in an economic sense than in 1973."[128]

Regarding the depletion of non-renewable resources, there is a vast literature basis available. The first one to deal with modeling the optimal extraction of so-called exhaustible resources was Hotelling in 1931. Afterwards, many followed his path, and his approach was discussed, implemented and refined in countless papers, articles, and books on resource economics. Afterwards, in the course of decades, various modifications of his model were conducted. It is impossible to name all of them here. A few of the innumerous works which intended to modify Hotelling's model in order to incorporate more realistic features are: Hanson or Solow and Wan,[129] who assumed increasing extraction costs, Stiglitz or Khalatbari,[130] who included market imperfections in the original model, Farzin or Lin et al., [131] who concerned themselves with introducing technological progress into the model, or Hoel or Pindyck[132], who incorporated the concept of uncertainty.[133] Aside from Hotelling's original work – the work of Heal on the relationship of price and extraction costs,[134] Neumayer on scarcity or abundance of natural resources,[135] or Pindyck[136] on the optimal exploration and production of a non-renewable resource present valuable insight into the matter.
With respect to the issue of a monopoly in resource supply, the papers of Cremer and Weitzman[137] and Gilbert and Goldman[138] are also of great significance regarding a detailed analysis of the market for petroleum. In general, all of these papers are more or less directly related to the work and ideas of Hotelling's work.

However, there is another methodological stream of research inspired by the work of an expert in the field of the global petroleum market: M.A. Adelman. For some Adelman is "*the undisputed Grand Old Man of Energy Economics*"[139]. However, his ideas and criticism of widely-held beliefs with respect to mineral scarcity and depletion or market control and public policy directed at the world oil market, put him into the position of an "*unsung hero, […] who*

[128] Watkins, G.C., (2006)
[129] Hanson, D.A. (1980), Solow, R.M., Wan, F.Y. (1976)
[130] Stiglitz, J.E. (1976), Khalatbari, F. (1977)
[131] Farzin, Y.H. (1992, 1995), Lin et al. (2008)
[132] Hoel, G. (1978), Pindyck, R.S. (1980)
[133] Lyn, C.-Y., UC Davis, CA, USA
[134] Heal, G. (1976)
[135] Neumayer, E. (2000)
[136] Pindyck, R.S. (1977)
[137] Cremer, J., Weitzman, M.L., (1976)
[138] Gilbert, R.J., Goldman, S.M., (1977)
[139] Tempest, P., (1995)

has often been attacked by those not well-versed in economics, for telling the truth"[140]. The work of Adelman comprises several decades of articles, papers, and books dealing with various aspects and peculiarities of the American, as well as international petroleum, petrochemical, and gas markets. Of special interest regarding the analysis in this chapter is, of course, Adelman's work with respect to the global petroleum market in general and to OPEC in particular. But even in this case it is hard to dissect the vast amount of information and data and to concentrate on the message of Adelman's work of a lifetime of intensive research. Nonetheless, there are some reoccurring ideas - which have also been picked up and discussed by his followers in belief - that emerge as the essence of his work. These can be summarized as follows: First and foremost, Adelman strongly opposes the idea that there exists a fixed, and therefore depletable, stock of resource in general and of oil in particular. It is all just a matter of whether market price covers costs:

"The assumption dropped is that there exists an exhaustible natural resource… a fixed stock of oil to divide between two [or more] periods" (Stiglitz, 1976). There is no such thing. The total mineral in the earth is an irrelevant non-binding constraint. If expected finding-development costs exceed the expected net revenues […] the industry disappears. Whatever is left in the ground is […] unimportant."[141]

Second, oil "*production is quite insensitive to price changes*".[142] According to Adelman it depends mostly on a so-called decline rate which will be discussed in detail in section 4.1.3. As a result, Adelman also "*pointedly rejects Hotelling's rule*"[143] but derives his own rule regarding the value of in-ground reserves. Third, changes in the price of oil, may it be over time or abruptly as during the oil crises in 1951, '56, '67, '73, '79, and 1980, [144] are not caused by a ever looming increase in scarcity but rather by the market power of OPEC or other parties who "*obscure national and global welfare interests*"[145]. Overall, Adelman's work can be considered as a fairly unbiased and thorough analysis of price drivers and cost structures of the petroleum market. Papers of Cairns and Davis, as well as Watkins serve to complete the picture that will be presented on the work of Adelman in section 4.1.3.

After having gained some insight into the ideas of both Hotelling and Adelman in the following literature review, the information gained on the world petroleum market will be used to develop the model presented in section 4.2. The latter deals with identifying the issues that

[140] Verleger, P., in Tempest, P., (1995)
[141] Adelman, M.A., (1990)
[142] Cairns, R.D., Davis, G.A., (2001)
[143] See footnote 142.
[144] Adelman, M.A., (1982)
[145] See footnote 139.

might arise once oil exporting countries intend to introduce Green Energy technologies into their energy markets. Afterwards, some concluding remarks will finalize this chapter.

4.1 Literature Review

This section is meant to give an overview over the theories of Hotelling and Adelman and some of those affiliated with either one of them. Moreover, the following table illustrates both the most relevant literature as well as the author's focus of research regarding this chapter:

4-1 Literature and Research Overview Chapter 4

Relevant sections and authors:	**Research Topic**
Hotelling	Modelling optimal price and extraction path of a non-renewable resource, given demand function, interest rate, and resource stock. (Section 4.1.1)
Hubbert	Modelling the connection between resource discoveries, proven reserves, and resource production over time. (Section 4.1.2)
Adelman	Theoretical and empirical analysis of the world's oil and gas market. Defining inground reserve value. Critizing oil importing countries political approach in dealing with OPEC, e.g. advise of a price based tax on oil imports. Postulates: Observed oil prices are not a sign of scarcity but of market power and imperfect competition. (Section 4.1.3)
Wittmann	I. Novelty: Analysing the effects of differences in in-countries vs. export/ world market oil prices in a Hotelling style model setup. (section 4.2.2) II. Novelty: Translating these findings into a setting where Green Energy is supposed to compete with subsidized energy production based on fossil fuels. (section 4.2.3)

Source: Author's design

4.1.1 Hotelling

"Contemplation of the world's disappearing supplies of minerals, forests, and other exhaustible assets has led to demand for regulation of their exploitation."[146]

Hotelling's paper on *the economics of exhaustible resources* focuses on what he calls "absolutely irreplaceable assets". The first part of his analysis deals with finding the optimal rate of extraction under perfect competition. Hotelling assumes that the exogenously given

[146] Hotelling, H. (1931)

interest rate γ remains constant over time. In line with the basic economic "arbitrage" principle, Hotelling proposes that, in equilibrium, the owner of the resource cannot achieve any additional profit by extracting a marginal resource earlier or later. This results in the equilibrium condition, also known as *Hotelling's rule*, which describes the equilibrium price path of an exhaustible resource

$$p_t = p_0^{\gamma t} \tag{4.1}$$

where p_t denotes the net price at time t, $\forall t \in [0,T]$.

The initial price p_0 will depend on demand q=f (p, t) and the given amount of total resource stock, S. Over the entire time T, it is assumed that the entire resource will be extracted, which results in the following condition, that overall extraction must equal total supply:

$$\int_0^T q\,dt = \int_0^T f(p_0^{\gamma t}, t)dt = S \tag{4.2}$$

In the last period of extraction, i.e. T, price will be equal to demand's reservation price. Therefore, the extracted and demanded amount at time T will equal zero:

$$f(p_0^{\gamma t}, T) = 0 \tag{4.3}$$

This equation render optimal total extraction time T, given γ and p_0. Extraction time will also depend on the shape of the demand function. Hotelling assumes that demand is negatively related to price and does not change over time.[147] Subsequently, Hotelling turns to identifying the maximum social value of the resource and thereby formally deducts equation (4.1). Afterwards, the case of a monopoly owning the exhaustible resource is discussed. Again, equation (4.2) has to hold, although in this setting, Hotelling lets T become/approach infinity, i.e. $T \to \infty$. Hence, the monopolist maximizes the present value (J) of his profits π:

$$\pi = \int_0^\infty qp(q)^{-\gamma t}\,dt \tag{4.4}$$

Hotelling continues to present examples to exemplify his analysis and discusses various different modifications to his basic models such as the introduction of taxes or cumulated production and its effect on price.

In the following Hotelling's findings are presented in the way Perman et al.[148] have done in their book on *natural resource and environmental economics*. The equations which determine optimal values for price and extraction paths, i.e. p_t and q_t, as well as extraction

[147] At least not in such a way, that it matters.
[148] Perman et al. (2003), Ch. 15, p. 519

time T are given in the following table[149]. In addition to the variables, which have already been defined, Perman et al. also introduce demand reservation price K, as well as a demand function which includes exogenously given parameter a and – in case of monopoly - the constant h[150], and the results of both perfect competition and monopoly are calculated.

4-2 Optimization Program

	Perfect Competition (PC)		Monopoly (M)
Objective	$\max \int_0^T p_t q_t^{-\gamma t} dt$		$\max \int_0^T p_t(q_t) q_t^{-\gamma t} dt$
Constraint	$\int_0^T q_t dt = S$		$\int_0^T q_t dt = S$
Demand Curve	$p_t(q_t) = K^{-aq_t}$		$p_t(q_t) = K^{-aq_t}$
Exhaustion Time	$T = \sqrt{\frac{2Sa}{\gamma}}$		$T = \sqrt{\frac{2Sah}{\gamma}}$
Initial Royalty	$p_0 = K^{-\sqrt{2\gamma Sa}}$		$p_0 = K^{-\sqrt{\frac{2\gamma Sa}{h}}}$
Royalty Path	$p_t = p_0^{\gamma t}$		$p_t = p_0^{\frac{\gamma t}{h}}$
Initial Extraction	$q_t = \frac{\gamma}{a}(T-t)$		$q_t = \frac{\gamma}{ha}(T-t)$
Extraction Path	$q_0 = \sqrt{\frac{2\gamma S}{a}}$		$q_0 = \sqrt{\frac{2\gamma S}{ha}}$

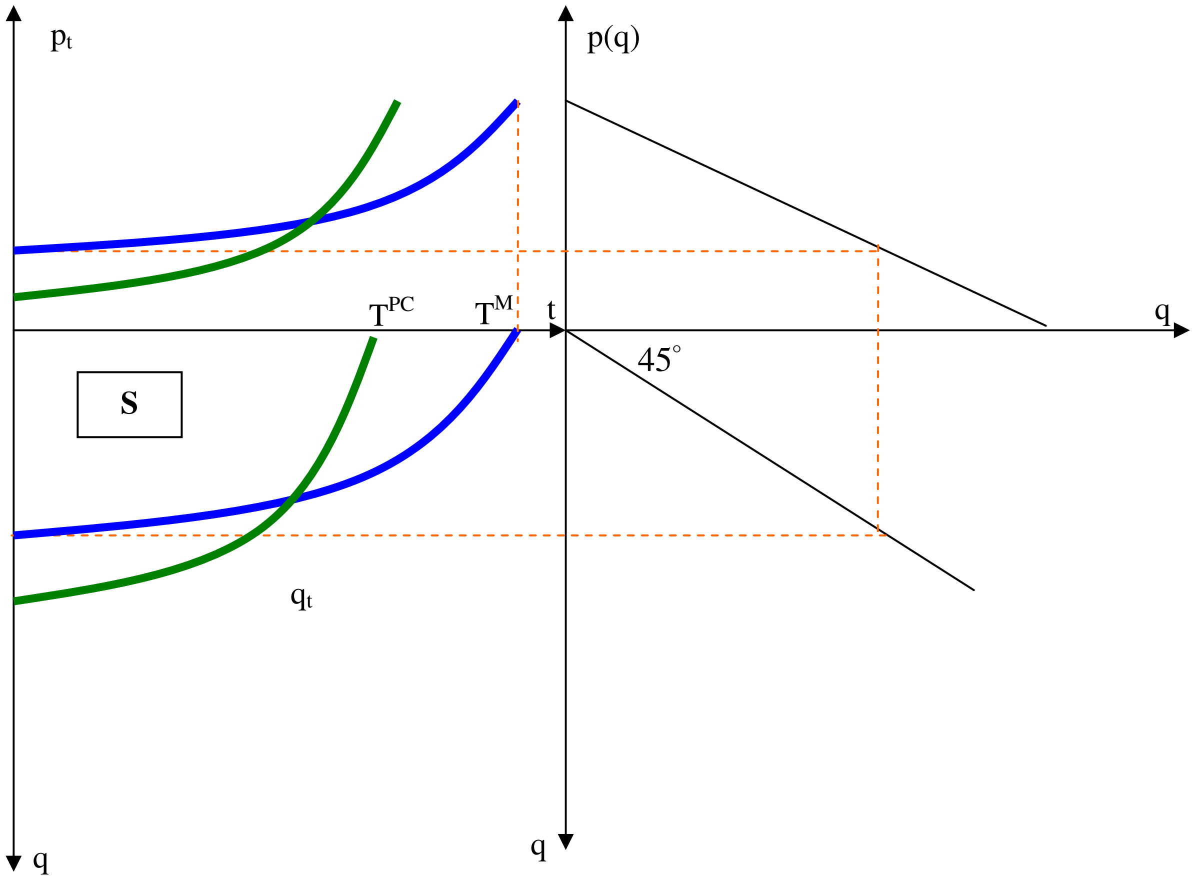
Source: Perman et al. (2003) p. 519

As it is known that h > 0, the results can be analyzed as follows: in case of monopoly, extraction time is prolonged, i.e. $T^M > T^{PC}$. A lower demand, due to a higher initial royalty, causes extraction of the fixed stock to take longer than under perfect competition. Therefore, in case of resource markets, it is said that a monopoly is more favorable in the eye of conservationists as production is lower than under perfect competition. However, the monopolist will also exploit the entire resource in the given setting, it will only take longer. The following graph illustrates the findings of the previous table:

[149] Some of these findings will be needed later on in section 4.2, therefore they are presented in such detail.

[150] In the course of their calculation, Perman et al. assume that $K(-aq_t+1)e^{-aq_t} \approx Ke^{-ahq_t}$ where h=2.5. For more details, please refer to Perman et al. (2003), p.535.

4-3 Hotelling: Optimal Resource Extraction



Source: Perman et al., (2003), p. 519

Overall, as much acclaimed Hotelling's findings and, consequently, Hotelling's rule certainly are one cannot deny that it only holds true under some quite restrictive assumptions. Hartwick and Hagemann[151] summarized these into four major points:[152] First, mineral, i.e. resource, quality is constant. Second, there are no uncertainties included regarding market structure or stock size. Third, prefect information and foresight is assumed for all agents. Fourth, future markets are anticipated perfectly. Therefore, mineral stock owners are able to maximize discounted future profits and rents will increase overtime at the rate of interest.

In reality, of course, experts like Neumayer (2000) are of the opinion that these assumptions can hardly hold true. Therefore, according to Neumayer, several experts propose that the present or future scarcity of a resource can only be measured in terms of its *relative price*. However, a study by Norgaard (1990) strongly opposed this approach. Norgaard states that, as no agent or decision maker in the market will ever possess perfect information and foresight, "*cost and price paths their decisions generate are as likely to reflect their ignorance as reality. To control for whether or not allocators are informed, however, we would have to*

[151] Hartwick, J.M., Hagemann, A. (1993)
[152] Neumayer., E. (2000)

know whether resources are scarce. Since this is the original question, the exercise is logically impossible."[153]

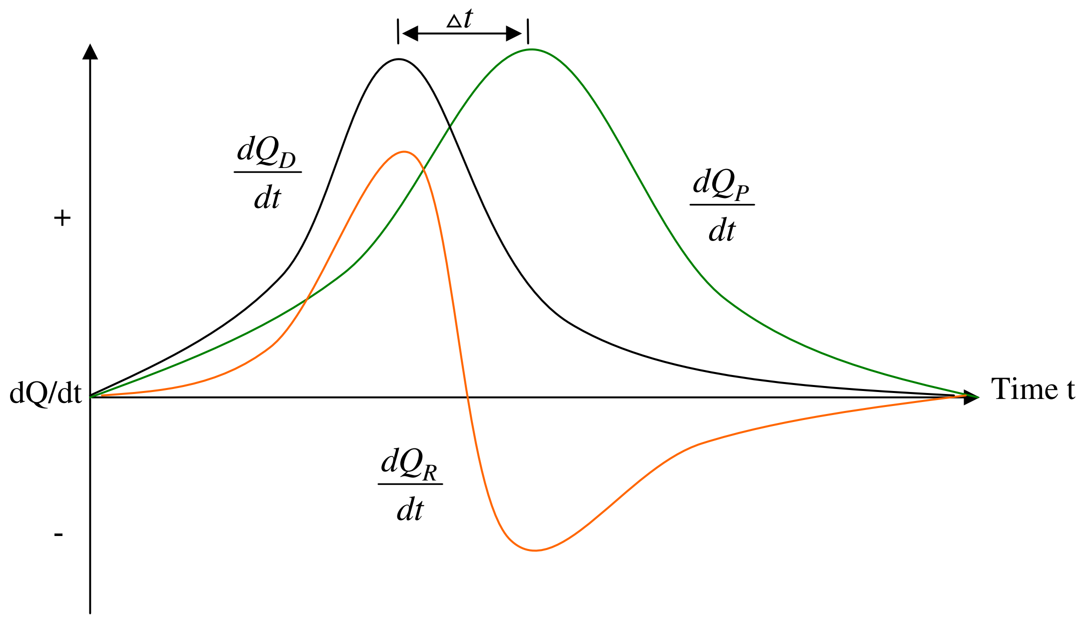
On the contrary, looking back at Hotelling's model, the exercise does not seem impossible at all: Equation (4.2) shows that as time moves on and extraction continues, less and less of the initial resource stock is available. According to Hotelling, the level of decrease in stock will be reflected by an increase in price, which can serve as a hint for identifying the level of scarcity. During the 1970's, the publications of the Club of Rome on "Limits to growth"[154] which were, amongst other things, concerned about natural resource availability, Hotelling's rule received a lot of attention, not so much from economists but rather the wider public.[155] This was mostly caused by the rise in oil prices, as OPEC cut down on supplies, mainly for political reasons. This led to statements of politicians like that of US President Carter in 1977: "*We could use up all the proven reserves in the entire world by the end of the next decade…* ".[156] This political frenzy was also fed by the existence and development of other models such as the life-curve approach of Hubbert which will be analyzed in the following section.

4.1.2 The Hubbert Approach

In 1962 Hubbert's report to the Committee on Natural Resources was published. He has investigated into the matter whether the world in general and the United States in particular would be running out of oil and, if so, how it would go about and, more importantly, when this would occur. According to his analysis, the life-cycle of oil resources can be pictured as a symmetrical uni-modal "Bell" shaped curve. In his update on Hubbert's work Ivanhoe (1997) lists the most important properties of the curve postulated by Hubbert: "*The production rate begins at zero, increases exponentially during the early period of development, and then slows down, passes through one or more principal maxima, and finally declines negative exponentially to zero.*" (Hubbert 1962). In his report, Hubbert depicted the development and connection between the rates of change (dQ/dt) in resource discovery Q_D, production Q_P and reserves Q_R over time. Hubbert assumes that there exists a time lag between the peak in discovery and the peak in production, as shown in the following graph:

[153] Norgaard, R.B. (1990), in Neumayer, E. (2000)
[154] Meadows et al. (1972)
[155] Neumayer, E. (2000)
[156] Watkins, G.C. (2006)

4-4 Hubbert Curve



Source: Hubbert, M.K. (1962), p. 56 fig. 24

This is the extended version of the graph that is generally associated with Hubbert, which only denotes the change in production. A formal analysis of this graph is also conducted by Hubbert. According to Hubbert, for every period t, "*proven*" discoveries (Q_D) have to equal *proven reserves* (Q_R) plus *cumulative production* (Q_P) which results in

$$Q_D = Q_R + Q_P . \tag{4.5}$$

Hence, the rates of change are related in the following manner:

$$\frac{dQ_D}{dt} = \frac{dQ_R}{dt} + \frac{dQ_P}{dt} \tag{4.6}$$

Most crucial to his findings is the analysis of the relationship between the three curves. Once proven reserves reach their peak, their rate of change will equal zero, i.e. $\frac{dQ_R}{dt} = 0$. At that point, equation (4.6) will boil down to $\frac{dQ_D}{dt} = \frac{dQ_P}{dt}$ and the two curves cross. From that moment on, cumulative production will always be higher than proven discoveries and, hence, reserves will be destined to vanish in the future. Hubbert's report also dealt with other issues, such as a method for estimating the time lag between discovery and production peak or the question at what time world oil production will hit his peak. Hubbert's guess on the latter part was at around the year 2000.

Overall, a great part of his popularity can certainly be ascribed to the fact that Hubbert predicted the time at which the oil production peak of the United States would occur correctly.[157] Supporters of Hubbert's approach such as Ivanhoe[158] envision the global energy crisis to occur within the first half of the 21st century. According to Watkins[159], the Hubbert curve serves as a basis for several models which deal with forecasting oil supplies, such as the work of Lynch[160]. The foundation of the ASPO, i.e. the Association of the Study of Peak Oil, or the M. King Hubbert Center for Petroleum Supply Studies are also an indicator of how popular Hubbert's approach has been and still is to date. Among the few experts to openly oppose Hubbert's belief is Watkins, who is affiliated to Adelman and his work. According to his understanding of econometrics, "*Hubbert's model is a classic example of omitting key variables, specifically price and technology."*[161] To Watkins, these variables determine investment processes and are completely neglected by Hubbert and his supporters: *"To ask Hubbert curves to handle an economic commodity such as oil is akin to asking to eunuch to sire a family."* (Watkins 2006). This citation gives a clear insight on Watkins opinion on Hubbert's approach.

Overall, to Watkins, the most troublesome assumption that is included not only in Hubbert's but also in Hotelling's work is the notion of *ultimate reserves.* Both Adelman and Watkins belief, that the idea of a fixed resource stock directs attention *to the wrong track*[162]. To them, future science and technology, as well as future demand determine the level of future reserves. Neither can be known today and only vague estimates can be made. Therefore, ultimate reserves are unknowable and do not make up a binding constraint in economic terms. These ideas comprise part of the essence of the work of Adelman which will be presented in the following section.

4.1.3 Adelman

"We will never get to the end of our oil resources.
We will stop impounding them into reserves when it no longer pays."[163]

[157] Böske, J. (2007)
[158] Ivanhoe, L.F. (1997)
[159] Watkins, G.C. (2006)
[160] Lynch, M.C. (2002)
[161] Watkins, G.C. (2006)
[162] Watkins, G.C. (2006)
[163] Adelman, M.A. (1992)

Adelman joined the economics department at MIT in 1948.[164] Since then he focused on the field of mineral economics. In the course of his academic career, his attention was directed mainly at analyzing the workings of the petroleum market. In over 50 years, Adelman has published a vast number of articles and several books. His book on *the economics of petroleum supply*, which was published in 1993, is comprised of his most significant papers in that field. In 1997, he published a paper called *My Education in mineral (especially oil) economics* in which he examined and summarized his work in retrospect. Therefore, the following analysis of Adelman's work will focus on these sources, in addition to the work of some of his followers, such as Watkins or Cairns and Davis.

4.1.3.1 Mineral Scarcity and Depletion

Working through Adelman's impressive academic output, one cannot help but notice that oftentimes he starts with an introductory remark somewhere along the line of "*the assumption of an initial fixed mineral stock is superfluous and wrong."*[165] On reading his somewhat memoirs-like paper *my education in mineral (especially oil) economics",* one can certainly infer some of the reasons why this constant reiteration is of great importance to him. In general, Adelman's ideas and theories tended to be of rather unpopular nature. In his opinion, political results influence both market structures and the behavior of market participants. Therefore, several issues, i.e. *depletion, knowledge, monopoly and politics*[166]*,* must be analyzed individually, before a general picture of the forces driving the petroleum market can emerge. Market prices do not just render information on demand and supply, but are also prone to react to the exertion of market power or politics affecting the expectations of market participants. According to Adelman, fluctuations in oil prices do not at all reflect uncertainty of supply or an in- or decrease in scarcity. It just reflects the problems of OPEC to control the output of its members in order to keep prices at the target level and to anticipate demand correctly. Adelman names the early 1980's as a period of especially highly fluctuating prices which he ascribes to defecting cartel members.

He intended to investigate further into the matter, focusing on 1) the historical evolution of the cartel up to and beyond the price maximum and 2) a better analysis of mineral scarcity. All but one funding proposals were rejected and Adelman found himself called an "*obstinate crank*" in several referee's reports. As a result, Adelman suspected: *"Perhaps my denial of the consensus looked like an argument for a flat earth."*[167]

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[164] Adelman, M.A. (1997)
[165] Adelman, M.A., de Silva, H., Koehn, M.F. (1990)
[166] Adelman, M.A. (1997)
[167] See footnote 166

4.1.3.2 World Oil Prices, Reserve Prices, and User Costs in Oil Production

Adelman published various articles which dealt with estimating and analyzing production costs of petroleum supply. Among these is his paper with de Silva and Koehn in 1990 on user cost in oil production, his work on world oil production and prices 1947-2000 published in 2002, and a paper by Adelman and Watkins on reserve prices and mineral resource theory published in 2008.

In his work Adelman always precisely distinguishes OPEC and Non-OPEC suppliers. In case of production costs and oil prices this approach serves best to make the points clear which Adelman strives to convey. While OPEC exports and market share have decreased significantly since the early 1970's, the output of Non-OPEC nations has increased. With respect to production costs this means that higher-cost, i.e. Non-OPEC, reserves are exploited, while low-cost, i.e. OPEC, reserves are hold back. According to Adelman, Non-OPEC nations are competitors, who do not have excess capacity, but produce as much as they can. This setting can only be explained by OPEC being a profit-maximizing cartel of low cost producers.[168]

Looking at marginal cost estimates, one can get a glimpse of how significant the differences in costs really are. Adelman and Watkins estimate a marginal cost of about $24/barrel in 2005 dollars with respect to Non-OPEC areas. In case of OPEC, although data is hard to attain, Adelman and Watkins calculate marginal cost of Saudi Arabia at around $3.35/barrel in 2005 dollars, although they belief that this is actually an overestimate. This difference of about $20/barrel explains why, in economic terms, Adelman compares the production pattern in petroleum supply to a "*river flowing uphill*"[169] – it makes absolutely no sense and "*is a waste of public money*" [170]. The panic over the threat of oil scarcity and the longing for alternative oil supplies in 1970-80 has caused this paradoxical situation to occur and to persist up until the present day.

In the course of his work, Adelman is relentless at his attempt to convey the idea that there is no such thing as a binding constraint on mineral resources available. In contrast to this widely held belief, Adelman postulates that measuring *user cost*[171], i.e. resource rent, is key to the analysis and that mineral resources had better be treated as a renewable inventory whether it comes to private or national accounting.[172] According to Adelman, Hotelling's

[168] Adelman, M.A., Watkins, G.C. (2008)
[169] Adelman, M.A. (2002)
[170] Adelman, M.A. (2002)
[171] User cost (resource rent) is defined as the difference between in-ground market value and development cost of the resource in question.
[172] See footnote 165

theory presents valuable information as soon as the assumption of a fixed stock is removed. If done so, the true measure of mineral scarcity can be identified, which is the present value of a mineral *reserve* to be extracted.

First, however, a connection between investment and reserve value is needed. *Investment* in oil production comprises two aspects: *discovery* and *development* (costs). New reserves must be both discovered and developed, while known, i.e. already discovered, reservoirs only need to be developed to turn them into "*proven reserves"*. Adelman, de Silva, and Koehn, calculate development cost of an increase in production using two assumptions. First, there is no resource limitation, which implies that production (Q) and reserve (R) increase at the same rate, i.e. $\frac{dR}{R}=\frac{dQ}{Q}$. Second, reserve inventory, i.e. R, remains fixed. This implies that investment (K) can only speed up output, i.e. $\frac{dR}{dQ}=0$. In combination with a quadratic cost function, these assumptions lead to the result that investment is twice as high as it would be if only new reserve inventories could be created, as $a=Q/R$ increases proportionally:

$$\frac{dK}{dQ}=2ka \tag{4.7}$$

where k = empirical constant, reflecting geological aspects.[173]

Investment is also often referred to as *replacement cost*. At any point in time, *discovery and development costs* are compared, and the least cost alternatives are chosen. Due to the fact, that the two actually are alternatives, changes in development costs are an indicator of changes in discovery costs and, hence, in resource rents.[174]

For the calculation of reserve value, we turn to the article of Cairns and Davis (2001), who presented this so-called Adelman rule in a concise manner.

4.1.3.3 The Adelman Rule

In their paper on reserve asset values and the "Hotelling Valuation Principle", Adelman and Watkins reject the idea that the net price of a mineral resource has to rise according to the discount rate based on an empirical data analysis.[175]

[173] Adelman, M.A. (1993), p. 244
[174] Adelman, M.A. (1990)
[175] Adelman, M.A., Watkins, G.C. (1992)

Rather, Adelman approved of the industry rule of thumb that the value V of a proven reserve R equals approximately one half of net wellhead price of oil p, i.e. taking into account unit cost of extraction c.[176]

$$V \approx \frac{1}{2}(p-c)R \tag{4.8}$$

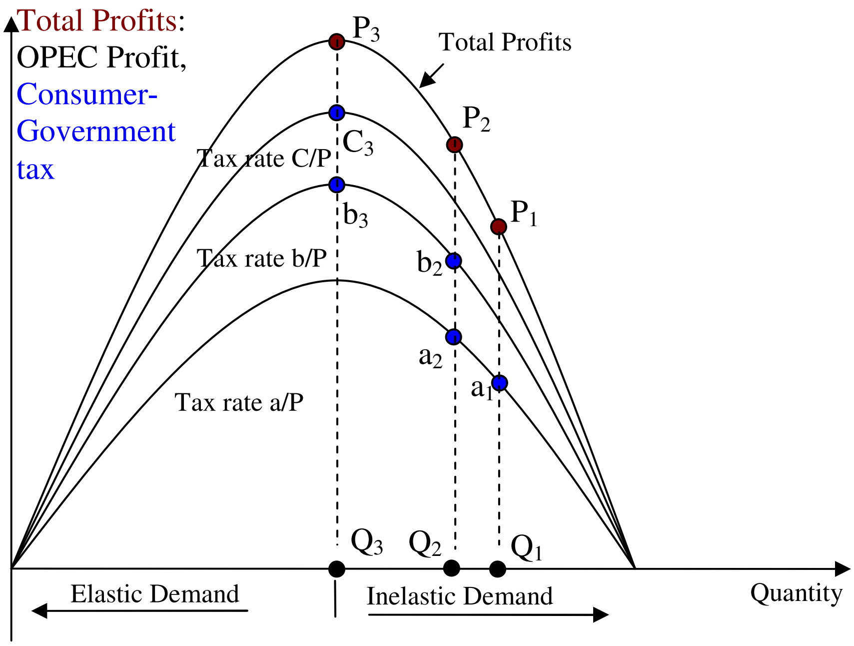
This valuation is mainly due to the physical principle that oil wells are operated in a "bang-bang", i.e. on-off, manner. Another crucial issue of the analysis is that, according to Adelman, the only scarce resource in an oil reserve under "free-flow" is the pressure which forces the oil to the surface. In many cases, the pressure inherent in the oil reserve is created artificially by injecting gas or water at strategic points. This leads to an increase in oil production. Thereby, the level of pressure added determines oil production output, and turns oil reserves into an endogenous variable dependent on the amount of pressure that is technologically available. Therefore, Cairns and Davis (2001) agree on Adelman's belief that a fixed reserve stock does not exist. Due to these technological aspects, Adelman's rule is often perceived as a technical approach to valuating oil reserves. In short, Cairns and Davis summarize their findings as follows: "*The problem […] does not exhibit a fixed stock of reserves, but a fixed pressure. […] Having more oil in the ground without more pressure provides no value. […] Hotelling's rule is more parable than prediction. Adelman's rule is the tool of valuation.*"[177]

4.1.3.4 The Clumsy Cartel and World Oil Monopoly Prices

As has already been hinted at in the previous sections, Adelman fervently supported the idea that oil prices never reflect the level scarcity but are only a symptom of a non-competitive market structure with respect to petroleum supply. Several of his papers deal explicitly with examining and commenting the effects of the monopoly structure of petroleum supply. Although OPEC's market share has declined significantly since the 1970's, its market power remains generally undisputed.[178] In his paper of 1978, Adelman suggests that oil consuming countries could very well control OPEC through proper tax policy. If consumer countries introduce taxes rates proportional to oil prices, OPEC would be aware of the fact that higher prices would only increase tax revenues and not its own, and its incentive to restrict output to increase price and profits was stifled. This effect, however, only exists if the tax rate is not a constant but a function of oil prices. Adelman explains his idea in the following graph, using three different tax rates:

[176] E.g. Adelman, M.A. (1993), p.251
[177] Cairns, R.D., Davis, G.A. (2001)
[178] Watkins, G.C. (2006)

4-5 Consumer Country Taxes absorb Profits



Source: Adelman, M.A. (1978), p. 6

In his opinion, consuming countries, however, do not implement such tools, but prefer to cooperate and play along with OPEC's game, instead. Generally, Adelman perceives OPEC as "*a loose cartel with a safety net*" (Adelman 1978). Among OPEC members, Saudi Arabia is the largest producer and is also endowed with the highest excess potential capacity. Apparently, Saudi Arabia has tried hard in the past to control oil prices and to make OPEC members restrict their output according to internal agreements. As is known from basic microeconomic theory, the problem Saudi Arabia faces is that there is always an incentive for OPEC members to defect from such agreements in order to increase, not overall, but their own profits. Naturally, this will lead to higher production levels, which lead to higher supply and in turn to lower market prices. Adelman suggests that - not for economic - but due to political and other reasons, Saudi Arabia manages, more or less, to control the cartel. In the long run, Adelman proposes that prices will approach the monopoly level, if turbulences among OPEC members can be avoided. Moreover, although OPEC certainly controls supply, they do not control demand. Supply and demand always match through price and the resource is allocated accordingly. Therefore, to Adelman, there is no need to fear any "gap" or "struggle with scarcity" or "problem of access".[179] Many people who are of the opinion that OPEC possesses an "oil weapon" and has already used it during the alleged 1973 oil embargo against the United States. However, due to the structure of the world oil market, a

[179] Adelman, M.A. (1979)

seller cannot isolate any buyer, and vice versa.[180] Therefore, Adelman stated, even back then in 1973 that such an embargo never existed: "*The miserable, mile long lines outside of U.S. gasoline stations resulted from domestic price controls and allocations, not from any embargo. We ought not to blame the Arabs for what we did to ourselves."*[181] Of course, this view is not the most popular, since, as Adelman puts it, "*no one ever lost political support by seeing evil and blaming foreigners."*[182]

Of course, not only Adelman has concerned himself with analyzing the effect of OPEC's market power. Other papers, like that of Cremer and Weitzman (1976) on *OPEC and the monopoly price of world oil*, who agree on Adelman's view that oil prices will approach static monopoly price. In 1982, M.J. Hwang presented a model which intended to explain the - back then - *continuously high price of crude oil*. In his paper, he uses a model of OPEC's crude oil market, which is based on the work of Adelman on petroleum supply and on papers by Gabelein (1975) and Piccini (1977) with respect to petroleum demand. Conventional theory demands that OPEC will want marginal revenue (MR) to equal marginal cost, i.e. c, which results in the following equilibrium condition

$$p(1-\frac{1}{e})=c \tag{4.9}$$

where p equals the market price and e denotes elasticity of demand, which equals $-\frac{dq}{dp}\frac{p}{q}>0$. Through differentiating (4.9) with respect to c Hwang arrives at

$$\frac{dp}{dc}=\frac{e}{\varepsilon-(1-e)} \tag{4.10}$$

where $\varepsilon=\frac{de}{dp}\frac{p}{e}$.

Thereby, Hwang is able to examine the effects of changes in marginal cost with respect to price, depending on the elasticity of demand. As elasticity depends mainly on the availability of substitutes, Hwang concludes that, assuming a given real income, a (nearly) perfect substitute implies a high cross-elasticity and results in a higher own-price elasticity of crude oil demand. Of course, elasticity of demand for the supply of any individual crude oil supplier would also increase if the market were characterized by competition. Overall, Hwang arrives at the result that the price rise of the early 1970's was due to the fact that short run elasticity

[180] Adelman, M.A. (2004)
[181] See footnote 180
[182]See footnote 179

of demand increased less rapidly than price. However, Hwang projects that in the long run, as price increases, demand becomes more elastic and price is to rise at a lower rate, due to the availability of substitutes. However, this does not automatically imply that prices will decline towards marginal cost as OPEC is still able to control prices through cut backs in production. As there is no perfect information and foresight, this adaptation in output cannot be expected to go about smoothly. This fact is explained best by a description given by Adelman himself in *the clumsy cartel*:

"*A diver in the sea cannot go lower than the sea floor, nor higher than the water's surface. In between, he is nearly weightless and can stay at rest at any depth. But a slight impact or effort sends him up or down. Similarly, in any market, the price cannot go below incremental cost, for that would choke of supply. It cannot go above the level that would maximize profit to a monopoly, for the monopoly would gain by putting the price back down. […] In this range [however] the price may respond […] to changes in demand.…"*[183]

4.1.3.5 Conclusion

Overall, Adelman's work is characterized by an elaborate effort to dissect the workings of the markets for mineral resources. The body of his work is incredibly vast and hard to summarize on a few pages. The previous sections 4.1.3.1 to 4.1.3.4 reflect this attempt. Adelman believes that there is no need to worry about economic growth being stifled by lack of oil. In his opinion, the constraints will stem from air and water pollution. Back in **1979** he argued that these issues need a lot more attention and that research had better focus on them than on worrying about oil scarcity. However, as no prophet is accepted in his own country, his ideas remained largely unheard especially by US politicians. In 2004, Adelman summarized his view on U.S. administration's policy as follows:

"U.S. oil policies are based on fantasies not facts: gaps, shortages, and surpluses. Those ideas are at the core of the Carter legislation, and of the current Energy Bill. The Carter White House also believed what the current Bush White House believes – that, in the face of all evidence, they are getting binding assurance of supply by OPEC, or by Saudi Arabia. That myth is part of the larger myth that the world is running out of oil."[184]

[183] Adelman, M.A. (1978)
[184] Adelman, M.A. (2004)

4.2 OPEC: How to transition from Black to Green Gold

In 1960, OPEC founding members were Iran, Iraq, Kuwait, Saudi Arabia and Venezuela. Nowadays, members are [185] Algeria, Angola, Ecuador, Iran, Iraq, Kuwait, Libya, Nigeria, Qatar, Saudi Arabia, United Arab Emirates, and Venezuela.

As has been pointed out by Adelman and Watkins, OPEC has always possessed a significant market share of international petroleum supply. While it used to occupy about 53 per cent of the entire market in the 60's and 70's of the last century, this number has declined to about 40 per cent today.[186] However, this is still an impressive share, especially since petroleum is still considered to be one of the most important and influential commodities. Whether one is a strong believer of what Watkins provocatively calls the *Severe Anaemic Reserves Syndrom (SARS)*[187] or beliefs that there is no evidence that oil is to become scarce any time soon, the increase in interest of several oil exporting countries and OPEC members in implementing solar and wind power systems cannot be denied.[188] This interest, however, cannot automatically be attributed to their petroleum reserves being completely exploited any time soon. Rather, the international discussions on projects like Desert Tec[189] might have sparked their interest to explore new fields of economic activity, as - especially Middle Eastern or African - OPEC members are located in climate zones which can be considered promising with respect to these Green Energy technologies. Therefore, it appears quite plausible that oil exporting countries, such as Saudi Arabia, are planning on further diversifying their production portfolio in that direction. The following section is meant to identify what problems might arise if Green Energy technologies - i.e. Green Gold – are introduced in an economy which is characterized by an abundance of Black Gold – i.e. cheap and readily available fossil fuels in all shapes and colors.

4.2.1 Price Does Matter

In the 1970's Heal[190] and others examined optimal extraction of a non-renewable resource, if there will emerge a substitute at an uncertain time in the future. The model presented in the following, however, is not concerned with finding the optimal extraction path of a non-renewable resource, once a substitute is available. The focus of attention lies on the fact,

[185] www.opec.org
[186] Watkins, G.C. (2006)
[187] Watkins, G.C., (2006): According to Watkins, SARS believers think that shortages in oil supply are due to a quickly growing scarcity.
[188] Trieb, F. (2007)
[189] www.desertec.org
[190] Heal, G. (1976)

that in OPEC member states, oil is supplied at an extremely low in-country price[191]. Due to this fact, alternative, i.e. renewable, resources are certainly destined to face a “harsh” competition. Looking at it from an economic, not environmental viewpoint, may it be electricity generation, water desalination, or transportation, who would – given these circumstances - consider solar energy, wind power, or an electric or hybrid car to be a reasonable substitute to technologies which are solely based on readily and cheaply available fossil fuels.

This issue turns out to be increasingly interesting, due to recent developments in several OPEC member states. In the following, Saudi Arabia, which appears to be one of the most influential OPEC member states, will serve as a show case for the theoretical analysis to come. This stems from the fact that Saudi Arabia seems to display an increasing interest in exploring its potential for various renewable resources in energy/electricity generation. Several studies and projects have focused on an implementation of solar and wind power based technologies[192]. Until recently, Saudi Arabia, as well as any other OPEC member state has relied mainly on fossil fuels as the sole or main input to satisfy their ever growing energy demand - in case of Saudi Arabia an increase of 5% p.a. in energy demand is a common estimate.[193] At first glance one might think that the amount of oil consumed by a nation of only about 27[194] million[195] residents cannot be highly significant. As presented in the following tables, Saudi Arabia is ranked number one among OPEC members when it comes to production capacity and number four in terms of global oil reserves.

4-6 Oil Production Capacity

Country	Rank	Production Capacity in bbl/day (2007)		Country	Rank	Production Capacity in bbl/day (2007)
Saudi Arabia	1	10,500,000		Libya	6	1,700,000
Iran	2	3,750,000		Angola	7	1,490,000
Kuwait	3	2,600,000		Algeria	8	1,430,000
Venezuela	4	2,450,000		Indonesia	9	860,000
Nigeria	5	2,250,000		Qatar	10	850,000

191 Said, S.A.M., El-Amin, I.M., Al-Shehbri, A.M.: http://webfea.fea.aub.edu.lb/fea/research/erg/RCW/Renewable%20Energy%20Potentials%20in%20Saudi%20Arabia.pdf
192 See footnote 188 and 191
193 See footnote 188 and 191
194 This is the population estimate of 2007, which has been chosen to match the numbers used in oil production and consumption.
195 https://www.cia.gov/library/publications/the-world-factbook/geos/sa.html#People

Source: US Department of Energy via Nationmaster [196]

However, it is also among the top ten nations regarding overall or oil consumption *in barrels/1,000 people per day*, which is shown by the following table:

4-7 Oil consumption p.c. (per 1.000 people)

Country	Rank	Oil consumption in 2007 (bbl/day, 1,000 people)		Country	Rank	Oil consumption in 2007 (bbl/day, 1,000 people)
Virgin Islands	1	845.382		France	53	32.839
Kuwait	6	128.758		Iran	73	24.28
Saudi Arabia	10	83.729		Russia	81	20.215
United Arab Emirates	11	82.174		China	144	5.733
United States	23	68.672		India	165	2.409

Source: CIA world factbook via Nationmaster[197]

So, the United States, which comes in first with respect to overall oil consumption, only occupies the 23rd place with respect to per capita consumption. China and India do not even make the top 100 and Russia comes in 81st place. In per capita terms, Saudi Arabia beats them by far. Moreover, looking at production capacity and consumption, it becomes clear that Saudi Arabia is certainly one of his own best clients as it consumes - *at least* - *20 percent* of its total oil production, taking into account the following table.

4-8 Oil consumption per country

Country	Rank	Oil consumption in 2007 bbl/day	Country	Rank	Oil consumption in 2007 bbl/day
United States	1	20,680,000	India	6	2,722,000
China	2	7,578,000	Germany	7	2,456,000
OPEC	**3**	6,600,000	Saudi Arabia (part of OPEC)	**10**	2,311,000

196 http://www.nationmaster.com/graph/ene_ope_abo_ope_ope_quo_and_pro_cap-opec-about-quotas-production-capacity
197 http://www.nationmaster.com/graph/ene_oil_con_percap-energy-oil-consumption-per-capita

Japan	4	5,007,000		France	13	1,950,000
Russia	5	2,858,000		Iran (part of OPEC)	16	1,679,000

Source: CIA Work Factbook via Nationmaster[198]

Taking all these findings into account, let us construct some simple mathematical example:
In 2007 Saudi Arabia consumed approximately 2,311,000 bbl/day times 365 days. This amounts to around 843,515,000 bbl/p.a.. There is data readily available for the world market price for Saudi Arabian crude oil. In 2007 its spot price ranged between around $58 and $88 per barrel. [199]
However, there is no data on in-country crude oil prices, only gasoline prices are easily available. [200] Of course, due to different tax levels and costs of refining the crude oil, this data does not allow for reliable estimates. However, it seems to be far from far fetched to assume that the in-country price of crude oil is close to marginal cost of production, which is estimated at around $3.35/bbl for Saudi Arabia.[201] Thereby, a difference in price of at least around $50/bbl can be assumed, which can be seen as the "gross" opportunity cost[202] of in-country oil consumption per barrel.[203] This means that in-country oil consumption in 2007 resulted in about $50 times 843,515,000 bbl of "gross" opportunity costs. This amounts to about $42,175,750,000 in 2007, which can certainly not be considered an insignificant number. However, from these roughly $42 billion, the costs of alternative energy production would have to be subtracted to arrive at the "net", i.e. actual opportunity cost of in-country oil consumption. Of course, this simple example can only serve as a hint at the significance and economic potential of abandoning the common panem et circenses pricing policy in oil producing nations. In the following, a theoretical economic model will be developed to present clearer and more reliable insight into the issue.

4.2.2 Model Setting

In the model presented below, the market structure characterizing the oil market is of little or no significance, as its results hold true in case of both simplifying assumptions, i.e. perfect competition or monopoly. It is known, that, while OPEC had about 53% of the entire market

198 http://www.nationmaster.com/graph/ene_oil_con-energy-oil-consumption
199 http://tonto.eia.doe.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=WEPCSAMED&f=W
200 http://money.cnn.com/pf/features/lists/global_gasprices/
201 Adelman, M.A., Watkins, G.C., (2008)
202 The author knows that the term "gross" or "net" opportunity cost does actually not exist: However, it seems an appropriate and not too absurd way to convey the idea that is expressed in this setting.
203 Of course, this is a simplified portrait of the situation. It is not taken into account that market prices are likely to drop if Saudi Arabia would suddenly stop consuming oil and supply an additional couple of hundred million barrels per year.

share in the 70's, nowadays it holds about 40%.[204] Naturally, this is far from characterizing either a competitive market structure or a monopoly. However, both assumptions have been implemented before in other models and serve to clarify the analysis. The outline of Hotelling's theory under both perfect competition and a supply monopoly has already been outlined in section 4.1.1. In the current setting, the demand side is altered and, instead of just one, i.e. global, demand the demand side is divided into an in-country demand (q^{ic}) and a demand for oil exports (q^{ex}). Due to geographical reasons, the two demand groups are easy to distinguish. For reasons of simplicity, it is assumed, that the two groups are characterized by identical demand curves. While the optimal price (p^{ex}) and extraction path for oil exports is calculated in line with Hotelling's model, in-country market price is set by government[205] at marginal production cost, i.e. ($p^{ic} = \overline{p} = c$), which is assumed to be constant over time.[206] Taking all preliminary assumptions into account, the maximization problem, which has already been introduced in section 4.1.1 is modified accordingly:

4-9 Hotelling Resource Extraction: Modified Optimization Program

	Perfect Competition (PC)		Monopoly (M)
Objective	(4.11) $\max\int_0^T\left[\left(p_t q_t^{ex}\right)^{-\gamma t} + \overline{p}q^{ic}\right]dt$		(4.12) $\max\int_0^T\left[\left(p_t(q_t^{ex})q_t^{ex}\right)^{-\gamma t} + \overline{p}q^{ic}\right]dt$
Constraint	(4.13) $\int_0^T\left[q_t^{ex} + q_t^{ic}\right]dt = S$		(4.14) $\int_0^T\left[q_t^{ex} + q_t^{ic}\right]dt = S$
Demand Curve (Export)	(4.15) $p_t^{ex}(q_t^{ex}) = K^{-aq_t^{ex}}$		(4.16) $p_t^{ex}(q_t^{ex}) = K^{-aq_t^{ex}}$
Demand Curve (In-country)	(4.17) $\overline{p} = p_t^{ic}(q_t^{ic}) = K^{-aq_t^{ic}}$		(4.18) $\overline{p} = p_t^{ic}(q_t^{ic}) = K^{-aq_t^{ic}}$

Source: Author's design

[204] Watkins, G.C. (2006)
[205] Given that gasoline prices, e.g. in Saudi Arabia, are also determined by government, this assumption is not far fetched.
[206] According to Adelman, M.A. and Watkins G.C (2008), this holds true for Middle Eastern oil production.

It is obvious from equations (4.17) and (4.18) that optimal in-country demand is predetermined through $\overline{p}$, K, and a. This means that q^{ic} and $\overline{p}q^{ic}$ enter the calculation as a constant and exogenous value. Therefore, the extraction path changes to[207]

4-10 Hotelling Resource Extraction: Extraction Paths

	Perfect Competition (PC)		Monopoly (M)
Extraction Path	(4.19) $q_t = q_t^{ex} + q^{ic} = \frac{\gamma}{a}(T-t) + q^{ic}$		(4.20) $q_t = q_t^{ex} + q^{ic} = \frac{\gamma}{ha}(T-t) + q^{ic}$

Equations (4.19)/(4.20) are used to calculate optimal exhaustion time, i.e. T^{PC} / T^{M}:[208]

$$S = \int_0^T \left[\frac{\gamma}{a}(T-t) + q^{ic} \right] dt \tag{4.21}$$

This results in

$$S = \left[\frac{\gamma}{a}(Tt - \frac{1}{2}t^2) + q^{ic}t \right]_0^T = \frac{\gamma}{2a}T^2 + q^{ic}T \tag{4.22}$$

which clearly differs from the previous result of section 4.1.1, where $S = \frac{\gamma}{2a}T^2$. If the new exhaustion time given through equation (4.22) is denoted by T_{ic+ex}, the following relationship between former and latter optimal exhaustion time emerges:

$$T^2 = T_{ic+ex}^2 + \frac{2a}{\gamma}q^{ic}T_{ic+ex} \tag{4.23}$$

As it is known that $\frac{2a}{\gamma}q^{ic}T_{ic+ex} > 0$, the given resource stock S is depleted earlier in the current setting, i.e. $T_{ic+ex} < T$. The optimal initial extraction level also changes, and is given by

$$q_0 = q_0^{ex} + q^{ic} = \frac{\gamma}{a}T_{ic+ex} + q^{ic}. \tag{4.24}$$

While exhaustion time is smaller and has a decreasing effect on q_0, in-country demand has the opposite effect. Hence, the overall effect depends on the shape of the demand function.

[207] Again, calculations are done according to Perman et al. (1999), p. 211-213.
[208] The following calculation refers to perfect competition only, as the calculation in case of monopoly is identical except for the additional constant h; for explanation see footnote 150.

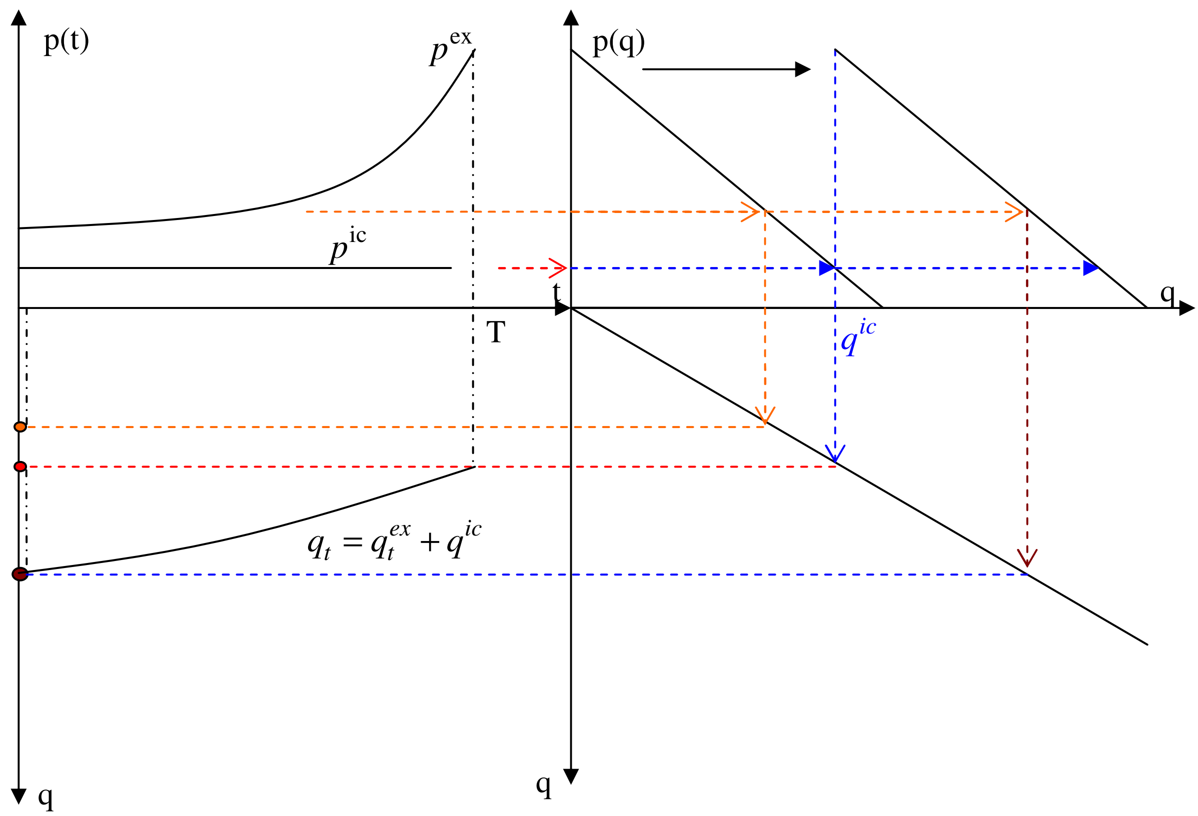
As has been mentioned before, the initial royalty and the royalty path with respect to in-country demand is assumed to be constant at $p^{ic} = \overline{p} = c$. With respect to export quantities, the optimal values are:

4-11 Hotelling Resource Extraction: Optimal Values

	Perfect Competition (PC)		Monopoly (M)
Initial Royalty (export)	(4.25) $p_0 = K^{-aq_0^{ex}} = K^{-\gamma T_{ic+ex}}$		(4.26) $p_0 = K^{-ahq_0^{ex}} = K^{-\gamma T_{ic+ex}}$
Royalty Path (export)	(4.27) $p_t = p_0^{\gamma t}$		(4.28) $p_t = p_0^{\frac{\gamma t}{h}}$

Overall, in-country demand acts as a parallel shift to aggregate demand, as it remains unchanged over time and is added to optimal export extraction levels (blue arrows). In the final extraction period, extraction is, therefore, greater than zero and equals q^{ic}. The graph presented on p. - 98 - is altered to fit these modified settings:

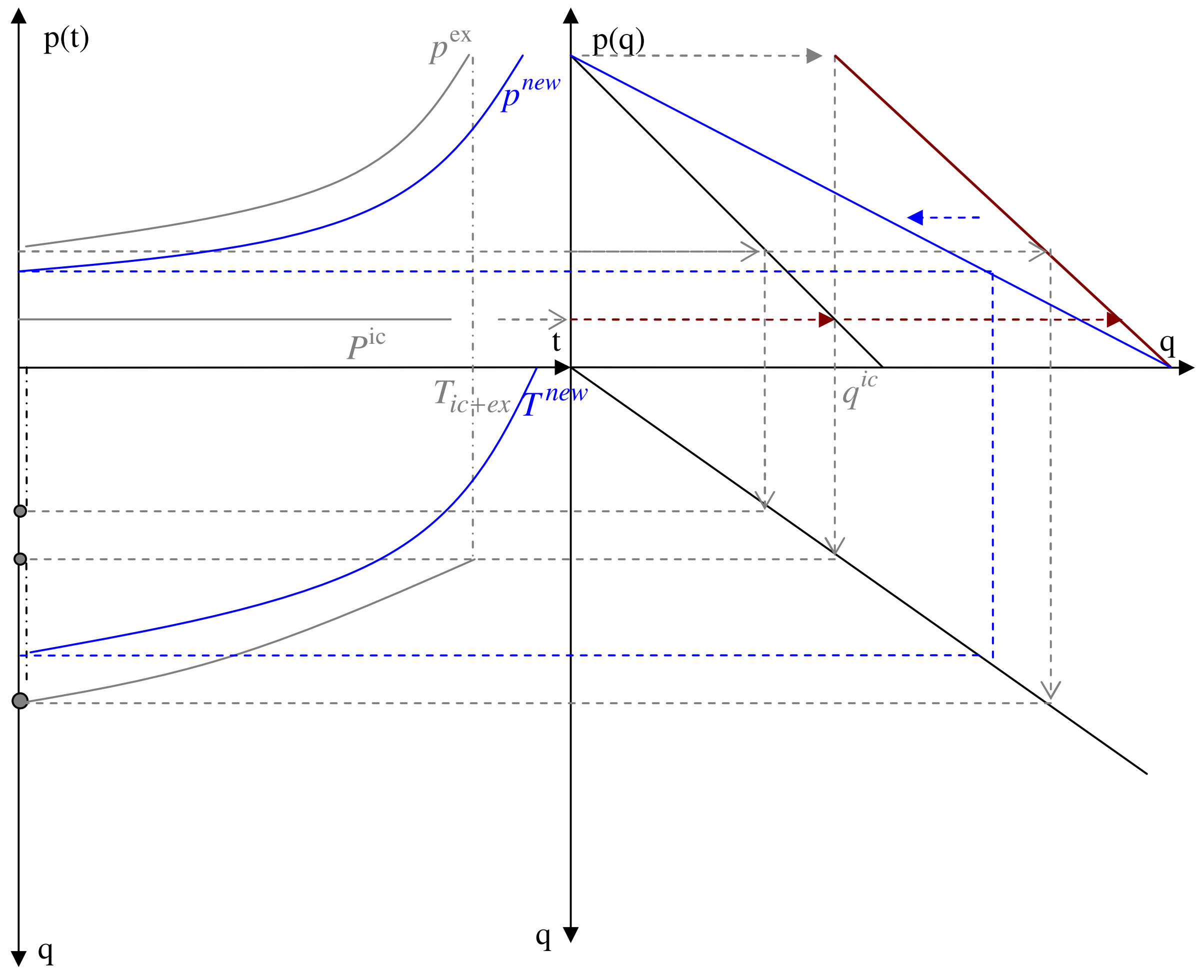
4-12 Hotelling: Resource Extraction II



Source: Perman et al (2003)., p. 519 combined with author's design

This has shown how this differentiation of demand affects the results of the optimal depletion program. However, the effects become most apparent, once the two alternatives, differentiated and combined demand are drawn into one graph. If in-country pricing policy is abandoned and the aggregate demand function enters the optimization program, the picture changes accordingly. The resulting increase in the in-country resource price leads to a reduction in in-country quantity demanded. Overall, results are in line with the case of a shift in demand analyzed by Perman et al.[209] and are sketched in the following graph:

4-13 Hotelling: Resource Extraction III



Source: Perman et al (2003), p. 519 combined with author's design

The grey and red lines and letters show the settings and results presented in the previous graph, regarding divided demand. The blue lines outline the new setting in which in-country and export demands are combined into an aggregate demand function. This means that the

[209] Perman, R., et al. (2003), p. 519

previous parallel shift of export demand (red arrows, length: q^{ic}) is abandoned and the new demand curve is depicted by the blue line (horizontal addition, double grey demand line). From this sketch it becomes clear, that in case of artificially low in-country price setting the resource is depleted earlier than in the case where demand is undivided and the price is allowed to follow Hotelling's valuation principle.

In general, the following conclusions can be drawn from the analysis presented in this section. Due to the extremely low in-country price, in-country demand is satisfied close to its saturation level and consumers enjoy high rents. It is quite clear that this kind of price signals does not help to encourage energy savings or a transition to implementing cleaner, i.e., Green Technologies. Of course, one could argue that this is not at all necessary as countries, such as Saudi Arabia, appear to be ruled by a powerful sovereign, and if he were to decide that Green Energy is the way to go, than it will be done. So why should anyone bother about market or price based incentives in such a market setting. Also, other aspects like political and social stability play an important role in keeping fuel and energy at ridiculously low prices. For example, in Venezuela, which is assumed to be a rather politically and socially instable system, partly due to poverty, unemployment and corruption, gasoline prices at around 0.12$/gallon appear to be the lowest of all OPEC members.[210] However, in case of countries like Saudi Arabia, which seem to be relatively prosperous as well as politically and socially stable, there is not apparent need for such panem et circenses oriented politics. Therefore, the following section is meant to show, why this approach might not be the best alternative – although it appears quite popular among politicians.

4.2.3 Implementing a Market for Green Energy

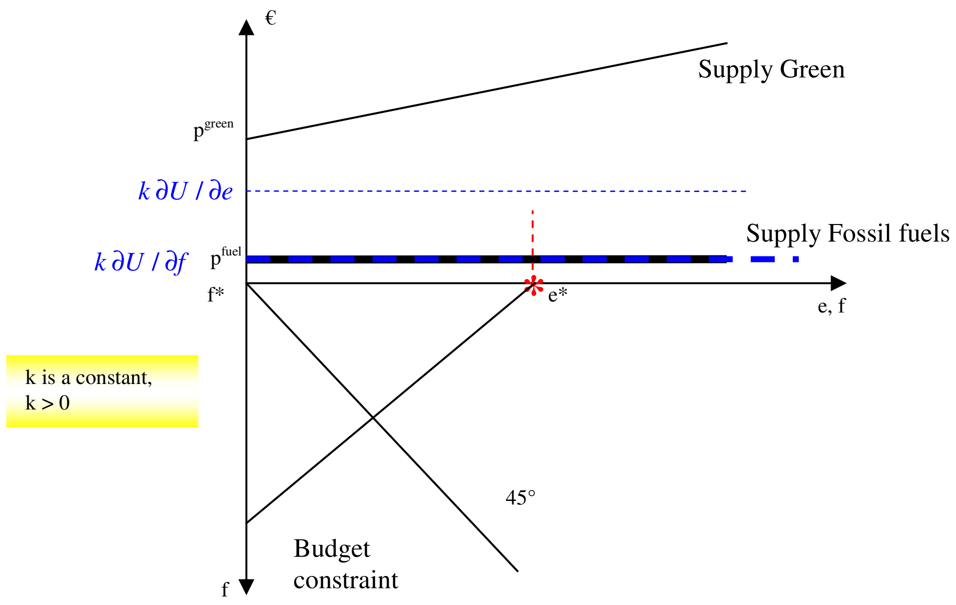
This model is related to the approach of Dasgupta and Heal who examine[211] under which conditions an exhaustible resource is essential.[212] However, the analysis presented in the following deals with a different aspect of the issue; nonetheless, the approach of Dasgupta and Heal, which has also been re-examined by Neumayer in 2000, renders some valuable information for the analysis to come.

Most OPEC member countries, especially those located in the Middle East or North Africa – also called MENA countries -, are considered to possess an extraordinary potential for solar

[210] CNN: http://money.cnn.com/pf/features/lists/global_gasprices/
[211] CES is short for "constant elasticity of supply".
[212] Dasgupta, P., Heal, G. (1979)

energy.[213] With respect to Saudi Arabia, studies have also found a significant potential for electricity generation by implementing wind farms.[214] In the following it is assumed that Green Energy (f) is supplied at price p(f) and fossil fuels (e) are supplied at p(e), and the latter is set by government at an extremely low level. Although this is certainly a simplifying assumption, the two goods are assumed to be perfect substitutes, e.g. desalinations plants could either be fuelled by solar or fossil based energy or customers could drive electric cars or regular gasoline cars. This results in a utility/production function for energy services which can be created using either Green Energy or fossil fuels, i.e. $U = U(e, f)$, given a certain budget constraint I. If we assume $U(e, f)$ to have similar properties as the function presented in equation (2.2) of section, results could turn out as follows:

4-14 Fossil Fuels and Renewables as Substitutes

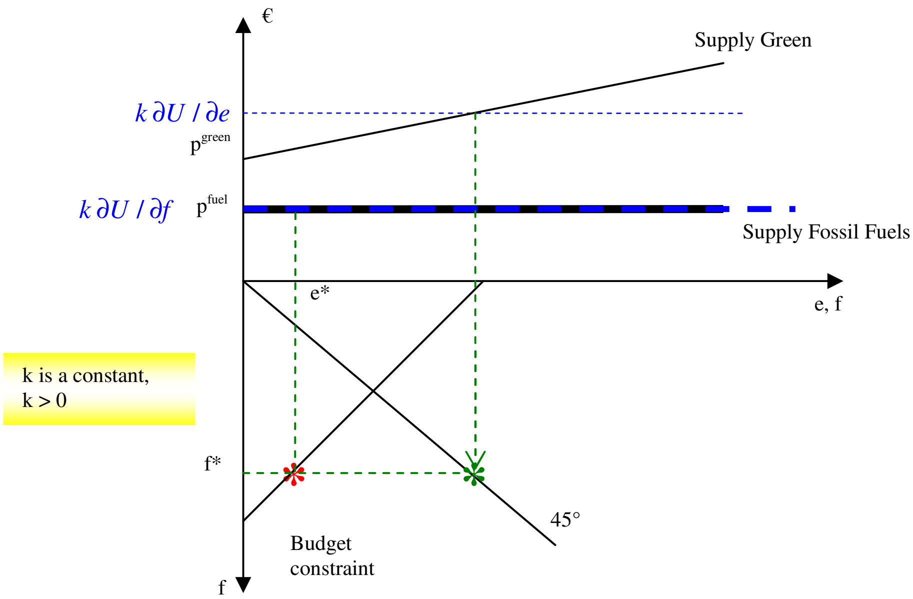


Source: author's design

In this case, price of fossil fuels is so low that there is no point at which there will be a demand for Green Energy greater than zero. Hence, an artificially low, subsidized price of fossil fuels will distort input demand patterns in favor of a high – or even sole - demand for fossil fuels. If this fact is changed and fossil fuel price is set closer to world market values, the situation might present itself quite differently as sketched in the following graph:

[213] Trieb, F. (2007)
[214] Rehman, S. (2005)

4-15 Fossil Fuels and Renewables as Substitutes II



Source: Author's design

In this case, demand for fossil fuels will be reduced significantly and demand for Green Energy will be greater than zero.

Overall, the analysis shows that without a change in energy policy in general or fossil fuel related pricing policy in particular, renewable energy sources are highly unlikely to compete successfully with cheaply available fossil fuels in OPEC countries in general or Saudi Arabia in particular. Said, El-Amin, and Al-Shehri come to similar conclusions in analyzing renewable energy potentials in Saudi Arabia: *"Effective utilization of solar energy in Saudi Arabia has not yet made reasonable progress mainly due to […] the wide availability of oil […] and its relatively low cost."*[215]

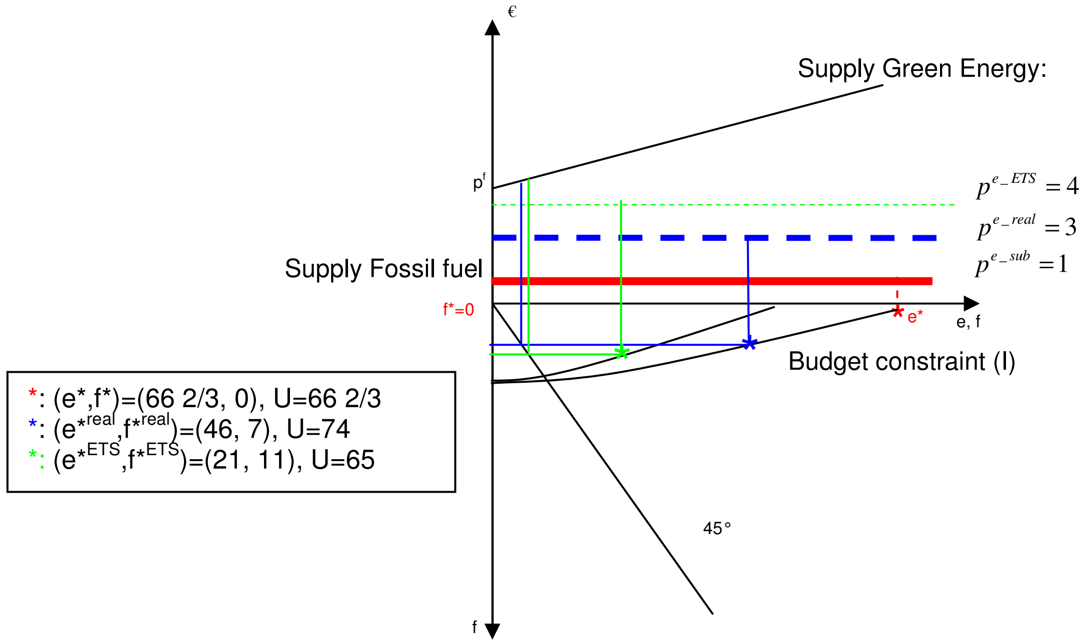
Another relatively unfamiliar but important fact mentioned by Said, El-Amin, and Al-Shehri is that the Saudi Arabian government subsidizes both oil and conventional electricity generation but there exist no such subsidies for renewable energy programs. Of course, these circumstances significantly stifle the implementation of renewable technologies and might, in reality, make matters even worse than in the model presented above.

[215] Said, S.A.M., El-Amin, I.M., Al-Shehbri, A.M..
http://webfea.fea.aub.edu.lb/fea/research/erg/RCW/Renewable%20Energy%20Potentials%20in%20Saudi%20Arabia.pdf

4.2.4 Numerical Example

The following numerical example is meant to illustrate the points made in the previous section. With respect to households, utility is defined as $U(e,f)=\alpha e+\beta f$ and the budget constraint is defined as $I(e,f)=p(e)e+p(f)f$. Moreover, we take $\alpha=1, \beta=4$ and $I=200$ as given. Supply of GE takes the form of $p(e)=\frac{1}{2}e+5$. Supply of fossil fuel based energy is supposed to take the form of $p(f)=cf$, with c>0, being constant marginal cost. We assume three different values regarding c. Initially, government subsidizes fossil fuels which leads to $c^{sub}=1$. Without subsidies, we have $c^{real}=3$, and if costs are increased, e.g. through a emission tax, we arrive at $c^{ETS}=4$. Given this model setup, equilibrium demand is given by $f^*=c\,\beta/\alpha-5$ and $e^*=\frac{I-\frac{1}{2}f^2-5f}{c}$. According to the different levels of c, this leads to the following three different results, which are: Subsidized c results in $(e^*,f^*)=(66\ 2/3,\ 0)$ and utility U=66 2/3. Supply at real marginal cost levels results in $(e^{*real},f^{*real})=(46,\ 7)$ and utility U=74, while a cost increase for fossil fuels leads to $(e^{*ETS},f^{*ETS})=(21,\ 11)$ and U=65. The following graph illustrates these results:

<u>4-16 Fossil Fuels vs. GE</u>



Source: Author's design

4.3 Summary

The answer to the question posed in the heading of this chapter is certainly hard to give. Are we running out of non-renewable resources? Looking at the preceding analysis, there is no economic scarcity apparent. It appears sensible to follow Adelman's idea that certain actors within the market exert their market power and thereby influence prices and the opinion of the general public. Overall, it appears far more likely that our present consumption rate of fossil fuels and other non-renewable resources will cause a level of Co2 emissions into and concentration in the atmosphere which will affect a climate change to occur in an undesirable short period of time, long before we will have to worry that we can no longer "spoil" our kids with cheap plastic toys because there is no oil left to produce them.

In many cases, facts and fiction can hardly be distinguished, simply because reality is characterized by asymmetric and imperfect information. Moreover, there are many reasons and incentives on behalf of decision makers and politicians that keep them from investigating further into the matter. As Watkins suggests, OPEC's policy of restraining production and keeping prices well above the Marginal Cost of Middle Eastern sources, is, at least secretly approved of by non-OPEC countries, such as the United States, with "sizeable, high-cost domestic production". Therefore, it seems not far-fetched to assume, that prices are not an adequate measure of scarcity, but rather reflect other, not so much economic, but rather political factors.

Therefore, it appears as though the question posed in the headline of this section should, even in the long term, be answered with "yes!". However, looking at the analysis in section 4.2, it appears sensible for oil producing countries in general and OPEC member states in particular to give their in-country fossil fuel pricing policy a second thought. Metaphorically speaking, just because your children love sweets and you as a parent have unlimited resources to provide such for them, it is neither considered pedagogically responsible nor healthy to stuff them with candy until they suffer from diabetes and obesity and eventually die of a heart attack.

Exploring the potential for alternative energy resources and creating more awareness for long-term climatological and ecological effects of human resource consumption, is key to preserving not just the environment but also the subsistence of mankind itself. The resources saved or postponed in consumption might later be used in a less wasteful and eco-friendly manner. They will certainly not become worthless or unprofitable in economic terms. Therefore, nations should not be afraid of taking on and exploring new routes.

5 Conclusion

Looking back at the analyses of the previous chapters, although each of them dealt with a different topic a common denominator emerges, which can be characterized by the following findings:

- Any regulation of economic activity is an instrument that has to be applied with caution.
- A simple microeconomic analysis can yield helpful information on the nature and the intensity of effects which a specific regulatory tool will inflict on the regulated market and the parties involved.
- Identifying the market structure and its relevant economic agents and other aspects is crucial to setting up a model that will render useful and meaningful results.

Moreover, in the face of a dawning climate change and the repercussions it presumably causes, e.g. droughts or floods, any economic activity has to be re-evaluated implementing higher environmental standards. But not only a stable climate and healthy eco-systems have become increasingly important to ensure the subsistence of and a further increase in global prosperity of mankind. The threat of various resources becoming increasingly scarce, e.g. drinking water or fossil fuels, forces experts and politicians alike to explore new paths and alternatives, both technologically and politically, and to look at economic processes or structures from a different angle. Whether there are external effects that need to be internalized, or a socially and environmentally sound product fails to be competitive and calls for political support – the reasons for or kinds of regulatory activities come in numerous shapes and colors. The work that has been presented in the preceding chapters is meant to shed some light onto the value as well as the vast applicability of economic theory and theoretical modeling. It shows that many fields of interest in environmental economics can be analyzed applying basic microeconomic theory.
Naturally, reality is complex and complicated and no model will ever be able to fathom and comprise all of it. However, just like in any other science, models never present the entire scope of the real setting, but are meant to depict and present the most important characteristics of reality. On reading current scientific environmental economic literature, it oftentimes appears as though issues in environmental economics can only be described either purely verbally with an endless list of tables, bubbles, and slogans or by complex computer generated models that simulate reality based on vast data bases, innumerous assumptions, and merely countless different variables. However, in the tradition of economic modeling, most of the time, it seems as though simple models with a small number of

relevant variables, which are able to boil down reality to its most crucial aspects regarding the problem in question, also present a comprehensible picture. As Krugman puts it "*a real economist starts not with a policy view but with a story about how the world works. That story almost always takes the form of a model- a simplified representation of the world, which helps you cut through the complexities.*"[216] The development of such models appears a lot easier and less time-consuming at first glance. However, this proves to be a serious misconception, after all. Paul Krugman probably made the point clearest in his book "*The accidental Theorist*". Therefore, this statement will serve as the closing remark for this work:

"If you want to be truly well-informed about economics (or anything else), you must go back to school - and keep going back, again and again. You must be prepared to work though little models before you can use the big words - in fact, it usually a good idea to try to avoid the big words altogether. If you balk at this task - if you think you are too grown-up for this sort of thing - then you may sound impressive and sophisticated, but you will have no idea what you are talking about."[217]

[216] Krugman, P. (1999), p. 113
[217] Krugman, P. (1999), p. 115

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Hiermit versichere ich, dass ich die vorliegende Arbeit selbstständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel benutzt habe, alle Ausführungen, die anderen Schriften wörtlich oder sinngemäß entnommen wurden, kenntlich gemacht sind und die Arbeit in gleicher oder ähnlicher Fassung noch nicht Bestandteil einer Studien- oder Prüfungsleistung war.

With this statement I declare, that I have independently completed the above thesis. The thoughts taken directly or indirectly from external sources are properly marked as such. This thesis was not previously submitted to another academic institution and has also not yet been published.[219]

Unterschrift der Verfasserin/ Author's Signature

(Nadine Wittmann)
Berlin, September 2010

[219] Wording according to:
http://dict.leo.org/forum/viewUnsolvedquery.php?idThread=266392&idForum=1&lp=ende&lang=de