

Johannes Herold

Microeconomic analysis of investment incentives under emission control

The case of carbon capture and storage

Diploma Thesis

YOUR KNOWLEDGE HAS VALUE



- We will publish your bachelor's and master's thesis, essays and papers
- Your own eBook and book - sold worldwide in all relevant shops
- Earn money with each sale

Upload your text at www.GRIN.com
and publish for free



Bibliographic information published by the German National Library:

The German National Library lists this publication in the National Bibliography; detailed bibliographic data are available on the Internet at <http://dnb.dnb.de> .

This book is copyright material and must not be copied, reproduced, transferred, distributed, leased, licensed or publicly performed or used in any way except as specifically permitted in writing by the publishers, as allowed under the terms and conditions under which it was purchased or as strictly permitted by applicable copyright law. Any unauthorized distribution or use of this text may be a direct infringement of the author s and publisher s rights and those responsible may be liable in law accordingly.

Imprint:

Copyright © 2008 GRIN Verlag
ISBN: 9783640347278

This book at GRIN:

<https://www.grin.com/document/129016>

Johannes Herold

Microeconomic analysis of investment incentives under emission control

The case of carbon capture and storage

GRIN - Your knowledge has value

Since its foundation in 1998, GRIN has specialized in publishing academic texts by students, college teachers and other academics as e-book and printed book. The website www.grin.com is an ideal platform for presenting term papers, final papers, scientific essays, dissertations and specialist books.

Visit us on the internet:

<http://www.grin.com/>

<http://www.facebook.com/grincom>

http://www.twitter.com/grin_com

TECHNICAL UNIVERSITY of DRESDEN
FACULTY of BUSINESS and ECONOMICS

CHAIR of ENERGY ECONOMICS and
PUBLIC SECTOR MANAGEMENT

Diploma Thesis

**Microeconomic Analysis of Investment Incentives under
Emission Control
The Case of Carbon Capture and Storage**

Submitted by: Johannes Herold

Dresden, August 2008

Abstract

The Kyoto Protocol has first set a price on carbon dioxide emission (CO_2). Participating economies are obliged to limit those emissions, with CO_2 emitting firms now facing an additional constraint in their profit maximization. The energy sector is, due to its nature, particularly afflicted. The combustion of fossil fuels emits massive amounts of CO_2 which need to be covered by means of limited emission permits. So in addition to the scarcity of fuel comes the scarcity of those allowances. Both increases pressure on electricity suppliers to switch to renewable or low carbon electricity production.

Coal is the fossil fuel which on the one hand is provided with the largest reserves (thus assuring future fuel availability at comparably low costs) but is on the other hand emitting the largest amount of CO_2 per MWhel. Therefore, technologies to capture and store that CO_2 are under development. Those technologies come with significantly higher capital cost for the plants and high energy losses in generation. Consequently, high carbon prices are required to incentivize investment into that innovative technology.

But the adoption and diffusion of innovations is not only a question of financial incentives. As on other markets, the market for innovation is characterized by potential failures which may impede or prevent the successful diffusion of advanced technologies.

The following thesis first provides an overview about the innovative technologies to capture CO_2 from large scale sources just reaching demonstration phase. Second, innovation from an industrial organizational point of view is analyzed. The focus here is set on market failures for innovation, in particular with respect to market failures which interact with failures on the market for pollution control.

Third, a model is introduced which simulates the adoption and diffusion of Carbon Capture and Storage (CCS) in a two player Cournot game. The producers are subject to emission control and can choose among several technologies to comply with that constraint.

The analysis shows that producers prefer a significant reduction in output and profit instead of investing into the expensive technology. The situation changes as nuclear energy production is phased out and learning effects are introduced. This indicates that a switch to environmentally friendly technologies needs strong policy support by stringent emission limits as well as by R&D support and public financed demonstration projects. Those can help to overcome early technical difficulties and assure that all marketers have access to that knowledge.

In extreme cases in which one player is initially equipped with a high share of coal while the other is nuclear based, no symmetric market shares develop. Then, despite being subject to a higher level of emission control, the fossil fuel based player dominates the market over a long time.

Table of Contents

Abstract	I
List of Figures	III
List of Tables	V
Abbreviations	V
1 Introduction	1
2 Carbon Capture and Storage	4
2.1 Technologies	5
2.1.1 The Post-Combustion Capture Process	5
2.1.2 The Pre-Combustion Capture Process	8
2.1.3 The Oxy-Fuel Process	9
2.1.4 Long-Term Technology Options	10
2.2 CO ₂ Transport	10
2.2.1 CO ₂ Storage	12
2.2.2 Geologic Storage	13
2.2.2.1 Enhanced Oil Recovery	14
2.2.2.2 Enhanced Gas Recovery	16
2.2.2.3 Enhanced Coal-Bed Methane Recovery	17
2.2.3 Ocean Storage	18
2.2.4 Mineral Storage	18
2.2.5 Monitoring	19
2.2.6 Costs	20
3 Innovation Economics	24
3.1 A Definition of Innovation	24
3.2 Innovation Behavior and the Structure of Markets	26
3.3 Cournot meets Bertrand: Innovation and the Nature of Competition	28
3.4 Failures on the Market for Innovation	31
3.4.1 Knowledge Externalities, Technological Spillovers and Patent Protection	31
3.4.2 Patenting	33
3.4.3 The Impact of Knowledge Spillovers on Innovation	33
3.4.4 Adoption of Technologies	35
3.4.5 Adoption Externalities	36

3.5	<i>Innovation under Pollution Control</i>	37
3.5.1	The Basics of Weitzman.....	38
3.5.2	The Nature of Electricity and External Effects in Generation	41
3.5.3	Incomplete Information	42
3.6	<i>Innovation and optimal pollution control</i>	43
3.6.1	Investment Incentives under Emission Permits	46
3.6.2	Investment into Carbon Capture and Storage	49
3.6.3	Critical Discussion of the Results.....	50
3.7	<i>Patent Race vs. Research Joint Venture under Emission Control</i>	51
4	The Model	58
4.1	<i>Model Description</i>	59
4.2	<i>Scenarios</i>	65
4.2.1	Base Case Calibration.....	65
4.2.2	Scenario 1 – Changing Input Parameters.....	67
4.2.3	Scenario 2 – Permit Reduction	69
4.2.4	Scenario 3: Only Nuclear Capacity Replacement.....	71
4.2.5	Scenario 4 – Withdrawal from the Nuclear Energy Program	73
4.2.6	Scenario 5 – Learning Effects.....	75
4.2.7	Asymmetric Players.....	79
4.2.7.1	Scenario 6 – Asymmetric Players, no Learning	79
4.2.7.2	Scenario 7 – Asymmetric Players, Learning	80
4.3	<i>Conclusion</i>	82
5	References	85
	Appendix A: GAMS Source Code, Base Case	91
	Appendix B: Price - Quantity Calibration	100
	Appendix C: An attempt to including Learning Rates into the Profit Maximization ...	101
 List of Figures		
	Figure 1: Cumulative Power-Sector Investment in the IEA Reference Scenario 2005-2030	1
	Figure 2: 2005 World Coal Reserves by Country.....	2
	Figure 3: Maturity of CCS Technology.....	5
	Figure 4: Post-Combustion Capture Plant with Optional Amine Solvent Storage Tank.....	7
	Figure 5: O ₂ /CO ₂ Recycle Combustion	9
	Figure 6: CO ₂ Transport Cost Comparison: On/ Offshore Pipeline vs Ship Transport	11
	Figure 7: Onshore/ Offshore CO ₂ Pipeline Transport Costs.....	12

Figure 8: Overview of Geological Storage Options	13
Figure 9: Original, Developed and Undeveloped US Oil Resources, Potentials for EOR	15
Figure 10: The Enhanced Gas Recovery Process	16
Figure 11: Sample Sorption Isotherms for CO ₂ , CH ₄ and N ₂ on San Juan Basin Coal, USA	17
Figure 12: Potential Leakage Routes and Remediation Techniques for CO ₂ in Saline Aquifers	19
Figure 13: Public Energy R&D Investments as a Share of GDP	32
Figure 14: Trends in Private Sector Energy R&D	32
Figure 15: Leader's and Follower's Payoffs.....	36
Figure 16: Cost Comparison of Technologies Facing Learning Effects under Pollution Control	37
Figure 17: The Basics of Weitzman I: If Damage Curve is Steep.....	39
Figure 18: The Basics of Weitzman II: If Mitigation Curve is Steep.....	40
Figure 19: Uncertainty about Future Carbon Prices	43
Figure 20: Potential Gains from Emission Control under Marketable Permits	47
Figure 21: Potential Gains from CCS under Marketable Permits.....	50
Figure 22: Cournot Duopoly under Capacity Constraints and Emission Control.....	53
Figure 23: Possible Gains/Losses in Producer Rent from Innovation under Pollution Control	54
Figure 24: Technology related Producer Rents without Emission Pricing	56
Figure 25: Cost Efficient Electricity Production according to Emission Price.....	56
Figure 26: Technology related Producer Rents under Emission Pricing (35€/tCO ₂)	57
Figure 27: Technology Mix, Scenario 1	68
Figure 28: Technology Investment, Scenario 1	68
Figure 29: Electricity and Emission Permit Price, Scenario 1	69
Figure 30: Technology Mix, Scenario 2	70
Figure 31: Technology Investment, Scenario 2	70
Figure 32: Electricity and Emission Permit Price, Scenario 2	71
Figure 33: Technology Mix, Scenario 3	72
Figure 34: Technology Investment, Scenario 3	72
Figure 35: Electricity and Emission Permit Price, Scenario 3	73
Figure 36: Technology Mix, Scenario 4	74
Figure 37: Technology Investment, Scenario 4	74
Figure 38: Electricity and Emission Permit Price, Scenario 4	75
Figure 39: Decline in CCS Capital Cost with Respect to Cumulative Investment.....	75
Figure 40: Technology Mix, Scenario 5	76
Figure 41: Technology Investment, Scenario 5	77
Figure 42: Electricity and Emission Permit Price, Scenario 5	77
Figure 43: Market Output for all Scenarios.....	78
Figure 44: Players' Annual Profits.....	78
Figure 45: Technology Investment, Scenario 6.....	80
Figure 46: Scenario 7 – Market Shares, no Learning	80
Figure 47: Technology Investment, Scenario 7, Learning.....	81
Figure 48: Scenario 7 – Market Shares, Learning	81
Figure 49: Scenario 7 – Players' Annual Profits, Learning.....	82

Figure 50: Scenario 7 – Permits Used for Electricity Production, Learning	83
Figure 51: Scenario 7 – Market Shares, Learning	83
Figure 52: Scenario 7 – Profits, Learning.....	84

List of Tables

Table 1: Cost Estimation of CO ₂ Storage Options in €/tCO ₂	14
Table 2: Cost Estimation, Fossil plants without Carbon Capture in 2020	20
Table 3: Cost Estimation, Fossil plants with Capture in 2020.....	21
Table 4: Cost Estimation, Fossil plants with Capture in 2040.....	22
Table 5: RECCS Estimation about future CO ₂ Abatement Costs by means of CCS.....	23
Table 6: Scenario Description of the Analysis of Emission Control Policies.....	43
Table 7: Evaluation of Investment Incentives under Various Control Settings.....	44
Table 8: Evaluation of Regulatory Regimes to Foster Innovation.....	45
Table 9: RECCS Assumption on Future, Electricity related Costs	55
Table 10: Base Case Model Assumptions and Results.....	66
Table 11: Base Case Market Results	66
Table 12: Change in Fuel Prices.....	67
Table 13: Initial Market Shares, Scenario 7	79

Abbreviations

°C	Degrees Celsius
C	Carbon
CCGT	Combined Cycle Gas Turbine
CCS	Carbon Capture and Storage
CH ₄	Methane
CO	Carbon Monoxide
CO ₂	Carbon Dioxide
d	Day
ECBR	Enhanced Gas Recovery
EGR	Enhanced Coal-Bed Methane Recovery
EOR	Enhanced Oil Recovery
et al.	And Others
ETS	European Emission Trading Scheme
EU	European Union
F.e.	For Example
G	Giga
GAMS	General Algebraic Modeling System
GHGs	Greenhouse Gases
GWh	Gigawatt Hours
h	Hour
H ₂ O	Water
HTFC	High temperature Fuel Cell
IEA	International Energy Agency

IGCC	Integrated Gasification Combined Cycle
IPCC	International Panel on Climate Change
K	Kilo
Kg	Kilogram
Kt	Kilo Tons
LNG	Liquified Natural Gas
M	Mega
MEA	Monoethanolamine
MPa	Mega Pascal
M€	Million Euro
Mt	Mega Tons
MW	Mega Watt
MWh	Mega Watt Hours
MWh _{el}	Mega Watt Hours electric
MWh _{th}	Mega Watt Hours thermic
NO _x	Nitrogen oxides
O ₂	Oxygen
OECD	Organization for Economic Co-operation and Development
PC	Pulverized Coal
ppm	Parts per Million
R&D	Research & Development
R&D3	Research, Development, Demonstration and Deployment
RJV	Research Joint Venture
SOFC	Solid Oxide Fuel Cell
SO _x	Sulphur Oxides
T	Terra
Toe	Tons of Oil Equivalent
US	United States
W	Watt
yr	Year