Knowledge Flows and R&D Co-operation

Dissertation

zur Erlangung des akademischen Grades
doctor rerum politicarum
(Dr. rer. pol.)

vorgelegt dem Rat der Wirtschaftswissenschaftlichen Fakultät
der Friedrich-Schiller-Universität Jena

am 6. Juni 2007

von: Dipl.oec. Tobias Schmidt

geboren am 09.08.1975 in Erlangen

Gutachter: Prof. Dr. Uwe Cantner

Gutachter: Prof. Dr. David B. Audretsch

Datum der Verteidigung: 22. Oktober 2007

Deutsche Zusammenfassung

Einleitung und Motivation

Innovationen entstehen in zunehmendem Maße nicht mehr isoliert sondern durch die Kombination von Wissen verschiedener Unternehmen und Institutionen. Immer kürzere Produktlebenszyklen und die Zunahme der Komplexität von Technologien und Produkten sind ein Grund dafür, dass immer weniger Unternehmen das gesamte Wissen, das für die Entwicklung innovativer Produkte und Prozesse nötig ist, selbst besitzen. Um dennoch erfolgreich Innovationsaktivitäten durchführen zu können, verschaffen sich die Unternehmen über verschiedene Kanäle Zugang zu externem Wissen, zum Beispiel durch die Analyse von frei zugänglichem Wissen oder durch Kooperationen mit anderen Unternehmen oder wissenschaftlichen Einrichtungen. Letztere Möglichkeit des Zugangs zu externem Wissen steht im Mittelpunkt dieser Arbeit.

Viele empirische Arbeiten haben gezeigt, dass sich Kooperationen im Zusammenhang mit Innovationsaktivitäten, einschließlich Forschung und Entwicklung (FuE) positiv auf den Erfolg eines Unternehmens mit innovativen Produkten und Prozessen auswirken. Das Interesse der Unternehmen an dieser Form des Wissenstransfers ist somit verständlich. Die theoretische wissenschaftliche Literatur und hier insbesondere die sog. „Non-tournament“ Literatur hat zudem gezeigt, dass FuE-Kooperationen helfen können das Marktversagen, das durch Wissensspillover im FuE-Prozess entsteht, zu korrigieren und die gesamtwirtschaftliche Wohlfahrt zu steigern. Nicht zuletzt deshalb hat auch die Politik ein Interesse an einer regen Kooperationstätigkeit der Unternehmen. Mit der umfangreichen Förderung von Kooperationen verfolgt die öffentliche Hand darüber hinaus das Ziel den Wissensfluss zwischen Universitäten und Unternehmen und den Unternehmen untereinander zu verbessern, um so die Innovationskraft eines Landes oder einer Region zu steigern.

Wie aus diesen Ausführungen deutlich wird, sind FuE-Kooperationen und Wissenstransfer bzw. Wissensspillover eng miteinander verbunden. Eine ganze Reihe von wissenschaftlichen Studien hat in den vergangen Jahren empirische Belege für die Existenz dieses Zusammenhangs geliefert. Die vorliegende Dissertation schließt an diese Arbeiten an, indem sie sich mit der Analyse des Einflusses von Wissensspillovern auf die Kooperationsneigung von Unternehmen im Bereich FuE und Innovation beschäftigt. Sie geht in mehrfacher Hinsicht über die bestehende Literatur hinaus, insbesondere im Bezug auf die Abbildung von Wissensspillovern im ökonometrischen Modell. Im Gegensatz zu den traditionellen empirischen Modellen in diesem Forschungsbereich wird (wie unten dargestellt) berücksichtigt, dass nicht das gesamte Wissen, das produziert wird, auch von allen Unternehmen genutzt werden kann. Bei der Konstruktion der Spillovermaße wird daher einerseits der Tatsache Rechnung getragen, dass Wissen durch Patente und Geheimhaltung geschützt werden kann, und andererseits, dass ein Unternehmen bestimmte Fähigkeiten („absorptive Fähigkeiten"- Cohen und Levinthal, 1989, 1990) besitzen muss, um externes Wissen nutzen zu können. Zudem werden Wissensspillover von Unternehmen aus der eigenen Branche, von denen aus Unternehmen anderer Branchen und wissenschaftlicher Einrichtungen unterschieden. Die beiden zentralen Hypothesen der Arbeit, die mit mikroökonometrischen Methoden überprüft werden, sind daher:

1. Die Höhe der tatsächlich auftretenden Wissensspillover hat einen positiven Einfluss auf die Kooperationsneigung von Unternehmen im Bereich FuE und Innovation.
2. Verschiedene Arten von tatsächlich aufgetretenen Wissensspillovern beeinflussen die Kooperationsneigung von Unternehmen im Bereich FuE und Innovation in unterschiedlich.

Die Arbeit gliedert sich in einen theoretischen Teil, der die empirische und theoretische Literatur zu dem Thema FuE-Kooperationen und Wissensspillover überblicksartig darstellt, und einen empirischen Teil, indem die oben erwähnten Spillovermaße generiert werden und der Einfluss dieser Spillovermaße auf die

Neigung eines Unternehmens FuE-Kooperationen einzugehen untersucht wird. Die wichtigsten Ergebnisse und Inhalte der einzelnen Kapitel werden im Folgenden zusammengefasst.

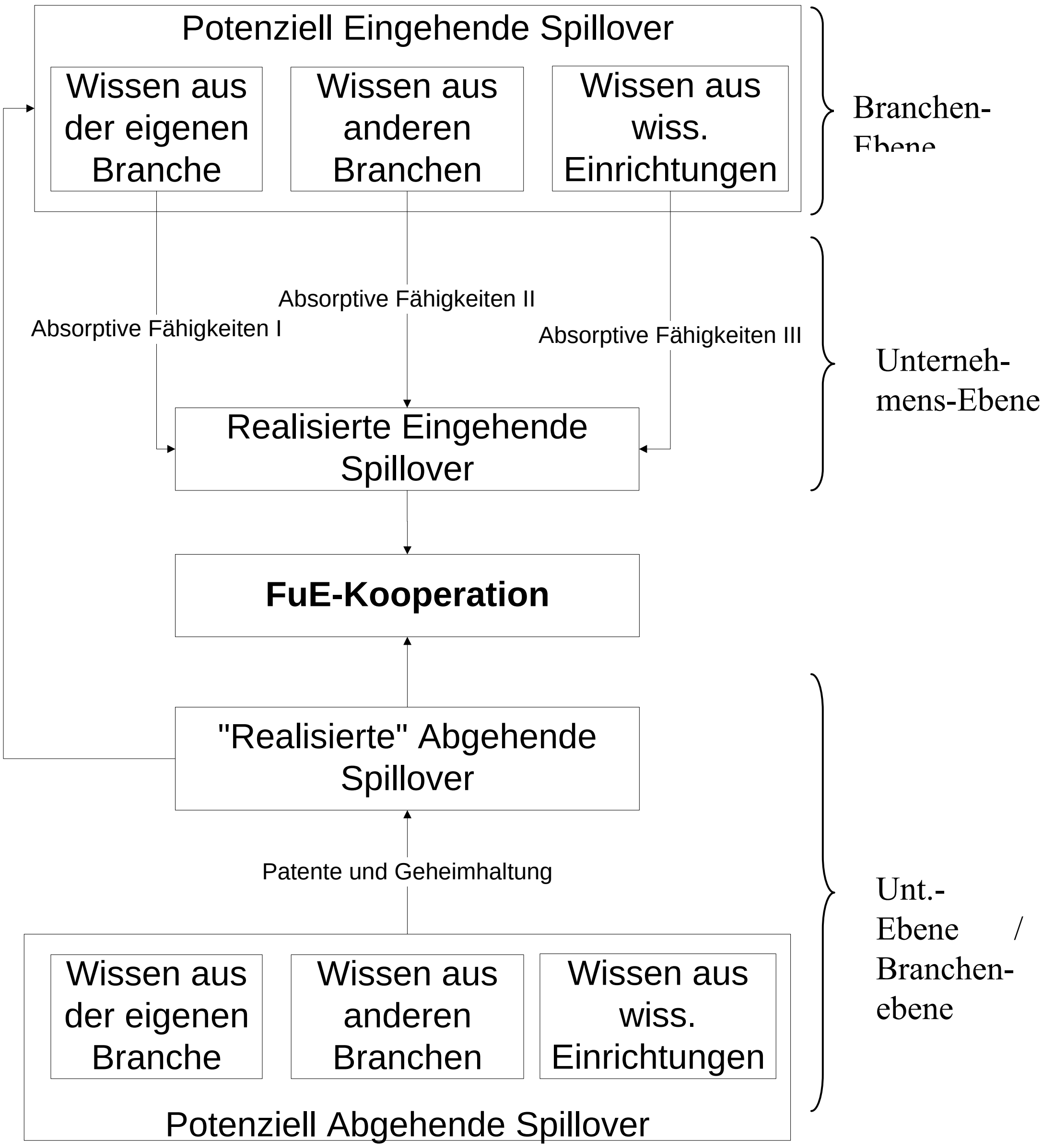
Empirische und theoretische Literatur zum Thema Wissensspillover und FuE-Kooperationen

Kapitel 2 der Arbeit gibt einen Überblick über die umfangreiche theoretische und empirische Literatur zum Thema Wissensspillover und FuE-Kooperationen. Der Überblick über die theoretische Literatur beginnt mit der Darstellung der industrieökonomischen Theorie und hier insbesondere von „non-tournament" und „tournament" Modellen. Dem schließen sich kurze Abhandlungen über die Ergebnisse der Transaktionskostentheorie und des Ressourcenbassierten Ansatzes an. Die Beschreibung der empirischen Literatur fokussiert sich auf Modelle, die Daten aus Innovationserhebungen nutzen, da auch für diese Arbeit derartige Daten Verwendung finden. Diskutiert wird insbesondere das Modell von Cassiman und Veugelers (2004), das die Grundlage für die vorliegende Arbeit bildet. Sowohl die empirische als auch die theoretischen Arbeiten kommen zu dem Ergebnis, dass sich Wissensspillover positiv auf die Wahrscheinlichkeit auswirken Kooperation im Bereich FuE und Innovation einzugehen. Sie liefern außerdem Argumente dafür, dass verschiedene Arten von Wissensspillovern die Wahrscheinlichkeit zu kooperieren auf unterschiedliche Art und Weise beeinflussen.

Analytischer Rahmen der empirischen Analysen

Kapitel 3 skizziert die Arbeitsschritte im empirischen Teil der Arbeit und erläutert den Zusammenhang zwischen der Höhe des generierten Wissens und den tatsächlich genutzten bzw. aufgetretenen Wissensspillovern. Dabei wird die Aufgliederung der Wissensspillover in Spillover von Unternehmen der gleichen Branche, Unternehmen anderer Branchen und wissenschaftlichen Einrichtungen ebenso angesprochen, wie der im weiteren Verlauf der Analyse untersuchte Einfluss von absorptiven Fähigkeiten und intellektuellen Eigentumsrechten auf die Höhe der tatsächlich auftretenden Wissensspillover. Der in dem Kapitel entwickelte umfassende analytischen Rahmen für den empirischen Teil der Dissertation kann in der folgenden Graphik zusammengefasst werden:

Abbildung 1 Überblick über den analytischen Rahmen für die empirische Analysen



Quelle: Eigene Darstellung.

Das Mannheimer Innovationspanel

Eine ausführliche Beschreibung des Mannheimer Innovationspanels (MIP) ist Gegenstand von Kapitel 4. Diese vom bmbf in Auftrag gegebene Innovationserhebung unter Unternehmen mit fünf und mehr Beschäftigten im verarbeitenden Gewerbe und Dienstleistungssektor des Zentrums für Europäische Wirtschaftforschung (ZEW) in Mannheim bildet die Datenbasis für die empirischen Analysen in den folgenden Kapiteln. Neben einer Beschreibung der für die Erhebung verwendeten Konzepte und Fragestellungen, beinhaltet dieses Kapitel auch Informationen über die verwendete Erhebungs- und Aufbereitungsmethodik, wie die Beschreibung der Grundgesamtheit und Rücklaufquoten.

Von potenziellen zu realisierten Wissensspillovern

Die eigentliche empirische Arbeit beginnt mit Kapitel 5. In diesem Kapitel wird mit Hilfe von Informationen über die FuE-Aufwendungen einzelner Unternehmen und ganzer Industrien ein empirisches Maß für den Wissensstock eines Unternehmens bzw. einer Branche generiert. Dabei kommt die sog. „perpetual inventory methode“ zum Einsatz, die es ermöglicht aus einem Anfangsbestand an Wissen und nachfolgenden Zugängen an Wissen einen aktuellen Bestand zu erzeugen. In die Berechnung dieses Bestands geht auch eine Abschreibungsrate für Wissen ein. Bisherige Studien haben meist eine für alle Branchen konstante Abschreibungsrate angenommen. Die vorliegende Arbeit geht über die bestehende Literatur hinaus, indem die Abschreibungsrate aus dem durchschnittlichen Produktlebenszyklus einer Branche berechnet wird und somit für jede Branche unterschiedlich ist. Das Ergebnis von Kapitel 5 ist ein geschätzter Bestand an Wissen für einzelne Branchen und Unternehmen im Jahr 2002, der potentiell zu Spillovern werden kann („potenziell abgehende Spillover“).

Kapitel 6 der Arbeit beginnt mit einer Diskussion verschiedener Faktoren, die den freien Fluss von Wissen zwischen Unternehmen einschränken können. Ausgangspunkt ist die Frage warum nicht der gesamte Bestand an Wissen (Kapitel 5) von allen Unternehmen in gleichem Umfang genutzt werden kann. Kapitel 6 gibt zwei Antworten auf diese Frage: Erstens, ein Teil des entstandenen Wissens kann durch Patente und Geheimhaltung vor einer Nutzung durch andere Unternehmen geschützt werden und zweitens, nicht alle Unternehmen haben die gleiche Fähigkeit externes Wissen zu identifizieren, assimilieren und schließlich in innovative Produkte und Prozesse umzusetzen („absorptive capacity“ Cohen und Levinthal, 1989).

Unter Verwendung von Fragen aus dem Mannheimer Innovationspanel kann mit Hilfe von Ordered Probit Modellen gezeigt werden, dass sowohl Patente als auch Geheimhaltung den Wissensfluss zwischen Unternehmen signifikant reduzieren. Auch die zweite These, dass nicht alle Unternehmen die gleichen absorptiven Fähigkeiten haben, kann mit multivariaten Verfahren (Multivariates Probit Modell) und Daten aus dem Mannheimer Innovationspanel, empirisch belegt werden. Die Analysen zeigen zudem, dass absorptiven Fähigkeiten für verschiedene Arten von Wissen von unterschiedlichen Unternehmenscharakteristika abhängen.

Die dargestellten Ergebnisse bilden zusammen mit dem in Kapitel 5 errechneten Bestand an Wissen die Basis für die Berechnung der tatsächlich entstandenen Wissensspillover aus Sicht eines Unternehmens. Kapitel 6 schließt mit einer Berechnung eben dieser tatsächlichen Wissenspillover. Dafür wird der Bestand an Wissen für jede Branche zunächst mit der durchschnittlichen Bedeutung von Patenten und Geheimhaltung in der Branche multipliziert, um vom Bestand an generiertem Wissen zum Bestand an frei verfügbarem Wissen („realisierte abgehende Spillover“ / „potentiell eingehende Spillover“) jeder Branche zu kommen. Für den Bestand an Wissen, der aufgrund von FuE Aufwendungen in wissenschaftlichen Einrichtungen entstanden ist, wird die Annahme getroffen, dass dieser komplett frei verfügbar ist. Ein entsprechendes Maß wird auch für jedes Unternehmen berechnet, indem der Wissensstock eines Unternehmens (Kapitel 5) mit der Bedeutung von Patenten und Geheimhaltung auf Unternehmensebene multipliziert wird („realisierte abgehende Spillover").

Der Bestand an frei verfügbarem Wissen in den einzelnen Branchen und wissenschaftlichen Einrichtungen, d.h. die potenziell eingehenden Spillover, wird anschließend mit der Höhe der absorptiven Fähigkeiten eines Unternehmens multipliziert. Dabei wurde berücksichtigt, dass sich die absorptiven Fähigkeiten für verschiedene Wissensarten unterscheiden, d.h. der Bestand an frei verfügbarem Wissen in der Branche zu der das jeweilige Unternehmen gehört (WB) wird mit den absorptiven Fähigkeiten für Wissen aus der eigenen Branche (ACB) multipliziert, der Bestand an frei verfügbarem Wissen aus anderen Branchen (WE) und wissenschaftlichen Einrichtungen (WW) mit dem entsprechenden absorptiven Fähigkeiten (ACE bzw. ACW) für diese Wissensarten. Die Höhe der gesamten entstandenen Wissensspillover, die das Unternehmen von außen aufnimmt („realisierte eingehende Spillover"), ergibt sich als Summe aus den mit den absorptiven Fähigkeiten gewichteten einzelnen Beständen. In einer Formel zusammengefasst lässt sich dieser letzte Schritt folgendermaßen darstellen, wobei j die Branche des Unternehmens repräsentiert und i alle anderen Branchen:

$$\textit{Realisierte eingehende Spillover} = (ACB * WB) + ACE * \sum_{i \neq j} WE_i + (ACW * WW)$$

Ergebnisse, Schlussfolgerungen und Ausblick

In Kapitel 7 wird schließlich der Einfluss, der in den vorherigen Kapiteln berechneten Spillovermaße, auf die Kooperationsneigung von Unternehmen untersucht. Als Vergleichsmodell dient das Modell von Cassiman und Veugelers (2002), das mit wesentlich einfacheren Spillovermaßen arbeitet und nicht nach der Herkunft der Spillover (eigene Branche versus andere Branchen und Wissenschaft) unterscheidet. Neben seiner Rolle als Vergleichsmodell liefert das Modell von Cassiman und Veugelers (2002) auch Ansatzpunkte für die Konstruktion von Variablen, die Kooperationsmotive abbilden können, die über reine Wissensspillover hinausgehen. In die Instrumentenvariablenschätzung in der vorliegenden Arbeit gehen daher zum Beispiel auch Indikatoren für andere Kooperationsmotive ein, wie etwa die Größe des Unternehmens, ein Indikator für den Erhalt öffentlicher Förderung oder die Zahl der Hauptkonkurrenten eines Unternehmens, die in Anlehnung an die Arbeit von Cassiman und Veugelers (2002) berechnet werden.

Die Ergebnisse der multivariaten Analysen zeigen, dass insbesondere die in der Vergangenheit realisierten eingehenden Spillover, d.h. externes Wissen, das ein Unternehmen tatsächlich genutzt hat, einen positiven Einfluss auf die Kooperationswahrscheinlichkeit von Unternehmen im Bereich FuE und Innovation haben. Für die in der Vergangenheit realisierten abgehenden Spillover, d.h. das vom Unternehmen generierte Wissen, das nicht durch Patente oder Geheimhaltung geschützt wurde, findet sich hingegen kein eindeutig positiver Zusammenhang.

In einem zweiten Analyseschritt werden die realisierten eingehenden Spillover in Wissensspillover aus der eigenen Branche und von außerhalb der Branche unterschieden. Letztere Gruppe setzt sich aus den Spillovern aus anderen Branchen und der Wissenschaft zusammen. Aufgrund methodischer Überlegungen (Korrelationsanalyse) wurde auf einer weitere Aufspaltung verzichtet. Bei der nach Herkunft der Spillover getrennten Analyse zeigt sich, dass die realisierten Wissensspillovern von außerhalb der eigenen Branche einen signifikant positiven Einfluss auf die Kooperationswahrscheinlichkeit haben, während die Spillover aus der eigenen Branche keinen Einfluss haben.

Insgesamt bestätigt die vorliegende Studie den positiven Zusammenhang zwischen eingehenden Wissensspillovern und Kooperationen von Unternehmen im Bereich FuE und Innovation. Sie zeigt damit, dass die in der bestehenden Literatur verwendeten einfacheren Spillovermaße die realisierten eingehenden Spillover adäquat abbilden.Im Gegensatz zu anderen Arbeiten findet sich in der vorliegenden Arbeit allerdings kein eindeutiger Zusammenhang zwischen realisierten abgehenden Spillovern und der Kooperationsneigung von Unternehmen. Die Nicht-Berücksichtigung des Bestands an erzeugtem Wissen in der empirischen Literatur könnte ein Grund für diese Unterschiede sein.

Die Untersuchung von Wissensspillovern und Kooperationen könnte um in dieser Arbeit nicht berücksichtigte Aspekte erweitert werden. Als erstes ist hier die Unterscheidung zwischen den Unternehmen, die nicht kooperieren wollen und den Unternehmen die nicht kooperieren können, zu nennen. Dies würde eine detailliertere Analyse des Einflusses von Wissensspillovern auf die Kooperationsneigung erlauben, die aufgrund der Datenlage in dieser Arbeit nicht durchgeführt werden konnte. Ein zweiter Ansatzpunkt für weitergehende Studien ist die Untersuchung des Zusammenhangs zwischen Wissensspillovern und Kooperationspartnern im Zeitablauf. Mit Hilfe von Panelanalysen könnten Fragestellungen wie etwa der Einfluss von Spillovern auf die Dauer einer Kooperationsbeziehung zwischen verschiedenen Unternehmen untersucht werden. Dazu wäre aber auch ein Datensatz nötig, der es erlaubt die Partner in einer Kooperation zu identifizieren. Die Analyse von Netzwerken, bei der die jeweiligen Partner in einer Kooperationsbeziehung bekannt sind, bietet für die Beantwortung dieser Fragestellungen eine gute Basis.

Die in der non-tournament Literatur getroffene Unterscheidung in endogene Wissensspillover (Spillover erhöhen sich wenn Unternehmen kooperieren) und exogenen Spillovern (Spillover bleiben trotz Kooperation konstant) liefert weitere Ansatzpunkte für die Forschung in diesem Bereich. Zum Beispiel könnte empirisch untersucht werden, ob sich die Kooperationsneigung eines Unternehmens erhöht, wenn sich die Spillover bei Kooperation um einen gewissen Betrag erhöhen.

Durch Kooperation und Wissensspillovern zwischen Wissenschaftlern und Praktikern wird es sicherlich gelingen, auch diese Forschungslücken zu schließen.

Acknowledgements

"All men by nature desire to know."

Aristotle (Metaphysica 330 BC)

I would like to thank each and everyone that kept my desire to know more about knowledge spillovers and R&D co-operation alive.

First and foremost I am indebted to my Ph.D. advisor, Prof. Uwe Cantner, who provided critical comments on my work and stirred my interest in the topic of innovation economics while I was still a student at the University of Augsburg. I am garetfull to my co-supervisor Prof. David Audretsch for his support and encouragement.

I would like to thank the Centre for European Economic Research (ZEW) and in particular its president Prof. Wolfgang Franz for supporting this dissertation with time, funds and the ability to publish some parts of this dissertation in ZEW Discussion papers.

This dissertation would not have been complete without the support of many of my colleagues from the department of Industrial Organisation and International Management. I would like to thank in particular Wolfgang Sofka, who not only provided me with scientific advice and comments but also kept an upbeat mood in our office. Furthermore, I would like to express my gratitude for many helpful and challenging comments to Dr. Christian Rammer, Dr. Georg Licht and Dr. Bettina Peters.

This dissertation would probably not be readable, if not for the help of four native speakers Andrew Flower, Tyler Schaffner, Alexis Develle and Jörg Dallmeier, who provided excellent support, by correcting my spelling mistakes.

Finally I would like to thank my whole family: My parents for supporting me while I was at the University of Augsburg and at Wayne State University in Detroit and my wife Carmen for being very supportive and understanding through the hard times of writing this thesis.

Even though she is not able to read yet, I also thank my daughter Tabea for smiling at me each time I set of to work on this thesis.

Tobias Schmidt, November 2007

Table of Contents

List of Figures XVII

List of Tables XVIII

List of Abbreviations XXI

1 Introduction 1

2 The Relationship between Knowledge Spillovers and R&D Co-operation: A Review of Related Theoretical and Empirical Literature 7

2.1 Industrial Organisation Theory 8

2.1.1 Non-Tournament Models 8

2.1.2 Tournament Models 29

2.2 Transaction Cost Theory 32

2.3 The Resource Based View of the Firm 34

2.4 Empirical Studies 36

2.4.1 Descriptive Studies 37

2.4.2 Econometric Studies Using Data from Innovation Surveys 38

2.4.3 Econometric Studies Using Data from Other Databases 52

2.5 Different Types of R&D Partnerships and R&D Spillovers 53

2.5.1 R&D Partnerships 54

2.5.2 R&D Spillovers 58

2.6 Deduction of Hypotheses for the Empirical Part of the Study 64

3 Overview of the Empirical Part of the Study 66

4 The Mannheim Innovation Panel 71

4.1 Introduction 71

4.2 Goals of the MIP Innovation Surveys 72

4.3 Methodology for Data Collection 74

4.3.1 Basic Definition of Innovation and Innovating Firms 74

4.3.2 Populations, Sample and Non-Response Analyses 76

4.3.3 Survey Questionnaire and Survey Process 81

4.3.4 Data Preparation, Data Quality and Expansion 82

4.3.5 Publications and Usage of the Microdata 84

4.3.6 Main Results of the 2005 Mannheim Innovation Panel 85

5 The Construction of the Potential Outgoing Spillover Pools/Knowledge Stocks at the Industry and Firm-Level.. 88

5.1 Empirical Measures for Knowledge Flows and Knowledge Stocks... 88

5.2 Database for the Construction of the Knowledge Stock..................... 92

5.3 Construction of Industry-Specific Knowledge Depreciation Rates.... 94

5.4 The Knowledge Stocks of Selected Industries................................... 97

5.5 The Knowledge Stock of a Firm.. 98

6 From Potential Outgoing to Realized Incoming Spillover Pools 100

6.1 Factors Moderating the Free Flow of Knowledge 100

6.2 Different Types of Knowledge Spillover Pools............................... 105

6.3 From Industry-Level Potential Outgoing Spillovers to Firm-Specific Realized Incoming Spillovers – Analytical Framework..... 108

6.4 The Effects of Patents and Secrecy on Knowledge Spillovers......... 110

6.4.1 Legal versus Strategic Protection Methods as a Mean to Reduce Knowledge Spillovers – A Review of Related Literature 112

6.4.2 Estimation of the Effects of Patents and Secrecy on Knowledge Spillovers 117

6.4.3 Results of the Empirical Model 127

6.4.4 Conclusions and Implications for the Next Steps of the Analysis 132

6.5 The Construction of the Potential Incoming Spillover Pools at the Industry-Level and the Realized Outgoing Spillover Pool at the Firm-Level 133

6.6 Absorptive Capacity as the Determining Factor of Realized Incoming Knowledge Spillovers.. 137

6.6.1 Related Literature on the Components and Determinants of Absorptive Capacity for Different Types of Knowledge 140

6.6.2 Data, Construction of the Variables and Empirical Model 147

6.6.3 Results 155

6.7 Construction of the Realized Incoming Spillover Pool at the Firm-Level.. 165

7 The Relationship between Knowledge Flows and R&D Co-operation – A Multivariate Analysis 166
7.1 Motives and Determinants of R&D Co-operation: Going Beyond Knowledge Spillovers 166
7.2 Estimating the Impact of Knowledge Spillovers on the R&D Co-operation Decision of Firms 177
7.2.1 The Model of Cassiman and Veugelers – Benchmark Case 177
7.2.2 Estimating the Impact of Knowledge Spillovers on R&D Co-operation decisions of Firms with the Constructed Spillover Variables 188
8 Summary and Conclusion 198
Appendix 203
Literature 233

List of Figures

Figure 1-1 Share of Publicly Funded R&D Projects in Germany between 1980 and 2004 5
Figure 3-1 Overview of the Analytical Framework for the Empirical Part of this Study 70
Figure 4-1 Goals of the Mannheim Innovation Panel Surveys 74
Figure 4-2 Share of Innovators in Germany, 1992-2004 86
Figure 4-3 Innovation Expenditure of German Firms, 1992-2005 87
Figure 6-1 From Potential to Realized Incoming Spillover Pools 110
Figure 6-2 Expected Effects of Different Types of Protection Methods on Knowledge Spillovers 119
Figure 7-1 Reasons for R&D Co-operations – Results for Four German Bundesländer 167
Figure 7-2 Potential Factors Influencing a Firm's Decision to have at Least one R&D Co-operation with External Partners 179

List of Tables

Table 2-1 Main Findings on the Link Between Spillovers and R&D Co-operation in the Non-Tournament Literature 24
Table 2-2 Main Findings of Econometric Studies Using Innovation Survey Data 46
Table 4-1 Sample Sizes of the MIP Survey of 2001, 2003 and 2005 (Selected Industry Groups) 80
Table 5-1 Estimated Depreciation Rates for R&D Capital (in %) and Average Product Life-Cycle (in Years) for Selected Industry Groups 96
Table 5-2 Estimated Knowledge Stocks for Selected Industry Groups in 2002 .. 98
Table 6-1 Regression Results of Ordered Probit Estimations (Dependent Variable: Importance of Lack of Information on Technologies as an Obstacle to Innovation) 129
Table 6-2 Estimate Potential Inter-Industry Knowledge Spillover Pools in 2002 and the Average Importance of Patents and Secrecy in 2002-2004 .. 136
Table 6-3 Coefficients of Probit and Trivariate Probit Estimation on the Determinants of Absorptive Capacity 157
Table 6-4 Coefficients of Five Different Probit and Trivariate Probit Estimations on the Determinants of Absorptive Capacity 158
Table 7-1 An overview of Motives for (Strategic) Inter-Firm Technology Co-operation 169
Table 7-2 Coefficients of Probit Estimations of the Probability to have at Least one R&D Co-operation between 2002 and 2004 187
Table 7-3 Results of Instrumental Variable Probit Estimations on the Determinants of R&D Co-operation between 2002 and 2004 196
Table A-1 Intramural R&D Expenditure in Industry and Services in Billion (current) Euros form 1995 to 2002 204

Table A-2 Gross domestic R&D expenditure (GERD) by Government and Higher Education Institutes in Billion (current) Euros from 1995 to 2002 in Germany 205
Table A-3 Variables included in the Model on the Relationship between Patents and Secrecy and Knowledge Spillovers 206
Table A-4 Industries Included in the Model on the Relationship between Patents and Secrecy and Knowledge Spillovers 208
Table A-5 Additional Descriptive Statistics for the Sample used to Estimate the Effect of Patents and Secrecy on Knowledge Spillovers 208
Table A-6 Descriptive Statistics (Means) for the Sample used to Estimate the Effect of Patents and Secrecy on Knowledge Spillovers 209
Table A-7 Coefficients of Ordered Probit Estimations of the Effect of Patents and Secrecy on Knowledge Spillovers 210
Table A-8 Variables Included in the Empirical Model of the Determinants of Absorptive Capacity 212
Table A-9 List of Industry Dummies Included in the Model of the Determinants of Absorptive Capacity 214
Table A-10 Descriptive Statistics for Variables included in the Model of the Determinants of Absorptive Capacity 215
Table A-11 Regression Results from Probit (1) and Trivariate Probit (2)-(4) Estimations of the Determinants of Absorptive Capacity 217
Table A-12 Construction of Variables for the Benchmark Case on the Importance of Knowledge Spillovers for R&D Co-operation 220
Table A-13 Descriptive Statistics (Means) for the Benchmark Case on the Importance of Knowledge Spillovers for R&D Co-operation 223
Table A-14 Results for the First Stage OLS Regressions of the Two Stage Probit Estimations of the Probability of Cooperating 224
Table A-15 Construction of Variables for the Model on Knowledge Spillovers for R&D Co-operation using the Constructed Spillover Measures 225

Table A-16 Descriptive Statistics (Means) of the Sample used for the Model on Knowledge Spillovers for R&D Co-operation using the Constructed Spillover Measures 227
Table A-17 Results for the First Stage of the Instrumental Variable Probit Estimations of the Model on Knowledge Spillovers for R&D Co-operation using the Constructed Spillover Measures 229
Table A-18 Results for the Instrumental Variable Probit Estimations of the Model on Knowledge Spillovers for R&D Co-operation using the Constructed Spillover Measures 231

List of Abbreviations

ANBERD	Analytical Business Enterprise Research and Development
AUT	Austria
BERD	Business Enterprise Expenditure on R&D
CATI	Cooperative Agreements and Technology Indicators Database
CEO	Chief Executive Officer
CIS	Community Innovation Survey
DESTATIS	German Statistical Office
EU	European Union
FhG-ISI	Frauhenhofer Institute for Systems and Innovation Research
FIN	Finland
FRA	France
GER	Germany
GERD	Gross Domestic Expenditure on R&D
Infas	Institute für angewandte Sozialwissenschaft
IV Probit	Instrumental Variable Probit Estimation
MIP	Mannheim Innovation Panel
NACE	Nomenclature générale des activités économiques dans les Communautés européennes - Standard Classification of Industries EU
OECD	Organisation for Economic Co-operation and Development
R&D	Research and Development
RJV	Research Joint Venture
SIC	Standard Industrial Classifications Index
SPA	Spain
SPRU	Science Policy Research Unit, University of Sussex
TC	Theory Transaction Cost Theory
UK	United Kingdom
ZEW	Centre for European Economic Research (ZEW)

1 Introduction

"The whole is more than the sum of its parts."

Aristotle (Metaphysica 330 BC)

This famous quote by Aristotle is quite fitting for the study I will conduct on the following pages, as my study is on combining knowledge from different actors via R&D co-operation to form a whole that is supposedly better than the whole that would have resulted if no R&D co-operation or no combination of knowledge would take place.

A "historic" example of such a combination of knowledge from different domains via R&D co-operation is the disc that changed the way music and data is distributed today, the "Compact Disc" or "CD"[1]. In 1979 a joint team from Philips and Sony started to work on a way of storing digital audio tracks on a disc. They came up with a version that was based on Acrylic glass, which bent under high pressure. At that stage the technology to put digital music on a disc was already developed but the technology for a suitable carrier was not. A product developed by the chemical giant Bayer finally provided the solution. The characteristics of the polycarbonate that was previously used and is still used for things like stadium roofing and lenses for glasses proved to be ideal for the production of Compact Discs. Today all the firms involved in the development of the CD have profited from combining their knowledge, as 750.000 CDs are produced daily in just one plant of Philips in Hannover-Langenhagen. Not only have the firms profited, but also the consumers who were given a new way of listening to music in high quality. Beethoven lovers in particular were delighted, as the playing time of a CD was based on the length of Beethoven's ninth symphony instead of the originally proposed one hour (Philips, 2006a).

1 For a more detailed description of the case see Rammer (2003).

In retrospective, Philips writes on its website "Nobody even invented one part of the technology alone. The CD was invented collectively by a large group of people working as a team. […] 'We needed all the skills that you would find in a large lab,' says Piet Kramer, […] 'Electronics engineers, photographic experts, mechanical engineers, control engineers, you have to bring all of these experts together, and then look to see if it can be done.' The pooling of creativity like this is typical of the way in which technological progress is made nowadays." (Philips, 2006b). This is just one example of how the combination of knowledge can lead to greater success than if it were kept at two different locations.

A fundamental issue with combining knowledge is how it should be done. Knowledge has features of a public good, which cause market failure and lead to the problem of organizing the transfer and combination of knowledge held at different locations. One way to overcome the market failure and to structure the transfer of knowledge between firms or between firms and research institutions is by co-operation. Since the exchange of knowledge is particularly relevant and important for the innovation process of firms, as the case of the CD has highlighted, the discussion on co-operation has focused on co-operation in research and development activities and other innovation activities. These types of co-operation and their relation to knowledge flows between firms are at the centre of this study.

The successful R&D co-operation between Philips, Sony and Bayer is not the only evidence that co-operating on R&D and innovation is indeed a profitable strategy. Many authors have empirically investigated the effect of R&D partnerships in general and R&D partnerships with certain types of partners (consumers, suppliers, research institutes, etc.) on the technological and economic success of firms. Almost all of them found a positive effect (see Aschhoff and Schmidt, 2006 for an overview). This positive impact of knowledge exchange and R&D co-operation on the performance of firms – and, as a result, on the performance of the whole economy - has drawn a lot of interest from academic researchers, practitioners and policymakers alike.

It is hard to pin down exactly when academic researchers started to investigate R&D co-operations at the firm-level in their various forms. Kogut (1988) reviews the empirical and theoretical literature on joint ventures (not only R&D joint ventures) and cites studies from the late 1960s that investigated the sectoral distribution of joint ventures. The analysis by Hagedoorn (2002) is evidence that not only joint ventures in general, but also research joint ventures have drawn the interest of empirical researchers for decades, as he analyses 40 years of data on research partnerships. Theoretical research on R&D partnerships can be traced back to the 1980s when the number of R&D partnerships grew considerably and they become a more and more popular mode of organizing business (Hagedoorn, 2002; OECD, 1996). As most other theoretical and empirical strains of literature, the research on R&D partnerships is build on concepts and models that are much older, like the concept of market failure and incentives.

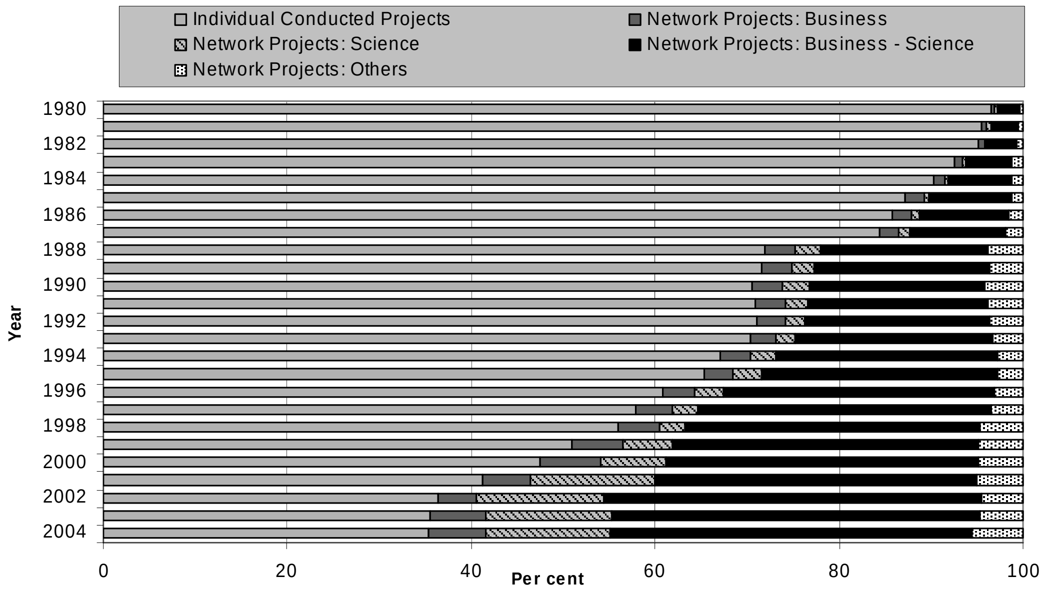
The focus of research on R&D partnerships has undergone changes over time in terms of the type of partnership analysed as well as the topic analysed. Early empirical and theoretical studies almost exclusively analyse research joint ventures (RJV), both in the form of equity joint ventures and as non equity joint ventures. While the former covers arrangements where two or more firms jointly form and own a separate firm or organization that carries out R&D, the latter includes a variety of contractual agreements, for examplemore often than not involving the exchange of knowledge or certain technologies (see Hagedoorn, 1993, Killing, 1988, Siebert, 1996; Kogut, 1988). More recently, the term "research joint venture" has been replaced by "R&D co-operation" in theoretical and empirical papers alike. "R&D co-operation" covers not only contractual partnerships but also looser forms of collaboration between firms and sometimes even informal agreements (e.g. Bönte and Keilbach, 2005; Wiethaus, 2005). This change to a broader perspective on collaborative R&D and research partnerships was made possible in part by the advent of the Community Innovation Surveys in the European Union that ask firms for details of collaborative research not only within joint ventures but also outside of them.

With the transition from the RJV to a broader spectrum of R&D partnerships there was also a shift from the analysis of effects of R&D co-operation on competition and social welfare to a consideration of the motives of R&D co-operation and in particular the role of knowledge in the R&D co-operation process.[2] This change in the research focus is associated with the switch from a more defensive view of R&D co-operation, i.e. that R&D co-operation has a negative influence on competition, to a more optimistic view, i.e. R&D co-operation as a vehicle for knowledge sharing. The emergence of the "knowledge-based economy" has further strengthened the role of R&D co-operation. With the increasing complexity of products and technologies and shorter product life-cycles "tapping external sources of know-how becomes a must" (Tsang, 2000: 225) and the exchange of knowledge becomes even more important.

Even though the positive effect of co-operation on success and the increased pressure to use external knowledge means that private firms have an incentive to cooperate on R&D and innovation activities, the market failure caused by knowledge spillovers leads to an amount of knowledge sharing and R&D co-operation that is below the socially desirable level. Hence policy intervention can improve the current situation. Theoretical and empirical research has shown that through R&D co-operation spillovers can be internalised and the incentives for private R&D activities restored. What is more, R&D co-operation helps to increase the knowledge flow between firms, as well as between firms and research institutions, which is also in the interest of public policy. For these reasons, a great amount of funding for R&D and innovation activities now goes to supporting co-operative R&D activities as the following figure shows for Germany as an example:

2 The link between knowledge spillovers and firms' co-operation decisions had already been assumed and used by the early theoretical models, though (see e.g. D'Aspremont and Jacquemin, 1988).

Figure 1-1 Share of Publicly Funded R&D Projects in Germany between 1980 and 2004



Source: Fier et al. (2005): 25.

The important role of knowledge spillovers and R&D co-operation between firms will be the starting point for my analysis. In particular I will build on the existing empirical literature on knowledge flows in and out of the firm as a motive for R&D co-operation among firms and between firms and public institutions. The well-known empirical model by Cassiman and Veugelers, 2002 and the empirical studies building upon it will serve as the role-model for my study. However, I will extend this literature in several directions:

One of the main novelties of this study is that I take into account the fact that not all knowledge is equal and that different types of knowledge require different internal capacities and capabilities ("absorptive capacity") to be efficiently acquired, disseminated and exploited (Section 6.6). The distinction between absorptive capacity for knowledge from universities, knowledge from firms from the same industry and knowledge from other industries has not been analysed in the literature thus far. This separation allows us to construct measures of different pools of (realized) knowledge spillovers at the firm level and investigate their effect on the R&D co-operation decisions of firms separately.

In order to construct a measure of the amount of knowledge a firm actually uses, the knowledge stock of an industry and of a firm will be estimated using the perpetual inventory method (Chapter 5) with industry-specific depreciation rates. Previous studies have almost exclusively used a single depreciation rate to take into account that knowledge becomes obsolete. I will extend the existing literature in this area by calculating industry-specific depreciation rates based on the average product life-cycle in each industry (Section 5.3). The knowledge stocks of each industry will then be weighted by the individual firm's absorptive capacity. Before weighting the knowledge stock with the firms' absorptive capacity I take into account that not all knowledge generated spills out into the public domain. Some of the knowledge can be appropriated using patents or secrecy as a protection method (Section 6.4). This is to say that I construct measures of realized spillover pools for each firm based on their absorptive capacity and the level of knowledge protection chosen by the firms producing the knowledge. I end up with mesures of knowledge spillovers that are considerably closer to the actual knowledge flows than previous studies.

Finally, the data I use is rather new (in particular CIS IV data) and has not previously been used to estimate these types of relationships.

The analysis will proceed as follows: In the next section I will review the empirical and theoretical literature on the link between R&D co-operation and knowledge spillovers. This will be supplemented by an overview of different concepts, definitions and types of spillovers and R&D partnerships. In chapter 4 I will describe the Mannheim Innovation Panel (MIP) which will serve as the databasis for my analysis. Chapter 5 I will estimate the knowledge stock of a firm and selected industries, before proceeding to the construction of the realized spillover pools (i.e. the knowledge a firm has access to as opposed to all knowledge available in an economy) in chapter 6. The spillover measure constructed in chapters 5 and 6 will then be used to estimate the impact of knowledge spillovers on the decision to cooperate in R&D in chapter 7. Chapter 8 will conclude and provide some suggestions for future research.

2 The Relationship between Knowledge Spillovers and R&D Co-operation: A Review of Related Theoretical and Empirical Literature [3]

The link between spillovers and R&D partnerships[4] has been analysed from a variety of perspectives. Researchers have provided insight into the formation, development and effects of R&D co-operation as well as the rationale behind their formation using theoretical models from game theory, transaction cost theory and the resource based view. Empirical research has shown that the link between spillovers[5] and incentives to form R&D partnerships actually exists. The empirical evidence and theoretical models developed will be reviewed below. Considerable attention will be given to the review of the non-tournament literature since this strand takes the link between spillovers and R&D partnerships most directly into account. The resource based view and transaction cost theory are more concerned with the explanation of the existence of R&D co-operations than the impact of spillovers. They provide some insight into the motives for R&D co-operation, however, and will thus be included in this review.

The review of the empirical literature will focus on empirical studies based on innovation surveys in many European countries, most prominently the Cassiman

3 The literature cited here only focuses on the role of knowledge and R&D spillovers as a motive for firms to form research partnerships. Other motives for R&D co-operation will be discussed in the empirical parts of this study (see Section 7.1). Empirical as well as theoretical studies related to certain topics and concepts relevant for our study, like absorptive capacity and the generation of R&D stocks, will be discussed in the sections and chapters dealing with them. Macroeconomic papers are beyond the scope of this work. For other reviews of the microeconomic literature see De Bondt (1996), Hagedoorn et al. (2000), Caloghirou et al. (2003), Veugelers (1998).

4 The terms “R&D partnership” and “R&D co-operation” will be used interchangeably in this study. As will become clear in section 2.5 many forms of R&D partnerships exist and researchers have used the term “R&D co-operation” for many different types. A detailed description of the concept I use for the empirical part of the study will be given in section 3. Unless otherwise noted the term “co-operation” refers to R&D co-operation and not co-operation in general.

5 The term “spillover” stands for R&D spillovers and knowledge spillovers alike. A delineation of different concepts will be given in section section 2.5.

and Veugelers (2002) paper and the empirical studies following their approach. Some empirical studies using databases other than innovation surveys will also be included in the review.

The review chapter will conclude by providing an overview of different definitions, concepts and terminology used in the literature for R&D partnerships and R&D spillovers.

2.1 Industrial Organisation Theory

Industrial organization is a branch of the neoclassical literature and analyses and explains the behaviour of firms on the market. From the neo-classical point of view firms are described by their production and cost functions and react to changes in the market environment. They also shape the market structure with their behaviour. To analyse R&D partnerships and their effects on the market, R&D spending and social welfare, two game theoretic approaches have been employed in the theoretical industrial organization literature: non-tournament and tournament models.

2.1.1 Non-Tournament Models

Non-tournament models are the theoretical models that take into account the relationship between research joint ventures (RJV)/R&D co-operation and spillovers most directly.

They all have a similar structure and are usually set up as follows:

- Firm operate in an industry whose structure can be described as a duopoly/oligopoly.
- Competition can be described by a Nash Game.
- There are two stages to the game, the product market stage (2^{nd}) and R&D activities stage (1^{st}). Firms compete or cooperate/collude in one or both.

- There are different research paths available to every firm to come up with a certain degree of cost reduction or demand increase through high-quality products. “An equivalent amount of R&D spending will generate an equivalent reduction in production costs or enhancement in demand”. (De Bondt, 1996: 10). As a consequence each firm in an industry can reach a level of cost reduction or demand increase equal to that of its competitors by spending the same amount on R&D as its competitors (Katsoulacos and Ulph, 1990).
- R&D investment in the 1st stage influences the (aggregate) output or the prices in the 2nd stage through cost reductions or increases in demand and thus impacts welfare.
- If firms cooperate they choose an R&D level that maximizes joint profits at the output stage.

As far as spillovers are concerned, a fundamental assumption of almost all the non-tournament models dealing with RJVs is that spillovers are a source of market failure[6], because they reduce the private incentive to invest in R&D (see e.g Spence, 1984; Katz, 1986; Teece, 1986; De Bondt et al., 1992; Suzumura, 1992; Levin and Reiss, 1988) below the socially desirable level (Dasgupta and Stiglitz, 1980; Beath et al., 1998; Bernstein and Nadiri, 1989). These spillovers occur because of the public good character of knowledge (Arrow, 1962a; Jaffe, 1986; Liebeskind, 1997; Hagedoorn et al., 2000).

R&D co-operation is seen as one way to internalize the spillover arising from R&D activities and consequently to correct the market failure associated with spillovers (Beath et al., 1998; De Bondt et al., 1992; D'Aspremont and Jacquemin, 1988). In order to implement spillovers in non-tournament models research-

6 That spillovers can cause market failure is not specific to knowledge spillovers, but rather a generally accepted fact (Rosen, 2002; Baumol, 1982). Bernstein and Nadiri (1989) show empirically that in the presence of R&D spillovers the social return on R&D is higher than the private return on R&D in each industry they studied.

ers assume, that the cost reductions achieved by one firm through investment in R&D, positively affect the cost reduction of other firms.[7] The total cost reduction for firm i is thus a function of firm i's own R&D investment and spillovers, which are in turn a function of firm j's R&D investment.

The model by D'Aspremont and Jacquemin (1988; 1990) has been the most influential in this area of theoretical research and can serve as a role model of the non-tournament literature's treatment of research joint ventures.

The main goal of D'Aspremont and Jacquemin (1988; 1990) was to analyse the effect of research joint ventures on social welfare in a two stage game. The game is carried out in a duopoly where firms decide in the first stage on R&D spending levels (x_i; x_j) and in the second stage on the quantity of production (q_i; q_j). The authors compare four different settings: (1) competitive behaviour of both firms in both stages, (2) co-operation in the first stage and competitive behaviour in the second stage, (3) co-operation in both stages ("monopoly"), and (4) the first-best solution where social welfare W is maximized. The inverse demand function for the market is given as

$$D^{-1}=a-b(q_1+q_2)$$

with q_i the quantity produced by firm i. Firms are described by their cost function C which has the following form:

$$C_i(q_i, x_i, x_j) = [A-x_i-ßx_j]q_i \text{ for } i=1,2 \text{ and } i\neq j$$[8].

The cost of production of output q_i is thus given as a function of a firm's own R&D spending and R&D spending of the other firm in the market, which spills over (see Levin and Reiss, 1984). The magnitude of the spillover is determined by the value of ß which is larger than zero (no spillovers at all) and smaller than 1 (perfect spillovers). Their main finding is that for spillover levels (ß) larger

7 This type of relationship has been proposed among others by Dasgupta and Stiglitz (1980), Levin and Reiss (1988) and Levin and Reiss (1984).

8 A number of conditions for the parameters have to be satisfied: a,b>0; 0<A<a, 0<ß<1; $x_i-ßx_j \leq A$; $q_1+q_2 \leq a/b$ (see D'Aspremont and Jacquemin, 1988: 1133)

than 0.5 the aggregate (cooperative) level of R&D spending is higher than in the non-cooperative case[9], in contrast to their expectation that R&D levels would drop because of the reduction of duplicative research and competition moving closer to the monopolistic type.[10] What is more, for large spillovers the aggregate output of the duopoly is also higher in the case of co-operation in the first-stage than in the non-cooperative case.[11] D'Aspremont and Jacquemin (1988; 1990) suggest that if profits are higher in the cooperative case as well, this might give rise to private incentives for co-operation without any public policy intervention.

The basic framework has been extended in a variety of ways[12]: Authors analyse oligopolies instead of duopolies, differentiated products instead of homogenous products, Bertrand instead of Cournot competition in the product market stage, and product innovations instead of process innovations. Other extensions include splitting up the first stage (R&D) into separate stages and introducing upstream industries with vertical spillovers and co-operation.[13]

---

9 Note, De Bondt et al. (1992) find that the cost reduction through R&D is maximized in a homogeneous oligopoly for spillover levels equal to 0.5 and in a differentiated oligopoly with many rivals for spillover levels between 0.5 and 1. They also find that "spillovers that maximize effective R&D also maximize firm output, consumer surplus and profits from production." (De Bondt et al., 1992: 46).

10 For smaller values of $ß \leq 0.4$ the results change. In this case, the aggregate R&D spending level is only higher in the cooperative than in the non-cooperative stage if the two firms cooperate in both stages of the game.

11 Again, for smaller values of $ß \leq 0.4$ the results change. In that case, the aggregate output level is always higher if the two firms do not cooperate.

12 Google Scholar (http://scholar.google.com/ (Google Scholar, 2006) a search tool for scientific articles listed 501 papers and articles that cite D'Aspremont and Jacquemin (1988) on February 1st, 2006. To review them all would be beyond the scope of this mainly empirical study. The subsequent paragraphs will thus sketch the main extensions and deviations from the D'Aspremont and Jacquemin model only exemplarily.

13 Other authors have extended the model but also shifted the focus to other aspects of the R&D process and R&D co-operation formation. They include, Yi and Shin (2000), Poyago-Theotoky (1995) (number of research partners) and Hinloopen (1997) (subsidizing R&D vs. allowing R&D co-operation). These aspects are not relevant for our empirical study and will thus not be discussed in detail.

Suzumura (1992) considers an industry containing n firms which all produce a homogeneous product. His inverse demand function consequently depends on the total amount of output produced and can be written as p=f(Q), where p is the price and Q the aggregated output. Suzumura (1992: 1312, 1314) further extends the model of D'Aspremont and Jacquemine by evaluating the outcome of cooperative R&D not only with respect to the first best welfare solution

$W^F(x):W(x, q^F(x))$

but with respect to a second best welfare solution

$W^F(x):W(x, q^N(x))$

where $q^F(x)$ is the "socially first-best output profile corresponding to x" (Suzumura, 1992: 1312) and $q^N(x)$ "is the second-stage Cournot-Nash equilibrium [output] given x" (Suzumura, 1992: 1310). His results show that neither non-cooperative nor cooperative R&D behaviour (1st stage) leads to (first- or second-best) socially desirable R&D levels. Regardless of the level of spillovers, cooperative R&D leads to R&D levels below the socially desirable level (the same result was found by D'Aspremont and Jacquemin, 1988). Non-cooperative behaviour leads to underinvestment as compared to the socially optimal levels if spillovers are high. If spillovers do not exist, non-cooperative R&D leads to overinvestment. Suzumura (1992) also shows that the D'Aspremont and Jacquemin (1988) result - that cooperative R&D outperforms the non-cooperative case if spillovers are significantly higher - holds in his setting.

One paper related to Suzumura (1992) is by Simpson and Vonortas (Simpson and Vonortas, 1994). They also analyse the R&D investment levels in competitive and cooperative R&D scenarios. Their contribution to the non-tournament literature is that they use more general demand functions than D'Aspremont and Jacquemin (1988) analyse oligopolies and make no functional assumption about the spillover effect. Instead the spillover is included in their model by specifying that the derivative of the cost function of firm i with respect to R&D expenditure of firm j is non-negative. Simpson and Vonortas (1994) find that even in the absence of spillovers, a RJV will spend more on R&D than individual firms, given demand is concave. If demand is linear cooperative R&D expenditure is increasing in the level of spillovers.

Kamien et al. (1992) extent the D'Aspremont and Jacquemin (1988) framework in several ways, they introduce Bertrand competition in the product market and analyse oligopolies instead of duopolies. In contrast to Suzumura (1992), their model also allows for differentiated products. The basic spillover process is similar in D'Aspremont and Jacquemin (1988) and Kamien et al. (1992): R&D spending reduces costs and the results of R&D can spill over to competitors. Spillovers can have two different effects according to Kamien: The "competitive-advantage externality" (Kamien et al., 1992: 1294), which arises because the spillover reduces competitors' costs and thus intensifies competition, and the "combined-profit externality" (Kamien et al., 1992: 1295). The latter occurs because one firm's investment affects the profits of all other firms through cost-reducing spillovers. The equation including spillovers is the one for effective R&D, which is defined as "firms i's effective R&D investment, that is, the amount of money it alone would have had to invest in R&D, if no other firm invested in R&D, to achieve the same unit cost reduction." The equation looks like this (Kamien et al., 1992: 1297):

$$X_i = x_i + \beta * \sum x_j$$

x_i is the total amount firm i spends on R&D and β the share of other firms' R&D that spills over to firm i. Kamien et al. (1992) analyse four different scenarios which can be distinguished by the level of spillovers and the type of competition. The authors assume that the level of spillover changes with the type of cooperative partnership formed. In the D'Aspremont and Jacquemin (1988) model, the level of spillovers is fixed regardless of firms cooperating or not. The first dimension along which the scenarios in Kamien et al. (1992) are evaluated are thus spillovers. In a research joint venture (RJV) spillovers are (deliberately) perfect (β=1). The opposite scenario is labelled "R&D" and stands for the case in which only involuntary spillovers occur and β is between zero and one. The second dimension of the scenarios is competition, if firms do not coordinate their R&D activities at all this is called "competition", if they do coordinate their R&D Kamien et al. (1992) call it "cartelization". The extreme cases are then R&D competition and RJV cartelization, with R&D cartelization and RJV competition as mixed forms. They identify the RJV cartelization mode (close co-operation) as the most desirable from a social welfare perspective and the RJV competition mode as the least desirable if spillovers are sufficiently high, regardless of the type of competition (Bertrand or Cournot) assumed for the product market. RJV competition leads to the lowest prices and the highest profits for individual firms and consequently to the highest total welfare (consumer plus producer surplus) if spillovers are significantly high. Kamien et al. (1992) argue that R&D cartelization outperforms R&D competition if the rate of spillovers between partners is high enough. They also show that regardless of the agreement on spillovers (full sharing or only involuntary spillovers) it is better for firms - in terms of profits - to cooperate than not.

Katz (1986) proposes a model using a non-tournament game with four different stages: at the first stage firms decide if they want to join a co-operation (membership stage), in the second stage they decide on the specific form the cooperative agreement will take in terms of R&D output and/or cost sharing (agreement stage), at the third stage R&D is conducted by each firm independently (development stage) and finally at the fourth stage the level of output is determined (production stage). Spillovers occur because R&D expenditure by one firm lowers the production costs of other firms. Unlike in D'Aspremont and Jacquemin (1988; 1990) the spillover rate changes, i.e. it is endogenously determined by the partners in the agreement, if the firms are part of a cooperative agreement. The spillover rate changes because they choose a cost-sharing rule in the second stage that leads to a level of R&D in the third stage that maximizes profits. Katz (1986) argues that no firm would have an incentive to leave an industry-wide cooperative agreement if the spillover level for non-cooperating firms is equal to zero. If non-cooperative spillover levels are equal to one (perfect spillovers) no firm would have an incentive to conduct R&D, because if R&D were beneficial, firms would move to an industry–wide agreement. An industry-wide R&D co-operation is found to lead to more R&D and consequently higher social welfare if competition on the product markets is low, non-cooperative spillover levels are high and the R&D agreement focused on basic research. The last finding is driven by the assumption that basic research results are more likely to spill over to competitors than results from development R&D, even if the firms do not cooperate.

Katsoulacos and Ulph (1998) model is not a non-tournament model in its pure form, as it does not include a demand equation.[14] In the Katsoulacos and Ulph (1998) model the profits firms make are exclusively dependent on R&D expenditure. They see their paper as an extension of the Katz (1986) study and are mainly concerned with the amount of knowledge shared between firms, with or without co-operation. Besides endogenous spillovers they allow for multiple research labs, consider product and process innovations and intra- and inter-industry spillovers. The level of spillovers in Katsoulacos and Ulph depends on "the adaptability of the research to the other firm […] and the amount of information sharing" (Katsoulacos and Ulph, 1998: 335) or the technical substitutability or complementary between R&D results. If firms form a research joint venture they maximise joint profits but do not (necessarily) fully share all knowledge (in contrast to Katz, 1986). If firms operate in the same industry, spillovers to rivals will result in lower profits than no spillovers if they operate in complementary industries the opposite will be true. The game is played in three stages: First firms choose their R&D strategy, which determines how easily their findings can

14 Because it is possible to implement cases in their model in which only one firm innovates this model could also be considered a tournament model. Since they claim to extend the study by Katz (1986) and compare their findings with his study I included their paper in this section. What is more, they do not explicitly model the race, but assume (exogenously) that one firm becomes the leader and the other the follower.

be adapted by other firms. In the second stage the level of R&D spending is determined, before firms decide in the third stage on how much of the discovery should be shared with the other firm. The outcome of the model depends on whether both firms innovate or just one and whether the two firms operate in a single industry or in complementary industries. Katsoulacos and Ulph (1998) show that firms operating in complementary industries may share all their knowledge even in the absence of any cooperative agreement, regardless of whether one or both firms are successful with their R&D activities. Consequently, a cooperative agreement cannot improve on knowledge sharing. The only scenario in which the cooperating firms (definitely) share more knowledge than the non-cooperating ones is in the case where both are successful innovators and from the same industry.

Leahy and Neary (1997) are mainly concerned with developing an optimal policy strategy for R&D. They analyse an oligopoly which has the option to cooperate on the first stage (R&D) and competes in the second stage à la Bertrand or Cournot. As in the other models, the spillover effect is included in the model by introducing a variable for the total amount of R&D spending by all firms in the economy into the cost function of the firm in question. If firms choose their R&D level in a way that maximizes industry profits, they are considered as cooperating by Leahy and Neary (1997). A special focus of their paper is on strategic behaviour ("R&D levels are choosen in the anticipation of their effects in the second stage game" Leahy and Neary, 1997: 648) vs. non-strategic behaviour. Leahy and Neary (1997) find that strategic behaviour reduces the benefits incurred when firms cooperate on R&D. It leads to lower levels of R&D spending and output than in the non-strategic case. As far as co-operation itself is concerned they show that under the assumption that spillovers are strictly positive and no strategic behaviour occurs co-operation is always positive as it increases R&D and output levels compared to the non-cooperative setting. If strategic behaviour is present co-operation leads to higher output, R&D spending and welfare if and only if spillovers are significantly high.

Motta (1992) supports the findings of D'Aspremont and Jacquemin (1988), that when spillover levels are high, co-operation increases welfare. He extends the basic model by analysing innovations that are quality-improving instead of cost reducing. He also allows the spillover parameter to change if firms move from non-cooperative to cooperative behaviour, in a manner similar to Katz (1986). The critical level of spillovers for which co-operation becomes welfare improving is not a fixed value but depends on the relationship between the level of spillovers with cooperative agreements and without and the number of firms in an industry. The main result found by Motta (1992) is that if the spillover level is high enough then "quality level, output, net profits and welfare are higher under cooperative R&D behaviour than under fully non-cooperative behaviour" (Motta, 1992: 655).

Vonortas, 1994 also assumes that the spillover rate can change if firms cooperate. This assumption actually drives his results, as he finds that improved knowledge sharing among members of a joint venture leads to higher welfare even if spillover levels are relatively low and the opportunities for innovative processes are poor. If the spillover level does not change even though firms cooperate (called "secretariat joint venture" Vonortas, 1994: 422), the spillover rate has to be higher than 0.5 in order for the cooperative solution to be better form a social welfare point of view than the non-cooperative. Vonortas (1994) obtains these results, which are similar to those of D'Aspremont and Jacquemin (1988; 1990), even though he splits up the R&D stage into two separate stages, a stage where the firm decides whether to conduct generic research and how much to spend on it and a stage where they spend money on development R&D.[15]

Beath et al. (1998) split the R&D process up into two separate stages. First firms invest in R&D and produce knowledge. In the second stage, this knowledge is used to generate cost reducing innovations. Spillovers can occur at both

15 Vonortas (1994) argues that R&D should not be aggregated, but rather that generic R&D is different from development R&D with respect to spillovers and other characteristics; a fact that will become relevant in the empirical part of this study.

stages. At the first stage a spillover arises from "the effort-increasing effect of being in competition with rival scientist and imparts an element of 'racing' in this non-tournament model" (Beath et al., 1998: 52). At the second stage knowledge spills over from one firm to the other, increasing effective R&D and consequently reducing production costs. They assume that the second stage spillover becomes perfect if firms cooperate. Beath et al. (1998) do not conduct a welfare analysis, but show that RJV can achieve the same level of cost reduction with less R&D expenditure than if the two firms had carried out R&D independently. Their argument for this finding is that research joint ventures can "economize on scarce R&D resources" (Beath et al., 1998: 57).

The modelling of spillovers is the starting point for the theoretical model of Kamien and Zang (2000). They argue that the level of effective R&D, i.e. a firm's own R&D plus R&D spillovers (Kamien and Zang, 2000: 997), depends on the absorptive capacity of the firm (Cohen and Levinthal, 1989) represented by a firm's R&D spending and its R&D orientation (basic vs. firm-specific approach), which influences the spillovers between two firms. In addition the total amount of spillovers also depends on the exogenous spillover level. In their 3-stage game firms first choose their R&D approach, then the amount to spend on R&D and finally the output levels under Cournot competition. Similarly to the aforementioned models, the outcome of the model should now depend on the interplay between the R&D approach and the exogenous level of spillovers. Kamien and Zang (2000) show, however, that joint profits are maximized (given co-operation in the first and second stage) if both firms choose a very broad R&D approach, regardless of the exogenous spillover level. Kamien and Zang (2000) thus conclude that if firms cooperate they choose an equally broad R&D approach in the first stage of the game. They confirm D'Aspremont and Jacquemin's finding that for spillover levels larger than 0.5 social welfare is higher if firms cooperate than if they compete.[16]

16 An empirical application of Kamien and Zang (2000) model can be found in Kaiser (2002a).

General demand and cost functions, product differentiation and price competition are the extensions of the D'Aspremont and Jacquemin (1988) model introduces by Ziss (1994). His aim is to compare four different settings: no co-operation, co-operation at the first stage (R&D joint venture) only, co-operation at the second stage (prices or output) only and co-operation at both stages (“merger”). He challenges the finding by D'Aspremont and Jacquemin (1988), that joint ventures are mutually beneficial if spillovers are high.[17] Ziss (1994) argues that due to “offsetting internalisation of R&D spillover and strategic effects” (Ziss, 1994: 377) cooperative R&D is no guarantee for increased social welfare if high spillovers are present. His finding rests on the assumption that research joint ventures have a negative strategic effect, i.e. that firms involved in a R&D joint venture try “to move along the contract curve from the joint-profit-maximum point to the monopoly point.” (Ziss, 1994: 376).[18] If this is the case collaborative firms will reduce joint R&D in order to reduce output (Cournot competition) or increase prices (Bertrand Competition), which leads to a negative effect of co-operation on R&D and consequently social welfare. Ziss (1994) makes the point that the findings of D'Aspremont and Jacquemin (1988) for co-operative R&D are driven by their assumption of linear demand functions with homogenous products.

The studies mentioned above deal exclusively with a single industry and analyse only inter-industry R&D partnerships (with the exception of Katsoulacos and Ulph, 1998). This shortcoming has been addressed by Banerjee and Lin (2001), Inkmann (2000) and Steurs (1995).

Banerjee and Lin, 2001 introduce an upstream firm that produces inputs for downstream firms and allows for cost-reducing spillovers between firms in the

17 However, Ziss (1994) supports D'Aspremont and Jacquemin (1988), as he shows that D’Aspremont and Jacquemines’s findings with regard to the monopoly case are robust to the specification of the cost and demand functions.

18 This is in contrast to most other non-tournament studies, which assume that R&D co-operation is intended to achieve the joint-profit maximizing R&D levels.

same industry and between the two industries. They extend their model further by allowing oligopolistic competition in both the upstream and downstream markets. Even though spillovers play a role in determining the outcome of the model in terms of the optimal size of the research joint venture, Banerjee and Lin (2001) provide no explicit analysis of how the transmission works. They just state that the positive externality created by upstream firms' R&D activities poses an incentive for upstream firms to "invite downstream firms to join in the R&D and share the cost of innovation" (Banerjee and Lin, 2001: 288).

Inkmann (2000) addresses the relationship between inter-industry spillovers and R&D investment under co-operation and competition more directly. He identifies a "spillover parameter space", i.e. combinations of inter- and intra-industry spillover levels, for which R&D investment levels and firms' profits are higher in the (vertical or horizontal) co-operation scenarios than the non-cooperative ones. He finds that for a large spillover parameter space, vertical co-operation ("one downstream firm cooperates with one upstream firm" Inkmann, 2000: 13) is the most profitable form of conducting R&D. His study is very similar to that by Steurs (1995).

Steurs (1995) extends the D'Aspremont and Jacquemine model by introducing two industries, each consisting of two firms. Given this setting he allows spillovers and co-operation both within an industry and across industry borders. Similar to the findings by Inkmann (2000) he shows that the interplay of intra- and inter-industry spillovers is important in determining the profitability and welfare effects of R&D partnerships. To be more precise, he finds that intra-industry co-operation profit-levels are higher than non-cooperative profit levels if inter-industry spillovers are higher than zero and intra-industry spillover levels are larger than 0.5. If intra-industry spillover levels fall below 0.5, the inter-industry spillover level has to be small to guarantee the stability of the R&D co-operation. If no intra-industry spillovers exist, intra-industry R&D is always more profitable for firms than non-cooperative behaviour. Inter-industry R&D co-operation is only less profitable than R&D competition if both intra- and inter-industry spillovers are small. Comparing both forms of cooperative agreements Steurs (1995) shows that "inter-industry R&D co-operation is more likely to result in higher R&D investment, output and welfare than intra-industry R&D co-operation" (Steurs, 1995: 268).

Kesteloot and Veugelers (1994) focus on the stability of R&D co-operations formed in a repeated non-tournament model. If firms deviate from the agreement, they face punishment in the form of lower profits in future periods than they would have gained through co-operation. Not only is the repeated structure of the game different from other studies, but so is the treatment of spillovers. In Kesteloot and Veugelers (1994) model there are "unintended (exogenous) spill-overs", which exist because knowledge is not perfectly appropriable, and "intended (endogenous) spillovers" due to knowledge sharing among partners in an agreement. They find that "cooperative profits are higher with large positive (exogenous, unitended) knowledge spillovers" (Kesteloot and Veugelers, 1994: 651). The stability of a cooperative agreement is higher with lower spillovers (if firms products are substitutes), however. If cooperating firms can improve on knowledge sharing within the agreement (intended spillovers), they are able to reduce the incentives to cheat.[19]

Kesteloot and Veugelers (1994) build in dynamic aspects of the co-operation decision by repeating the non-tournament game infinitely. Rosenkranz (1995) takes this one step further in her model, which is hard to classify as either a non-tournament model or a tournament model. It can serve as a case that bridges both strands of literature. The analysis is conducted in a duopoly setting where firms invest in R&D in order to speed up the innovation process and to improve the quality of their products. If the two firms cooperate they maximize joint profits by sharing all of the know-how developed in the R&D process, i.e. spillovers

19 De Bondt and Veugelers (1991) find in a similar setting that after a certain threshold of spillovers is reached, additional knowledge spillovers increase the incentive for firms to conduct R&D in co-operation with others. Hagedoorn et al. (2000) writes that "R&D co-operation performs considerably better […] the higher the rate of knowledge spillovers" (Hagedoorn et al., 2000: 574).

between partners are perfect. They then compete in the product market in Bertrand competition. Rosenkranz (1995) shows that firms will always form a R&D partnership since joint profits are higher than if they did not cooperate. This result holds even in the absence of ex-ante (pre-cooperative) knowledge spillovers. The incentive comes from "competitive spillovers" (Rosenkranz, 1995: 14), i.e. the innovation of one firm will affect the other firm's profit negatively because of competition in the product market. If both firms cooperate, they are able to internalize this spillover by monopolizing the market and sharing the total profit obtained equally. Because of the monopolistic market after co-operation, consumer surplus decreases compared to the non-cooperative stage and, the total welfare effect becomes negative (Rosenkranz, 1995: 14-16).

To summarize: The non-tournament literature in all of its facets clearly shows that spillovers have an effect on firms' decisions to cooperate. This is because co-operation not only increases social welfare under certain circumstances (including the spillover level), but also provides the firms with an opportunity to maximize their joint profits.

The reasons provided for the superior performance of research partnerships are:

- R&D co-operation internalizes spillovers and thus increases the incentive to undertake R&D investment, which leads to higher levels of R&D expenditure in the cooperative case than in the non-cooperative case (e.g. D'Aspremont and Jacquemin, 1988; Katz, 1986; Suzumura, 1992; De Bondt and Veugelers, 1991; Kamien et al., 1992; Motta, 1992). As a result of the higher R&D investment level and because the relationship between R&D and cost reduction or product improvements is assumed to be the same for both cooperating and non-cooperating firms (Beath et al., 1998), the total cost reduction or quality improvement of cooperative R&D is higher than in the non-cooperative case or as Kamien et al. put it "unit costs tend to decline more with R&D cartelization than with R&D competition" (Kamien et al., 1992: 1294).

- Firms co-operating on R&D can achieve the same amount of cost reduction or similar quality with less R&D expenditure (e.g. Simpson and Vonortas, 1994; Motta, 1992).
- Cooperative R&D levels can be chosen in a way that maximize joint profits (e.g. Kesteloot and Veugelers, 1994; Suzumura, 1992 ; Vonortas, 1994; Katsoulacos and Ulph, 1998)
- R&D co-operation reduces needless duplication of research efforts (e.g. Beath et al., 1998; Kamien et al., 1992; Katz, 1986; Poyago-Theotoky, 1995; Rosenkranz, 1995)

Table 2-1 Main Findings on the Link Between Spillovers and R&D Co-operation in the Non-Tournament Literature

Author	**# Stages**	**Industry**	**Spillovers**	**Product Market Competition**	**Main Finding**
Katz (1986)	4-stage	Oligopoly	Cost-reducing R&D, endogenous[20]	Cournot, Homogenous products	Industry-wide co-operation is welfare improving if spillovers without co-operation exist or spillovers within agreements are high.
D'Aspremont and Jacque-min (1988)	2-stage	Duopoly	Cost-reducing R&D, exogenous	Cournot, Homogenous products	For significantly high spillovers coop-erative R&D leads to higher output, higher R&D spending and higher wel-fare than non-cooperative behaviour.
Kamien et al. (1992)	2-stage	Oligopoly	Cost-reducing R&D, exogenous	Bertrand/Cournot, Heterogenous prod-ucts	For significantly high spillovers, R&D co-operation and coordination leads to higher firm profits than in the non-cooperative case.

20 “Endogenous” means that the spillover rate is assumed to be higher (most times equal to 1) if firms cooperate, than if they do not.

Author	**# Stages**	**Industry**	**Spillovers**	**Product Market Competition**	**Main Finding**
Motta (1992)	2-stage	Oligopoly	quality-improving R&D, endoge-nous	Cournot, Heterogenous prod-ucts	For specific spillover ranges R&D co-operation leads to higher output, prof-its, quality and welfare.
Suzumura (1992)	2-stage	Oligopoly	Cost-reducing R&D, exogenous	Cournot, Homgeous products	Cooperative R&D outperforms the non-cooperative case if spillovers are sig-nificantly high.
Simpson and Vonortas (1994)	2-stage	Oligopoly	Cost Reducing R&D, endogenous	Cournot, homogenous products	RJV will spend more on R&D even in the absence of spillovers than individ-ual firms.
Kesteloot and Veugelers (1994)	2-stage	Duopoly	Cost-reducing R&D, endogenous and exogenous	Cournot, homogenous products	Profits of cooperating firms are higher if unintended spillovers are large. In-creasing endogenous spillovers through knowledge sharing leads to more stable co-operations.

Author	# Stages	Industry	Spillovers	Product Market Competition	Main Finding
Vonortas (1994)	3-stage	Duopoly	Cost-reducing R&D, endogenous	Cournot, Homogenous products	If spillovers are high, R&D co-operation is beneficial. If firms improve knowledge sharing within a RJV it is beneficial at low levels of spillovers as well.
Ziss (1994)	2-stage	Duopoly	Cost-reducing R&D, exogenous	Bertrand/Cournot, Heterogenous products	Cooperative R&D does not necessarily increase welfare, output or R&D expenditure.
Rosenkranz (1995)	2-stage	Duopoly	Knowledge spillovers and competition spillovers, endogenous	Bertrand, Heterogenous products	If firms share all knowledge generated through R&D in a cooperative agreement, they will monopolize the product market and profits will be higher than if they compete.

Author	# Stages	Industry	Spillovers	Product Market Competition	Main Finding
Steurs (1995)	2-stage	Duopoly	Cost-reducing R&D, exogenous	Cournot, Homogenous products (upstream and downstream firms)	Intra-industry co-operation is more profitable than competitive R&D if inter-industry spillovers are small or equal to zero. Inter-industry co-operation is only less profitable than R&D competition if both types of spillovers are small.
Leahy and Neary (1997)	2-stage	Oligopoly	Cost-reducing R&D, exogenous	Bertrand/Cournot, Homogenous products	Cooperative R&D raises output, R&D and welfare if firms behave non-strategically. If firms behave strategically, spillovers need to be significantly high to lead to the same outcome.
Beath et al., (1998)	3-stage	Duopoly	Cost-reducing R&D, endogenous	Cournot, Homogenous product	Co-operation increases the level of spillovers and as a result helps firm to reach the same level of cost reduction with less R&D expenditure.

Author	# Stages	Industry	Spillovers	Product Market Competition	Main Finding
Katsoulacos and Ulph (1998)	3-stage	Duopoly	Knowledge Spill-overs, endogenous	No product market	R&D co-operation does not necessarily lead to higher knowledge sharing than non-cooperative behaviour
Inkmann (2000)	3-stage	Oligopoly	Cost-reducing R&D, exogenous	Cournot, Homogenous products (upstream and downstr. firms)	For a wide spillover parameter space firms' profits are higher if they cooperate vertically than if they cooperate horizontally or not at all.
Kamien and Zang (2000)	3-stage	Duopoly	Cost-reducing R&D, endogenous with absorptive capacity	Cournot, Homogenous products	Total welfare is higher if firms cooperate than if they compete, for spillover levels above .5. If firms cooperate they choose broad R&D approaches.
Banerjee and Lin (2001)	2-stage	Oligopoly	Cost-reducing R&D, exogenous	Cournot, Homogenous products (upstream and downstream)	Positive externalities arising from upstream firms' R&D provide incentives to form joint ventures with downstream firms

Source: Own illustration

2.1.2 Tournament Models

"Technological competition often has several of the characteristics of a race." (Grossman and Shapiro, 1987: 372). This is the basic assumption of the tournament literature, which is concerned with the timing of innovation, the number of firms involved in the tournament and the dynamics of R&D expenditure during the tournament (Reinganum, 1989). The success and timing of innovation activities in these models basically depends on the amount of R&D spending on the part of the firms taking part in the tournament. The firm that spends most on R&D wins the tournament and is awarded the (eternal stream of) profits from it (Reinganum, 1989). The reason for this is that in contrast to the non-tournament models only one research path for any given innovation exists (Katsoulacos and Ulph, 1997, Hagedoorn et al., 2000) and the first to complete it wins the game. There are models in which the relationship between R&D investment and the date of success is deterministic ("auction models") in others it is stochastic ("racing models") (see Reinganum, 1989 for examples of both types of models). Since the tournaments analysed have only one winner, the profits from an innovation go to only one firm[21] even though all firms in the tournament have spent some amount on R&D while the race was still on. The common verdict of tournament models is thus that firms (on aggregate) over-invest in R&D (see Katsoulacos and Ulph, 1997; Hagedoorn et al., 2000). In the words of Jennifer Reinganum "… aggregate expenditure on R&D is too high relative to the cooperative optimum; there are too many firms and each invests too much." (Reinganum, 1989: 850). Katsoulacos and Ulph (1997) argue that the reason for this market failure is as follows: since the total profits from the innovation are awarded to the firm that invests more in R&D than its rivals, the incentives for firms to undertake innovation activities are higher than socially desirable.

21 There are some exceptions: Martin (2002) for example argues that some of the profits from the innovation will spill over to losers of a racing model, if appropriability is not perfect.

As in the case of non-tournament models R&D co-operation and research joint ventures are seen as a way to overcome this market failure at least partially, by allowing the firms to coordinate their R&D activities. Whether R&D co-operation is mutually beneficial from the viewpoint of the firms or a social planer depends on the specific settings of the model. Grossman and Shapiro (1987) for example find that certain forms of co-operation (licensing, intermediate-stage patents and research joint ventures) lead to higher expected profits[22] only in environments where competition would have been fierce without co-operation.

The relationship between R&D co-operation and spillovers in tournament models has been studied by Choi (1993). He analyses a duopoly where the results of R&D activities by one firm can be used by the other firm to a certain degree. One of his central assumptions is that co-operation increases the spillover rate between the partners. Choi (1993) results are quite similar to those of the non-tournament literature. He finds that firms have an incentive to conduct R&D co-operatively if the spillover rates are high.[23] An additional result is that the social incentive for R&D co-operation is higher than the private one.

Martin (2002) arrives at a different result for the private incentive to form a research joint venture. He shows that “secretariat RJVs” (firms carry out independent R&D activities, but share the results afterwards - Martin, 2002: 15) are more likely if the spillover level without co-operation is low. The reason for this finding is that the benefit of forming a RJV is assumed to be an increase in spillovers received, compared to the non-cooperative case. Martin (2002) assumes that the firms engaging in a secretariat RJV will fully share their research findings, i.e. spillovers are perfect. If the level of spillovers without the cooperative agreement is high already the benefit from cooperating will be low and consequently so will

22 Grossman and Shapiro (1987) give two reasons for this finding: first, RJVs reduce rivalry and second they reduce duplicative R&D activities.

23 Some doubts remain about the robustness of Choi’s results, as he himself writes “It is possible to construct examples where cooperative R&D agreements are preferred […] for low spillover rates.” (Choi, 1993: 563).

the private incentive to form R&D joint ventures. As far as social welfare is concerned, Martin (2002) argues that cooperative R&D activities always lead to higher social welfare than non-cooperative R&D and that under certain settings (e.g. high spillovers) firms have less incentive to form RJVs than would be desirable from a social point of view. The difference between the findings of Martin (2002) and those of the non-tournament literature can be explained by a different focus: Martin (2002) assumes that the main goal of a firm is to increase "input spillovers", i.e. knowledge spilling over from its rivals, while the non-tournament literature is more concerned with the effect of outgoing spillovers, i.e. knowledge a firm has generated through R&D spilling out into the public domain.

Reinganum (1981) looks at spillovers during a race between two identical firms. The R&D activities of firms are accompanied by knowledge spillovers if they cooperate. These spillovers contribute to the accumulated knowledge of both firms and allow them to reach given levels of knowledge at a lower cost than under competition. She finds that without spillovers the non-cooperative firm innovates earlier than the cooperative one and with perfect spillovers the opposite is true. For spillover levels in between these two extreme cases it is not per se clear whether cooperative or non-cooperative R&D leads to earlier innovation. The time of innovation rather depends on other factors, like the value of the innovation or the discount rate for revenue streams generated through the innovation and patent assigned to it.

A different type of spillovers is analysed in the study by Marion Stewart (1983). She investigates spillovers that occur because an innovating firm is not able to appropriate all of the value of its discovery. De Bondt (1996) labels spillovers of this type "post-racing" because they arise after the race is over (De Bondt, 1996: 6) in contrast to spillovers that occur during the race. Each firm in the oligopoly gains similarly from the spillover. Stewart (1983) finds that the choice of firms' exploration rates (R&D effort) depends critically on the spillover parameter. If the (exogenously given) spillover level is below the spillover level that would maximize firms' profits, non-coopertive R&D efforts will be lower than cooperative ones. De Bondt (1996) sees this as an indication that a critical spillover level exists above which cooperative outcomes are better than non-cooperative ones.

2.2 Transaction Cost Theory

While tournament and non-tournament models primarily explain and analyse the effects of cooperative behaviour and spillovers on social welfare, the transaction cost theory is more concerned with the existence and origin of cooperative R&D activities.

The theory of transaction cost can be traced back to Coase (1937), who argues that transaction costs cause market failure and firms exist because they help to reduce the cost of transactions (see also Williamson, 1975). The classical question related to that branch of literature is the make-or-buy decision of the firm, i.e. whether transactions should be organized and carried out through market mechanisms or through internal organization and hierarchical relations. From the viewpoint of transaction cost (TC) theory firms will not only minimize production costs but also the costs of conducting transactions (Williamson, 1975; Williamson, 1985). Transaction costs include among other things the costs of drawing up, monitoring and enforcing contracts and the costs of performing a transaction (Kogut, 1988). The level of transaction costs (and consequently the form of governance chosen) is largely determined by asset specificity (Caloghirou et al., 2003), i.e. "the degree to which an asset can be redeployed to alternative uses and by alternative users without sacrifice of production value." (Williamson, 1988: 70). Asset specificity increases transaction costs because it can cause opportunism and augments the problems of small numbers bargaining. In addition to this, incomplete contracts are seen as a source of high transaction costs. Because of the nature of technological knowledge, i.e. it gives rise to spillovers, its production involves high uncertainty and its dissemination sometimes leads to opportunistic behaviour, contracts including technological knowledge (or intangible assets in general) will tend to be incomplete (see Hagedoorn et al., 2000; Caloghirou et al., 2003).

Up until the early 1990s the transaction cost theory analysed only the two extreme cases of organizing transactions, the firm versus the market, as Tsang puts it "the proliferation of […] inter-organizational collaboration […] was […] beyond the explanatory domain of TC theory." (Tsang, 2000: 220). That changed in 1991 when Williamson (1991) published an article in response to the criticism that "transaction-cost economics […] deals with polar forms – markets and hierarchies – to the neglect of intermediate or hybrid forms." (Williamson, 1991: 269). In that article the "hybrid form" of organizing transactions is introduced. It is hybrid in the sense that it is between the market and a hierarchy. Examples for such hybrid forms are co-operation and strategic alliances (Pisano, 1990; Mariti and Smiley, 1983). As for the two classical forms of transacting - hierarchies (firms) and arm's length markets – the choice of hybrid forms is made if the sum of production and transactions costs is lower for the hybrid form than for the other two. The following reasons/conditions for the existence of research joint ventures are identified as having been put forward by transaction costs theory:

- The specificity of assets involved is of an intermediate degree (Tsang, 2000).
- "High uncertainty over specifying and monitoring performance" exists (Kogut, 1988: 320; see also Williamson, 1991).
- The behaviour of the parties involved in the transaction/contract is uncertain, since joint ventures allow the "alignment of incentives to reveal information, share technologies, and guarantee performance" (Kogut, 1988: 320).
- The market for intermediate goods is inefficient (Hennart, 1988)
- The activity to be undertaken is related to technological knowledge (Hagedoorn et al., 2000).

The link between knowledge spillovers and the existence of research joint ventures is not as prominently discussed in transaction costs theory as in the non-tournament or tournament literature. Nonetheless the models and arguments put forward by transaction costs theory provide some evidence that the link exists, by stressing the fact that technological knowledge and the spillovers associated with it are a source of incomplete contracts that favour the existence of hybrid organizational forms such as research joint ventures.

2.3 The Resource Based View of the Firm

The resource bases view of the firm goes back to the seminal work of Penrose (1959). The basic assumption of this strand of strategic management literature is, that a firm's behaviour and competitive advantage can be explained by the valuable, rare, and not easily substitutable or imitable resources and capabilities it possesses[24], which include the knowledge and technological capabilities of a firm (Wernerfelt, 1984; Barney, 1991; Prahalad and Hamel, 1990; Mowery et al., 1998). The aim of any firm is thus to maximize profits by using and improving its resources (Penrose, 1959; Tsang, 2000). This may involve separating resources that are core to a firm from those which are not, and disposing of the latter (Prahalad and Hamel, 1990).

The resource based view has at first sight relative little to say (directly) about the formation of cooperative agreements or research joint ventures. It is possible, however, to interpret the arguments of the resource based literature in light of R&D partnerships and draw some conclusions about how knowledge spillovers are related to the formation of co-operations according to the resource based view (see Tsang, 2000 for examples.). Starting points for this exercise are the papers by Richardson (1972), Barney (1991) and Teece (1986). They argue that it might be necessary for firms to access complementary external resources to exploit their own resources better. This is the case in particular if firms' own resources are immobile. The immobility of a resource may not only stem from physical or cognitive restrictions but also from a lack of willingness on the part of the firm to share them with external partners (see Tsang, 2000: 222). If the former is true firms which want to profit from these immobile resources can cooperate with the firm that possesses the complementary resources (Hagedoorn et al., 2000; Tsang, 2000). Mowery et al. (1998) summarize their discussion of the research based view and partner choice for co-operation by stating "the resource based-view argues that a key motive for the formation of alliances is the desire of participants to acquire capabilities from an external source." (Mowery et al., 1998: 511).

When firms (initially) do not want to share resources, co-operation will only happen if the benefits of co-operation are higher than the expected loss from sharing ones own resources[25]. Tsang (2000) argues that this might very well happen. Technologies and technological knowledge can be seen as a resource of the firms, which is immobile to a certain degree, because it is "specific to the context in which it has been created and adapted" (Cantwell, 1991: 36).

The studies by Mowery et al. (1998) and Cantner and Meder (2006) are mainly empirical. They provide some empirical insight on the theoretical arguments underlying the resource based view theory. These authors look at the decision to co-operate with a specific partner, instead of the decision to co-operate at all in R&D. Mowery et al. (1998) finds that co-operating firms have a high degree of technological overlap than non-cooperating firms. Similarly, Cantner and Meder (2006) confirm their hypothesis that the probability to cooperate is higher if the technological overlap among the potential partners is higher and that "the higher and the more balanced the potential knowledge flows between firms are expected to be the higher is the probability of research cooperation between them." (Cantner and Meder, 2006: 8). In that sense, the authors take a step back

---

24 For a detailed description of the terms "capability" and "resource" see Barney (1991). I will treat the resource and capability based view as one strand of literature, since they are very similar.

25 In the word of Dickson: the "fundamental motive, underlining all other reasons for combining firms' resources and skills, will always be some form of 'gain' to the firm" (Dickson et al., 1991: 148).

from the actual knowledge spillovers and take a look at the prerequisites for knowledge spillovers. They find that if the prerequisites for knowledge spillovers are given, firms are more likely to co-operate.

The literature cited above implies that gaining access to external resources and knowledge is a motive for firms to cooperate. Even though the literature does not specifically distinguish between R&D or innovation co-operations and other types co-operations, it can be seen as further evidence for the argument proposed by Martin (2002) tournament model, that generating knowledge inflows is a motive for firms to cooperate when it comes to innovation and R&D activities.[26]

This point is strengthened by authors analysing the dynamic perspective of resource and capability building (e.g. Prahalad and Hamel, 1990; Hamel, 1991; Teece, 1992). Their findings can be interpreted as follows: Co-operation between firms are undertaken in order to learn from the partners in the cooperative agreement (Caloghirou et al., 2003; Tsang, 2000).

2.4 Empirical Studies

The theoretical literature reviewed above has discussed the effect of spillovers on the likelihood that firms form R&D partnerships. Solid empirical studies on the relationship were relatively scarce up until 2002, when Cassiman and Veugelers (2002) published their paper in the American Economic Review. Veugelers even stated in 1998 that empirical studies on the topic are "virtually non existent" (Veugelers, 1998: 20). Since the publishing of Cassiman and Veugelers (2002) paper empirical interest in the relationship between spillovers and co-operation has been awakened. Several studies dealing directly with this relationship will be reviewed below.[27]

---

26 Note, the resource based view stresses the fact that the external resources and knowledge have to be complementary to ones own in order to generate profits, while the non-tournament literature does not distinguish between complementary or substitutive knowledge.

27 I restrict the overview of the empirical literature to papers that focus directly on the effect of spillovers on R&D co-operation. Some other studies analyse the relationship indirectly, by e.g. talking about

2.4.1 Descriptive Studies

An example for a descriptive study on the link between spillovers and R&D partnerships is Mariti and Smiley (1983), even though they do not use the term spillovers. These authors look at data on cooperative agreements that were announced in the European financial press in 1980 and interviews they conducted with these firms. 70 agreements could be identified and analysed. Mariti and Smiley (1983) find that 70% are related to knowledge sharing, of which 21% include technology transfer (one-directional) and 49% "technological complementarity" , i.e. long term knowledge exchange (Mariti and Smiley, 1983: 440), providing evidence that gaining access to external knowledge is a motive for R&D agreements.

A similar type of analysis is conducted by Veugelers and de Bondt (1992) who supplement their theoretical study of spillovers and R&D investment levels in joint ventures and looser cooperative agreements with a short empirical section. Based on a sample of 161 cooperative partnerships (87 joint ventures, 52 cooperative agreements, 22 mergers) announced in the Belgium's financial press during 1986-1988, they find that the number of joint ventures is significantly (t-tests) higher in industries which can be described as having high knowledge spillovers than in low-spillover industries[28]. Equally, the number of cooperative agreements is also significantly higher in high-spillover industries.

In Felder et al. (1994) the focus is not on analysing the relationship between R&D co-operation and knowledge spillovers directly. Their finding that R&D co-operations are more prevalent in industries where legal protection methods do not provide significant protection of innovations and inventions, can however be seen as an indication that knowledge spillovers and their prevention are a motive for co-operation (see Gottschalk and Licht, 2003).

---

openness (Fontana et al., 2003), screening or signalling (Fontana et al., 2005), or complementarities (Rocha, 1999).

28 "High spillover industries are (tele)communication, semi-conductors, instruments, chemicals, electronics, …" (Veugelers and de Bondt, 1992: 296).

Based on data from the CIS III for Flandern, Veugelers (1998) finds that cooperating firms use all chanels and mechanisms to acquire external information more often than non-cooperating firms. Firms involved in R&D co-operations also assign a significantly higher value to mechanisms used to appropriate knowledge (patents, secrecy, …) than non-cooperating firms. Veugelers (1998) sees these descriptive statistics as an indication that spillovers are an important motive for firms to engage in research partnerships.

2.4.2 Econometric Studies Using Data from Innovation Surveys

One of the earliest econometric studies on the relationship between spillovers and R&D co-operation using innovation survey data was conducted by König et al. (1994). These authors use data from the Mannheim Innovation Panel's first wave of 1993 to analyse size specific spillover effects during 1990 and 1992. Their spillover measure is constructed using a factor analysis of the importance of secrecy, first mover advantages, complexity of design and restrictions on R&D employee turnover as a method to protect innovations. To be able to analyze size specific effect they include separate spillover measures for firms with less than 50, 50-249, 250-999, and 1000 or more employees in their model. They find that only for large firms (1000+) do spillovers have positive and significant influences on the probability of co-operation, for very small firms the impact is even negative. The results of three additional regressions (Tobit, Poisson, and Negbin models) indicate that potential spillovers increase the variety of different co-operation partners.

Wölfl (1998) conducts a similar study also using the Mannheim Innovation Panel of 1993. She distinguishes between R&D co-operations involving firms (with suppliers, competitors and customers) and R&D co-operations in general, which additionally includes research institutions, universities and consultancies. Her focus is on the difference between size-specific spillovers and industry-specific spillovers. Both are calculated using the mean of the importance of various protection methods ranging from patents to secrecy. Her main finding from logit regression models is that for co-operation with firms spillovers are a determinant regardless of size. She also finds that the effect is increasing with size, i.e. for larger firms the internalization of spillovers is a more important motive for co-operation than for smaller firms. Her results also point to the existence of industry effects. She finds that in very competitive industries, like automobiles and electronics, spillovers can be a hindering factor for the formation of R&D co-operations. The explanation provided by Wölfl (1998) for the different effect of spillovers in different industries, is that competitive pressure is not the same across all industries.[29]

Cassiman and Veugelers (2002) added a new dimension to the analysis of the relationship between knowledge spillovers and R&D co-operation, by distinguishing between incoming spillovers and appropriability. The concept of incoming spillovers is used for knowledge the firm acquires from the environment in contrast to appropriability or outgoing spillovers, i.e. knowledge a firm generates and tries to protect from flowing out. They start their analysis by assuming that firms try to manage spillovers. From their literature review they conclud that firms try to maximize incoming spillovers and minimize outgoing spillovers. In order to analyse the effect of spillovers on the likelihood of co-operation in R&D activities, they use data from the Belgian part of the first Community Innovation Survey, conducted in 1993, and focus on innovating firms from manufacturing industries only. To address the problem that spillovers (and some other variables in their model) are endogenous they use a two-step estimation procedure. In addition to one measure for incoming spillover (based on a question of the usage of external sources for information) and one for approbriability (based on a question of protection methods), they include several other variables to control for R&D co-operation motives other than knowledge spillovers. They include variables for

29 For co-operation in general (including universities, etc.), which is treated as a comparison group in the study by Wölfl (1998) the industry-specific spillover variables are no longer significant for most industries and the size-specific spillovers change their signs to negative for small and medium sized firms.

cost and risk-sharing as a motive for R&D co-operation, the need for complementary knowledge, and the size of the enterprise. The main result that Cassiman and Veugelers (2002) obtain by estimating their model with cross-sectional data for 411 firms, is that "incoming spillovers and appropriability have important and separately identifiable effects" (Cassiman and Veugelers, 2002: 1181). They find both a positive relationship between the level of incoming spillovers and the probability of cooperating in innovation activities, and a positive relationship between the level of appropriability and the likelihood to cooperate. In their study Cassiman and Veugelers (2002) also investigate how spillovers may affect the likelihood of cooperating with specific partners. Their results indicate that R&D co-operation with suppliers and customers is not affected by the level of incoming spillovers, but by the level of appropriability. For the probability of cooperating with research institutions the opposite is true.

Kaiser (2002a) uses the German innovation survey of 1996 for the service sector to estimate the impact of horizontal and vertical spillovers on firms' co-operation decision in general and with horizontally (competitors) or vertically (customers and suppliers) related partners. Firms can either form cooperative agreements with one or the other type of partner or with both partners at the same time. Analysing 1,233 firms he finds that horizontal spillovers have a positive (and weakly significant) effect only for the decision to cooperate at all. However, they do not affect the propensity of cooperating with vertically related partners or with both types of partners at the same time. According to Kaiser's (2002a) findings, vertical spillovers do not influence the probability of cooperating in general.

In an earlier study on the manufacturing sector Kaiser and Licht (1998) found the opposite. Using data from the first wave of the Mannheim Innovation Panel conducted in 1993 they find that vertical spillovers increase the likelihood of RJVs significantly. Horizontal R&D spillovers do not seem to have a significant impact on a firm's decision to engage in joint R&D in their model.

The finding that knowledge spillovers might affect different types of R&D co-operation differently has been picked up by Belderbos et al. (2004). They estimate the effect of knowledge spillover on three types of R&D co-operation: co-operation with competitors (horizontal), clients and suppliers (vertical) and universities or other research institutions (institutional). Analogue to this distinction by type of co-operation partner they also distinguish incoming spillovers by the source producing the knowledge and end up with three types of spillovers: horizontal, vertical and institutional. To control for the effect of appropriability they include a variable for outgoing spillovers. In contrast to the Cassiman and Veugelers (2002) study they use the importance of patents and the importance of competitors as a source of information as their measure of outgoing spillovers rather than the importance of protection methods, which can be seen as an indirect measure of outgoing spillovers. Using data from the 1997 and 1998 innovation surveys from the Netherlands they were able to construct a panel data set of 2,156 innovating establishments[30] from both manufacturing and services. Their main results obtained with a systems estimator (multivariate probit) are that vertical spillovers have a positive effect on the probability of cooperating with clients and suppliers and that institutional spillovers affect institutional co-operation significantly. No significant relationship between horizontal spillovers and horizontal co-operation could be found, however.

Lopez (2004) uses Spanish data from the third Community Innovation Survey to analyse the determinants of the probability of cooperating with competitors, suppliers and customers and research institutions on R&D and innovation activities. He estimates several conditional maximum likelihood models with 2,518 manufacturing firms. The results he obtains for the probability of cooperating in general are similar to those found by Cassiman and Veugelers (2002): The incoming and the appropriability variable are positive and significant in all his models. The estimated coefficients for the different types of co-operation partner are different from Cassiman and Veugelers (2002) for the incoming knowledge spillover variable, however. Incoming spillovers only influence R&D co-

30 This is one of the very few empirical studies that use information on the level of establishments in-

operations with research institutions in Lopez's (2004) study. The appropriability variable is only marginally significant positive for the model that explains the probability of cooperating with competitors and strongly positive and significant for the other two types of partners.

While the studies cited above have only looked at one country, Dachs et al. (2004) and Abramovsky et al. (2005) compare the relationship between spillovers and R&D co-operation across countries:

Finish and Austrian data from the third Community Innovation Survey are used by Dachs et al. (2004) to analyse the motives firm have to form cooperative R&D partnerships with other firms and institutions. The sample used in that study is restricted to the manufacturing sector and covers 258 innovating Austrian firms and 643 innovating Finish firms, which are analysed separately. Dachs et al. (2004) include several incoming spillover measures in their model[31], which are normalized to the industry (2-digit) mean: vertical spillovers, horizontal spillovers, institutional spillovers (universities and research institutions) and public spillovers (conferences, journals, fairs and exhibitions). Like Belderbos et al. (2004) they analyse the effect of these spillovers on R&D co-operation in general and on R&D co-operation with different partners. Using probit models they find that horizontal spillovers have a positive and significant impact on the probability of cooperating for Austrian firms, but a negative effect in Finland. For vertical spillovers the opposite is true, with the exception that the coefficient in the equation for Austria is not significant. The results for the different types of co-operation partners show similar differences between the two countries.[32] Vertical spillovers have a positive effect on co-operation with sup-

stead of the level of firms.

31 They also include two variables for the utilization of strategic or formal means of protection, but do not interpret them as appropriability or an inverse measure of outgoing spillovers. They find that both measures are positive and significant in the Finish equation used to explain the probability of cooperating, but insignificant in the estimation on the Austrian data.

32 These differences show up not only for the spillover variables but also for the variables included in the model to capture other types of motives for co-operation.

pliers, customers and institutions in Finland, while they are not significant in Austria. Horizontal spillovers decrease the likelihood of cooperating with suppliers and customers in Finland, but not in Austria. Only for co-operation with competitors similar results for both countries are obtained. This type of co-operation is positively influenced by horizontal spillovers only, in both countries.

Another study using CIS III data from different countries to estimate the same econometric model on the relationship between R&D co-operation and spillovers is Abramovsky et al. (2005). They analyse 3,590 French, 1,183 German, 2,747 Spanish and 1,145 British firms from the manufacturing and service sector. The spillover measures are almost identical to the ones used by Cassiman and Veugelers (2002), as is the method used. Abramovsky et al. (2005) estimate their models with and without controlling for endogeneity of the appropriability and incoming spillover variable. Regardless of the specification used, the importance of protection methods for innovations at the firm-level (appropriability) has a positive and significant effect on R&D co-operation in France, Germany and Spain. The variable is also significant in the UK, if no instrumental variable estimation approach is used. The findings for the incoming spillover variable are more sensitive to the estimation method employed. For France and the UK incoming spillovers have a positive and significant effect on the probability of co-operating, for Germany and Spain, however, incoming spillovers are significant only if a 2-step procedure with instrumental variables is used. Abramovsky et al. (2005) also split up the R&D co-operation variable into three different categories: co-operation with the research base, co-operation with suppliers and co-operation with customers or competitors. The robustness of the findings to the estimation procedure used is similar to that for R&D co-operation in general. Appropriability is positive and significant in virtually all countries for all types of R&D co-operation regardless of the method used. Exceptions are France for the R&D co-operation with research institutes which looses its significance if endogeneity is taken into account and the UK for which the appropriability variable is not significant. For incoming knowledge spillovers the pattern is that higher spillovers increase the likelihood of cooperating with any given partner in France and the UK, but not in Germany and Spain, in the single step estimation, and for all countries if instrumentation is employed. The authors conclude that appropriability and incoming spillovers are motives for firms to cooperate on R&D activities in all of the four countries. They see their study as support for the findings by Cassiman and Veugelers (2002).

Empirical evidence on the relationship between R&D co-operation and knowledge spillovers in France has been provided by Negassi (2004). He combines data from the first and second CIS with microdata on the financial situation of firms and several other firm characteristics to estimate the relation. He analyses national as well as international spillovers and both turn out to be not significant. For his sample of manufacturing firms he only finds a positive but not significant effect of pure knowledge spillovers on the R&D co-operation decision of firms.

Bönte and Keilbach (2005) have a different focus in their study of research partnerships. They analyse data from the German innovation survey of 1993 and 1994 to estimate the effect of knowledge spillovers on the extent of cooperative R&D agreements (formal vs. informal co-operation) with customers and suppliers respectively. They include three spillover measures: specific spillovers (knowledge from suppliers and customers), generic spillovers (knowledge flows from competitors, vertically related firms, universities and research institutions), and appropriability. The latter has a positive and significant influence on formal and informal R&D co-operation. As the marginal effect for this variable is not significant in the equation for informal R&D co-operation, the authors argue that a marginal increase of the importance of appropriability does not induce firms to cooperate informally. Generic incoming spillovers do not influence the co-operation decision significantly, while specific spillovers have a slightly positive effect on R&D co-operation with customers.

The following table summarizes the main findings of the literature analysing innovation survey data. It clearly shows that the impact of spillovers is different for different types of co-operation and that appropriability/outgoing spillovers and incoming spillovers have separate effects on firms' co-operation decisions.

Table 2-2 Main Findings of Econometric Studies Using Innovation Survey Data

Type of Co-operation	**Study**	**Data/Country/industries**	**Effect of Knowledge Spill-over on R&D Co-operation**[33]
Co-operation in general	König et al. (1994)	MIP 1993 / Germany / manufacturing	Appropriability: +++ (for large firms only)
	Kaiser and Licht (1998)	MIP 1993 / Germany / manufacturing	Vertical spillovers: +
	Wölfl (1998)	MIP 1993 / Germany / manufacturing	Appropriability: ++/+++
	Cassiman and Veugelers (2002)	CIS I / Belgium / manufacturing	Incoming spillovers: +/++ Appropriability: +

33 The construction of the variables for the type of knowledge spillovers and the type of R&D co-operation differs even if the same term is used by the different authors and vice versa. I use the terminology of Cassiman and Veugelers (2002) as far as possible. The results reported for Cassiman and Veugelers (2002) and Abramovsky et al. (2005) are those of a two-step estimation procedure with instrumental variables. For Wölfl (1998) the results for R&D co-operation with other firms (competitors, suppliers and customers) are reported.

Type of Co-operation	Study	Data/Country/industries	Effect of Knowledge Spill-over on R&D Co-operation[33]
Co-operation in general	Kaiser (2002a)	Mannheim Innovation Panel (MIP) 1995 / Germany / services	Horizontal spillovers: +
	Dachs et al. (2004)	CIS III / Austria and Finland / manufacturing	FIN:Horizontal spillovers: --- Vertical spillovers: +++
			AUT:Horizontal spillovers: ++
	Negassi (2004)	CIS I + II / France / manufacturing	Incom. spillovers: no effect.
	Lopez (2004)	CIS III / Spain / manufacturing	Incoming spillovers: +/+++ Appropriability: +++
	Abramovsky et al. (2005)	CIS III / France, Germany, Spain and the U.K. /manufacturing and services	FRA/GER/SPA/UK: Incoming spillovers: +++ FRA/GER/SPA: Appropriability: +++

Type of Co-operation	Study	Data/Country/industries	Effect of Knowledge Spill-over on R&D Co-operation[33]
Institutional co-operation with research institutions and universities	Cassiman and Veugelers (2002)	CIS I / Belgium / manufacturing	Incoming spillovers: +++ Appropriability: +
	Belderbos et al. (2004)	Dutch innovation surveys 1996 and 1998 / Netherlands / manufacturing and services	Institutional spillovers: +++
	Dachs et al. (2004)	CIS III /Austria and Finland / manufacturing	Horizontal sp.: FIN --/ AUT + Vertical spillovers: +++
	Lopez (2004)	CIS III /Spain/ manufacturing	Incoming spillovers: + Appropriability: +++
	Abramovsky et al. (2005)	CIS III / France, Germany, Spain and the U.K. /manufacturing and services	FRA/SPA/GER/UK: Incoming Spillovers:: ++/+++ FRA/SPA/GER: Appropriability: ++/+++

Type of Co-operation	Study	Data/Country/industries	Effect of Knowledge Spill-over on R&D Co-operation[33]
Vertical co-operation with suppliers and customers	Cassiman and Veugelers (2002)	CIS I / Belgium / manufacturing	Appropriability: +
	Belderbos et al. (2004)	Dutch innovation surveys 1996 and 1998 / Netherlands / manufacturing and services	Horizontal spillovers: - Vertical spillovers: +++ Institutional spillovers: +++
	Lopez (2004)	CIS III /Spain/ manufacturing	Appropriability: +++
	Abramovsky et al. (2005)	CIS III / France, Germany, Spain and the U.K. /manufacturing and services	FRA/SPA/GER/UK: Incoming Spillovers: ++/+++ FRA/SPA/GER: Appropriability: ++/+++
Co-operation with customers	Dachs et al. (2004)	CIS III /Austria and Finland / manufacturing	FIN: Horizontal spillovers: --- Vertical spillovers: +++ AUT: Public spillovers: +
	Bönte and Keilbach (2005)	MIP 1993 and 1994 / Germany / manufacturing	Appropriability: ---

Type of Co-operation	Study	Data/Country/industries	Effect of Knowledge Spill-over on R&D Co-operation[33]
Horizontal Co-operation with competitors	Belderbos et al. (2004)	Dutch innovation surveys 1996 and 1998 / Netherlands / manufacturing and services	Institutional spillovers: +++
	Dachs et al. (2004)	CIS III /Austria and Finland / manufacturing	FIN: Horizontal spillovers: +++ AUT: Horizontal spillovers: +++ Public spillovers: +
	Lopez (2004)	CIS III /Spain/ manufacturing	Appropriability: +
	Abramovsky et al. (2005)	CIS III / France, Germany, Spain and the U.K. /manufacturing and services	FRA/SPA/GER/UK: Incoming Spillovers:: ++/+++ SPA: Appropriability: ++

Type of Co-operation	**Study**	**Data/Country/industries**	**Effect of Knowledge Spill-over on R&D Co-operation**[33]
Co-operation with suppliers	Dachs et al. (2004)	CIS III /Austria and Finland / manufacturing	FIN: Horizontal spillovers: --- Vertical spillovers: +++ AUT: Institutional spillovers: ++ Public spillovers: ++
	Bönte and Keilbach (2005)	MIP 1993 and 1994 / Germany / manufacturing	Incoming Spillovers: + Appropriability: ---
Variety of co-operation partners	König et al. (1994)	MIP 1993 / Germany / manufacturing	Potential spillovers: +++ (for large and medium sized firms only)

Effect is positive and significant at the 10% level (+); 5% level (++) or 1% level (+++).

Effect is negative and significant at the 10% level (-); 5% level(--) or 1% level (---).

Source: Own illustration.

2.4.3 Econometric Studies Using Data from Other Databases

Research on R&D co-operation and spillovers has not been confined to innovation surveys. Other databases on R&D co-operation and research joint ventures existed before the innovation surveys were conducted.[34] Some studies using alternative databases will be presented below as examples.

Hernan et al. (2003) uses the so called “STEP to RJV” database that contains information on research joint ventures formed between 1986 and 1996 under two EU programs (EUREKA and the EU Framework Program). The database contains the names of participating firms and a description of the project. The advantage of this database compared to the innovation surveys is that it contains information on cross-boarder co-operation within the EU. The disadvantage is that it does not contain any purely domestic joint ventures. In order to analyse the influence of partner characteristics on R&D co-operation the authors combine the information in the RJV database with background information on the firms involved. In their empirical model Hernan et al. (2003) analyse 54,610 firms of which 798 participated in at least one research joint ventures during 1995-1996. The two spillover variables they construct are the time it takes for innovations to diffuse within an industry and the industry level of the effectiveness of patents (based on Levin et al., 1987). Hernan et al. (2003) find that firms become less likely to participate in research joint ventures the longer it takes for innovations to diffuse and the more effective patent protection is (both indicators for low levels of knowledge spillovers). They conclude that “knowledge diffusion is central to our understanding of RJV formation.” (Hernan et al., 2003: 87).

International co-operation is also the topic of Smith et al. (2001). They use Danish data from the EU’s 4th Framework Program to identify firms cooperating on R&D (with foreign partners) and merge it with data from the Danish business register and a survey of CEOs. In line with Cassiman and Veugelers (2002) they focus on the role of knowledge spillovers as a determinant of research co-operation. The incoming spillover measures are constructed using a question from the survey of CEOs on the motives behind co-operation in firms that already cooperate and the potential motives to cooperate for non-cooperating firms. The average score of the motives, access to technology, equipment and R&D networks is labelled "technological ingoing spillovers" and the average importance of access to financial sources and increasing market contact are used as a proxy of "economic ingoing spillovers". Outgoing spillovers are measured using questions on the protection of core competences and the usage of intellectual property rights for cooperating firms and potential risks in joint R&D and R&D strategies for non-cooperating firms.[35] All the variables included in the model could be calculated for 124 observations. In their logit model of the probability of cooperating within the 4th EU framework program both the variable for ingoing technological spillovers and the outgoing spillover variable are positive and significant. Due to the limited number of observations and the doubtful construction of some variables, the robustness of the results of this study can be questioned.

In summary, the empirical studies using databases other than innovation surveys arrive at results similar to those of the authors using innovation surveys, i.e. they find significant effects of knowledge spillovers on the probability of cooperating in R&D.

2.5 Different Types of R&D Partnerships and R&D Spillovers

The literature review of the theoretical and empirical papers has already shown that a variety of different terms, definitions and concepts can be used to describe spillovers and various forms of R&D partnerships. Before I proceed with the empirical study, I will review the concepts proposed on a systematic basis. Given that a wide array of definitions and concepts exists to describe R&D partnerships,

34 For an overview of alternative databases, see Hagedoorn et al. (2000) and Vonortas (1994).

35 The usage of different questions to construct the same variable is highly problematic from our point of view.

it is even more surprising that most of the studies cited above reach similar conclusions on the link between R&D and knowledge spillovers and R&D partnerships.

2.5.1 R&D Partnerships

R&D partnerships between firms or between firms and research institutions can take various forms, just like any other partnerships. There are forms in which contracts are signed or even an entire new entity is set up and much loser forms of partnerships and collaboration. In this subsection I will present two classifications of R&D partnerships. The first will use the dimension of the type of agreement and the second the type of partners involved in the agreement[36].

Classification by Type of Agreement

A first dimension along which R&D partnerships can be classified is the type and intensity of the agreement:

Kogut (1988) reviews the empirical and theoretical literature on joint ventures (not only R&D joint ventures) and cites studies from the late 1960s that investigated the distribution of joint ventures among different industries. He uses the transaction cost literature to identify the difference between a mere contract and a research joint venture. According to Kogut (1988) a joint venture can be distinguished from other forms of collaboration by two properties "joint ownership (and control) rights and the mutual commitment of resources." (Kogut, 1988: 320). It is clearly the tightest form of R&D partnership, as it usually involves setting up a new firm or establishment which is co-owned by all partners in the partnership. In the taxonomy of Hagedoorn et al. (2000) this type of R&D partnership where a new entity is formed is called "equity joint ventures" or "research corporation" as opposed to "research joint ventures" (RJV) or "non-equity

36 Mariti and Smiley (1983) paper defines a co-operative agreement as "any long term, explicit agreement amongst two or more firms" (Mariti and Smiley, 1983: 437), indicating that R&D partnerships could also be classified by their duration.

joint ventures", which are formal agreements based on contracts. In the categorization proposed in Hagedoorn et al. (2000) even research contracts, i.e. one firm commissioning another firm to perform R&D, are included under research joint ventures. Vonortas (1994) distinguishes between "Secretariat RJVs" and "operating entity RJV". The former represents the form of partnerships where firms coordinate their R&D activities but R&D is performed separately at each firm, while the latter involves founding a new firm. The use of the term "research joint ventures" for the type of partnership that does not involve forming a new firm is not very widespread, however. Even Hagedoorn (1993) uses the term joint venture only for forms of R&D partnerships where a separate firm is set up for the R&D activities to be performed and labels other forms of formal partnerships "contractual agreements" in his 1993 study. The latter include "joint R&D agreements, technology exchange agreements, customer supplier relationships and one-directional technology flows" (Hagedoorn, 1993: 374). In 2002 he uses the term "R&D partnerships" to represent formal agreements not involving a joint firm (Hagedoorn, 2002). Similarly, Veugelers and de Bondt (1992) use the term "joint venture" for co-owned R&D firms only and "strategic alliances" for forms without equity commitments. Others that have used "research joint venture" to describe the type of partnership with a separate firm, are Mariti and Smiley (1983), Beath et al. (1998), Grossman and Shapiro (1987), Kamien et al (1992), Caloghirou et al. (2003) to name a few.

Kamien et al. (1992) introduces the additional form of partnership "RJV cartelization" and "R&D cartelization". Both can be described as cooperative forms where firm coordinate their R&D expenditure but do not share any of the results of their independently conducted R&D activities. Caloghirou et al. (2003) describe RJVs as a subset of "strategic technological alliances". According to Teece (1992) strategic alliances are agreements between partners to coordinate their activities and pool their resources in order to reach a goal, jointly determined by both partners.

In summary, the term “research joint venture” has been used to describe different types of partnerships, but for most authors it represents joint R&D at a specific facility, set up by the partners of the R&D agreement.

More recently, the term “research joint venture” has been replaced by “ R&D co-operation” in theoretical and empirical papers alike. “R&D Co-operation” covers not only contractual partnerships but also looser forms of collaboration between firms, like informal agreements (e.g. Bönte and Keilbach, 2005; Wiethaus, 2005)[37]. This change to a broader perspective on collaborative R&D and research partnerships was made possible in part by the advent of the Community Innovation Surveys (CIS) in the European Union that asks firms about collaborative research within joint ventures but also outside of them. The definition used in the CIS surveys of 2001 and 2005 are based on the Oslo Manual (OECD and Eurostat, 1997):

“Innovation co-operation involves active participation in joint innovation projects with other organisations. These may either be other enterprises or non-commercial institutions. The partners need not derive immediate commercial benefit from the venture. Pure contracting out of work, where there is no active collaboration, is not regarded as co-operation. Co-operation is distinct from open information sources and acquisition of knowledge and technology in that all parties take an active part in the work.” (OECD and Eurostat, 2005: § 271).

This definition goes beyond that of a RJV by not only focusing on R&D activities but also on other innovation activities, which includes production start-up for technological innovations or marketing for new and improved products.[38] Even though all empirical studies using the Community Innovation Surveys use the question on innovation co-operation to construct their co-operation variable, the term “R&D co-operation” is still used. Following this convention I will also talk

37 The share of firms cooperating informally, i.e. without a contract, on R&D activities is fairly high according to Link and Bauer (1989) and Bönte and Keilbach (2005).

38 For a list of other innovation activities see OECD and Eurostat (1997): Section 5.2.

about “R&D co-operation” for the rest of this study, even though I use the broader definition cited above.

Almost all forms of research joint ventures are included in this definition, except for “contract research” where one firms buys R&D services from other firms or institutions. It is noteworthy that pure “fishing for ideas”, i.e. looking for new ideas outside the firms boundaries, is also not included in this definition of R&D co-operation but informal agreements (not based on contracts or other formal/written agreements) are.

Classification by Type of Partners

Another way to distinguish R&D partnerships is by the type of partners involved in the cooperative agreement. R&D partnerships can be formed between two or more public firms/institutions (public-public co-operation), two or more private firms (privat-private co-operation) or between public and private firms/institutions (public-private co-operation) (OECD and Eurostat, 2005; Hagedoorn et al., 2000).

The private-private partnerships can be split up into horizontal co-operation and vertical co-operation, based on the position of the partners in firms’ value chains. Horizontal partnerships include agreements with competitors and vertical partnerships with customers and/or suppliers (Kaiser, 2002a; Belderbos et al., 2004).

R&D co-operation partners can also be grouped by their industry or country of origin, which leads to the concepts of international versus national R&D partnerships (see e.g. Cincera et al., 2003; Hamel, 1991; Qiu and Tao, 1998) and intra-industry versus inter-industry co-operation (see e.g. Atallah, 2002). Of course there are also mixed forms of co-operation, which involve various types of partners, competitors, universities and suppliers, from several industries and countries.

2.5.2 R&D Spillovers

R&D spillovers are (positive) externalities[39] (see e.g. D'Aspremont and Jacquemin, 1988; Griliches, 1992; Rosen, 2002), which occur because "[…] knowledge is inherently a public good" (Jaffe, 1986: 984; Liebeskind, 1997: 624)[40]. This means that knowledge has the features of non-rivalrousness in consumption and non-excludability (Hanusch and Cantner, 1993; Stiglitz, 1999a; Geroski, 1995). While the first feature of knowledge as a public good (non-rivalrousness), or as Samuelson (1954) originally calls it "collective consumption goods" (Samuelson, 1954: 387), has not been discussed widely[41], the "non-excludability" attribute can be seen as the basis for the analysis of knowledge externalities or spillovers. Because knowledge is (to a certain degree[42]) non-excludable in the sense that everyone has access to knowledge once it has been generated, it spills over from the producer of the knowledge to the (potential) user.[43] Romer for example acknowledges that knowledge spillovers are almost certain to occur: he writes that "investment in knowledge suggests a *natural* externality" (Romer, 1986: 1003). A few years later he equates knowledge spillovers to incomplete appropriability (Romer, 1990: 75).

39 A standard definition of externalities is provided by Rosen (2002). He writes "When the activity of one entity (a person or a firm) directly affects the welfare of another in a way that is outside the market mechanism, that effect is called an externality […]" (Rosen, 2002: 80).

40 The link between public goods and externalities is straight forward. Rosen (2002) writes that "public goods can be view as a special kind of externality." (Rosen, 2002: 81) He also uses the term "beneficial spillovers" as a synonym for positive externalities (of R&D).

41 Romer (1990) is an exception.

42 Knowledge can be appropriate to a certain degree through (patent) protection or because of its local/incremental character and might thus be at least a "partially excludable, non-rival input" (Romer, 1990: 74) for the innovation process, if not a private good (see Hanusch and Cantner, 1993 for a discussion of these topics).

43 Hanusch and Cantner (1993) discuss other implications of the public good character of knowledge, for example market failure and the consequences for technology policy in detail.

In summary, one can say, that knowledge spillovers occur because knowledge is only incompletely excludable and thus has some features of a public good or at least it is " a latent public good" (Nelson, 1989: 233).

Knowledge spillovers are, however, not the only spillovers that arise from R&D activities. Other types of R&D spillovers will be described below. Analogous to the description of R&D partnerships, spillovers arising form R&D activities will be categorized by type of spillover and by sources of spillovers.[44]

Classification by Type of R&D Spillover

A first distinction for R&D spillovers is attributed to the seminal work of Zvi Grilliches (Griliches, 1979a; 1992). He puts R&D spillovers into two groups: knowledge and rent spillovers. Knowledge spillovers or as Grilliches sometimes calls them "true spillovers" (Griliches, 1979a: 104) arise if information and ideas flow from one industry to another industry without payment.[45] This knowledge can be "borrowed or stolen from other sectors or industries" (Griliches, 1979a). In order to measure these knowledge spillovers he uses the weighted, aggregated stock of R&D expenditure by all industries but a firm's own.[46] Rent spillovers occur because firms pay less for inputs than the quality of these inputs is worth.

Knowledge spillovers or technological spillovers are also considered by De Bondt (1996). He defines knowledge spillover as the "involuntary leakage or

---

44 Research on spillovers and externalities started very early. Griliches (1992) mentions Edgeworth and studies from the 1940s and 1950s that model the effect that the outcome of activities of all firms in an industry influences a given firm's performance in terms of returns and productivities. Jaffe (1996) cites Marshall (1920) famous book "Principle of Economics" to illustrate that the investigation of R&D spillovers has a long history. I will start our overview with the seminal works of Griliches (1979a; 1992), which build on this literature, since they specifically focus on R&D spillovers and have been the basis for almost all studies relevant for our analysis.

45 Earlier studies that dealt with knowledge flows have used the term "borrowed" knowledge instead of "spillovers". An example is Terleckyj (1974), who constructed a technology flow matrix on the basis of input-output tables.

46 A more detailed description of his measurement of knowledge spillovers will be provided in section 5.1.

voluntary exchange of useful technological information" (De Bondt, 1996: 3). He stresses that not all knowledge exchange or flows between firms should be treated as knowledge spillovers, but rather only those that are useful for the firm at the receiving end of the knowledge transfer.

Jaffe (1996) lists three types of spillovers: knowledge spillovers, which are defined in line with Griliches (1979a; 1992), market spillovers and network spillovers. Market spillovers are present if the benefits of an innovation flow to market participants via the market. This happens if quality improvements are not fully reflected in a product's price or if performance increases in the production process lower the price of a good (Jaffe, 1996). These kind of spillovers are similar to the rent spillovers described by Griliches (1979a; 1992). The dividing line between market and knowledge spillovers in Jaffe's report is that knowledge spillovers result without market interaction, while market spillovers occur because firms interact on the market. A third group of spillovers are network spillovers. These "result when the commercial or economic value of a new technology is strongly dependent on the development of a set of related technologies." (Jaffe, 1996: 6).

Rosenkranz (1995) introduces "competitive spillovers", i.e. one firm's innovation affects other firms' profits negatively because of competition in the product market. Similarly, Katsoulacos and Ulph (1998) note that for firms operating in the same industry, spillovers to rivals will result in lower profits compared to a situation without spillovers. Kamien et al. (1992) considers the same effect under the headline of "combined profit-externalities". However, competitive spillover can be interpreted as a result of knowledge spillovers, because they materialize in the product market but are caused by R&D results flowing from one firm to another.

Spillovers differ also with respect to the willingness of the firm conducting R&D to prevent them. This difference has been noted by Katsoulacos and Ulph (1998) who incorporate involuntary spillovers into their model. The level of these spillovers depends on the technology and the effectiveness and usage of intellectual property rights. Similarly, Veugelers writes “spillovers can refer to both involuntary and voluntary leakage of knowledge” (Veugelers, 1998: 6).[47]

Katsoulacos and Ulph (1998) argue that the total progress achieved by a firm’s innovation activities depends on their own progress and that of others (“received progress”). They also mention that the actual relationship between total progress and the other two types depends on the substitutability and complementarity between one’s own and others’ discoveries. This suggests that external knowledge (spillovers) can be substitutive for or complementary to ones own knowledge. A similar distinction can be found in Baumol (1993) and the unpublished paper by Veugelers and Koen (1999).

The theoretical literature has developed different ways to incorporate spillovers in its models, which are the basis for four additional terms used to describe spillovers. Spillovers can be modelled as symmetric, i.e. all firms receive the same amount of spillovers, or asymmetric, which means that firms differ with respect to the level of spillovers they receive because one firm is the leader and another the follower or because of different absorptive capacities (De Bondt and Henriques, 1995; De Bondt, 1996; Von Graevenitz, 2004). The other two groups are “exogenous” and “endogenous” spillovers which are related to the two groups just mentioned. If the level of spillovers is treated as a given/fixed parameter in the model, as e.g. in D'Aspremont and Jacquemin (1988; 1990), this is called an exogenous spillover; if it depends on firms’ characteristics or cooperative activities, as in Katsoulacos and Ulph (1998) or Kaiser (2000), it is called endogenous. To be more precise, spillovers are considered as endogenous if the spillover rate changes if firms form an R&D agreement (Beath et al., 1998; Katsoulacos and Ulph, 1998).

47 See also De Bondt (1996).

Classification by Source of R&D Spillover

The classification of spillovers by type of source is very similar to that of R&D partnerships. There are vertical and horizontal spillovers, depending on whether the source of spillovers is a customer/supplier or a competitor (Atallah, 2002; Kaiser, 2002b), and spillovers from universities (Adams, 2004; Nadiri, 1993). The distinction between spillovers from public and private sources can be attributed to the different types of knowledge these sources create (Becker and Peters, 2000; Nelson and Wolff, 1997). A different terminology for these classes of spillovers has been used by Bönte and Keilbach (2005). They analyse specific spillovers (knowledge from suppliers and customers) and generic spillovers (knowledge flows from competitors, vertically related firms, universities and research institutions).

Spillovers can also be classified by the geographical distance between the sender(s) and recipient(s) of the spillover: There are international and national spillovers (Branstetter, 2001; Harabi, 1997; Jaffe and Trajtenberg, 1999; Bernstein and Mohnen, 1994; Keller, 2002) and regional or intra-regional spillovers (Fritsch and Franke, 2004; Arndt and Sternberg, 2000; Acs et al., 2002). These distinctions are warranted since many studies have documented that knowledge and technology diffusion is attenuated by distance and in particular by the existence of a border between partners (Jaffe et al., 1993; Porter and Stern, 2000; Branstetter, 2001; Peri, 2005).

The focus of other studies is to analyse differences between intra-industry (from a firm's own industry) and inter-industry spillovers (between different industries) (e.g. Kaiser, 2002b; Bernstein, 1988; Cincera et al., 2003). The arguments for that distinction are similar to those presented for the separation by geographical distance. Griliches (1992) states that external knowledge is more useful to firms if it is from an actor within the same industry (3 digit SIC). Cohen and Levinthal (1990) and Lane and Lubatkin (1998) argue that it is easier to learn from similar partners and in areas where a firm posses some prior knowledge and experience. This is more likely to be the case within an industry than outside of it. Bernstein (1988) and Steurs (1995) analyse both types of spillovers and find separate effects for intra- and inter-industry spillovers. Empirical studies using R&D stocks and spillover pools also take these separate types of spillovers into account when they assign different weights (technological proximity) to different industries' R&D expenditure (e.g. Adams, 1990; Griliches, 1992; Jaffe, 1986; Cincera, 2005).[48]

Cassiman and Veugelers (2002) and the empirical studies following them have confirmed that it is worth separately including measures for "incoming spill-overs" and "outgoing spillovers" in empirical models trying to explain R&D co-operation, because they have different effects on the co-operation decision (see above). Incoming spillovers can be described as the knowledge received by a firm, whereas outgoing spillovers consist of the knowledge flowing out from a firm.

Beyond these more widely used concepts, other distinctions include the following: Monjon and Waelbroeck (2003) use a question on information sources in the French CIS survey of 1997 to separate direct spillovers from indirect spillovers. Direct spillovers are present if firms use knowledge from a single source (e.g. customers, suppliers) for their innovation activities, while indirect spillovers arise if transmission channels such as patent applications or conferences are used to acquire external information. Rouvinen (2002) calls the latter "disembodied inward spillovers" in his study of Finnish CIS data for the manufacturing sector.

The whole process of invention and innovation provide the basis for the conclusion by Orlando (2004) that spillovers from innovation activities could be different in nature from those resulting from inventive activity. Similarly, Vonortas (1994) notes that knowledge from basic research is different from knowledge from development research.

A very specific distinction is made by Geroski et al. (1993). He splits his spill-overs into "production spillovers" and "use spillovers". Production spillovers are

48 Orlando (2004) analyses technological and geographical aspects of spillovers simultaneously.

measured as the “total number of innovations produced by all members of the two-digit industry” and use spillovers by the “total number of innovations used by all members of the two-digit industry“(Geroski et al., 1993: 210).

Obviously, most of the proposed terminology and concepts are complements rather than substitutes, in the sense that a spillover can be described using several different concepts, e.g. an international, horizontal, outgoing knowledge spill-over.

2.6 Deduction of Hypotheses for the Empirical Part of the Study

The review of the empirical and theoretical literature has clearly shown that a link between knowledge spillovers and R&D partnerships exist. What is more, most studies indicate that the relationship is a positive one, i.e. the higher the level of spillovers the more profitable (and thus likely) are R&D partnerships. I will focus on realized knowledge spillovers, i.e. the knowledge a firm can not appropriate and involuntarily spills over into the public domain (“realized outgoing spillovers”) and the knowledge a firm actually acquires from its environment (“realized incoming spillovers”), instead of knowledge spillovers in general. My empirical study is thus in line with the empirical literature using innovation survey data from the CIS.

A first hypothesis to be tested in the empirical part of my study would thus be:

H1: The level of realized knowledge spillovers has a positive effect on the probability that firms will cooperate on R&D and innovation activities.

However, in light of the empirical findings that appropriability and incoming spillovers have different effects on firms’ co-operation decisions, I will chose a more differentiated approach and split up this first hypothesis into two separate hypotheses:

H1a: The level of realized outgoing knowledge spillovers has a positive effect on the probability that firms will cooperate on R&D and innovation activities.

H1b: The level of realized incoming knowledge spillovers has a positive effect on the probability that firms will cooperate on R&D and innovation activities.

The assumption that both types of knowledge spillovers affect the likelihood of cooperating on R&D positively is drawn from the empirical literature on the topic. One might argue, however, that the level of knowledge spillover has a negative effect on the likelihood for cooperating. If realized incoming knowledge spillover levels are high, firms do not necessarily have to co-operate on R&D to get access to valuable knowledge and thus may be less likely to co-operate. Because both types of spillovers are related as actual outgoing spillovers will become potential incoming spillovers eventually, high levels of outgoing spillovers can have the same negative effect as high levels of realized incoming spillovers. On the contrary, firms with high levels of realized outgoing spillovers have a high incentive to co-operate in order to reduce the involuntary and uncontrolled outgoing spillovers and control their knowledge outflows through co-operating with external partners (internalize the spillover).

Some studies distinguish between different types of spillovers and different types of co-operation and find that some incoming spillovers are more relevant in determining a firm's decision to cooperate with specific partners than others.[49] The focus in the literature is on horizontal vs. vertical spillovers. I will extend this literature to intra-industry, inter-industry and scientific incoming knowledge spillovers. The hypothesis I want to test is:

H2: Realized Incoming knowledge spillovers from different sources influence a firm's decision to cooperate on R&D and innovation activities differently.

49 Cassiman and Veugelers (2002) conclude "Different spillover measures seem to have seperately identifiable effects on the firm's co-operation decisions." (Cassiman and Veugelers, 2002: 1179).

3 Overview of the Empirical Part of the Study

The main aim of the empirical part of this study is to investigate the relationship between realized knowledge spillovers[50], as defined by Griliches (Griliches, 1979a; 1992), and R&D co-operation, as defined by Eurostat and the OECD (OECD and Eurostat, 2005: § 271) at the firm level, using data from the Mannheim Innovation Panel (see section 3).

The exact formulation of the question I will use is „Did your enterprise cooperate on any of your innovation activities with other enterprises or institutions during 2002-2004?" (Eurostat, 2004 Question 6.2). The accompanying guidelines for the respondents, which gives the exact definition of R&D co-operation for my study is "Innovation co-operation is active participation in formal or informal innovation projects with other enterprises or non-commercial institutions. Both partners do not need to commercially benefit. Exclude pure contracting out of work where there is no active co-operation." (Eurostat, 2004 Question 6.2). I will restrict my analysis to R&D co-operations with external partners and exclude R&D co-operations with firms form a firms own industry group. External partners are suppliers, customers, competitors, commercial laboratories/R&D enterprises, universities, or government or private non-profit research institutes.

The starting point for this analysis will be the construction of appropriate knowledge spillover measures. The construction of these measures is a shortcoming of most empirical studies on the link between spillovers and R&D co-operation. Especially the modelling of outgoing spillovers is rather crude in the empirical literature, since it is almost exclusively based on the importance of protection methods for inventions and innovations and not on the actual knowledge pools available or created by a given firm. As far as incoming spillovers are concerned, the existing studies focus on the actual or potential uses of external in-

50 The term "spillovers" will be used as a synonym for knowledge spillovers for the reminder of this study.

formation sources as a proxy for incoming spillovers. Again the actual amount of knowledge created within an economy, i.e. the knowledge that can potentially spill over to rivals has been neglected in most of the previous literature.

These issues will be addressed in the subsequent chapters of this study. The empirical investigation is split up into three parts:

1. Construction of the potential outgoing spillover pools/knowledge stock of industries and individual firms.
2. Construction of the realized outgoing and realized incoming spillovers pools.
3. Estimation of the impact of incoming and outgoing spillovers on firms' R&D co-operation decision.

The first part (chapter 5) deals with the construction of the knowledge stocks of an industry and individual firms in Germany, i.e. the amount of knowledge an industry or firm has accumulated up until a given point in time. I will distinguish between knowledge generated within a firm's industry, outside a firm's industry and in universities and research institutions. The OECD Analytical Business Enterprise Research and Development databases (ANBERD), which contains R&D expenditure data for Germany and many other countries will be used to construct these three knowledge stocks, i.e. I assume that the total amount of knowledge generated in an economy can be approximated by the total amount spent on R&D activities. The results of part one will be three separate knowledge pools.[51] The first will be for knowledge generated by private firms in each industry, the second for knowledge generated by scientific institutions and the third knowledge generated by each individual firm.

In the second part of the empirical study (chapter 6) the pools of knowledge generated by private firms will be used to construct the "realized" outgoing spill-

51 Vonortas criticises the existing literature because they "lump all R&D together in a single category and distinguish between different kinds of technological knowledge only arbitrarily" (Vonortas, 1994: 414).

over pools of firms and the potential incoming spillover pools at the industry-level. The assumption in that part of the empirical study will be that not all knowledge produced in an economy becomes publicly available, since firms undertaking R&D and producing knowledge can appropriate some part of it through patents and secrecy. In the second part of the empirical study I will thus try to determine empirically how much knowledge can be appropriated by the use of protection methods or rather how much of the generated knowledge actually spills over into the public domain. By using the industry level of the importance of legal and strategic protection methods as a filter between the knowledge generated in an industry and the knowledge available outside a firms boundaries, I will be able to construct industry specific outgoing spillover pools ("realized outgoing spillovers"), which are equal to the potential incoming spillover pools for that industry.[52] These "realized" outgoing spillover pools will also be constructed for each individual firm in my sample. For the construction of the firm specific pools, a firm's knowledge stock will be weighted by its valuation of patents and secrecy as protection methods for inventions and innovations.

In order to get from the potential incoming spillover pools at the industry level to the realized incoming spillover pools for an individual firm, I employ the concept of absorptive capacity developed by Cohen and Levinthal (Cohen and Levinthal, 1989; 1990). I argue that the total amount of external knowledge actually used depends on firms' absorptive capacity.[53] The second part of the empirical study will thus also focus on the effect of absorptive capacity on knowledge flows (Section 6.5). To be more precise, I will determine the level of absorptive capacity of an individual firm, depending on certain firm characteristics. The re-

52 Under the assumption that all scientific knowledge becomes publicly available, I am also able to construct the pool of potential scientific knowledge spillovers. For a given firm the potential incoming spillover pool for intra-industry knowledge is the industry-level potential incoming spillover pool reduced by the firm's (accumulated) R&D expenditure.

53 Compare, "The amount of spillover from one firm to the other actually depends on two factors: the *adaptability* of the research to the other firm (the firm's *capacity* to utilise the research) and the amount of *information sharing*." (Katsoulacos and Ulph, 1998: 335)

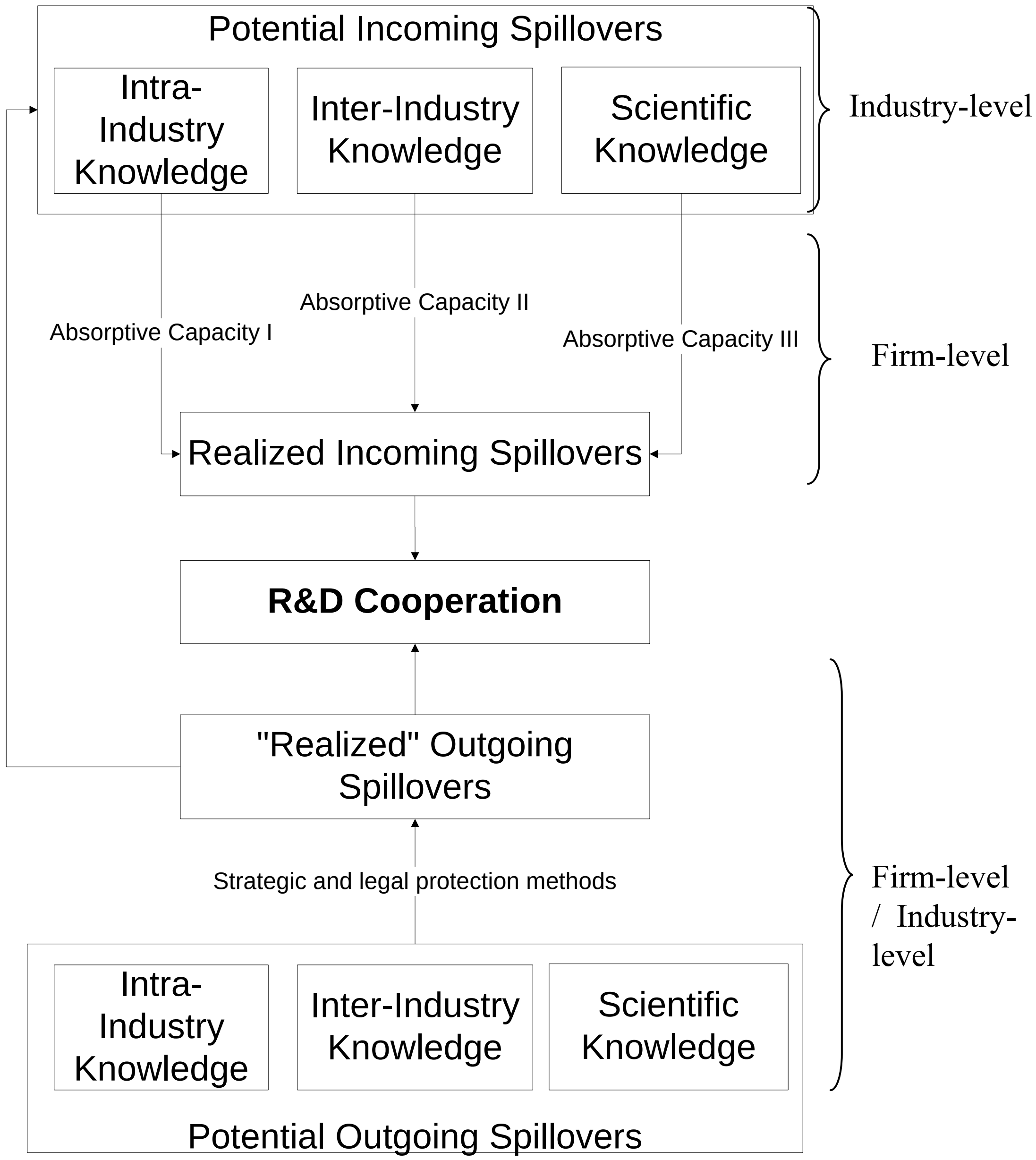
alized incoming spillover variables will then be constructed by multiplying the potential (industry-level) incoming spillover pool with the firm-level absorptive capacity. Since the distinction between the three different types of knowledge will be retained for the part on absorptive capacity, I will be able to construct three different realized incoming knowledge spillover pools for each individual firm.

The third and last part of the empirical study (chapter 7) will then deal with the impact of the realized incoming and outgoing spillovers (at the firm level) on firms' decision to engage in cooperative R&D and innovation activities. As a benchmark case I will estimate a model that is set up similar to that of Cassiman and Veugelers (2002).

Figure 3-1 on the next page provides an overview of the full model. The lower part of the model will be applied at the industry level and the firm level to arrive at the industry level of potential incoming spillovers and the firm specific pools of "realized" outgoing knowledge spillovers.

The main database for the empirical part of this study will be several waves of the Mannheim Innovation Panel, an annual survey conducted by the Centre for European Economic Research (ZEW) and its partners, which will be described in more detail in the following chapter.

Figure 3-1 Overview of the Analytical Framework for the Empirical Part of this Study



Source: Own illustration.

4 The Mannheim Innovation Panel

In this chapter the Mannheim Innovation Panel (MIP), a large scale survey of the innovation behavior of German firms, will be presented. It is the main source of data for the empirical parts of the study that follow below. Instead of going into details this chapter will provide a general overview of the surveys alongside the basic concepts used. Similar overviews and documentation for the long running project of the ZEW have been published in Janz et al. (2001), Janz et al. (2002), Janz et al. (2003), Rammer et al. (2005c), Schmidt et al. (2005). The description here closely adheres to that of Schmidt et al. (2005) and Rammer et al. (2005c).

4.1 Introduction

In 2005 the Centre for European Economic Research (ZEW) conducted the 14th innovation survey in the manufacturing sector and the 11th in the service sector. The surveys on innovation activities of German firms with 5 or more employees are conducted annually since 1993 (manufacturing) and 1995 (services) in co-operation with infas - Institut für angewandte Sozialwissenschaft [Institute for Applied Social Sciences] and the Frauenhofer Institute for Systems and Innovation Research (FhG-ISI) (partner in 1995, 1997-1999, and 2005-). The studies are commissioned by the Federal ministry of Education and Research (bmbf). The survey's outline varies according to a design scheme with more or less comprehensive versions alternating. While in odd years the questionnaires includes questions on framework conditions relevant for innovation activities, like e.g. obstacles to innovation, R&D activities, or innovation strategies, the questionnaire in even years concentrates on core indicators, like the indicators for product and process innovation. The definitions of the core concepts and the survey methodology follow the "Proposed Guidelines for Collecting and Interpreting Technological Innovation Data (Oslo Manual)" (OECD and Eurostat, 1997), which are published by the OECD and Eurostat and are the basis for all innovation surveys in the OECD.

From the very beginning, the innovation surveys of the ZEW were part of the international system of innovations surveys, such that in 1993, 1997, 2001 and 2005 the Mannheim Innovation Panel was the German part of the so called "Community Innovation Survey" (CIS I- CIS IV) of the European Commission. These Europe-wide surveys are conducted every fourth year in all member states of the European Union and are coordinated by Eurostat. In 2004 a Commission Regulation (European Commission, 2004a) was adopted by the EU member states, requiring member states to deliver data on key innovation indicators to Eurostat biannually.

The annual innovation surveys of the ZEW are set up as a panel survey ("Mannheim Innovation Panel"), i.e. each year the same sample of enterprises is surveyed. Biannually a random sample of new firms is drawn to "refresh" the sample – usually from the population of newly founded enterprises, i.e. corrected for sample attrition due to firm closure or drop out. The panel structure allows the analysis of innovation activities over time, which is particularly beneficial for questions such as concerning the effect of innovation activities in the past on present employment growth or performance. Because of the panel structure, the Mannheim Innovation Panel is a solid basis for the analysis and evaluation of economic and technology policy issues.

4.2 Goals of the MIP Innovation Surveys

The foremost goal of the Mannheim Innovation Panel is to describe and assess the innovation activities of German firms in a comprehensive way. Figure 4-1 provides an overview of the topics that are covered in the surveys. The questions are not just pertaining to relevant inputs for the innovation process (e.g. human capital, financial resources), but also on indicators of innovation success (e.g. turnover from innovations, cost reduction due to process innovations and return on turnover.). Questions on key figures of the firms sampled, like the number of employees and turnover as well as indicators for product and process innovation and market novelties are also included in the survey on annual basis. In the more comprehensive survey design these are supplemented by other questions on topics relevant for innovation and technology policy, covering questions on obstacles to innovation, external relations in the innovation process and public R&D and innovation support.

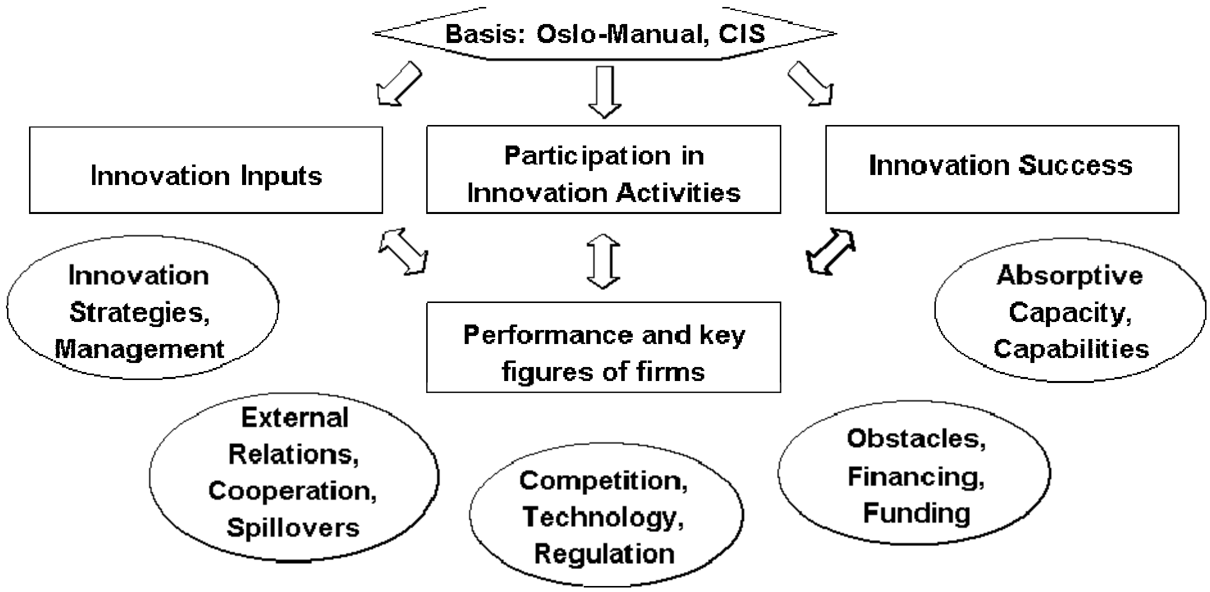
These topics are not only part of the innovation surveys in Germany, but are also recommended by the Oslo Manual. The Oslo Manual[54] recommends the inclusion of the following topics in innovation surveys, which are also covered in the German surveys[55] (some only in the more comprehensive surveys):

- Indicators for technological product and process innovations
- Turnover with product innovations and market novelties
- Objectives of innovation activities
- Sources of information for innovation
- Factors hampering innovation activities
- Protection and appropriation of returns to innovation
- Expenditure on innovation

54 The list is based on the 1997 version of the Oslo Manual (OECD and Eurostat, 1997). In 2005 the OECD published a revised Oslo Manual (OECD and Eurostat, 2005), which essentially covers the same topics but extends the coverage to non-technological innovations, i.e. marketing and organizational innovations.

55 The German surveys sometimes go beyond the suggested coverage of the Oslo Manual, e.g., to investigate current policy topics in more detail.

Figure 4-1 Goals of the Mannheim Innovation Panel Surveys



Source: ZEW Mannheim (2005) in Schmidt et al. (2005).

4.3 Methodology for Data Collection

The Oslo Manual provides not only the basis for the questionnaire design, but also for the methodology of innovation data collection though surveys. This further helps to generate comparable data on innovation activities of countries in the EU and OECD. The recommendations of the Oslo Manual with regard to survey procedures are also conformed with when conducting the Mannheim Innovation Panel surveys. In this section I will present the key aspects of the survey procedures used for the MIP by the ZEW.

4.3.1 Basic Definition of Innovation and Innovating Firms

Following the recommendations of the Oslo Manual, an innovation is defined as follows:

"Technological product and process innovations (TPP) comprise implemented technologically new products and processes and significant technological improvements in product and processes. A TPP innovation has been implemented if it has been introduced on the market (product innovation) or used within the production process (process innovation): TPP innovations involve a series of scientific, technological, organisational, financial and commercial activities. […]" (OECD and Eurostat, 1997: 47, §130)

Innovators are firms that have introduced at least one technological product or process innovation during the last three years (reference period) prior to the survey period. To give an example, a firm which introduced an innovation in 2001, would be an innovator in the 2002 survey (reference period 1999-2001), 2003 (reference period 2000-2002) and 2004 (reference period 2001-2003). For questions on innovation expenditure only the last year of the reference period is relevant.[56]

An important feature of the innovation concept as defined in the Oslo Manual is also the minimum entry level. The Oslo Manual sets the minimum entry level, as "new (or significantly improved) to the firm" (§131, p.47), i.e. a new technological process is an innovation if it is (subjectively) new to the firm developing it. It does not have to be new to the world or the market it operates in. Consequently, the innovation concept of the MIP surveys does not only cover world-first innovations but also the diffusion of innovations and the imitation of product and process innovations. However, it does not allow the diffusion of particular technologies or a specific innovation to be analysed, as the so-called "subject approach" is applied in all Mannheim Innovation Panel surveys. With this approach the focus is on the firm as a whole and not on individual innovations. Some MIP questionnaires ask for the most important innovation.

Another important concept is that of an "innovating firm" or rather "innovation active firm". These are firms that either introduced at least one innovation during the three year reference period, or have ongoing or abandoned innovation activities.

56 For a discussion of the three year reference period see Rammer et al. (2005c).

4.3.2 Populations, Sample and Non-Response Analyses

The target population of the MIP are all legally independent enterprises[57] in Germany with at least 5 employees from the following NACE divisions (2-digit) or NACE sections (1-digit)[58]:

Manufacturing:

- Mining and quarrying and Manufacturing (C+D)
- Electricity, gas and water supply (E)
- Construction (F)

Services:

- Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods (G)
- Transport, storage and communication (I)
- Financial intermediation (J)
- Real estate, renting and business activities (K)
- Motion picture and video activities and Radio and television activities (92.1+92.2)
- Sewage and refuse disposal, sanitation and similar activities (90)

The number of enterprises, employees and the total turnover in each NACE division and section are taken from official statistics compiled by the German sta-

57 In the Council Regulation 696/1993 (European Commission, 1993), the enterprise is defined as "the smallest combination of legal units that is an organisational unit producing goods or services, which benefits from a certain degree of autonomy in decision making, especially for the allocation of its current resources. It may carry out one or more activities at one or more locations and it may be a combination of legal units, one legal unit or part of a legal unit."

58 The list provided here is based on the 2003 survey. Every other year, the coverage is adapted to current policy interests and increased importance of certain industries. In 2003, e.g. the media sector was covered for the first time in the German innovation survey. The empirical part of this study will be restricted to industries included in all surveys, as described below.

tistical office (DESTATIS), if available.[59] For all those industries without official statistics the population is estimated using information from associations, administrative bodies and the statistics on turnover tax ("Umsatzsteuerstatistik", Fachserie 14, Reihe 8) from DESTATIS. For most service industries no distribution of firms across size classes and regions was available until 2003. Consequently this distribution was estimated along with the figures for the last year of the reference period, because of publication delays of the official statistics. The new statistics on services industries ("Dienstleistungsstatistik", Fachserie 9) contains information on size classes and has been used since 2004 as a basis for constructing the total population of enterprises in selected service industries (NACE I+K). The East-West distribution is still based on turnover tax statistics.

The stratified random sample for the survey is drawn from the CREDITREFOM database.[60] This database is compiled by the credit rating agency Creditreform and contains (almost) all active enterprises in Germany. It is the best basis for drawing the sample, given that only the German statistical office has access to the business register.

The sample is stratified by industry, size and region. There are eight size classes for manufacturing industries (5-9, 10-19, 20-49, 50-199, 200-499, 500-999, 1000+) and seven size classes for the service sector industries, i.e. there is only the size class 500+ for service industries. Up until 2004 the industries used for sampling are not NACE divisions, but rather combinations of NACE divisions: 10-14, 15+16, 17-19, 20-22, 23-24, 25, 26, 27-28, 29, 30-32, 33, 34-35, 36-37, 40-41, 50+52, 51, 60-63+64.1, 65-67, 70-71, 72+64.2, 73+74.2+74.3, 74.1+74.4, 74.5-74.8+90, 92.1+92.2. Since the Commission regulation cited above requires member states of the EU to submit data on the innovation behaviour of firms at the NACE division level, the industry stratification was changed

---

59 Foe example, manufacturing (NACE C-F): Fachserie 4, Reihen 1.2; 2.1, 6.1, and 5.2 / wholesale and retail trade (NACE G): Fachserie 6, Reihe 1.2 and 3.2 / Transport, storage and communication (NACE I) Fachserie 8 Reihe 2, 3, 4 and 8.

60 For a description of the database see Almus et al. (2000).

in 2005, basically to 2-digit NACE groups, with a few exceptions, e.g. NACE 10-14 and 15+16. The main change in 2005 was that NACE 50 and 52 (retail trade), NACE 70 and 71 (real estate and renting) and NACE 45 (construction) are no longer included in the core sample.[61] The regional dimension of innovation activities is gaining importance for policy makers. This is particularly true for East and West Germany. In order to be able to analyse the differences between the two German regions, the sample is also stratified by these two regions. All in all this leads to more than 350 strata for the sampling. The sample fractions for each cell are not proportional. Some restrictions have been imposed to increase the validity of the results. These restrictions are:

- All large enterprises are included in the sample.
- East German firms have a higher sample probability than West German ones.
- Firms in industries with a low overall number of firms have a higher probability to be drawn than firms in large industries.
- At least 10 firms should be drawn from each cell.
- To maintain the panel structure of the survey, all enterprises that have answered at least once in previous years are included in the sample.

The gross sample size is about 25,000 enterprises for the large scale survey with its long questionnaire (odd years) and about 7,000 enterprises for the short version (even years). The number for the smaller surveys is lower because the short questionnaire is sent out to the panel firms only, while the large survey is targeted at panel firms and other firms. In 2005 the sample size was increased considerably to about 33,000 firms to increase the reliability of the results. Between 20 and 25% of all enterprises that are considered as valid respondents – some firms are not eligible because they have gone out of business or merged with other firms - answer the questionnaires. The response rates for Germany are

61 To maintain the panel structure, firms from these industries that answered at least once in the past are still part of the sample.

lower than in most other countries conducting voluntary surveys. For the CIS III survey for example the response rate in Germany was 21%, in Belgium und Denmark it was 30%, in Sweden 48%. The highest response rate for a voluntary survey was Luxemburg and Estonia with 73% and 62% respectively. [62] These two countries did not however solely rely on written questionnaires but did also conduct face-to-face interviews.

Some descriptive statistics on the samples and response rates of the MIP surveys I use in the empirical part of this study are presented in the table on the next page.[63]

62 Figures are taken from European Commission (2004b).

63 I will use three MIP surveys, that of the year 2001 (reference period 1998-2000), 2003 (reference period 2000-2002) and 2005 (reference period 2002-2004).

Table 4-1 Sample Sizes of the MIP Survey of 2001, 2003 and 2005 (Selected Industry Groups[64])

NACE	Gross Sample (corrected)[a)]			Net Sample[b)]			Response-Rate		
	2001	2003	2005[c)]	2001	2003	2005[c)]	2001	2003	2005[c)]
15-16	723	607	1080	160	133	146	22%	22%	14%
17-19	526	573	815	117	129	141	22%	23%	17%
20-22	851	896	2476	168	173	321	20%	19%	13%
23	60	81	81	19	17	17	32%	21%	21%
24	556	641	1014	115	144	172	21%	22%	17%
25	605	659	939	160	157	175	26%	24%	19%
26	472	502	681	101	105	101	21%	21%	15%
27-28	1328	1340	1866	307	319	362	23%	24%	19%
29	1399	1534	1668	306	314	307	22%	20%	18%
30-32	825	972	1241	190	196	231	23%	20%	19%
33	600	836	925	136	188	218	23%	22%	24%
34-35	403	520	752	79	123	123	20%	24%	16%
36-37	409	495	679	81	113	124	20%	23%	18%
40-41	323	387	926	109	91	194	34%	24%	21%
45	530	574	291	162	114	123	31%	20%	42%
50-52	3011	2276	1804	592	343	342	20%	15%	19%
60-64	1914	1879	2500	430	344	432	22%	18%	17%
65-67	1081	1091	1512	235	171	244	22%	16%	16%
70-71	877	885	266	169	146	111	19%	16%	42%
72	833	936	919	165	188	185	20%	20%	20%
73	416	523	548	129	121	124	31%	23%	23%
74	3176	3621	4343	693	675	751	22%	19%	17%
Sum	20918	21828	27326	4623	4304	4944	22%	20%	18%

a) Gross sample reduced by neutral non-response (enterprises closed during observation period)

b) Filled-in questionnaires

c) In 2005 the NACE coverage of the MIP was changed. For details see section 4.3.2.

Source: Own calculations.

64 The MIP also covers NACE 10-14, 90, 92.1, 92.2.

In order to correct for possible differences in the innovation behaviour of respondents and non-respondents, a non-response analysis is conducted. The sample frame for this non-response analysis, where firms are contacted by telephone and asked about the key innovation indicators, are all enterprises from the main sample that did not return a filled in questionnaire. The size of this non-response survey is about 4,000 enterprises. The results are used to correct the standard expansion factors for non-response bias.

4.3.3 Survey Questionnaire and Survey Process

The MIP surveys are conducted as voluntary sample surveys among German firms with at least 5 employees. The firms drawn from the total population of firms in Germany receive a standardised questionnaire usually in late March or beginning of April each year. The length of this questionnaire is between 4 (even years) and 16 pages (odd years). The length of the questionnaire and consequently the response burden can be seen as one of the main reason for low response rates. The ZEW is thus always trying to reduce the number of questions and the length of the questionnaire as far as possible. The 2005 CIS IV questionnaire is evidence of that goal, whereas the 2001 CIS III questionnaire in Germany had 16 pages the CIS IV questionnaire in Germany had just 8 pages and 44 questions. Each questionnaire contains a list of examples of product and process innovation in manufacturing and services.

In order to increase the response rates for the survey the firms in the sample which did not return a filled in questionnaire until a given date receive a written reminder supplemented by a new questionnaire. The methodological guidelines for the CIS IV recommend two such reminders. Some times three reminders have been sent out in the past.

After this first phase of the innovation survey, the non-response sample is drawn from the firms in the original sample which did not return a filled-in questionnaire. These about 4000 firms are contacted by telephone and asked to answer a very short questionnaire on the key innovation indicators and their number of employees and turnover.

4.3.4 Data Preparation, Data Quality and Expansion

The raw data from the questionnaire is collected by infas. The ZEW then conducts a number of data preparation and consistency checks on this data in order to be able to calculate reliable and representative figures for the total population.

The first step is to check the data for consistency of answers. Typical inconsistencies that occur are that firms report more R&D than innovation expenditure, which includes R&D expenditure, or report R&D in millions instead of thousands. Another type of inconsistency is corrected by using "back-filtering". This procedure applies if firms answer some questions in one direction and other, related questions to the contrary. For example, if a firm reported R&D expenditure for 2002, it should also have ticked "yes" for the question on ongoing innovation activities during the reference period 2000-2002. If it did not, the answer is "back-filtered" and the answer for ongoing innovation activities is changed from "no" or "missing" to yes. Consistency is also required for the scope of the figures reported. The MIP targets only German firms. Thus, if firms report world-wide figures a correction factor has to be determined and applied to the data. While the first two inconsistencies can be detected by semi-automated procedures and checks using the panel, the last one is harder to detect, especially for small and medium sized enterprises.

The next step is to make sure that all large companies are included in the survey. This is particularly important for the calculation of quantitative figures in the data, most prominently the innovation expenditure data and the measures of success of innovations. If some of these large companies are missing from the sample, the innovation expenditure and other quantitative figures would be underestimated when calculating statistics for the total population of German firms. Large companies and groups that are of interest are those with more than 10.000 employees and their headquarters in Germany. For industries that do not have companies with more than 10.000 employees, the largest four are considered. If large companies did not return the questionnaire, company reports and publications are used to gather information about their key financial and economic figures (relevant for expansion) and as far as possible for their innovation activities (R&D spending etc.). If some legally independent divisions of a large group returned the questionnaire the results are "consolidated" and only figures for those divisions that are missing are added, if possible. If some values cannot be collected from company reports and publications, imputations are made based on the panel, i.e. previous answers of the same company.

Imputations are not only made for large firms, but also for other firms to correct "item non-response". The method of imputation varies with the type of variable to be imputed. For variables that are included in the survey annually, like success with innovations or innovation expenditure, missing values are replaced by the extrapolated value of previous answers (longitudinal imputation). A firm might have provided innovation expenditure in previous surveys for 1999, 2000 and 2001, but did not report any expenditure figures in 2002. In that case the 2001 to 2002 growth rate would be estimated by the growth rate between 1999 and 2001 and applied to the 2001 innovation expenditure. If quantitative questions are only asked in one year, this method cannot be used. In that case the average value in the industry or cell is imputed. Imputation is more complex for qualitative questions, as no meaningful growth rates or industry averages can be calculated for these answers. In that case the imputation is done using estimation techniques. A propensity score is estimated based on firm characteristics, like size and industry and imputed.

Imputation is necessary in order to be able to expand the sample results to the German statistical population. Depending on the type of variable to be expanded, different expansion factors and methods are used. For qualitative figures the free expansion method which is based on the number of enterprises in each Strata in the sample and the population is used, corrected for non-response bias of course. For quantitative indicators the bound expansion method is used, where the expansion factor of the simple expansion method is multiplied by the inverse of the ratio of the turnover calculated based on the simple expansion factor divided by the turnover in the population. For the manufacturing sector a third expansion factor is calculated with this method using the number of employees instead of the turnover.[65]

4.3.5 Publications and Usage of the Microdata

The usage of the innovation survey is twofold. The data is used both for innovation and technology policy advice and evaluation and reporting on innovation activities in Germany, as well as for scientific purposes.

For each innovation survey a report is published that describes the development of the key innovation indicators like the share of innovators or the innovation expenditures, for the manufacturing and the service sector, respectively. Special attention is given to differences between small and large firms and innovation activities in East and West Germany.[66] Likewise, reports on 22 industries and industry groups are published annually which document the development in specific industries and compare the industry dynamics with that of manufacturing or services as a whole. A comprehensive report on MIP surveys with the long questionnaire is published after the survey is completed. It provides analyses of the questions only included in that specific survey and, thus, a more in-depth look at various developments and effects of innovation than the regular indicator reports.

Beyond the publications of the ZEW, the results of the innovation surveys are used in various government and EU reports, e.g., "Innovation in Europe" (European Commission, 2004b) and "Bundesbericht Forschung" (BMBF, 2004).

The use of the MIP data for scientific purposes has increased in recent years. A whole range of topics have been empirically analysed by ZEW employees as well

65 The respective formulas for calculating the expansion factors can be found in the introductory chapter of Rammer et al. (2005c).

66 These and other reports can be downloaded from http://www.zew.de/innovation. Some are available in English.

as external scholars, who are granted access to anonymised micro-data in the form of scientific use files under certain circumstances. The topics investigated include: determinants of innovation behaviour of firms, the role of innovation activities in determining the economic and technological success of firms, employment effects of innovation and the importance of framework conditions (IPR, public funding, obstacles, co-operation, etc.) for innovation activities in Germany, to name a few.[67]

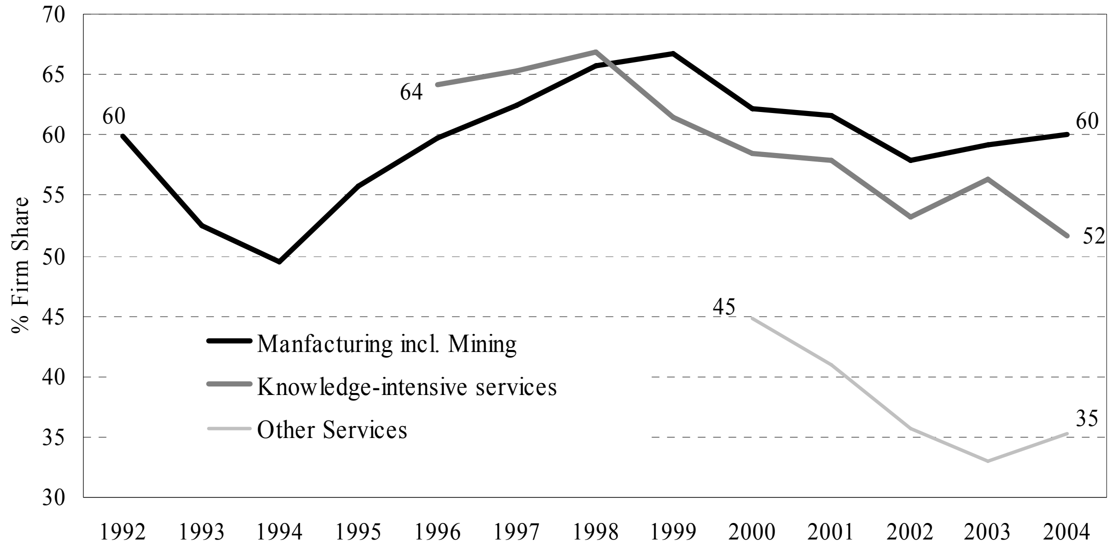
4.3.6 Main Results of the 2005 Mannheim Innovation Panel

The following figures show the latest results from the Mannheim Innovation survey of 2005, which was part of the CIS IV. These are included here to give the reader some impression on how the data is used beyond scientific analysis.

The share of firms with innovation activities has gone down from 2003 to 2004 for knowledge-intensive services and gone up for manufacturing and mining and other services. 52% of all firms from the knowledge-intensive service sector have introduced at least one innovation during the three year period 2002 to 2003, the corresponding figures for firms from manufacturing or mining are 60% and 35% for other services. The development over time shows the knowledge intensive service sector and the manufacturing and mining sector to move almost parallel between 1998 and 2003. Only in 2003 did both curves separate again. The innovation participation in other services has been below that of the other two sectors since 2000.

67 The reader of Janz and Licht (2003) summarises the scientific usage of the MIP data up to about the year 2000. More recent articles are available from the website mentioned above.

Figure 4-2 Share of Innovators in Germany, 1992-2004



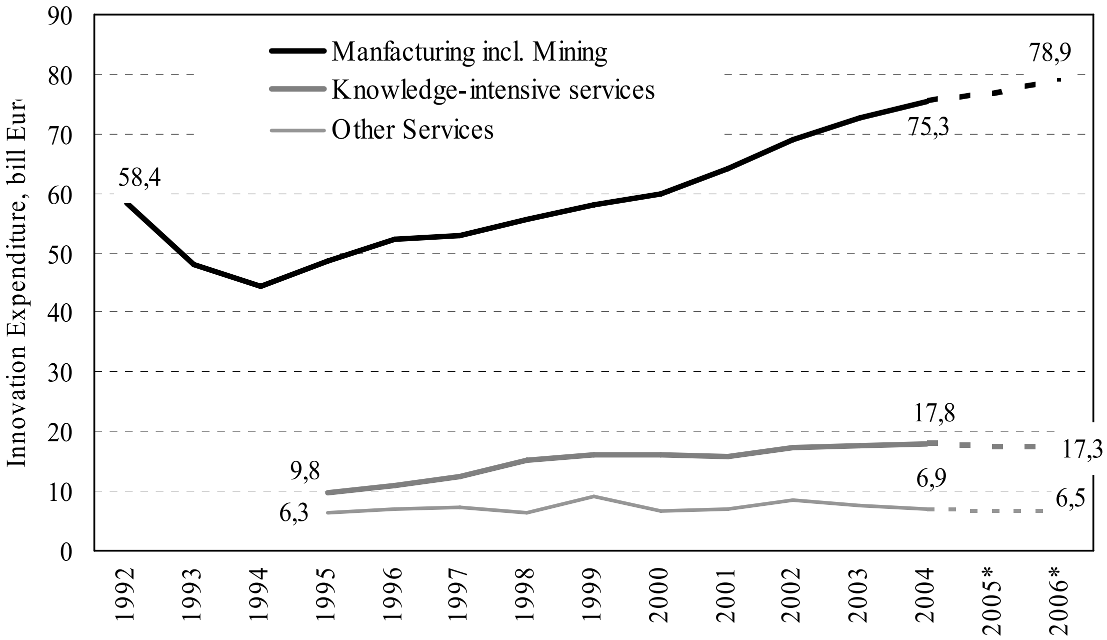
Source: Aschhoff et al. (2006): 2.

Notes: Innovator share: innovators as a percentage of all firms. Figures for 2003 and 2005 are tentative. Figures for the service sectors are only available from 1996 on. Other services figures from 2000 on are not comparable with those from previous years and are only shown for 2000 and later. All figures are projected for the total firm population (firms with 5 or more employees) in Germany.

The innovation expenditure figures displayed in Figure 4-3, show that the manufacturing sector spends by far the most on innovation and R&D activities. In 2004 the total amount spent on innovation activities for this sector adds up to 75.3 billion Euro. In mid-2005 the manufacturing firms planed to increase their expenditure by 3.6 billion Euros between 2004 and 2006. In contrast, both service sector plan to reduce their innovation expenditure over the same period by 0.9 billion Euros to a combined 23.8 billion Euros.[68]

68 Additional figures and discussion of the innovation behaviour of German firms can be found in Aschhoff et al. (2006).

Figure 4-3 Innovation Expenditure of German Firms, 1992-2005



Source: Aschhoff et al. (2006): 4.

* Data for 2005 and 2006 are based on firm plans and expectations at mid-2005.

Notes: Figures for 2003 and 2004 are tentative. Figures for the service sectors are only available for 1995 and later. Data for 2005 and 2006 are based on projected firm figures and expectations at mid-2005. Figures for other services from 2000 on are only partially comparable with those from previous years. All figures are projected for the total firm population in Germany.

5 The Construction of the Potential Outgoing Spillover Pools/Knowledge Stocks at the Industry and Firm-Level

This chapter of the study is devoted to developing a measure for the stock of knowledge accumulated by an industry up to a certain point in time, i.e. a firm's or an industry's knowledge stock. In the first part of this chapter I will review the literature on measurement of knowledge flows and the construction of knowledge stocks. In the second part I will describe the construction of the knowledge stocks of firms and industries relevant for my study.

5.1 Empirical Measures for Knowledge Flows and Knowledge Stocks[69]

In this section I construct a measure for the amount of knowledge created in an industry over a given period of time, i.e. the "potential outgoing knowledge spillover pool"[70] or "knowledge pool".

A methodological issue in creating the knowledge stock of an industry or firm is how to measure knowledge empirically, mainly because knowledge flows are not observable, that is to say they are "invisible" (Krugman, 1991: 53). As Jaffe (1986) has stated, it is extremely difficult to observe the actual spillovers between firms. Some types of knowledge are impossible for researchers to track and, what is more, are not directly measurable and quantifiable.[71] Several other authors have also acknowledged the fact that knowledge and spillovers are hard to measure (Geroski, 1995; Arrow, 1962a; Peters, 2003; Los and Verspagen, 2000; Agrawal and Henderson, 2002).

---

69 The terms "knowledge stocks" and "knowledge pools" will be used interchangeably.

70 The term "potential spillover pool" has been used by Jaffe in a similar setting. While Jaffe (1986) used the term for the "weighted sum of other firms' R&D" (Jaffe, 1986: 986), I use it for the unweighted sum of all R&D undertaken in an industry. The weighting, which is definitely important for the analysis of spillovers, will be done in the subsequent sections.

71 Arrow (1962a) has already noted that the quantity of knowledge is hard to measure (Arrow, 1962a: 155). This view is also held by Peters (2003). He writes that tacit knowledge is "[…] difficult to codify and measure." (Peters, 2003: 370)

Since knowledge is not directly traceable, proxies for the knowledge flows and stocks have been used, among them are trade-flows or trade-relations (Coe and Helpman, 1995) and patent citations[72], which can be seen as a paper trail left by those involved (see Peri, 2005 literature review). Geroski et al. (1993) use innovation counts gathered from the Science Policy Research Unit (SPRU) innovation database to measure spillovers and knowledge stocks.

With the advent of innovation surveys, several authors have used questions on the importance of external sources of information for the innovation activities of firms as a proxy for knowledge flows (e.g. Belderbos et al., 2004; Bönte and Keilbach, 2005; Cassiman and Veugelers, 2002; Dachs et al., 2004; Schmidt, 2005b). These questions can also be seen as a paper trail of spillovers, but rely heavily on the subjective assessment and power of recollection of the person filling in the questionnaire. While a patent is registered at the patent office, the importance of an external knowledge source for a firm's innovation process is normally not registered anywhere. The use of survey data increases the coverage of spillovers to those not registered in patents, e.g. spillovers generated by inventions and innovations that are not patented or patentable.

In order to be able to analyse the influence of knowledge spillovers on various input and output indicators of the innovation process in spite of these problems, researchers have used the accumulated stock of R&D in empirical studies (e.g. Griliches, 1979a; 1990; Bernstein, 1988; Jaffe, 1986) as a proxy for the knowledge stock.[73] Starting with Griliches (1979a), empirical researchers have tried to estimate the amount of knowledge spillovers using R&D data. The assumption

72 The literature using citations in patents and patent applications as measures of knowledge flows and spillovers is quite extensive (e.g. Jaffe et al., 1993; Porter and Stern, 2000; Maurseth and Verspagen, 2002). However, a big drawback of patent data is that "not all inventions are patentable, not all inventions are patented" (Griliches, 1990: 1669) and firms use other methods of protection for their knowledge (Cohen et al., 2000; Levin et al., 1987).

73 Kaiser (2002b) discusses alternative proxies for the knowledge stock of an industry. Among them are number of patents, innovation expenditure, R&D investment and the R&D capital stock. Since most studies use the R&D stock however, I will use R&D stocks in this study.

behind the use of this proxy is that the main source of new (technological) knowledge is the innovation process (Romer, 1986; Brusoni et al., 2002). In Romer's model e.g. "Knowledge is accumulated by devoting resources to research." (Romer, 1986: 1007). What is more, the main focus of the theoretical literature was to analyse the effect of spillovers arising from R&D and innovation activities (e.g. D'Aspremont and Jacquemin, 1988; Katsoulacos and Ulph, 1998; De Bondt, 1996). This focus has certainly also influenced the empirical literature. Cameron's observation that "most researchers have chosen to use R&D spending as their measure of technological change, usually because R&D data are easiest to compile and most reliable." (Cameron, 1996: 2) might also go some of the way to explaining the popularity of R&D proxies for knowledge.

This method of constructing the knowledge spillover pool - using R&D expenditure data - has some drawbacks. One can easily see that this method is subject to a problem of double counting: If R&D of firms in an industry is duplicative, i.e. they do research on the same problem, the knowledge stock based on R&D expenditure would be biased upward.[74] In addition to that knowledge can be generated not only by investing in R&D but also by investing in other innovation related activities.[75] Lacking a better measure of the knowledge stock I use the accumulated R&D stock in this study.[76]

It is widely accepted that knowledge is subject to depreciation, i.e. knowledge becomes more and more obsolete over time.[77] Almost all studies I surveyed that use the R&D stock as a proxy for the knowledge spillover pool took this into account by including a depreciation rate in their calculations (e.g. Jaffe, 1986;

74 This has been noted by Reinganum (1981), who argues that the spillover parameter depends on either the feasibility of transferring knowledge between partners and "the degree to which the new knowledge generated by […] firms overlaps" (Reinganum, 1981: 31).

75 For a list of other innovation activities that require investment and expenditure see OECD and Eurostat (1997).

76 This is not without problems, because of the well-known fact that the service sector is less R&D intensive. The knowledge stock of service industries is thus potentially underestimated.

77 See e.g. Griliches (1979a).

Griffith et al., 2004; Peri, 2005; Los and Verspagen, 2000). The size of this depreciation rate differs from study to study. While Keller (2002), Peri (2005), Bernstein (1988) and Mohnen et al. (1986) use a 10% depreciation rate, most other studies (e.g. Jaffe, 1986) have followed Griliches and Mairesse (1984) and assumed a 15% depreciation rate for all industries included in their sample. Some authors have experimented with depreciation rates of 0 percent (see Griliches and Mairesse, 1984). [78] I will deviate from these approaches in that I will generate the R&D stocks using industry-specific depreciation rates instead of one depreciation rate for all industries included in my study. This is certainly an improvement, because it is logical to assume that knowledge becomes obsolete faster in industries which are more dynamic than others.

To generate an industry specific depreciation rate I will utilize a question from the Mannheim Innovation Panel[79] on the length of the average product life cycles of a firm's products. I argue that the longer (shorter) the product life cycle the smaller (higher) the depreciation rate. I therefore use the inverse of the average product live cycle as the depreciation rate for the two R&D stocks based on firms' R&D spending. In doing so I assume that all knowledge will become obsolete after the product life-cycle has come to an end. However, it is very likely that at least some knowledge will remain valuable and can spill over to other firms. It is not possible to determine the amount of knowledge that is still valuable after the "death" of the product with the data I have at hand, thus the simplifying assumption. This approach is similar to one taken by Goto and Suzuki (1989). They take the inverse of the average "life span" of firms' patents as their rate of depreciation for R&D capital.

---

78 Hall and Mairesse (1995), who argue that different depreciation rates do not influence their estimation results of the effect of R&D stocks on total factor productivity significantly, only varied the depreciation rate with respect to its level, not between industries. Orlando (2004) and Bernstein and Nadiri (1989) also state that their results are not affected by the depreciation rate chosen for the construction of the R&D stocks. They do not differentiate between industries, either.

79 See chapter 4 for a description of the survey.

In essence, the potential incoming spillover pools of an industry and the knowledge stock of an individual firm are constructed according to the following (perpetual inventory) method[80]:

$$S_i = S_i^0 * (1-\partial_i)^T + \sum_{t=1,\ldots,T} (1-\partial_i)^{(T-t)} (R\&D_i^t)$$

Where S_i is the potential outgoing spillover pool of industry i in year T, S_i^0 the starting value for the knowledge stock in industry i, ∂_i the time-invariant industry-specific depreciation rate and $R\&D_i^t$ the R&D expenditure of industry i at time t.

The following section will describe the data used for the construction of the potential outgoing spillover pools and the knowledge stock of a firm and the detailed methodology for arriving at the industry-specific pools.

5.2 Database for the Construction of the Knowledge Stock

In order to be able to construct the knowledge stocks for German industries from the manufacturing and service sector I use two different sources of data. One is the OECD's ANBERD "Analytical Business Enterprise Research and Development database (OECD, 2003), which provides information on the R&D expenditure of enterprises at the industry level and governments' R&D spending. The other is the R&D statistics of the "Stifterverband für die Deutsche Wissenschaft"[81] (Stifterverband), which reports figures on the (intramural) R&D expenditures of German firms. The use of these two sources was necessary, since the recent OECD database only provided up-to-date information until 1999 and reports estimated figures for 2001 and 2002, while the Stifterverband publications provide new data for 2001 and 2002. For the years before 2000 both databases

80 Note, as Los and Verspagen (2000) state, that using this method requires to assume that the depreciation rate is constant over time.

81 Stifterverband für die Deutsche Wissenschaft-Wissenschaftsstatistik (2005).

are identical since the OECD database is a collection of the data of the national R&D surveys, the German version of which is conducted by the Stifterverband.[82]

The use of the data poses some problems:

First, R&D data at the industry level is only available from 1995 onward. Thus I use a method used by Jaffe (1986) and Peri (2005) to construct an initial R&D stock (S_i^0), i.e. the initial stock is calculated by multiplying the 1995 R&D expenditure with the inverse of the sum of the depreciation rate and the average growth rate of R&D expenditure between 1996 and 2002.

Second, the R&D data is not available for all service industries (2-digit NACE) and some 2-digit NACE industries are only reported aggregated. Data is available for the following NACE: 40+41 (Electricity, gas and water supply), 45 (Construction) , 50-52 (Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods), 60-63 (Land transport; transport via pipelines; Water transport; Air transport; Supporting and auxiliary transport activities; activities of travel agencies), 65-67 (Financial intermediation), 72 (Computer and related activities), 73 (Research and development), and 74 (Other business activities).[83]

The service industry data poses another problem: it is available only for every other year.[84] To calculate the R&D expenditure for 1996, 1998, and 2000 I added the half of the difference between the values for one year before and after the respective date to the R&D expenditure for the previous year.

Finally, the most recent data from the Stifterverband for some industries is not available at the same level of detail as the OECD data. In order to be able to keep the level of detail provided in the ANBERD database, I distributed the more ag-

82 Note, I did not deflate the R&D expenditure figures (see e.g. Griffith et al., 2004 or Orlando, 2004), but used the current expenditure on R&D in Euros.

83 In order to ensure consistency of the different chapters, this grouping of NACE classes in the service sector was retained throughout the study, i.e. the term "NACE2" stands for the adapted NACE 2-digit classification instead of the original NACE 2-digit classification.

84 R&D expenditure data for NACE 72, 73 and 74 is available for the year 2000.

gregated figures from the Stifterverband for 2001 and 2002 according to the distribution of the OECD data from 1999. To give an example of the procedure: The Stifterverband reported the 2001 R&D expenditure for NACE 27+28 at € 853 billion and the 1999 R&D expenditure at € 776 billion, while the OECD's database provided separate figures for NACE 27 (€ 259 billion) and NACE 28 (€ 517 billion) for 1999. To come up with separate estimates of NACE 27 and 28 for 2001 the following calculations are performed € 259*(853/776) and € 517*(853/776), respectively.[85]

Since I want to investigate spillovers from the public domain, I also constructed a potential knowledge spillover pool for R&D conducted by the government and higher education institutes in Germany. The R&D figures (GERD by government and higher education in Germany) for these actors are readily available from the OECD ANBERD database and are reported in the Appendix.

By restricting my observations of R&D expenditure to Germany I will not be able to analyse the impact of knowledge spillovers from foreign firms and research institutions on the R&D co-operation behaviour of German firms.

5.3 Construction of Industry-Specific Knowledge Depreciation Rates

It has already been mentioned above that I want to construct industry specific depreciation rates from a question firms answered about the average product life cycle of their products in the 2003 survey of the Mannheim Innovation Panel.

This is not unproblematic. The firms were not only asked about the length of the product life cycle but also if the life cycle concept was applicable in their industry and 38% in service industries and 30% in manufacturing industries stated that the concept was not applicable in their industry. Especially in industries like transportation, the proportion of those who think the concept is not applicable is high. However, in all industries there were some firms which gave an estimate of the average product life cycle. Despite these drawbacks I decided to use this data

85 The final dataset of R&D expenditures used is reported in Table A-1 in the appendix.

for the construction of an industry-specific depreciation rate for knowledge capital. I did not calculate a rate for each 2-digit NACE industry, however, but rather aggregated some industries into larger groups to end up with more reliable estimates.[86] The results are presented in Table 5-1 on the following page. Another issue is that I am only able to construct one average product life cycle measure for all the years instead of one for each year. Because of that I have to assume that the depreciation rate does not change over time, although this is probably not the case in reality.

The results are mainly in line with what one could have expected, with high depreciation rates for the IT industry and low depreciation rates for established and less dynamic industries like electricity, gas and water supply.[87] The surprising results are those for the textile and leather industry (NACE 17-19). They can be explained by the fashion trends the textile and leather industry is subject to. Besides, the shift from classic textile to more advanced "technical" textiles in the last 30 years has led to an increase in innovation activities in the industry and shortened product life-cycles (Grosser, 2005).

The average life-cycle for all industries included in my study is 9 years, which would imply an average depreciation rate of 11.1%, closer to 10% than to 15%, these two values most widely used in the literature.

Data for the life-cycle of scientific knowledge is not available. However, NACE 73 (R&D services) depreciation rate might give an estimate of how fast university knowledge might depreciate as this industry is quite close to university R&D. Accordingly 16% is used as the depreciation rate for public R&D.

---

86 This aggregation was necessary because some 2-digit industries had very few observations for the product life cycle. The grouping for manufacturing was done in accordance with the regular reporting on industries by the ZEW (see e.g. Schmidt, 2004; Rammer et al., 2005a). The service industries were grouped according to the grouping reported in the R&D statistics (Stifterverband für die Deutsche Wissenschaft-Wissenschaftsstatistik, 2005).

87 Our results are very much in line with Goto and Suzuki (1989), who found that "industries in which technology is advancing rapidly […] were found to have higher rates of obsolence" than industries which are less rapidly advancing."(Goto and Suzuki, 1989: 557).

Table 5-1 Estimated Depreciation Rates for R&D Capital (in %) and Average Product Life-Cycle (in Years) for Selected Industry Groups

NACE	Industries	Product Life-Cycle	Depreciation Rate
15	Manufacture of food products and beverages	7	15.2%
17-19	Manufacture of textiles and textile products, leather and leather products	5	20%
20-22	Manufacture of wood and wood products, pulp, paper and paper products; publishing and printing	11	8.5%
23-24	Manufacture of coke, refined petroleum products and nuclear fuel, chemicals and chemical products	14	7.2%
25	Manufacture of rubber and plastic products	12	8.6%
26	Manufacture of other non-metallic mineral products	22	4.6%
27-28	Manufacture of basic metals and fabricated metal products	12	8.5%
29	Manufacture of machinery and equipment n.e.c.	10	9.9%
30-32	Manufacture of office machinery and computers, electrical machinery, radio, television and communication equipment and apparatus	8	13.1%
33	Manufacture of medical, precision and optical instruments, watches and clocks	7	14.4%
34-35	Manufacture of transport equipment	10	9.2%
36-37	Manufacturing n.e.c.	8	12.8%
40-41	Electricity, gas and water supply	20	4.9%
45	Construction	30	3.4%
50-52	Wholesale and retail trade; repair of motor vehicles, motorcycles and personal and household goods	9	11.7%

NACE	Industries	Product Life-Cycle	Depreciation Rate
60-63	Transport and storage	11	8.9%
65-67	Financial intermediation	8	12.4%
72	Computer and related activities	5	20.9%
73	Research and development	6	16.1%
74	Other business activities	8	12.3%

Source: Own calculations.

5.4 The Knowledge Stocks of Selected Industries[88]

Using the results for the industry-specific depreciation rates and assuming that this rate is constant over time I construct a first approximation of the knowledge pools. The results for the industries are reported in Table 5-2. The knowledge stock available from public sector R&D is estimated at 68737.657 billion Euro. Note that this is not the value of the knowledge stock but rather the amount of money it took to generate it.

The highest value can be found for NACE 34 (manufacture of motor vehicles, trailers and semi-trailers). The knowledge stock of NACE 34 and NACE 35 (manufacture of other transport equipment) combined is higher than that of the whole university and research institute sector. NACE 24 (manufacture of chemicals and chemical products) and NACE 29 (manufacture of machinery and equipment n.e.c.) take second and third place, respectively. This result reflects the commitment of these industries not only to R&D but also to innovation ac-

88 When constructing the firm specific level of realized incoming spillover, I will take into account the fact that the intra-industry stock of *external* knowledge is the intra-industry stock minus the R&D carried out by the enterprise itself, i.e. each firm will have its own individual intra-industry knowledge stock. Here the total amount of knowledge generated in an industry is estimated.

tivities in general, as the regular indicator reports on the innovation behaviour[89] of German firms show (most recent report: Rammer et al., 2005a). The two service industries with the highest knowledge stocks in 2002 are NACE 73 (Research and Development) and NACE 72 (Computer and related activities). Their estimated knowledge stock is higher than that of some manufacturing industries, despite their high depreciation rates.

Table 5-2 Estimated Knowledge Stocks for Selected Industry Groups in 2002

NACE 2	R&D stock by industry	NACE 2	R&D stock by industry
15	986.673	31	5833.025
16	143.582	32	18619.922
17	714.389	33	8379.555
18	135.704	34	52058.848
19	18.133	35	14682.061
20	152.795	36	845.304
21	430.916	37	23.733
22	141.924	40-41	605.884
23	363.199	45	542.766
24	35033.947	50-52	675.135
25	3179.315	60-63	2737.901
26	2149.938	65-67	85.096
27	1603.361	72	3059.725
28	2916.270	73	3384.591
29	19551.832	74	2206.796
30	3668.365	Sum	184930.68

Source: Own calculations.

5.5 The Knowledge Stock of a Firm

The knowledge stock for an individual firm is constructed in the same way as the knowledge stock for an industry. The total amount of knowledge generated

89 Note that the total amount spent on R&D is just a proxy for the knowledge generated and that the results should thus be interpreted with care. In particular the knowledge stock for service industries, which are known to have less R&D-intensive innovation and knowledge production processes (see e.g. Rammer et al. (2005a): in the retail trade less than 1% of all enterprises conduct R&D continuously), might be higher than estimated.

by an individual firm is proxied by that firm's R&D expenditure. The firm level R&D expenditure data comes from the Mannheim Innovation Surveys, which include a question on the total amount spent on in-house R&D in a given year. Since the first MIP survey for service industries was carried out in 1996, the initial stock of knowledge is constructed for the year 1996, using the growth rate of R&D expenditure for each firm from 1997 to 2002, as at the industry level. To depreciate firms' R&D expenditure I used the estimated industry level of depreciation instead of the firm's in order not to lose too many observations so early in the empirical part of my study.

The average knowledge stock of all firms for which R&D data is available is 15.48 billion Euros. In 2002, almost 95% of all firms had knowledge stocks valued at less than 1 billion Euros.

6 From Potential Outgoing to Realized Incoming Spillover Pools

"If you have an apple and I have an apple and we exchange apples then you and I will still each have one apple. But if you have an idea and I have an idea and we exchange these ideas, then each of us will have two ideas."

George Bernard Shaw

In the previous section I constructed the knowledge stocks of industries and individual firms. Potentially all of this knowledge could spill over to over actors in an economy; this is if it were a pure public good as suggested by the quote of Georg Bernard Shaw. In the following sections I will argue that this is not the case. I will argue that some knowledge can always be appropriated by the firm producing it and that not all knowledge that nonetheless spills over into the public domain can be used by each firm equally. I start with a short literature review on factors moderating the free flow of knowledge.

6.1 Factors Moderating the Free Flow of Knowledge [90]

Even though knowledge exhibit features of a public good (see above and Arrow, 1962b) there are some factors moderating the free and costless flow of knowledge from the producer to the user of the knowledge:

The first moderating factor is the possibility to appropriate knowledge through a system of formal or informal intellectual property protection methods. Stiglitz, 1999a for example argues that if trade secrets and patents allow the producer of

90 This section will review the methodological issues in assessing the spillovers between firms and industries empirically, as this is the main focus of this section. I will not report the results of the studies analysing the effect of spillovers on productivity or output measures. The interested reader might start from the overviews of literature on spillover effects collected by Nadiri (1993) (rates of return on R&D), Harabi (1997) ("spillovers are prevelant and important" p.628), Griliches (1992; 1994) (productivity), De Bondt (1996) (theory), among others.

new knowledge to appropriate some of the returns of his efforts at least some degree of excludability is present. Empirical evidence on the effect of appropriation methods on knowledge flows has been provided by Cohen and Walsh (2000) who show that the use of secrecy significantly reduces the information flows between firms in the same industry. They also find that patents do not exert a significant negative effect on knowledge flows within industries. This might be due to the fact that the patent system requires firms to disclose their knowledge in the patent application. Kaiser (2002b) argues that knowledge spillovers arise because protection methods are not perfect, indirectly saying that protection methods can reduce the flow of knowledge between firms.[91]

Even though Spence left it open whether appropriability is "created by circumstances or policy" (Spence, 1984: 102), his model can be used to represent the moderating effect of protection mechanisms on knowledge spillovers. Spillovers in his model are represented by (Spence, 1984: 103):

$$\text{Spillovers} = \theta \sum_{j \neq i} m_j(t)$$

where m_j is the current R&D expenditure of firm j and θ the parameter that represents the level of spillovers. If θ is equal to 1 all new knowledge spills over, if θ is equal to 0 nothing spills over.

A second moderating factor is the absorptive capacity of individuals and firms. While the first moderating factor affects all firms in an industry equally or at least does not depend on the knowledge receiving firms' characteristics (see Griliches, 1992: 37: "symmetric approach") the second moderating factor does, because firms' have different absorptive capacities.[92] Cohen and Levinthal (1989; 1990) have shown that a firm has to posses certain capabilities in order to be able to source knowledge from the environment and to turn it into inno-

91 More information on the effects of different protection methods on knowledge flows will be providedin section 6.4.

92 To put it in another way, following Kaiser (2002b), its not very likely that all firms can equally gain from the pool of external knowledge.

vative products or processes.[93] This capacity is build up in their model by investing in in-house R&D. The literature that follows Cohen and Levinthal (1989; 1990) has identified a whole range of factors other than R&D that influence absorptive capacity.[94] The methods and mechanisms that determine absorptive capacity have in common, that they require substantial effort and the investment of resources. In general the acquisition of external knowledge can thus be seen as costly instead of free (see Stiglitz, 1999a). A theoretical model building on the assumption that learning is costly and taking into account that absorptive capacity matters for knowledge acquisition has been presented by Von Graevenitz (2004).

Cohen and Levinthal (1989) model expands the framework proposed by Spence, 1984 by introducing a variable which stands for firms ability to assimilate and exploit external knowledge (γ) (Cohen and Levinthal, 1989: 571) [95]:

$$\text{Spillovers} = \gamma_i * (\theta \sum_{j \neq i} m_j(t) + T)$$

Kamien and Zang (2000) apply this equation to their formulation of "effective R&D"[96] (spillovers plus a firm's own R&D expenditure) (Kamien and Zang, 2000: 997):

$$\text{Effective R\&D} = x_i + (1-\delta_i)(1-\delta_j)\beta x_i^{\delta_i} x_j^{1-\delta_i}$$

where x_i represents a firms own R&D expenditure, and x_j its rival's, δ is the R&D approach chosen and β the exogenous spillover parameter. By multiplying both R&D expenditure levels, the second part of the equation will be zero, if the

---

93 For a more detailed survey of the literature on absorptive capacity see section 6.5.

94 See Daghfous (2004) and Zahra and George (2002) for a review of the literature.

95 T is the extra-industry knowledge pool.

96 The term "effective R&D" has been traced back to Ruff (1969) by De Bondt (1996) and is usually defined as "the amount of money it alone would have had to invest in R&D, if no other firm invested in R&D, to achieve the same unit cost reduction." (Kamien et al., 1992: 1297).

firm does not invest in R&D itself, i.e. if it does not have any absorptive capacity.

Finally, the effect of the distance between the user and producer of knowledge on the level of knowledge spillovers, have been intensively studied.[97] Researchers have focused on two different types of distance, geographical distance and technological distance. Despite the rather pessimistic assertion of Griliches (1979a) that the "concept of such 'distance' is hard to define empirically" (Griliches, 1979a: 103), a variety of empirical distance measures has been suggested.

To measure the technological distance between firms Jaffe (1986) method has been very influential. He positions firms in "technology space" by analysing the patents of firms. To be more precise, he locks at the distribution of a firm's patents over 49 technological categories (patent classes). The exact weight is then determined by calculating the un-centred correlation of the patent class vectors for each firm.[98] A major drawback of this method is that not all innovations and inventions are patented or patentable and thus the measure based on patent statistics can be biased[99]. Other methods to determine the technological proximity of firms have been proposed: Orlando (2004) assumes that firms in the same 4-digit SIC are technological close, Adams (1990) uses the distribution of the scientific workforce as a measure of technological distance, Goto and Suzuki (1989) asses the distance between two industries by using Jaffe's formula on matrixes of R&D expenditure in 30 different product areas. Kaiser (2002b) describes Inkmann and Pohlmeier (1995) method, which suggests to use the Euclidean distance between firm characteristics to asses the extend of the technological distance.

A second distance measure is the geographical distance. The measurement of the geographical distance is straight forward. It has been measured in distance

97 Overviews can be found in Kaiser (2002b), Cincera (2005) and Griliches (1992).

98 For the exact formula see Jaffe (1988).

99 For a discussion of this and other problems with Jaffe's method see Cincera (2005).

units like kilometres (Kaiser, 2002b; Keller, 2002) or by grouping firms in the same region (Greunz, 2003; Peri, 2005; Orlando, 2004).

In a recent paper Orlando (2004) jointly analysis technological and geographical distance, by separating the total stock of knowledge into four groups: technological close – geographical distant, etc.

The discussion on the distance between firms can be summarized with the following formula adapted from Griliches (1979a: 103):

$$Spillovers = \sum w_{ij} m_j$$

Where w_{ij} represents the distance between firm i and firm j and m_j is the stock of R&D expenditure.

As Kaiser (2002b) has shown the particular distance measure used can have a significant impact on the size of the estimated knowledge spillover and should thus be chosen wisely.

Negassi (2004) has combined the discussion on technological distance and protection in his formula for "national pure spillovers", which he defines as (Negassi, 2004: 371)

$$Npsspill_{git} = \sum_{j \neq i} v_{ij} a_{ij} RD_j$$

Where v_{ij} is a measure of the effectiveness of patent protection as seen by firm j, a_{ij} is the technological distance between firm i and j calculated from the patent portfolio of the firms, similar to Jaffe (1986) and RD_j is the R&D expenditure of firm j.

The literature cited above indicates that the amount of spillovers a firm actually uses does not only depend on the total amount of knowledge generated in an industry but also on the characteristics and behaviour of firms. This is the main reason why I distinguish between the *potential* spillover pool and the *realized* spillover pool in my study. The former being the pool of knowledge that is generated in an industry (potential outgoing spillover pool) or available (potential incoming spillover pool) to a given firm and the later being the one not protected or protect-able by firms (realized outgoing spillovers) or actually used by firms (realized incoming spillover).

6.2 Different Types of Knowledge Spillover Pools

Knowledge can be tacit or formal (e.g. Polanyi, 1967; Cowan et al., 2000; Bartholomaei, 2005), specific or generic (see e.g. Breschi et al., 2000), embodied or disembodied (Romer, 1990) or in the form of information and know-how (Kogut and Zander, 1992), to name a few widely used distinctions for knowledge. However, knowledge cannot only be distinguished by the form it takes but also by the source it stems from and the channels through which it is transmitted (Harabi, 1997). For the analysis of spillovers both distinctions play an important role. Both influence the ease and the costs with which knowledge can be acquired by firms.

Despite the importance of the type of knowledge for the level of spillovers, I will only focus on the "actors" generating knowledge in an economy[100], mainly because I lack data for the type of knowledge actually generated by the firms in the sample I want to analyse empirically. As noted above (see section 3), I will distinguish between knowledge that is generated by other firms in a firm's own industry (intra-industry), firms from other industries (inter-industry) and universities or other public research institutions (science).[101] [102] This distinction is not

100 As will become clear shortly, I will not analyse all the actors in the so called "national innovation system" (Lundvall, 1988), but rather focus on firms and research institutes like universities.

101 Note, this segmentation is not equivalent to weighting the knowledge generated by the technological distance between two firms. Employing the weighting assumes that per se the more distant two firms are the less knowledge flows between them. Separating intra-industry from inter-industry knowledge flows is more general, because I just have to assume that the level of spillover is affected differently by different moderating factors, like absorptive capacity.

102 The distinction by sources could also be done by looking at academic versus industrial sources Adams (2004) or suppliers, customers, competitors and research institutes separately (see Von Hippel, 1988).

arbitrary, but rather well established in the literature (see also section 2.5.2). However, early empirical studies and most theoretical models have only investigated intra-industry spillovers, as Bernstein (1988) and Steurs (1995) argue in their papers. Both authors see this as a drawback of existing studies and include inter-industry spillovers in their models. Bernstein, 1988 shows empirically that both intra- and inter-industry spillovers reduce average production costs in an industry and that inter-industry spillovers do so more than inter-industry spillovers. Steurs (1995) is able to show in his theoretical model, that inter-industry spillovers matter for firms output and profits. In contrast, Veugelers and Koen (1999) show in their empirical study that inter-industry spillovers do not significantly increase industries' output. There are some studies that do not use the terms intra-industry and inter-industry spillovers, but deal with the same topic. Griliches (1992) argues that the usefulness of external knowledge is higher for knowledge within the same 3-digit SIC industry, than for knowledge from outside of it. In that sense he is taking the opposite position than Bernstein (1988). Orlando (2004) uses a similar delimitation and shows that spillovers within the same industry are not very elastic with regard to inter-firm distance, while spillovers across industry boundaries are. Goto and Suzuki (1989) suggest that R&D activities of (in particular input supplying) industries affect productivity growth in other industries further down the supply chain. Nadiri (1993) summarizes the literature on technology flows with the conclusion that "substantial spillover effects among different industries [exist]."(Nadiri, 1993: 22). The spillover effects across industries need not be symmetric, Bernstein and Nadiri (1991) show that some industries' knowledge spills over to more industries than other industries' knowledge.

The private sector is not the only one which generates knowledge, however. The public sector is also spending large amounts on R&D either by funding private firms or by funding universities and public research institutes. Public R&D activities are different from those of firms in the private sector because one of the goals of public R&D is to generate spillovers that benefit the economy as a whole, while firms seek to prevent spillovers through appropriability.[103] Probably with that in mind Stiglitz (1999b) once said that "The objective of the government is not to pick winners, but to identify externality-generating innovations." (Stiglitz, 1999b: 22). Hanusch and Cantner (1993) also make the case that governments should support the generation of external effects and not try to limit them.[104] Becker et al. (2002) argue that public R&D funding of "socially valuable projects" (Becker et al., 2002: 11), i.e. projects with large externalities or spillovers, is in the interest of the general public. The BMBF (2004) acknowledges that scientific knowledge is a public good and the government's role in providing funding for the generation of new scientific knowledge. Drejer and Jorgensen (2005) see spillovers arising from universities through the training of students that leave the university and go on working in the private sector, which occurs naturally.

Other studies have shown that the generation of spillovers is taken as a given in public R&D activities: Cohen et al. (1998) writes that academe's commitment is to "both basic research as well as […] free disclosure […]." (Cohen et al., 1998: 171-172) and that "the norm of open science [is] valued by researchers as an end in itself." (Cohen et al., 1998: 191). Monjon and Waelbroeck (2003) argue that it is valid to assume that spillovers from universities to firms are substantial, because "universities pride themselves on having a culture of open 'science'." (Monjon and Waelbroeck, 2003: 1257). There is also empirical evidence that public R&D does lead to spillovers (Cameron, 1996). A quite impressive case for substantial benefits and spillovers from academia to industries is provided by Mansfield, 1998. He finds that a considerable a,mount of innovations of 77 major firms could not have been developed without knowledge from academic research.

103 For a discussion and literature review of the different incentive for firms and scientist, see Cohen et al. (1998).

104 This policy is however not specific for public R&D. In general, appropriability possibilities and the diffusion of knowledge have to be balanced.

Spillovers from public R&D are not only different from private knowledge spillovers, because they stem from differently motivated actors, they are also different in other ways. Becker and Peters, 2000 and Nelson and Wolff, 1997 for example have shown that scientific knowledge requires different absorptive capacities.

To summarize, the review shows clearly that different types of knowledge spillovers exist and suggests from my point of view that it is worth to distinguish between spillovers from private R&D in a firm's own industry, private R&D in other industries and public R&D.

6.3 From Industry-Level Potential Outgoing Spillovers to Firm-Specific Realized Incoming Spillovers – Analytical Framework

To summarize the literature on knowledge pools and stocks, it's clear from the previous discussion that not all knowledge generated in an industry or scientific institution is available to everyone within that industry or outside the industry. What is more, technological or geographical distance as well as absorptive capacity further decreases the usability of externally available knowledge for a given individual.

Accordingly, my empirical analysis of knowledge spillovers will proceed as follows: The stock of generated knowledge or the potential outgoing spillover pool (S_{pot}) constructed in chapter 5 will be used to estimate the total stock of knowledge *available* to firms in an industry (potential incoming spillover pool). To arrive at the latter measure I will employ information on the use of protection methods (patents and secrecy) to reduce the stock of knowledge generated in an industry to the part that is not protected and thus potentially (not costless!) available to all actors in the economy (section 6.4).

The main goal in this chapter of the study is to arrive at the pool of external knowledge that is *actually used* by a given firm (realized incoming spillover pool). To calculate that pool, I reduce the pool of available knowledge in an industry by the firm's own knowledge pool, since a firm obviously does not have to absorb its own knowledge. Employing this method will generate a different potential intra-industry incoming knowledge pool for each firm.

Instead of a weighting function representing the distance between two potential partners I use the level of absorptive capacity of a firm to asses how much of the potential incoming knowledge spillover pool is actually used by a given firm. In my opinion, this is not a drawback but rather an advantage. The levels of absorptive capacity for intra-industry knowledge, inter-industry knowledge and scientific knowledge should capture some part of the technological distance effect and at the same time go beyond technological distance. To give an example: Firms with high absorptive capacity for inter-industry knowledge are either technological close to industries other than their own or have invested in building up capacities that allow them to bridge larger technological distances. [105] This is not true for geographical distance, however. The inclusion of the geographical distance between firms and industries in my study is not possible, since I do not have information on the location of the R&D performers in each industry.[106]

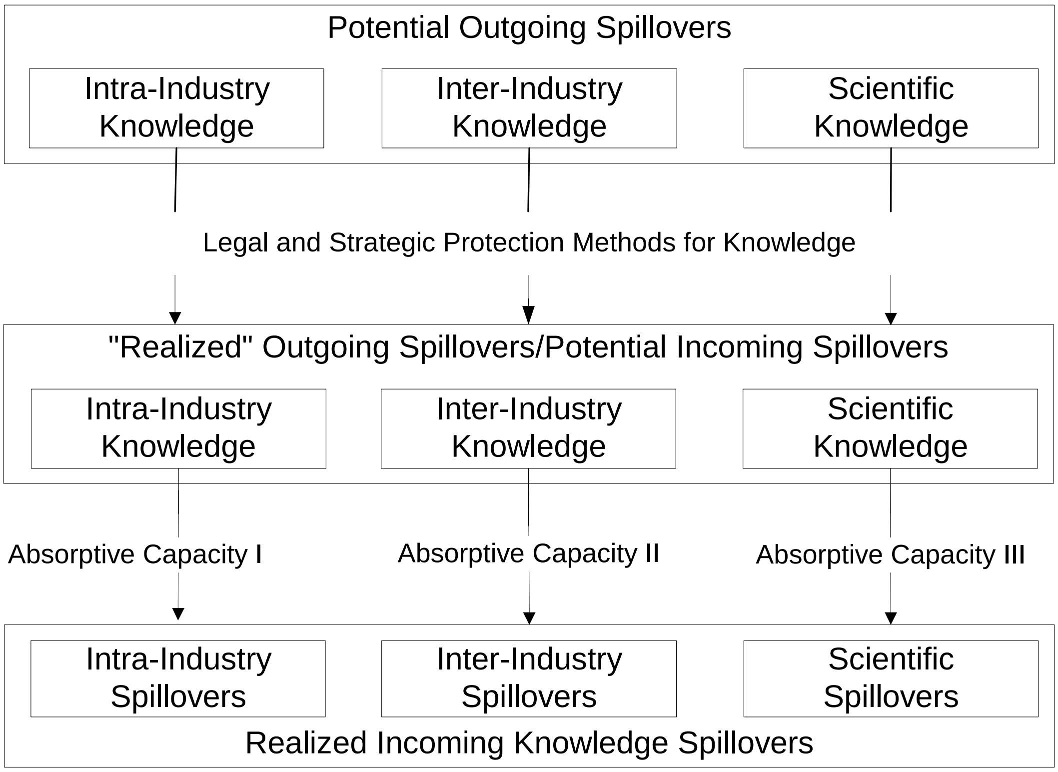
To summarize, the level of absorptive capacity of a firm for knowledge from its own industry, other industries, and science will be estimated and used as a mediating factor between the potential incoming knowledge pool and the realized incoming knowledge spillover pools. By using the characteristics of a firm to weight the knowledge stock generated and publicly available in each industry, I will be able to construct the incoming spillover pools at the firm level.

A graphical representation of this empirical framework is presented below.

105 The use of absorptive capacity instead of technological distance might also control for a problem raised by Cincera et al. (2003), i.e. that technological distance does not allow for asymmetric knowledge spillovers between industries and firms, respectively. In our setting two firms which are technologically close could have different levels of spillovers if they have different levels of absorptive capacity.

106 Kaiser (2002b) uses data on the location of the firms participating in the Mannheim Innovation panel to construct a measure of the distance between two firms. This could also be done in our case. However, I am not able to assign the total R&D done in an industry to the firms in the sample, since not all firms in an industry returned the innovation survey.

Figure 6-1 From Potential to Realized Incoming Spillover Pools



Source: Own illustration.

6.4 The Effects of Patents and Secrecy on Knowledge Spillovers[107]

The amount of knowledge available in an economy is becoming an important factor for innovation and growth. It depends on the amount of knowledge generated and the amount of knowledge appropriated by the producers of new knowledge. In this section I will focus on the latter aspect and investigate the impact of the importance of two different appropriability methods in an industry on the innovation activities of firms in that industry. To be more precise, I will analyse the effect of the usage of patent protection and secrecy in an industry on knowledge spillovers. Since spillover effects cannot be directly observed, I will lock at the results of these spillovers which can partially be observed, by analysing the innovation activities of firms (potentially) using external knowledge. I argue that the usage of patents and secrecy should affect the level of spillovers and thus de-

107 This section is largely based on Schmidt (2006).

crease or increase (depending on the method used) the importance of a lack of information as a hampering factor for firms using technological innovation processes in a particular industry.

The difference between secrecy and patents has been analysed to a great extend in previous studies (see next subsection). However, few attempts have been made to empirically assess their effect on knowledge spillovers. While secrecy, as the word implies, reduces spillovers through non-disclosure, the effects of patents is less clear. Patents can generate knowledge spillovers through the disclosure requirements laid down in patent laws, but at the same time limit knowledge spillovers by allowing firms developing new knowledge to use it exclusively for a given period of time.

The difference between formal and strategic protection methods with respect to knowledge spillovers is interesting from a policy point of view. If both groups of protection methods influence the importance of the lack of technological information as an obstacle to innovation with the same order of magnitude and direction, this would be an indication that the patent system does not have the desired effect of disclosing valuable and usable knowledge or at least that the firms requiring external knowledge for their innovation activities, cannot get access to the relevant knowledge flows.[108]

In the next subsection I will review the relevant literature on the effect of different legal and strategic protection methods on knowledge flows. Particular attention is given to mechanisms that are able to explain the gap between the desired effect of protection and the actual effect of protection. To be more precise, I will shed some light on the question why patent protection methods may fail in disclosing useful knowledge and why strategic protection methods like secrecy will not be perfectly efficient in reducing the outflow of knowledge.

---

108 Note, the lack of information on technology might also be a hampering factor for the innovation activities of firms, because they lack the absorptive capacity to access and use relevant knowledge. In the empirical part, I will try to take this into account.

6.4.1 Legal versus Strategic Protection Methods as a Mean to Reduce Knowledge Spillovers – A Review of Related Literature

Because "rents derive from idiosyncratic knowledge" (Liebeskind, 1997: 623), securing the returns and rents from innovation activities is one of the main concerns of firms developing new products and processes. Moreover, it is in the public interest to make sure that at least some part of the rents can be appropriated by the firm that developed an invention or innovation, in order to set incentives for private R&D and innovation activities. Put differently, firms would not have an incentive to invest in the development of new knowledge if all the benefits would spill over to their competitors. The well known free rider problem arises because "[…] knowledge is inherently a public good" (Jaffe, 1986: 984; Liebeskind, 1997: 624; Peters, 2003), i.e. it is non-rival in consumption and (partially) non-excludable[109] (Hanusch and Cantner, 1993; Stiglitz, 1999a). Because of the latter feature of knowledge, firms can profit from the inventions of others, either in the form of rent spillovers or knowledge spillovers (Griliches, 1979b). However, not all knowledge is available to everyone in an economy for free. There are some factors that hinder the flow of knowledge, e.g. firms might have to invest in R&D in order to develop the capacity to understand and be able to utilize the knowledge generated by others ("absorptive capacity"), as shown by Cohen and Levinthal, 1989; 1990. Another factor is the technological and geographical distance between the firm that produces the knowledge and the firm that wants to use it.[110]

While the absorptive capacity and the distance between two firms reduces the amount of knowledge spilling over because of the set-up of the receiving firm,

109 Arrow, 1962b wrote on this issue *"No amount of legal protection can make a thoroughly appropriable commodity of something as intangible as information. The very use of the information in any productive way is bound to reveal it, at least in part. [...] Legally imposed property rights can provide only a partial barrier, since there are obviously enormous difficulties in defining in any sharp way an item of information and differentiating it from similar sounding items."* (Arrow, 1962b: 615).

110 An overview of factors moderating the flow of knowledge can be found in Section 6.1.

the firm generating the knowledge can also reduce the flow of knowledge by employing certain protection methods. These protection methods for new knowledge can be placed into two large groups: legal protection methods (such as patents, copyrights and trademarks) and methods that rely on secrecy, complexity of design and fast- or first-mover advantages (hence forth called "strategic protection methods").[111] The two famous reports on the Yale survey (Levin et al., 1987) and Carnegie Mellon survey (Cohen et al., 2000) have shown that firms use both methods to protect their intellectual property and their knowledge. These and other studies (e.g. Arundel and Kabla, 1998; Harabi, 1995) also revealed that the importance firms give to legal and strategic mechanisms varies by industry and the type of innovation to be protected. Sometimes an invention is even protected by more than one type of appropriability measure (e.g. Cohen and Walsh, 2000 or Arora, 1997 for an example from the chemical industry). Other factors that influence the choice of the appropriability mechanism and the importance assigned to one or the other mechanism have been put forward: Anton and Yao (2004) theoretical model shows that the "size" of innovations in terms of cost differentials and pre- and post-innovation market shares plays a role for the choice of appropriability strategy. Arundel (2001) analysis of data from the Community Innovation Survey (CIS I) reveals that firm size reduces the relative importance of secrecy compared to patents while co-operation in R&D increases the importance of patents relative to secrecy. König and Licht (1995) find that the amount spent on R&D and the size of a firm positively influence the number of patent applications. Laursen and Salter (2005) and Liebeskind (1997) argue that the type of knowledge influences the choice of protection methods.

My focus in this section is, however, not on the mechanisms that lead firms to use one or the other method or to assign different importance to different measures, but on how the use of different protection methods affects knowledge spillovers. While knowledge disclosure and dissemination is at the core of the legal

111 See e.g. Harabi (1995), Cohen and Walsh (2000), Laursen and Salter (2005)

protection system, strategic protection methods are mostly targeted at preventing knowledge spillovers.

The rationale behind setting up a legal protection system is to grant an inventing firm the right to use their new knowledge exclusively for a given time (Levin et al., 1987) and thus setting incentives for private investment in innovation activities[112], while at the same time making the new knowledge available to outsiders by requirements to disclose knowledge (see e.g. Gallini, 2002; Markiewicz, 2003). In principle, the patent system is designed to exclude others from *using* the new invention and particularly the knowledge associated with it, while allowing them to access the new knowledge and learn from it. Legal protection methods provide protection for knowledge that is enforceable in court, but knowledge physically spills over through the text of the patent. As a result firms might see the knowledge published in the patent application as protected ("useless") knowledge rather than a knowledge spillover. However, the disclosure of (protected) knowledge can also be a source for new ideas for new products or processes and provide information about the developments of competitors and consequently knowledge spillovers beyond those protected by law. If the protection effect outweighs the disclosure effect, legal protection actually reduces knowledge spillovers rather than fostering them.[113] This has been argued to be the case by several empirical studies using the importance of legal protection measures as an inverse measure of outgoing spillovers, thus implying that legal protection methods limit outgoing spillovers rather than inducing them (see Bönte and Keilbach, 2005; Cassiman and Veugelers, 2002; Belderbos et al., 2004).

---

112 Arrow (1962b) already noted that the appropriability conditions play an important role for the innovation activities of firms.

113 The protection effect can only outweigh the disclosure effect if knowledge spillovers are defined as the disclosure of *freely usable* knowledge. If they are defined as the disclosure of knowledge in general, patent protection is always increasing knowledge spillovers. I would argue that firms at the receiving end of the knowledge transfer are likely to favour the first definition. Similarly De Bondt (1996) writes " spillovers only refer to the useful part of the information that has been exchanged." (De Bondt, 1996: 4)

The requirements to disclose (novel) knowledge when using legal protection methods is usually seen as a disincentive for adopting a strategy that is based on legal protection (Laursen and Salter, 2005; Levin et al., 1987; Arora et al., 2005; Arundel and Kabla, 1998; Hussinger, 2006). The reason for this may be that the patent system fails to exclude others from using the disclosed knowledge. The famous Mansfield et al. (1981) study shows that 60% of all patented innovations in their sample were imitated within 4 years.

Then again, Bessen (2005) cites some studies that shows that firms do not assign much value to the information disclosed in patents, raising doubts that significant knowledge spillovers arise from patents. In an early work on the topic Malchup and Penrose (1950) write that "only unconsealable inventions are patented" (Malchup and Penrose, 1950: 27), indirectly saying that the knowledge disclosed in patent applications would also have spilled out through different channels. Cohen et al. (2002) stress that the information disclosed in patents is not very valuable because of the lag between publication of the patent and application for the patent. By the time the patent is published the disclosed knowledge has usually become outdated. Before the patent is in force, the knowledge is rather secret.[114]

Strategic protection methods are used by firms without any legal basis and consequently without any requirements to disclose knowledge. Because of that, "firms that do not wish to disclose information can forgo patenting and use secrecy to protect their investment in innovation" (Arundel, 2001: 612). The effect of strategic protection methods on knowledge flows has been mostly analysed with respect to secrecy. Secrecy is - as the word already implies - the non-disclosure of knowledge. Atallah (2004) theoretical model is an example that uses this feature of secrecy. In his model the use of secrecy increases the cost of rivals by limiting knowledge spillovers. Empirical models analysing the co-operation decision of firms also assume that strategic protection methods limit outgoing knowledge spillovers (e.g. Belderbos et al., 2004; Cassiman and Veugelers, 2002; Bönte and Keilbach, 2005; Schmidt, 2005b). Strategic protection methods other than secrecy, however, do not (exclusively) rely on keeping knowledge secret, but on being first with the introduction of a novel product or process, reaping first mover benefits or by designing an innovation in a complex way that hinders competitors to reengineer them. These help to appropriate the returns of an innovation (Levin et al., 1987), but discloses knowledge.[115]

The view that secrecy decreases knowledge spillovers has been challenged by a number of authors. Liebeskind (1997) shows, that keeping inventions and knowledge secret is very hard and costly. Levin et al. (1987) see a problem for keeping product related knowledge secret, because the product has to be advertised and put into the hands of the customers (and thus potentially also in the hands of their competitors) in order to earn money with it. By putting the product on the market, the knowledge embodied is disclosed and cannot be kept secret any longer.[116] Kultti et al. (2002) state that there will always be some spillovers, even if firms try to keep innovations secret. Their view is indirectly supported by studies that assume that methods to protect inventions and to prohibit knowledge flows are never perfect.

Secrecy might also be an imperfect method to appropriate knowledge if the knowledge itself is of a specific kind. Cohen and Walsh (2000) for example argue that more generic knowledge makes secrecy "less effective as an appropriability strategy" (Cohen and Walsh, 2000: 10).

---

114 Note, this was a peculiarity of the US patent system until 2001, the European Patent Office publishes the patent *application* a short time after it was received.

115 Some doubts remain whether first-mover advantages are beneficial, because smart followers might imitate the original innovation quite fast. This can of course only be done because knowledge becomes available outside the firms boundaries if a protection method based on lead-time advantages is chosen (see Sofka and Schmidt, 2004 for an overview of first-mover advantages and disadvantages).

116 One has to distinguish between invention and innovation here. An invention might very well be kept secret until it becomes an innovation, i.e. is introduced into the market (see Arundel, 2001: 613).

Hypotheses

The hypothesis I derive form the review of the literature in this subsection are the following:

H1: *Patent* protection is used to prevent knowledge spillovers. Thus, an increase in the usage of *patent* protection methods in an industry does increase the perceived importance of the lack of technological knowledge as a hampering factor for innovation[117].

H2: *Protection by secrecy* does moderate knowledge spillovers. Thus, an increase in the usage of *secrecy* in an industry does increase the perceived importance of the lack of technological knowledge as a hampering factor for innovation.

As far as hypothesis 1 is concerned, it is not unlikely that the protection effect of patents might outweigh the disclosure effect since the firm developing an innovation will usually try to reduce the spillovers to others in order to increase their rent, even if they choose patents instead of strategic protection.

6.4.2 Estimation of the Effects of Patents and Secrecy on Knowledge Spillovers

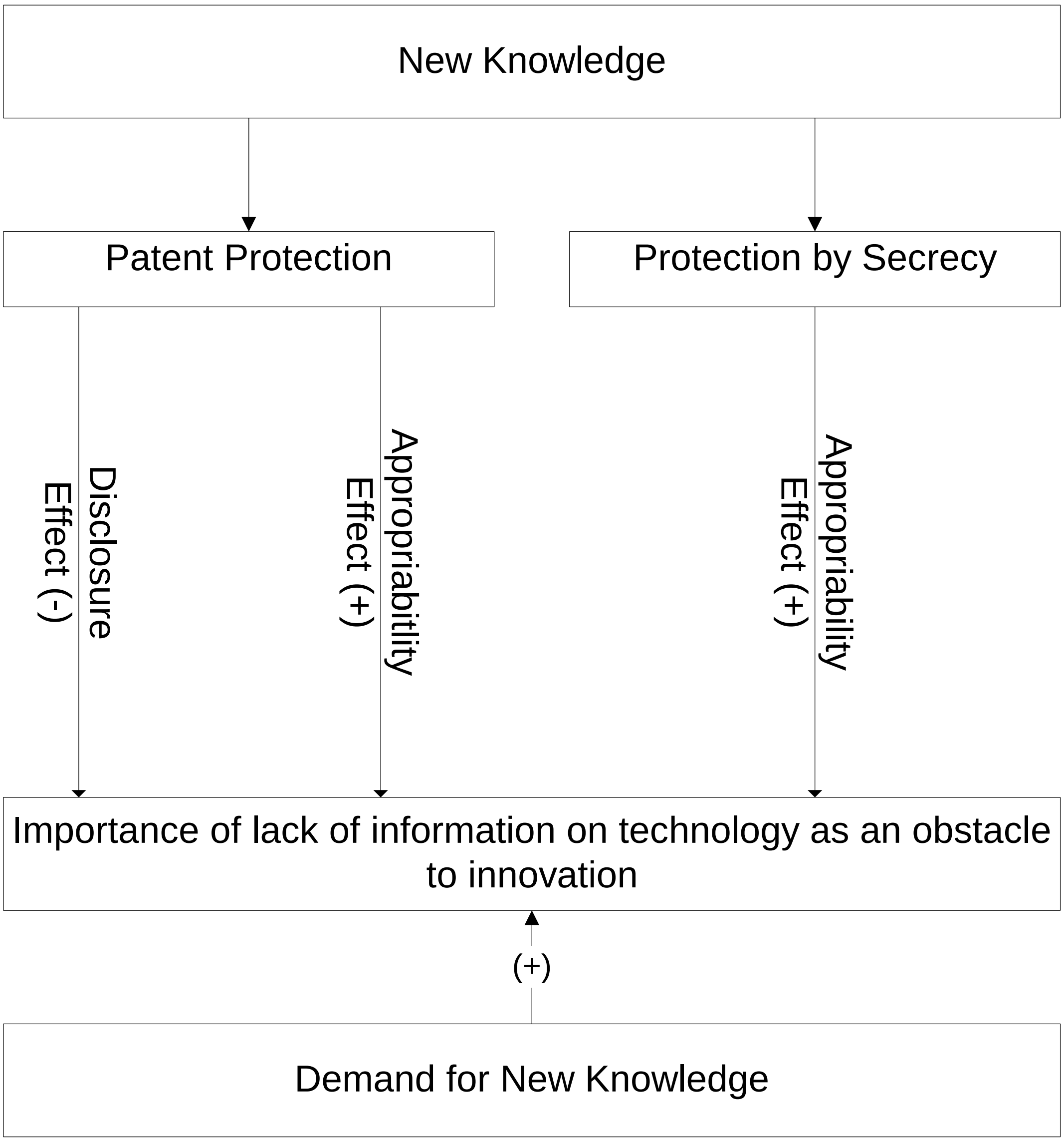
My focus in this section is to assess the impact of the usage of different protection methods in a particular industry on the perceived importance of a lack of information on technologies for innovation activities of firms in that industry. Two basic assumptions guide my approach: First, the importance of a lack of technological knowledge is higher (lower) if knowledge spillovers are lower (higher). Second, the level of knowledge spillovers is determined by the protection method used, i.e. patents or secrecy.

117 The importance of a lack of technological knowledge as a hampering factor for innovation activities will be used in the empirical model of this subsection as our measure of spillovers or rather the lack of spillovers. For this reason it is included in the hypothesis.

The following figure summarizes the empirical model I have in mind. It represents the arguments from the literature that patents and secrecy differ with respect to the disclosure requirements, i.e. that patents have both a disclosure and an appropriability effect while secrecy only has an appropriability effect. I also include the demand for knowledge in the analytical model. It is certainly a factor that influences the importance firms assign to knowledge spillovers. Firms that need a lot of knowledge, because of their size, technology or specific innovation and R&D activities will be more likely to run into problems with acquiring knowledge for their innovation processes[118].

118 For some empirical evidence on this issue see the study by Rammer et al. (2005b) on SMEs.

Figure 6-2 Expected Effects of Different Types of Protection Methods on Knowledge Spillovers



Source: Own illustration.

The set-up chosen poses some measurement issues: The first one concerns the measure of knowledge spillovers a firm receives: By looking at obstacles to the innovation activities of firms relying on external knowledge (at the receiving end of the knowledge spillover) I am not able to measure a lack of "actual" spill-overs, but rather a lack of "perceived" spillovers. These two types of spillovers are likely to be very different. While the former is a measure of the amount of knowledge in an industry that is not generated or not available, the lack of perceived spillovers, is the amount of knowledge not apprehended (or deemed not accessible) by firms. In my opinion, the lack of perceived spillovers should be higher than the lack of actual spillovers.

Since the knowledge spillovers I am interested in do not arise within a single firm, but between firms, [119] I will investigate the impact of the usage of protection methods by firms in an industry (excluding the firm in question) on the importance of the lack of technological knowledge as hampering factor at a given firm. This is not without problems, as the importance of this obstacle to innovation activities will not only be influenced by the use of protection methods but also by certain firm characteristics that are related to the demand for knowledge, the ability to generate knowledge in-house and the firms ability to access external knowledge. The latter is usually referred to as “absorptive capacity” (Cohen and Levinthal, 1989; 1990; Daghfous, 2004; Zahra and George, 2002). I will include variables for these three concepts in my estimation model, but cannot control for these aspects in full. In particular the demand for knowledge is hard to measure and can thus only be approximated.

A third issue is that the appropriability and disclosure effect of patents do not coincide in time for a single patent. The appropriability effects sets in when the application is filed (“first to file” rule in European patent law) and the disclosure effect when the application is published (1.5 years after filing). Since I do not analyse single patents but the overall effect of the importance of patents on knowledge spillovers, this problem is partially mitigated for my study. What is more, I am interested in the overall effect of the usage of patents in an industry during a three year period and not on the effect of a single patent.

119 This is probably one reason, why according to Laursen and Salter (2005) most studies in this field have been conducted on the industry level.

Data and Estimation Strategy

In this subsection I use firm-level data from the fourth Community Innovation Survey (CIS IV), which was carried out in 2005 and examined innovation activities during the period 2002 - 2004. In Germany, the CIS IV survey was conducted by the Center for European Economic Research (ZEW) and Frauenhofer Institute for System- und Innovationresearch (Fh-ISI) on behalf of the German Federal Ministry of Education and Research (bmbf). It is part of a larger effort to gather data on the innovation behaviour of German firms in industry and services through annual innovation surveys called the Mannheim Innovation Panel (MIP).[120] Even though the survey is conducted annually in Germany and set-up as a panel, I only analyze cross-sectional data, mainly because the questions needed to construct my variables are not included every year. Most other studies using the innovation survey[121] only use firms with innovation activities. For my study, however, the data needed is available for almost all firms in the sample, i.e. I analyze about 3,900 firms from industry and services with 5 or more employees.

The independent variable is representing the importance of the lack of information on technology as a hampering factor for innovation (hemm_tech_info). It is directly derived from a question on the hampering factors firms experienced in their innovation activities during the period 2002-2004. In this question firms were asked to rate the importance of 14 different hampering factors on a 4 point-likert scale ranging from 0 (not relevant) to 3 (very important). Because of this natural ordering of the responses to this question, I use the ordered probit procedure, which will be described in more detail below, for estimating my empirical model. It is noteworthy, that the question does not ask specifically for a lack of *external* information on technology. Assuming that firms which lack technologi-

120 For a more detailed description of the MIP survey see chapter 4.

121A list of studies conducted with the Mannheim Innovation Panel can be found at http://www.zew.de/de/publikationen/innovationserhebungen/wissaufsaetze.php3.

cal information internally would either invest in overcoming that lack or try to fill the void by looking for information beyond their own boundaries, I argue that the question mainly captures the external lack of information. I also argue that if they cannot invest in overcoming the lack of technological knowledge themselves, they would rather see the lack of finance as a hampering factor, which was also listed in that question, than the lack of information.

The four key explanatory variables - representing the importance of patent protection and protection by secrecy in an industry[122] - were constructed using a question on the importance of patents, registration of design patterns, industrial designs, trademarks, copyrights, secrecy, complexity of design, and lead-time advantages on competitors:[123]

Patent protection (pat_ind) is represented by the industry (NACE 2) average of the importance of patents for protecting innovations or inventions, rescaled between one (highly important) and zero (not important at all). The same measure is also included at the sector level (manufacturing vs. services) to control for intra-industry spillover effects (pat_sector).[124]

Protection by Secrecy (secr_ind) is constructed as the industry (NACE 2) mean of the importance of secrecy for protecting innovations or inventions, rescaled

122 To reduce a possible endogeneity, I calculated these two measures for each firm separately, i.e. the industry average was calculated without the firm in question. It thus represents the average over all other firms in the industry.

123 The question in the German questionnaire differs from the standard CIS IV question on intellectual property rights by not only asking for the usage of different methods, but for the importance of the measure. The question in the German questionnaire is: "During the period 2002-2004 did your enterprise use any of the following intellectual property protection methods? If so: Please indicate the importance of these methods for protecting innovations and inventions of your enterprise." Each method was rated on a 4 point likert-scale from 0 (not used) to 3 (highly important).

124 The industry average is calculated for each firm individually by subtracting a firms own evaluation of patents or secrecy from the industry total and dividing this sum by the total number of firms in the industry minus one (see also footnote 123). Similarly, the sector average is calculated by subtracting

between one (highly important) and zero (not important at all). The same measure is also included at the sector level (manufacturing vs. services) to control for inter-industry spillover effects (secr_sector).[125]

As it turns out the industry-level measures of the importance of patent protection and protection by secrecy are highly correlated (Spearman Correlation coefficient: .88), not only at the industry level but also at the level of the individual firm, indicating that firms use both methods together, as already proposed by Cohen and Walsh (2000) and Arora (1997). Because of that, they cannot be included in the same regression equation. In order to be able to investigate differences between the effect of patent protection methods and secrecy with respect to knowledge spillovers nonetheless, I calculated the relative importance of patents and secrecy in an industry as the share of enterprises that indicated that secrecy is more important than patents (rel_secr_ind) and the share of enterprises that indicated that patents are more important than secrecy protection (rel_pat_ind)[126]. At the firm level 19% of all enterprises indicated that secrecy is more important than patent protection, 67% assigned equal importance and 14% rated patents as more important.

In addition to these core variables a number of control variables were added at the right hand-side of the model. These variables are meant to control for characteristics and capabilities of a given firm that are assumed to influence its ability to use external sources of knowledge and could thus increase the likelihood that a firm perceives the lack of information on technologies as an obstacle to innovation. To give an example, if a firm has little absorptive capacities, it is usually not able to access and use the knowledge available outside its boundaries, not be-

---

the industry evaluation (without the firm) form the total in the sector and dividing this sum by the number of firms in all industries but the firms.

125 See footnote 124.

126 In order to control for inter-industry effects the equation used to estimate that model also contains a variable for the importance of patent protection and secrecy in the sector (manufacturing or services) of the firm (prot_sector).

cause knowledge is not there or because it is protected by appropriability mechanisms, but simply because it is unable to understand, assimilate or use it.

Four variables are included to represent the absorptive capacity of a firm (see Daghfous, 2004; Schmidt, 2005a for reviews on the determinants of absorptive capacity). The R&D intensity (R&D_int), calculated as the share of R&D spending of turnover, and the squared R&D intensity to allow for a non-linear effect (R&D_int2), a dummy indicating that the firm undertakes R&D continuously (R&D_con)[127], and the share of employees with higher education degrees of total employees (grads). The R&D related measures also represent firms' ability to generate knowledge in-house through own R&D and their demand for knowledge, if one assumes that the more R&D a firm does the more knowledge it needs.

The demand for knowledge is also represented by the innovativeness of the firm. In a study on hampering factors for small and medium sized enterprises (SME) Rammer et al. (2005b) report that in 2002 the share of SMEs reporting obstacles to innovation is higher for firms which are more deeply involved in innovation activities. The authors argue that intensively innovating firms are more likely to report the existence of obstacles than less innovative firms because their projects are more complex and they undertake more projects at the same time, which can also be interpreted as a higher demand for knowledge. To control for this I include two dummy variables, one indicating whether the firm has introduced a product innovation that was new to its market (mneu) and one indicating whether the firm has introduced a process innovation (pz) between 2002 and 2004.

As an additional control for the effect that some firms might in general have a higher probability to be (subjectively) more hampered by obstacles to their innovation activities than others my models include a dummy variable that takes the

127 The R&D intensity and the variable continuous R&D is constructed using a question that was only asked for firms which did report innovation activities. For firms without any innovation activities I set these variables to zero.

value one if the firm indicates that at least one of the 13 other obstacles to innovation was at least of medium importance (bed_hemm).

The analysis of the data from the Mannheim Innovation Panel has revealed that East and West German firms still differ considerable with respect to their innovation activities (see e.g. Rammer et al., 2005a; Sofka and Schmidt, 2004). A dummy variable, which takes the value one if the firm is from the Neue Länder is thus also included in my model (east). In addition to that, two variables for the size of the firm were included, the log of the number of employees (lnempl) and a squared term (lnempl2).

To ensure that the two industry-level variables for the protection methods do not just pick up any industry specific effects, I included three industry group dummies for medium-low-tech manufacturing (NACE 23; 25-28; 351) high-tech manufacturing (NACE 244, 30, 32, 33, 353), and high-tech services (NACE 64, 72, 73), with other manufacturing and services (NACE 10-29 (exc. 244) , 31, 34, 35-37 (excl. 353), 40+41, 45, 50-52, 55, 60-63, 65-67, 70, 71, 74, 75, 90, 92) being the reference group.[128]

The average firm in my sample has about 710 employees. Over 20% of the employees of these firms are highly educated. More than 30% of the firms do R&D continuously and spend on average 3% of their turnover on R&D activities. 24% have introduced product innovations that were new to their market between 2002 and 2004, and 42% introduced process innovations. Almost half of the firms have experienced the lack of technological information as a hampering factor for their innovation activities, 38% said it was only somewhat important, about 10% it was an important hampering factor, and around 1% indicated it was very important. 32% of all my enterprises are from East Germany. The share of high-

128 The inclusion of more detailed industry dummies would certainly have benefited our analysis, but most other industry dummies I tried to include were correlated with other right hand side variables I wanted to keep. Most notably was the correlation between the industry dummies and the variable for continuous R&D.

tech manufacturing firms in the sample is 9% and the share of high-tech services is 7%.[129]

Since the responses to my dependent variable are in natural order from 0 to 3, I will use an ordered probit estimation procedure, which outperforms other models (e.g. multinominal probit and simple OLS) in this case (Greene, 2003, Kennedy, 1998). The model is similar to the regular binominal model in the sense that the observed variable is assumed to be related to an underlying continuous measure that is unobservable. Because this latent variable can take more than two values (as is the case in the probit model) several parameters or boundary values have to be estimated using a maximum likelihood procedure.

The formal model in my case looks like this:

$$y^{*} = \beta^{'} X + \varepsilon$$

where y* is the unobserved variable and X is the vector of all the independent variables described above. The boundary parameters (μ) for a change in the dependent variable hemm_tech_info can then be estimated according to the following formula:

$$\text{hemm\_tech\_info} = \begin{cases} 0 \; if \; \; y^{*} \leq 0 \\ 1 \; if \; \; 0 < y^{*} \leq \mu_1 \\ 2 \; if \; \; \mu_1 < y^{*} \leq \mu_2 \\ 3 \; if \; \; \mu_2 < y^{*} \leq \mu_3 \end{cases}$$

129 A table with additional descriptive statistics can be found in the appendix on page 208.

6.4.3 Results of the Empirical Model

The results from the ordered probit regressions indicate that both patent protection and protection through secrecy increase the perceived lack of information on technology as a hampering factor for innovation activities significantly.[130] However, only the industry-level variables are significant. This indicates that the use of protection methods by other firms from a firm's own industry hampers its innovation activities more than the use of protection methods by firms in other industries. Consequently, hypothesis 1 and 2 can only be confirmed for the industry-level of protection. Furthermore, the estimations suggest, that the appropriability effect of patents outweighs the disclosure effect in an industry. If this were not the case, the coefficient on patent protection should have been either negative or not significant, as is the case for the importance of patent protection in all industries in a firm's sector beside its own. Since both coefficients for the industry-level measure, that for patent protection and that for secrecy are positive and significant there is evidence that they both reduce knowledge spillovers, i.e. the amount of valuable and usable knowledge available to others in an industry. Both mechanisms can be seen as a way to hinder the innovation activities of competitors and other firms in the same industry and appropriate the returns from inventions and innovations through limiting the availability of useful knowledge outside ones own boundaries. Due to the high correlation between the secrecy and patent variable they cannot be included separately in a single equation. In order to test whether the effect of patents is significantly different from secrecy, I estimate the effect of the share of firms in an industry indicating that patents are more important than secrecy and the share of firms indicating the opposite is true on my dependent variable. The results in the last column (3) of Table 6-1 show

130 To test the robustness of the results, I ran the same regressions with slightly modified measures for patent protection and secrecy. I used two dummies indicating if the respective appropriability mechanisms were at least of medium importance. In both cases the results did not change.

that both variables are not significant, providing further evidence that both protection methods influence the innovation activities of firms similarly.[131]

The insignificance of the sector-level variables is surprising. One interpretation of this result is that firms' innovation activities rely more on knowledge from a firms own industry and less on knowledge from other industries. Then again, some empirical studies have found intra-industry spillovers of particular relevance for firms' innovation behavior and performance (e.g. Inkmann, 2000; Steurs, 1995). An alternative explanation is more technical, maybe my measure of protection at the sector level is too broadly defined and should rather than include all industries outside a firms own industry only include industries with which the firm is closely related, e.g. through input-output relations or similar technologies. A third explanation is that firms protect knowledge that is relevant for the innovation activities of a firm in the same industry only, but not for firms in other industries. If this were the case patents and secrecy would reduce knowledge flows between firms, but would only have a constraining effect on the innovation activities of firms within an industry and not across industry boundaries. This is the most likely explanation since I know from the significance of the importance of protection methods in a firm's own industry that some fraction of the knowledge a firm produces is protected.

131 Joint significance of the two variables could also be rejected.

Table 6-1 Regression Results of Ordered Probit Estimations (Dependent Variable: Importance of Lack of Information on Technologies as an Obstacle to Innovation)

Variables	**Patents (1)**	**Secrecy (2)**	**Patents + Secrecy (3)**
Importance of _____ protection (industry level)	0.261**	0.349**	
	(0.149)	(0.176)	
Importance of _____ protection (sector level)	0.134	0.208	
	(0.236)	(0.396)	
Share of firms indicating that patents > secrecy (industry level)			0.289
			(0.496)
Share of firms indicating that secrecy > patents (industry level)			0.706
			(0.434)
Importance of protection by secrecy + patents (sector level)			0.177
			(0.298)
Share of employees with higher education degree in %	-0.003***	-0.003***	-0.003***
	(0.001)	(0.001)	(0.001)
R&D intensity	0.174	0.176	0.245
	(0.268)	(0.266)	(0.266)
R&D intensity, squared	-0.069	-0.068	-0.084
	(0.105)	(0.104)	(0.106)
Continuous in-house R&D	-0.096*	-0.099*	-0.090*
	(0.055)	(0.055)	(0.054)
Importance of other hampering factors	3.186***	3.184***	3.184***
	(0.315)	(0.315)	(0.315)
Market novelty (dummy)	0.004	0.003	0.006
	(0.052)	(0.052)	(0.052)
Process Innovation (dummy)	0.114***	0.113***	0.110***
	(0.040)	(0.040)	(0.040)
Number of employees, log	0.055	0.054	0.053
	(0.047)	(0.047)	(0.047)
Number of employees, log, squared	-0.006	-0.006	-0.005
	(0.004)	(0.004)	(0.004)
East Germany (dummy)	-0.159***	-0.156***	-0.155***
	(0.048)	(0.048)	(0.048)
Industry Groups (dummy)	YES	YES	YES
Observations	3,403	3,403	3,403
Loglikelihood	-3019.98	-3019.64	-3020.05

Significant at 10%; ** significant at 5%; *** significant at 1%;
Robust Standard Errors in parentheses

Source: Own Calculations.

My control variables offer some interesting insights as well. Only one of the proxies for absorptive capacity is highly significant and has the expected sign. The more absorptive capacity a firms has in the form of highly educated employees the less likely it is that this firm perceives the lack of information on technologies as an obstacle to innovation, i.e. the more likely it is to receive knowledge spillovers. The negative and slightly significant coefficient of the continuous in-house R&D activities provides further evidence that higher absorptive capacity increases the ability to access knowledge and thus mitigates the problem of a lack of information on technology.

The lack of significance for the R&D intensity variables can be explained by differing effects of R&D on absorptive capacity and the demand for knowledge. R&D is not only conducted in order to build absorptive capacities, which would decrease the importance of the obstacle, but also to generate innovations. If firms invest heavily in the development of innovations, their knowledge requirements are higher if they invest only a small fraction of their turnover in R&D. At the same time their own research generates ideas and opens their mind to technological opportunities, for which additional knowledge is required. These new projects are likely to be more of an explorative nature, which require more complex and not readily available knowledge than exploitive projects. As a result of the higher knowledge requirements the likelihood that these firms run into the problem of a lack of technological innovation is higher as well. To summarize this point, firms with a larger share of R&D expenditure per turnover, see a whole range of technological opportunities and thus perceive the lack of information to be more relevant than firms which have a low share and as a result a more narrow field of view with respect to technological opportunities. These "perception" effects clearly works in the opposite direction as the effects of absorptive capacity on knowledge spillovers discussed in the previous sections and as my results for R&D activities suggest, cancel each other out (partially). For continuous R&D activities the same arguments can be brought forward. My estimation results suggest, however, that for continuous R&D activities the effect on absorptive capacity is stronger than the perception effect.

The variable for other obstacles is highly significant, indicating that the obstacles to innovation are highly related to each other. I think that the inclusion of this variable controls for this baseline effect.

Process innovators are significantly more hampered in their innovation activities than non-innovators, while innovators with market novelties are not. This is surprising, since usually it is assumed that process innovations are based on internal knowledge and learning by doing while product innovations and in particular market novelties require more external knowledge. My results suggest the opposite, however

Size matters for the perception of the importance of information on technologies as an obstacle to innovation, as expected. However, the relationship between size and the obstacle is not a linear one, but is inverse U-shaped. The turning point is at about 90 employees for equation one, 95 employees for equation two and 200 employees for equation three. For smaller firms it might be a less important obstacle, because they just follow a small number of (innovation) projects at the same time (Rammer et al., 2005b) or focus on technologies where they have all the knowledge required to bring inventions to markets. They rather lack the marketing knowledge and financial means to introduce innovations. Large firms, on the opposite, have many projects going on at the same time and require lots of knowledge. They nonetheless assign less importance to the lack of information as medium sized firms. A reason for this might be that they have the capability, resources and established channels to gather the external knowledge needed in their innovation processes and are thus not hindered as much in their innovation activities as medium-sized firms.

Finally, East German firms assign a lower importance to the lack of information on technology, than West German firms. The difference is only marginally significant and only in two out of three equations, however. The difference might stem from the fact that East German firms are more likely to adopt a follower strategy in their innovation activities (see Sofka and Schmidt, 2004). If they rely on a follower strategy the lack of information becomes less of a problem, because all the information required for imitating a new product or process has to be available before it can be imitated. Their strategy is more one of exploiting available knowledge instead of exploring new opportunities. As a result they adopt a more narrow innovation approach and decreases the amount of external knowledge required.

6.4.4 Conclusions and Implications for the Next Steps of the Analysis

In this subsection I looked at the influence of the usage of patent protection and protection by secrecy in an industry on knowledge spillovers. Since knowledge spillovers cannot be measured directly I investigated the effects of protection on the lack of knowledge spillovers, i.e. technological knowledge. I treated the two appropriability mechanisms separately, because their basic set-up is quite different, while patents have a build-in requirement to disclose knowledge and provide a legal basis for the protection of knowledge, secrecy relies on non-disclosure, but is not defendable in court. My findings indicate that both patents and secrecy decrease knowledge spillovers to other firms in an industry and consequently pose obstacles to their innovation activities. Because of that I am able to conclude, that the appropriability effect outweighs the disclosure effect of patents within an industry.

As a consequence of this finding, I will weight the total amount of knowledge produced with the combined importance of patent protection and protection by secrecy at the industry level below, instead of using separate weights for the two different types of protection methods. A separation in the following analysis would have required to split-up the total R&D expenditure or rather the pool of potential outgoing spillovers into a part that is protected by secrecy and a part that is protected by patents which is not possible given the data I have.

I do not find a significant effect of protection methods used in other industries on the lack of information on technologies a firm is faced with, which is a surprising result. I will follow the third explanation for this finding from above, which is that firms use protection methods to reduce knowledge flows between firms, but those restrictions only have a constraining effect on the innovation activities of firms within an industry and not across industry boundaries. This indicates that some fraction of the knowledge a firm produces is indeed protected. I will thus weight not only the intra-industry spillover pool, but also the inter-industry-spillover pool with the importance of patents and secrecy.

A caveat of this method is that I have not only have to assume that the influence of protection on knowledge flows is constant over time but also that the importance of patents and secrecy for protecting a firms innovation does not differ (significantly) over time.

6.5 The Construction of the Potential Incoming Spillover Pools at the Industry-Level and the Realized Outgoing Spillover Pool at the Firm-Level

In this section I will construct the potential incoming spillover pools at the industry level and the realized outgoing spillover pool at the firm level. The difference between the two concepts is that the realized outgoing spillover pool at the firm level is the knowledge stock of a firm weighted by the importance of patents and secrecy as indicated by the individual firms, while the potential incoming spillover pool at the industry level is constructed by weighting the knowledge stock of each industry, with the average importance of patents and secrecy at the industry level. The potential incoming spillovers at the industry level will be used in the next step of the analysis to construct the realized incoming spillover pools (see below and Figure 6-1) for knowledge from a firm's own industry and from other industries, which equals the sum of the potential incoming spillovers of all other industries. Similar to the construction of the knowledge stocks above the average importance of patents and secrecy in each industry will be calculated without the answer of the firm in question and without the answer of the industry of the firm in question, respectively, leading to different (industry-level) values for each firm. The scientific knowledge stock is not weighted by the importance of protection methods. I argue that knowledge generated in scientific institutions is intended for dissemination and is thus not protected ("Open Science" e.g. David, 2003; Cohen et al., 1998) or cannot be protected, because of its basic nature. Nelson, 1959 writes on this topic "Although significant external economies are probably rare, they almost certainly exist […] in basic research" (Nelson, 1959: 298). As a result of this assumption the potential incoming knowledge spillover pool for knowledge from scientific institutions is equal for all firms. It is estimate at 68737.657 billion Euro as mentioned above.

The following formulas summarize the method used to construct the potential incoming knowledge spillover pools and the realized outgoing spillover pool:

$$S_{inter}^{pot} = \sum_{i \neq j} (K_i * IPROT_i)$$ inter-industry spillovers

$$S_{intra}^{pot} = (K_{stock}^{industry} - K_{stock}^{firm}) * \frac{(IPROT^{industry} - IPROT^{firm})}{n-1}$$ intra-industry spillovers

$$S_{out}^{real} = K_{stock}^{firm} * IPROT^{firm}$$ outgoing spillovers

K_i	total knowledge stock in industry i
$K_{stock}^{industry}$	knowledge stock of the industry the firm in question is in
K_{stock}^{firm}	knowledge stock of the firm in question
$IPROT_i$	average importance of patents and secrecy in industry i
$IPROT^{industry}$	sum of the importance of patents and secrecy in the industry of the firm in question is in
$IPROT^{firm}$	sum of the importance of patents and secrecy of the firm in question
j	industry of the firm in question
i	all other industries
n	number of firms in the industry of the firm in question

As described in Chapter 5, K_i and $K_{stock}^{industry}$ are based on the ANBERD data for industries and the average length of the product-life cycle in each industry, while K_{stock}^{firm} is based on information on individual firms' R&D expenditure from the Mannheim Innovation Panel. $IPROT_i$ and $IPROT^{industry}$ can be calculated for each industry based on answers of the 2005 Mannheim Innovation Panel survey. More problematic is the calculation of the measure $IPROT^{firm}$ used in the equation for the realized outgoing spillover pools and intra-industry incoming spillover pools. This measure is only available for those firms that answered the respective question in the 2001 Mannheim Innovation Panel. As a result, the sample for the construction of the potential incoming intra-industry knowledge spillover pool and the realized outgoing spillover pools has to be reduced to those firms for which information on the importance of protection and secrecy is available in the 2001 Mannheimer Innovations Panel. This reduced the sample to 2,804 observations.

This does not mean, however, that the potential incoming spillovers at the industry level only comprises of the value of these 2,804 observations. Since the measure of the potential incoming knowledge spillover pool at the industry-level is calculated using the industry-level knowledge stock and the industry valuation of protection methods, it is still based on the expanded figures from the ANBERD database and the average product life-cycle for each industry.

Using this method I estimate the average potential inter-industry incoming knowledge spillover stock at 100,371 billion Euro. This figured cannot be compared directly to the total knowledge stock of all industries estimated above because it only includes industries other than the firm's own, while the total knowledge stock is the sum over all industries. As expected the potential inter-industry incoming spillover are lowest for the vehicles and automobile industry (NACE 34, 35), the chemical industry (NACE 24), the electronics industry (NACE 32) and the mechanical engineering industry (NACE 29). These industries are very R&D intensive and are known to generate a lot of spillovers for other industries (see e.g. Rammer, 2003 for the chemical industry). For all other industries the potential inter-industry incoming spillover pools are fairly equal and are valued between 100,000 and 104,000 billion Euros (see Table 6-2).

Table 6-2 Estimate Potential Inter-Industry Knowledge Spillover Pools in 2002 and the Average Importance of Patents and Secrecy in 2002-2004

NACE 2	Average Importance of Patents and Secrecy in 2002-2004 at the industry level	Potential Inter-Industry Knowledge Spillover Pools in 2002
15	0.106	103,125
16	0.125	103,832
17	0.128	103,386
18	0.046	103,832
19	0.077	103,934
20	0.161	103,821
21	0.134	103,609
22	0.077	103,825
23	0.313	103,722
24	0.443	86,720
25	0.295	101,727
26	0.194	102,413
27	0.221	102,800
28	0.194	101,803
29	0.386	93,770
30	0.273	101,682
31	0.358	100,574
32	0.416	92,976
33	0.429	99,861
34	0.337	76,724
35	0.363	95,357
36	0.181	103,367
37	0.077	103,930
40	0.066	103,384
45	0.084	103,461
50	0.081	103,340
60	0.036	101,419
65	0.067	103,873
72	0.228	101,738
73	0.438	102,418
74	0.123	102,080

Source: Own Calculations.

Averages for the pools of potential intra-industry knowledge spillover at the industry level and realized outgoing spillovers at the firm level could also be calculated. I do not present them here, however, because they are only partially interpretable, due to the fact that they are only available for the restricted sample and not for the whole economy as the potential inter-industry incoming knowledge spillover pool. Since the sample that will be used to estimate the empirical model on the relationship between R&D co-operation and knowledge spillover uses a sample that is further restricted to innovating firms and firms for which a measure of absorptive capacity can be generated (see below), they are not of interest here anyway. Descriptive statistics on the sample used for the final empirical model on the effect of realized knowledge spillovers on the likelihood of co-operating on R&D and innovation will be presented in subsection 7.2.2 and the appendix.

The realized outgoing knowledge spillover pool at the firm will be used directly in the estimation of the model on the determinants of R&D co-operation (see subsection 7.2.2). For the potential intra-industry, inter-industry and scientific knowledge spillover pools further calculations are necessary to arrive at the realized knowledge spillover pools I am interested in. These calculations will be done following the following section.

6.6 Absorptive Capacity as the Determining Factor of Realized Incoming Knowledge Spillovers[132]

Since Cohen and Levinthal (1989; 1990) published their seminal work on “absorptive capacity”, a lot of empirical and theoretical work has been devoted to analyzing the absorptive capacity of firms. However, the use of the concept of absorptive capacity has not been limited to the firm level, it ranges from the level of the individual to that of entire nations (see Van Den Bosch et al., 2003; Narula, 2004). These levels are intertwined, as a nation’s absorptive capacity de-

132 This section largely builds on Schmidt (2005a).

pends on that of its organizations and the absorptive capacity of an organization depends on that of its individuals (Cohen and Levinthal, 1990). The absorptive capacity concept has proven to be flexible enough to be used not only for different units of analysis but also in many fields of research, e.g. industrial organization, strategic management, international business and technology management (see Zahra and George, 2002 for an overview). Despite this wide application of the concept and various modifications of its specific features[133], absorptive capacity has been used in most cases as a firm's ability to "identify, assimilate and exploit knowledge from the environment" (Cohen and Levinthal, 1990: 569).

The empirical operationalization of the concept has not been that focused, though, mainly because it is hard to construct good measures of absorptive capacity from the available information.[134] One reason for this is the lack of a paper trail for the acquisition of external knowledge which could be tracked and used by researchers. A solution to this problem is the use of surveys. Surveys can and have been used for research on absorptive capacity at the firm level. Even with surveys, however, researchers are not able to measure absorptive capacity directly because it is - despite its relatively simple definition - a fuzzy concept; practically no one can give a straightforward indication of his or her level of absorptive capacity. Using surveys thus requires developing an empirical concept of absorptive capacity. Popular proxies that have been used to capture absorptive capacity in recent empirical studies on the innovation and co-operation behavior of firms include R&D budgets, -stocks, and -intensities (Belderbos et al., 2004; Cassiman and Veugelers, 2002; Oltra and Flor, 2003; Stock et al., 2001), following up on the arguments presented by Cohen and Levinthal (1989). Other proxies and measures (primarily used by researchers from the field of business administration) include organizational structure and practices, like incentive systems

133 Zahra and George (2002), for example, cite Mowery and Oxley (1995), who define absorptive capacity as a set of skills needed to deal with tacit knowledge.

134 Among others Becker and Peters state: "The empirical measurement of absorptive capacities of firms is difficult." (Becker and Peters, 2000: 11).

and human resource and knowledge management (Lenox and King, 2004; Van Den Bosch et al., 1999; Vinding, 2000) and "production line performance in terms of labour productivity and conformance quality" (Mukherjee et al., 2000: 157).

The lack of a direct empirical measure of absorptive capacity has not only caused some problems with the comparability of research results[135]; it has also led to little research "on the process by which absorptive capacity is developed" (Lane et al., 2002: 5). This research shortage on the determinants of absorptive capacity was stressed not only by Lane et al., 2002), who reviewed about 180 papers citing Cohen and Levinthal (1998, 1990), but also by Veugelers (1997). She writes that "More work is needed to identify specific firm characteristics generating this absorptive capacity" (Veugelers, 1997: 314). Mahnke et al. (2005) also state that there is a lack of empirical literature on how a firm can increase its absorptive capacity.

In this section I will try to fill the gap by empirically analyzing the determinants of absorptive capacity of innovative firms. In order to be able to construct a more direct measure of absorptive capacity than previous studies, I propose a focus on the results of absorptive capacity instead of on the inputs that are assumed to build absorptive capacity. Using data from the Mannheim Innovation Panel I am able to assess whether firms' innovations incorporate or are based on knowledge obtained from external partners. I argue that firms that introduce innovations, which are based on external knowledge, necessarily have the ability to exploit knowledge from external sources, thus evincing absorptive capacities. I am therefore able to investigate this component directly and separately from the other two components of absorptive capacity (identification and assimilation of knowl-

135 Zahara and George highlight this problem by writing: " … it is unclear if these measures [of absorptive capacity] converge to capture similar attributes of the same construct, …" (Zahra and George, 2002: 186).

edge)[136]. However, a firm which is able to exploit external knowledge usually also has the ability to identify and assimilate it. Focusing on the ability to exploit external knowledge should allow us to rudimentarily distinguish between external knowledge that is useful and useless. This part of the study also contributes to the existing literature by including measures for the existence of human resource and knowledge management and the organization of knowledge sharing within a firm. I also analyze the differences among these and other measures with respect to exploiting knowledge from within a firm's industry, knowledge from outside its industry and knowledge generated by research institutes in order to be able to arrive at different levels of absorptive capacity for the different external knowledge pools.

6.6.1 Related Literature on the Components and Determinants of Absorptive Capacity for Different Types of Knowledge

In this subsection I will review the literature on absorptive capacity relevant for my study.[137] I will first take a closer look at the definitions of absorptive capacity, in particular with respect to the three components of absorptive capacity (identification, assimilation and exploitation). Afterwards I will focus on the determinants of absorptive capacity found in the literature and then discuss some of the findings for the acquisition and exploitation of different kinds of knowledge. The whole review is restricted to the application of the absorptive capacity concept at the firm level.

Components of Absorptive Capacity

Absorptive capacity at the firm level is relatively simple to define. Essentially, it is a firm's ability to deal with external knowledge. According to the highly in-

---

136 Zahra and George (2002) argue: "Substantial differences exist among these dimensions, which allow them to coexist and be measured and validated independently." (Zahra and George, 2002: 199), when talking about the three dimensions of absorptive capacity.

137 Other reviews have been compiled by Daghfous (2004), Van Den Bosch et al. (2003) and Zahra and George (2002).

fluential definition offered by Cohen and Levinthal (1989), it is firms' ability to "identify, assimilate and exploit knowledge from the environment" (Cohen and Levinthal, 1989: 569). Other authors have used some modifications of the concept (see Zahra and George, 2002 for an overview) but have still retained the notion that absorptive capacity is not a one-dimensional concept, consisting rather of various skills and dimensions. Lane and Lubatkin (1998) for example use the three components proposed by Cohen and Levinthal (1990) for their study on the prerequisites of a firm's ability to learn from another. Van Den Bosch et al. (2003) also suggest defining absorptive capacity as having three components "the ability to recognize the value of external knowledge, assimilate it, and apply it to commercial ends." (Van Den Bosch et al., 2003: 280).

There has been some discussion about whether there are more than three components of absorptive capacity. For instance, Zahra and George, 2002) expand the concept by introducing an additional component -- transformation of knowledge -- which is "a firm's capability to develop and refine the routines that facilitate combining existing knowledge and the newly acquired and assimilated knowledge" (Zahra and George, 2002: 190). However, they do retain the other three components. This additional component is potentially worth considering for analysis, as it explicates an aspect of the process of knowledge usage that has been implicitly assumed by other authors. In order for external knowledge to be exploited effectively, it has to be transformed in order to be used by various actors within the enterprise. Then again, it can be argued that the transformation dimension need not be made explicit, as it is an integral part of the "exploitation" component.

Moving away from the ability-based concept of Cohen and Levinthal, Van Den Bosch et al. (1999) analyze absorptive capacity along the dimensions of efficiency, scope and flexibility. This does not replace the ability-based definition but rather supplements it. Efficiency, for example, is defined as the costs and economies of scale associated with a certain level of identification, assimilation, and exploitation of external knowledge.

Determinants of Absorptive Capacity[138]

The application of the absorptive capacity concept in various fields and at various levels of analysis has led to the identification of a whole array of factors which are assumed to influence absorptive capacity. Most of these determinants come from theoretical considerations and empirical studies on the usage and management of knowledge in R&D and innovation processes. These factors can be assigned to the following three groups[139]:

a) R&D activities

Cohen and Levinthal, 1989 focus mainly on the role of R&D expenditures in building absorptive capacity and point to the dual role R&D plays in the innovation process of firms: building absorptive capacity and generating new knowledge and innovations. Many other scholars have thus used R&D-related measures and approaches to model absorptive capacity at the firm level.[140] Among them are:

- R&D expenditure: R&D intensity (R&D expenditure/total sales) (Stock et al., 2001; Rocha, 1999; Cantner and Pyka, 1998) and level of R&D investment (Leahy and Neary, 2004; Grünfeld, 2003)
- Continuous R&D activities (Oltra and Flor, 2003; Becker and Peters, 2000)
- Existence of an R&D lab (Becker and Peters, 2000; Veugelers, 1997)

---

138 Daghfous, 2004 gives an overview on the determinants of the components of absorptive capacity.

139 There is a fourth group of determinants that will not be discussed in this study. It includes networks and alliances with external partners and the knowledge environment in general (see, for example, Caloghirou et al., 2004; Nonaka and Takeuchi, 1995; Lim, 2004). Our focus is on internal factors only.

140 Lane and Lubatkin (1998) offer one of the few studies that calls the use of measures of absorptive capacity based on R&D spending into question.

b) Related prior knowledge and individuals' skills

In their 1990 paper Cohen and Levinthal expand the concept and argue that absorptive capacity is path-dependent because experience and prior knowledge facilitate the use of new knowledge. As a consequence, absorptive capacity is cumulative. This cumulative nature of absorptive capacity has not been taken into account by many empirical studies but has been extensively discussed in the literature on knowledge and spillovers[141], which are closely related to absorptive capacity.

The cumulative nature of knowledge may also be related to another determinant of absorptive capacity: employees' level of education. The more education and training an employee receives, the higher his or her individual ability to assimilate and use new knowledge will be. As firms' absorptive capacities depend on those of their employees, the general level of education, experience and training their employees have a positive influence on firms' level of absorptive capacity. Rothwell and Dodgson (1991) found that (small) firms need well-educated technicians, engineers and technological specialists to access knowledge from outside their boundaries. Frenz et al. (2004) take this into account in their analysis by including the share of scientists and engineers in total employees as well as training expenditures in their model of absorptive capacity.

In this context the presence of so-called "gatekeepers" play an important role in determining absorptive capacity. Vinding (2000) submits that gatekeepers, whose role is to create a language which can be understood by different departments, improve a firm's absorptive capacity through knowledge sharing. Gradwell (2003) stresses that gatekeepers' intermediary role involves screening the environment for knowledge and transforming the relevant knowledge so it can be understood by other employees. Cohen and Levinthal (1990) also intro-

141 Some of this literature is cited in Cohen and Levinthal (1990) and Daghfous (2004).

duce two types of gatekeepers, acting either as a “boundary spanner” within the firm or as an interface between the firm and its environment.

c) Organizational structure and human resource management practices

A firm’s absorptive capacity is not the simple sum of its employees’ abilities. According to Cohen and Levinthal (1990), it depends on the ability of an organization as a whole to stimulate and organize the transfer of knowledge across departments, functions, and individuals. This aspect of absorptive capacity has been incorporated into many studies: It has been shown that the absorptive capacity of a firm is determined by its expertise in stimulating and organizing knowledge sharing (Van Den Bosch et al., 1999) and the similarity of any two cooperating firms’ systems for doing so (Lane and Lubatkin, 1998). Daghfous (2004) review yields that the organizational structure of a firm and cross-functional communication have been found to improve absorptive capacity if they lead to improved knowledge sharing among departments and individuals within a firm (see also Welsch et al., 2001; Van Den Bosch et al., 1999, 2003; Lane and Lubatkin, 1998). In addition, according to Daghfous (2004), organizational culture has a positive influence on the level of absorptive capacity if it provides incentives for knowledge diffusion through the empowerment of employees and managers. Gradwell (2003) points to the strong influence of close networks and relationships within firms in stimulating the transfer of tacit knowledge.

Closely related to organizational structure and knowledge sharing is human resource and knowledge management. To name a few examples, forming workgroups made up of actors from different departments, stimulating job rotation, managing proposals submitted by employees and encouraging employees to read and monitor relevant literature and developments can certainly help facilitate the flow of knowledge (Mahnke et al., 2005; Jones and Craven, 2001; Cohen and Levinthal, 1994). Human resource management can also help to stimulate learning through reward systems and training (Mahnke et al., 2005; Daghfous, 2004) These actions lead to higher individual absorptive capacities and, consequently, to a higher capacity of the organization as a whole. Williamson (1967) argues that information gets lost or at least distorted if it is transferred through different layers of hierarchy. Thus, direct contact among employees from different departments, units and the like should lead to a more efficient transfer of knowledge and a subsequently higher absorptive capacity.

The structure of an organization and the tools and incentives it employs to stimulate knowledge exchange and learning are usually determined by the management of the firm. However, its role in building absorptive capacity goes beyond setting the organizational structure and culture. Lenox and King (2004) show, for example, that managers need to take part in the sharing and provision of knowledge to build absorptive capacity. This knowledge sharing can occur in the form of internal seminars or promotional brochures.

The determinants from all three groups have largely been treated as independent of each other. Nonetheless, it is feasible to assume that they are at least to some degree interrelated. Moreover, most of the determinants are complements rather than substitutes. As a firm's ultimate goal is to put acquired knowledge to good use -- i.e. turn it into new and innovative products and processes -- it has to ensure that all three components of absorptive capacity are built up and not just a single one. To give an example: A firm employing gatekeepers, which bring relevant knowledge into the firm, but lacking a system to provide that knowledge to those who can apply it to commercial ends obviously has the ability to identify relevant knowledge but cannot exploit it. It would thus fall into the category of firms with absorptive capacities but would fail to realize any advantages from this. Hence, its aim should be to build all of the components of absorptive capacity instead of a single one and invest accordingly in more than just one of the determinants described above.

The review of the literature leads us to formulate the following hypothesis, which will be tested empirically below:

H1: R&D activities are not the only building blocks of absorptive capacity. The organization and stimulation of knowledge transfer within a firm as well as the employment of qualified personnel play a critical role in determining the absorptive capacity of firms.

Absorptive Capacity for Different Types of Knowledge

The determinants of absorptive capacity discussed above focus on the firm at the receiving end of the knowledge exchange and how its structure and activities increase or decrease absorptive capacity. This is, however, only one side of the coin. Lane and Lubatkin (1998) make the case that a firm might not be able to learn equally from each external firm, arguing that certain characteristics of the "student-firm", i.e. the firm absorbing the knowledge, and of the "teacher-firm" -- the firm providing the knowledge to be transmitted -- have to be similar in order for the student-firm to be able to learn. According to these authors, the ability to learn from an external partner ("teacher") depends, among other things, on "the specific type of new knowledge offered by the teacher." (Lane and Lubatkin, 1998: 462). Dussauge et al. (2000) as well as Cohen and Levinthal (1990) conclude that a firm is better able to acquire and use external knowledge from areas it has some prior experience or related knowledge in (path-dependency of absorptive capacity). Becker and Peters (2000) and Nelson and Wolff (1997) argue that firms need higher absorptive capacities for scientific knowledge than for other types of knowledge. Mangematin and Nesta (1999) confirm this result. They find that higher absorptive capacities increase the ability to use more fundamental (as opposed to applied) external knowledge and firms with higher absorptive capacity have more contacts with research institutes than firms with lower absorptive capacities.

All these findings suggest that there are different absorptive capacities or varying levels of absorptive capacity required for different kinds of knowledge, one distinction being between science-based knowledge and knowledge from the private sector.

My second hypothesis for the empirical part of this section is thus:

H2: Different kinds of knowledge are associated with different absorptive capacities.

6.6.2 Data, Construction of the Variables and Empirical Model

To test the hypotheses mentioned above, I use data from the German innovation survey, the Mannheim Innovation Panel (MIP).[142] For my analysis I use the 2003 survey, in which data was collected on the innovation behaviour of enterprises during the three-year period 2000-2002. About 4,500 firms in manufacturing and services responded to the survey by providing information on their innovation activities. Almost 2,000 enterprises indicated that they had introduced at least one product or process innovation in the reference period. I restrict my analysis to firms which introduced innovations between 2000 and 2002 because most of the questions I use to construct my variables are only available for innovating firms, in particular the questions used to construct the dependent variables.

The 2003 MIP questionnaire provides data with which I can analyze the factors influencing the absorptive capacities of firms. I construct a measure of absorptive capacity using questions regarding impulses from external actors[143] used by firms to develop innovative products and processes.[144] I argue that successfully using such external sources of innovation is a rather direct measure of the exploitation component of absorptive capacity. A firm which is able to pick up impulses from external parties and turn them into innovations is certainly able to exploit external knowledge and thus possesses absorptive capacities.

142 For a more detailed description of the MIP survey see chapter 4.

143 Separate questions regarding impulses from customers, competitors, research institutes and universities and suppliers were asked.

144 The questions were phrased as follows: “Were any of the innovations introduced by your enterprise during the three-year period 2000-2002 triggered by new research results?”; “Were any of the innovations introduced by your enterprise during the three-year period 2000-2002 triggered by competitors’ innovations?” , etc.

The firms are also asked to indicate which industries (for suppliers and customers) provided these innovative impulses during the reference period. I use this information to construct different measures of absorptive capacity for intra- and inter-industry knowledge. To test the hypothesis that knowledge stemming from research institutions and universities requires specific absorptive capacities, I also included a measure of "exploitive absorptive capacities"[145] for knowledge from research institutes and universities used for developing product and/or process innovations.

The dependent dummy variables are constructed in the following way:

- *Absorptive capacity (Absorp)*

  One, if one of the absorptive capacities below equals one.

- *Absorptive capacity for intra-industry knowledge (Absorp_intra)*

  One, if at least one of the firm's innovations (in the period 2000-2002) has been developed and successfully implemented because of impulses from customers, suppliers or competitors from the firm's industry.

- *Absorptive capacity for inter-industry knowledge (Absorp_inter)*

  One, if at least one of the firm's innovations (in the period 2000-2002) has been developed and successfully implemented because of impulses from customers or suppliers from industries other than its own.

- *Absorptive capacity for scientific knowledge (Absorp_science)*[146]

  One, if at least one of the firm's innovations (in the period 2000-2002) has been developed and successfully implemented because of impulses from universities or other public research institutes.

145 The term "exploitive absorptive capacity" refers to the ability of firms to exploit external knowledge for their innovation activities.

146 I use the term "scientific absorptive capacity" for this concept in the remainder of the study.

The literature review yielded three main groups of determinants for absorptive capacity. In order to analyze their influence on my dependent variables I included the following independent variables in my model:[147]

- *R&D activities*

I measure the R&D activities of firms along two dimensions: the continuity (continuous vs. occasional) of their R&D engagements and their R&D spending as a share of total turnover. With the first measure (R&Dcon) I try to capture the path dependence of absorptive capacity, as firms which are continuously involved in R&D activities should have developed skills and experience in their specific fields of research. For firms which engage in R&D only occasionally the amount of related prior knowledge can be assumed to be limited or at least less than that of firms performing R&D continuously. I thus expect that firms with continuous R&D are more likely to have absorptive capacities than other firms.

R&D intensity (R&D_int), measured as share of R&D expenditure in total turnover, is to a large degree a measure of the scope of a firm's R&D commitment. I assume the absorptive capacity of firms to be higher the more they spend on R&D in a given year. I also include R&D intensity as a squared term (R&D_int2). This variable is included because I think that a firm which approaches the technological frontier, thereby researching at the forefront of its field, is no longer able to learn substantially from external parties. Hence, a larger part of R&D spending is targeted at knowledge generation rather than to improving absorptive capacity. In essence, I think that R&D intensity does not necessarily influence absorptive capacity linearly, but might rather exhibit a non-linear effect such that firms with very high R&D intensities are less dependent on external impulses with respect to their innovation activities.

147 Exact definitions of the variables can be found in Table A-8 and Table A-9 in the appendix.

- *Related prior knowledge and individuals' skills*

  The existence of related prior knowledge within firms is hard to operationalize with the data at hand, as I cannot determine in which specific field each firm does its research and possesses previously accumulated skills and experience. This determinant will thus only be represented by the aforementioned variable for continuous R&D (R&Dcon).

  Employee skill level can be fairly easily measured by the amount of employees with higher education degrees as a share of total employees (grads).

- *Organizational structure and human resource management practices*

  The literature provides evidence that the organization of knowledge transfer inside a firm has a positive influence on absorptive capacity. In order to be able to test my first hypothesis of this section I included several indicators of the way knowledge exchange is organized within a firm. These can be divided into two groups: measures intended to stimulate innovation activities and individuals' involvement in knowledge sharing, and collaboration between different departments. Both groups can be seen as determinants of absorptive capacity. While the former provides information on a firm's willingness and efforts to increase knowledge transfer and exploitation (incentives), the latter is a better measure of the actual knowledge transfer occurring between departments (organization); from my point of view, this is the more important determinant of absorptive capacity. I thus include a single indicator of the importance of measures meant to stimulate the involvement of individuals in knowledge sharing (stim_index)[148] and seven variables focusing on different means of collaboration between departments.

148 This index is the result of a principal components factor analysis of the importance of nine different methods of stimulating innovation and knowledge transfer. See Table A-8 in the appendix for a full list of the methods considered. The methods could not be included separately in the estimation since they were highly correlated with each other and with some of collaboration variables. The results of the factor analysis are presented in the appendix.

Two different aspects of collaboration will be investigated: hierarchical and sporadic information provision (mostly involving managers) as well as broad information provision (involving all employees). The former comprises joint development of innovation strategies (col_jointstrat), regular meetings of department heads to discuss innovation-related topics (col_heads), seminars and workshops for innovation projects involving several departments (col_seminar), mutual support of other departments with innovation-related problems (col_mutsup) and temporary exchange of personnel between departments for innovation projects (col_exchange). The latter is represented by informal contact among employees (col_infor), open communication of ideas and concepts between departments (col_opencom).

- *Control variables*

A number of control variables are included, most importantly two measures of size: number of employees (ln_emp) and number of employees, squared (ln_emp2). These two variables are meant to capture differences in absorptive capacity among small and large firms. Small firms might not have the same means and opportunities to exploit external knowledge, simply because they cannot risk betting on the wrong horse. Larger firms, on the other hand, often have multiple innovation projects running at the same time and can thus potentially exploit external knowledge better.

An additional dummy variable is included indicating whether a firm is situated in Eastern Germany (east), as Eastern German firms' innovation behaviour still differs significantly from that of Western German firms.[149] It is thus reasonable to assume that absorptive capacity also differs between the two regions.

149 See, for example, Rammer et al. (2004) or Sofka and Schmidt (2004).

To control for industry influences that are not picked up by other variables in the model, I include six industry group dummies[150], with "other manufacturing" being the reference group.

The construction of the dependent variables has two noteworthy implications for the empirical set-up: First, I am not able to observe the level of absorptive capacity directly, but rather only the existence of absorptive capacity. I argue that I will nonetheless be able to at least get a proxy for the level of absorptive capacity by estimating a probit model and using the predicted values as an indication of the level of absorptive capacity. The predicted value will technically give us the probability with which a given firm exploits external knowledge. My argument is that in order for that probability to be high, absorptive capacity of that firm has to be high. The second implication is that the interdependence among the three measures of absorptive capacity for the different types of knowledge have to be consider. Since I am allowing firms to have more than one type of absorptive capacity, I have to assume that their possession of one has an influence on the others. What is more, it is reasonable to assume that the determinants of absorptive capacity -- R&D expenditure, for example -- contribute to the accumulation of absorptive capacity for knowledge from universities and businesses alike. This is especially true if the usage and exploitation of different kinds of external knowledge requires the same or very similar competencies and experience. In order to take this interdependence into account in the empirical model, a trivariate probit model will be estimated, i.e. a simultaneous system of three equations, instead of three separate probits.[151] This will lead to an increase of the the validity of my estimates.

---

150 See Table A-9 in the appendix for details.

151 See Greene (2003) on "multivariate probit models".

The full empirical set-up then looks like this:

First a probit model for absorptive capacity in general estimated:

$$Absorp^* = \beta^{'} X + u \text{ with } Absorp_i = \begin{cases} 1 & if\ Absorp_i^* > 0 \\ 0 & otherwise \end{cases}$$

where X is the column vector representing the independent variables outlined above.

In the next step I estimate the following trivariate probit model for the three different types of absorptive capacity:

$$Absorp\_inter^* = \beta_1^{'} X + \varepsilon_1 \quad \text{with} \quad Absorp\_inter_i = \begin{cases} 1 & if\ Absorp\_inter_i^* > 0 \\ 0 & otherwise \end{cases}$$

$$Absorp\_intra^* = \beta_2^{'} X + \varepsilon_2 \quad \text{with} \quad Absorp\_intra_i = \begin{cases} 1 & if\ Absorp\_intra_i^* > 0 \\ 0 & otherwise \end{cases}$$

$$Absorp\_science^* = \beta_3^{'} X + \varepsilon_3 \quad \text{with} \quad Absorp\_science_i = \begin{cases} 1 & if\ Absorp\_science_i^* > 0 \\ 0 & otherwise \end{cases}$$

where the pair-wise correlation of the error terms is not equal to zero:

$$Cov(\varepsilon_1, \varepsilon_2) = \rho_1 \ ; Cov(\varepsilon_1, \varepsilon_3) = \rho_2 ; \ Cov(\varepsilon_2, \varepsilon_3) = \rho_3$$

This model can be solved by employing a maximum-likelihood procedure. To evaluate the likelihood of a certain outcome, the probability of an observation has to be calculated using a trivariate normal probability density function which takes into account $\varepsilon_1, \varepsilon_2, \varepsilon_3, \rho_1, \rho_2, and\ \rho_3$. This poses some problems: It has been shown that standard numerical calculation techniques cannot be used if the normal density function is of an order higher than two.[152] A way to solve this problem involves using simulation techniques. One, which is now implemented in many statistical packages, is the so-called "GHK-Simulator (Geweke-Hajivassiliou-

152 See Glasgow (2001) for a discussion of the topic.

Keane-Simulator)" for multivariate normal distributions[153]. For my model estimation I use a procedure developed by Antoine Terracol for the STATA statistical software package (triprobit), which relies on the GHK simulation procedure.[154]

For the model estimation I am able to use 1,650 which indicated that they had carried out innovation activities during the three-year period 2000-2002.

Of the 1,650 observations, 1,177 (71%) have at least one type of absorptive capacity. 575 have at least intra-industry, 956 at least inter-industry and 248 at least scientific absorptive capacity.[155] For those firms that only show one type of absorptive capacity I find a similar distribution. Just 47 firms, or 2.7% of the enterprises in my sample, have only scientific absorptive capacity, while 156 and 463 have only intra-industry and inter-industry absorptive capacities, respectively. 91 of the firms have all three types. The fairly large number of firms having more than one type of absorptive capacity (43% of all firms with absorptive capacity) provides further evidence that the manners in which the three types of absorptive capacity are accumulated are somewhat related and a trivariate probit estimation procedure should be used.

As far as the independent variables are concerned, I find only very few differences between the sample mean and the mean of firms with absorptive capacities. Notable exceptions are the share of employees with higher education, which is about two percentage points higher for firms with absorptive capacity, and the R&D intensity, which is one percentage point higher for the latter group. Additionally, the share of firms with continuous R&D is six percentage points higher for firms with absorptive capacity. The index for stimulating knowledge ex-

---

153 Other simulators could also be used. Hajivassiliou et al. (1996) review eleven simulators and find that the GHK is the most reliable method for multivariate normal distributions.

154 The method is known to be sensitive to the number of observations draw in each iteration. I thus tested several different settings. The results only change as far as the size of the coefficients is concerned, the significance levels and qualitative results stay the same. The model presented below uses 220 draws instead of the default number of draws which is 25.

155 Additional descriptive statistics can be found in Table A-10 the appendix.

change and innovation activities is also significantly higher for firms with absorptive capacity, but only by two percentage points.

Within the group of firms with at least one type of absorptive capacity, the same variables make a difference between those with scientific absorptive capacity and the other two types. Here, the differences are more pronounced. Firms with scientific absorptive capacity have an average share of employees with higher education of 42% and an R&D intensity of 14.8%. For the mean firm with intra-industry absorptive capacity the numbers read 28% and 7.7% and for the average firm with inter-industry absorptive capacity they are 30% and 8.7%.

6.6.3 Results

The results of the estimation are presented inTable 6-3. Let us first turn to the standard probit estimation of firms' absorptive capacities (equation 1).

A first striking result is that continuous R&D is significant and positive, while R&D intensity, which is widely used in the related literature as a proxy for absorptive capacity, is not. This indicates that continuous R&D engagement (and not necessarily the level of R&D expenditure) is relevant to absorptive capacity. A firm's current[156] expenditure on R&D is usually not primarily targeted at building absorptive capacity but rather at accumulating new knowledge and developing new products and processes, which might explain my findings. The results suggest that a firm's current R&D expenditure does not make an ad hoc contribution to the assembly of absorptive capacity; instead, it helps to develop the skills and knowledge necessary to source external knowledge over time. In this sense, absorptive capacity is cumulative. I will argue below that current R&D expenditure can also immediately contribute to exploitive absorptive capacities, but only for specific types of knowledge.

Another explanation for the insignificance of the R&D intensity variables is that firms with higher R&D intensities have a lower demand for external knowl-

156 In order to reduce a possible endogeneity bias, I use R&D intensity in the year 2001 instead of that of 2002.

edge than firms with lower R&D intensities. The more R&D is done in-house, the more knowledge is generated internally and the less external knowledge is required. It is also quite likely that firms with large in-house knowledge pools would generate more impulses and ideas from within and use less external impulses and ideas for their innovations. In that case firms would have the capacity and capability to use external knowledge in their innovation processes, but simply do not need to do it.[157] If this negative effect on demand for external ideas and knowledge dominates the effect of R&D on absorptive capacity, the R&D intensity would still have a positive effect on absorptive capacity, but it would not show in my estimations.

157 They might also not want to do it, if the sourcing of external knowledge is connected with certain costs.

Table 6-3 Coefficients of Probit and Trivariate Probit Estimation on the Determinants of Absorptive Capacity

Variable	Absorptive Capacity (1)	*Intra*-industry Absorp. Cap. (2)	*Inter*-industry Absorp. Cap. (3)	Scientific Absorp. Cap. (4)
R&D activities:				
R&D_int	0.004	-0.002	0.007*	0.014***
	(0.004)	(0.004)	(0.004)	(0.004)
R&D_int2	-0.00001	0.000005	-0.000028*	-0.00005***
	(0.00001)	(0.000014)	(0.000014)	(0.00002)
R&Dcon	0.306***	0.127*	0.222***	0.451***
	(0.078)	(0.076)	(0.073)	(0.089)
Skills/Size:				
Grads	0.003**	0.001	0.002	0.010***
	(0.002)	(0.002)	(0.002)	(0.002)
ln_emp	-0.199**	-0.134*	-0.079	-0.099
	(0.090)	(0.079)	(0.076)	(0.087)
ln_emp2	0.023***	0.021***	0.010	0.012
	(0.008)	(0.007)	(0.007)	(0.007)
Collaboration/* Stimulation*:				
col_infor	0.159**	0.218***	0.113	0.096
	(0.076)	(0.072)	(0.144)	(0.088)
col_opencom	0.030	0.102	-0.074	-0.238**
	(0.086)	(0.081)	(0.078)	(0.098)
col_jointstrat	-0.105	-0.138*	-0.022	-0.050
	(0.085)	(0.080)	(0.080)	(0.100)
col_mutsup	0.090	-0.180**	0.122	-0.089
	(0.084)	(0.079)	(0.077)	(0.096)
col_heads	-0.010	0.031	-0.032	-0.123
	(0.080)	(0.076)	(0.075)	(0.096)
col_exchange	-0.275*	-0.092	-0.127	0.117
	(0.150)	(0.147)	(0.140)	(0.160)
col_seminar	-0.009	-0.341***	0.013	0.243**
	(0.116)	(0.110)	(0.105)	(0.220)
stim_index	0.683***	0.293*	0.602***	0.798**
	(0.173)	(0.170)	(0.166)	(0.205)
Observations	1,650		1,650	
X^2	132.73		347.89	
Ald.-Nelson Pseudo R^2	0.137		0.231	
Rho		(2,3): 0.27 ***	(3,4): 0.19***	(2,4): 0.11**

Significant at 10%; ** significant at 5%; *** significant at 1%; Robust SEs in parentheses.

Source: Own calculations.

To investigate whether the results are driven by the choice of measure of R&D intensity, I estimate several additional model specifications. The results, which are reported in column 1 of Table 6-4, show that, regardless of the measure used for R&D intensity and the inclusion or exclusion of one of the two R&D-related variables, the coefficients of R&D intensity remain insignificant and continuous R&D remains highly significant, providing further evidence that current R&D intensity does not immediately determine the ability of firms to exploit external knowledge.[158]

Table 6-4 Coefficients of Five Different Probit and Trivariate Probit Estimations on the Determinants of Absorptive Capacity[159]

Variable	**Absorptive Capacity**	***Intra*-industry Absorp. Capacity**	***Inter*-industry Absorp. Capacity**	**Scientific Absorp. Cap.**
		Model 1: R&Dcon + R&D_int		
R&D_int	0.004	-0.002	0.007*	0.014***
R&D_int2	-0.00001	0.000005	-0.00003*	-0.00005***
R&Dcon	0.306***	0.127*	0.222***	0.451***
		Model 2: R&Dcon + R&D_int_empl		
R&D_int_empl	0.130	0.211	0.629	1.343**
R&D_int_empl2	-0.167	-0.862	-0.625	-0.708
R&Dcon	0.318***	0.135*	0.255***	0.504***
		Model 3: R&Dcon		
R&Dcon	0.320***	0.121	0.245***	0.504***
		Model 4: R&D_int		
R&D_int	0.007	-0.001	0.009**	0.017***
R&D_int2	-0.00002	0.00001	-0.00003**	-0.0001***
		Model 5: R&D_int_empl		
R&D_int_empl	-0.229	0.085	0.378	0.950
R&D_int_empl2	0.680	-0.682	-0.276	-0.153

Source: Own calculations.

A large body of literature has pointed to the positive influence of collaboration and stimulation of knowledge sharing on absorptive capacity, as described above. My results do not totally contradict these findings but raise some doubts about their importance in exploiting external knowledge. Like other studies I find that

158 The joint significance of the two R&D intensity variables can always be rejected.

159 The models all include the full set of independent variables not related to R&D as well as the variables shown. The full estimation results are available upon request.

collaboration between departments has an impact on absorptive capacity, lending support to the first hypothesis in this section. However, only informal contacts have a positive and significant effect on absorptive capacity. The variables representing hierarchical information provision are not or only very marginally significant. This suggests that it is more important to create a culture and organization that leads to informal knowledge transfer rather than a culture in which information provision is more centralized. One reason for this might be that the diffusion of new knowledge is faster and less prone to distortions through informal networks compared to formal systems (see Williamson, 1967). The insignificance of the other variables is puzzling still, as one would expect that every knowledge exchange regardless of the method used is helping firms to exploit external knowledge.

The measure for methods that try to stimulate employee participation in innovation activities is positively associated with absorptive capacity. This suggests that it is not only necessary to increase the knowledge flows between actors inside the firm (mainly through informal contacts), but also to leverage the knowledge of each individual in the innovation process. Almost all the stimulation methods included in the factor analysis are aimed at the involvement of the employees and mangers in the innovation process. These findings confirm, that a firm's absorptive capacity is related to that of its employees.

Further evidence for this result is provided by the importance of higher education for exploitive absorptive capacity. As expected, the share of employees with higher education positively influences the ability of firms to exploit externally available knowledge. This is also true for continuous R&D activities, which I use as an indicator of related prior knowledge. The results confirm other studies' findings that both indicators influence firms' absorptive capacities. My interpretation is that both the related prior knowledge of individuals -- gained through education -- and that of firms, which they have developed through steady R&D investment, positively influences the ability to exploit external knowledge. The positive influence might have something to do with the fact that this related prior knowledge is also necessary to identify and assimilate external knowledge.

I find a significant U-shaped effect of the number of employees on the likelihood that firms have exploitive absorptive capacity. This is surprising, as one would expect the number of employees to always have a positive effect on firms' absorptive capacities: Individuals' absorptive capacity is, after all, part of the firms. Because the U in question (turning point: 75 employees) is very flat, this finding should not be over-interpreted, however. One explanation for the U-shaped relationship might be that very small firms depend more on external knowledge than medium-sized ones. After the turning point of 75 employees is reached, the expected size effect sets in, i.e. every additional employee increases the ability of firms to exploit external knowledge. The demand effect suggested by the insignificance of the R&D intensity (see above), might also be able to explain the U-shaped relationship between the number of employees and absorptive capacity. Very small firms need external knowledge to further exploit their (only) inventions and innovations or to get new ideas for applications of their existing knowledge. After they have reached a certain size (and gained some experience in the market), they are more likely to focus on the exploitation and commercialization of their innovations and internal knowledge, rather than look for new ideas outside their boundaries. This seems to lower the demand for external knowledge by medium size enterprises. If their internal "potential" has been exploited they have to use more external knowledge to grow further.

In essence, the estimations support the hypothesis that not only R&D is relevant for the ability to exploit external knowledge. Besides R&D, highly skilled labor as well as knowledge management tools that stimulate the involvement of employees in innovation projects seem to be important. However, only informal contacts, and not as hypothesized almost all collaboration methods, influence the ability to exploit external knowledge positively.

The estimation results provide evidence supporting the second hypothesis of this section, as they clearly show that the ability to exploit different types of external knowledge is influenced differently by the factors considered.[160] Most pronounced is the difference between the exploitation of scientific knowledge and knowledge from the business sector. They particularly differ with respect to R&D variables. As mentioned above, there are differences between the effects of R&D intensity on the three different types of absorptive capacity. For scientific knowledge I find a highly significant effect of current R&D intensity; no such effect is evident for the other two types of knowledge. Firms that spend a large amount of turnover on research are usually in greater need of external knowledge and are thus more likely to exploit that knowledge. Additionally, as the share increases they become more and more similar to public research institutes and universities. The more similar firms are, the better they can learn from each other, as Lane and Lubatkin, 1998) argue. Their ability to exploit knowledge learned from similar partners also increases, as my results suggest. This similarity argument cannot be made for the other two types of actors providing knowledge, which might explain why I do not find significant signs for intra-industry absorptive capacity and only marginally significant signs for inter-industry absorptive capacity. In the long run, however, R&D seems to be relevant for inter-industry knowledge as well, as the positive effect of continuous R&D suggests. For intra-industry knowledge this variable is also significant, but only slightly.

Again, the robustness of the findings is tested by including different measures of R&D intensity in the estimations. The results remain quite similar to those for the original model. For scientific absorptive capacity the only more pronounced change I find is the significance of the squared R&D intensity when using the share of R&D employees instead of the share of R&D expenditure. This can be explained by the values the two variables can take. While the R&D intensity

160 Note, the test for the interdependence of the three equations in the trivariate probit shows that the equations are, in fact, not independent, as all Rhos are positive and significant at least at the 95% confidence level.

based on expenditure is not constrained to the interval [0;1][161], that which is based on employees is. If firms with R&D_int greater than one are dropped, I get the same result as for R&D_int_empl. For intra-industry absorptive capacity the results differ more than for the other two types. The prominent role of continuous R&D can at least be confirmed in all models.

The results for the three types of absorptive capacity differ not only with respect to R&D-related variables; differences with respect to the extent of collaboration among departments also show. These factors are only significant for intra-industry and scientific absorptive capacity. This is surprising, as one would expect the exploitation of inter-industry knowledge to be influenced by collaboration among departments as well. I argue that the exploitation of inter-industry knowledge for innovations might require less collaboration because a large amount of that knowledge is embodied in products from suppliers and each employee can take the knowledge needed for his or her innovation activities directly from the product. The insignificance and negative significance of some collaboration variables in the equations for intra-industry and scientific knowledge point to the fact that collaboration among departments, as beneficial as it might be for certain enterprise activities, does not necessarily contribute to exploitive absorptive capacity. On the contrary, a firm has to choose how it organizes collaboration with respect to the knowledge it wants to absorb and balance the need to exploit external knowledge with its other needs and goals.

Intra-industry absorptive capacity, for example, is negatively influenced by mutual support among departments. The latter reduces the probability of intra-industry knowledge being successfully exploited in innovations, suggesting that this method does not fit the type of knowledge to be exploited. Mutual support with innovation-related problems is likely to be associated with significant difficulties if different departments are configured distinctly or use procedures not

161 Note, some firms in the sample out-spend their turnover in financing R&D. They are all from NACE 73, “Research and Development”. For firms in that field it is not unusual to have R&D intensities above one.

known to others outside of the department, leading to an increase in costs and necessary efforts without leveraging the exploitation of external knowledge. Seminars involving actors from different departments and the development of joint innovation strategies also influence the likelihood that a firm exploits intra-industry knowledge negatively. The method best suited to exploiting intra-industry knowledge is to generate informal contact among employees. This suggests that it is especially beneficial to spread knowledge throughout the whole firm rather than distribute it through formal and more targeted mechanisms. One reason for this might be that knowledge from a firm's own industry can easily be understood by everyone within the firm. Broad dissemination should thus increase the potential use of information for innovation activities. For scientific knowledge the opposite is true: It cannot be easily understood and processed by all actors in the company but has to be "translated" into a form that is usable by everyone in the firm. The positive influence of seminars and workshops in the equation for scientific knowledge supports the notion that more translated knowledge implies a higher probability that it can be integrated into the existing knowledge base and utilized in the innovation process. This underscores the role of gatekeepers in the process of building absorptive capacity. In contrast, broad knowledge diffusion reduces the probability of scientific knowledge being exploited. This method is not beneficial since only very few actors inside the firm are able to profit from a more widespread dissemination of knowledge and considerable (opportunity) costs might be involved.

Stimulating employees to get involved in the innovation process as well as knowledge acquisition and distribution is of great importance in determining absorptive capacity for all three kinds of knowledge, as the estimation results suggest. The explanation is straightforward: The more knowledge is screened and the higher the incentives are to use acquired knowledge in the innovation process, the higher the potential to exploit external knowledge.

The differences between the three types of absorptive capacity are not limited to the collaboration and R&D variables, however. While I find a positive and significant coefficient for the share of employees with higher education in the scientific knowledge equation, it is insignificant in the other two equations. Naturally, one would assume that it is easier for employees who have attended university to use knowledge from this domain. They know how to use the knowledge as well as how and where to get it. The level of education does not significantly influence the ability to exploit intra- and inter-industry knowledge. For intra-industry absorptive capacity, size is more important. As in the case of absorptive capacities in general, a U-shaped relationship between the number of employees and intra-industry absorptive capacity is found (turning point: 25 employees). For inter-industry absorptive capacity neither the share of high-skilled labour nor size matters. The differences with respect to high-skilled labour can be explained by varying requirements for the exploitation of external knowledge. One can argue that in order to exploit knowledge from a firm's own industry, experience is more relevant than a high level of education. Even without a large share of highly educated personnel, firms should be able to exploit knowledge from within their own industries. On the other hand, the exploitation of very sophisticated methods and knowledge produced by public research institutes certainly require a similar kind of advanced training in a particular field. To absorb inter-industry knowledge more general skills in structuring problems and gathering information on previously unknown subjects might be more important than the initial education level of firms' employees.

The positive and significant effect of the dummy for Eastern Germany for intra-industry absorptive capacity is in line with what Sofka and Schmidt, 2004 find analysing first-mover and follower strategies for German firms: Eastern German firms are more often followers than leaders. Eastern German firms are thus more dependent on innovation and knowledge from their market rivals and are consequently more focused on exploiting knowledge from their own industry than West German firms.

6.7 Construction of the Realized Incoming Spillover Pool at the Firm-Level

The differences in the determinants for intra-industry, inter-industry and scientific absorptive capacity are striking and provide further evidence that a differentiated approach like the one chosen for this study is warranted.

In order to arrive at the firm specific realized incoming spillover pools the potential intra-industry, inter-industry and scientific knowledge spillover pools will be multiplied by the estimated levels of absorptive, i.e. the predicted value of the trivariat probit estimations of the previous section[162], for the three different kinds of knowledge. This calculation is only possible for firms for which the potential incoming knowledge spillover pools could be constructed (as argued in subsection 6.5 this pool is available for 2,804 observations) and which had answered the 2003 innovation survey used to estimate the model in the previous section (1,650 observations). As a result I obtain estimates of the realized incoming-spillover pools for intra-industry, inter-industry and scientific knowledge for 718 firms.

162 The predicted values are between zero and one, since they represent the probability of a given firm to have exploited external knowledge for their innovation process.

7 The Relationship between Knowledge Flows and R&D Co-operation – A Multivariate Analysis

This chapter starts out by reviewing the literature on R&D co-operation motives other than knowledge spillovers. Particular attention will be given to *empirical* evidence on firms' motives for R&D and innovation co-operation. The following sections will, however, not be restricted to a literature review but form the core part of my analysis. I will estimate the impact of knowledge spillover on the likelihood of R&D co-operation. First, as a benchmark model an empirical model similar to the one by Cassiman and Veugelers (2002) will be estimated using data from the MIP survey and the "standard" measures of knowledge spillovers as suggested by Cassiman and Veugelers (2002). The results of this model will then be compared to the outcome of an empirical model based on the knowledge spillover measures constructed in the previous sections.

7.1 Motives and Determinants of R&D Co-operation: Going Beyond Knowledge Spillovers

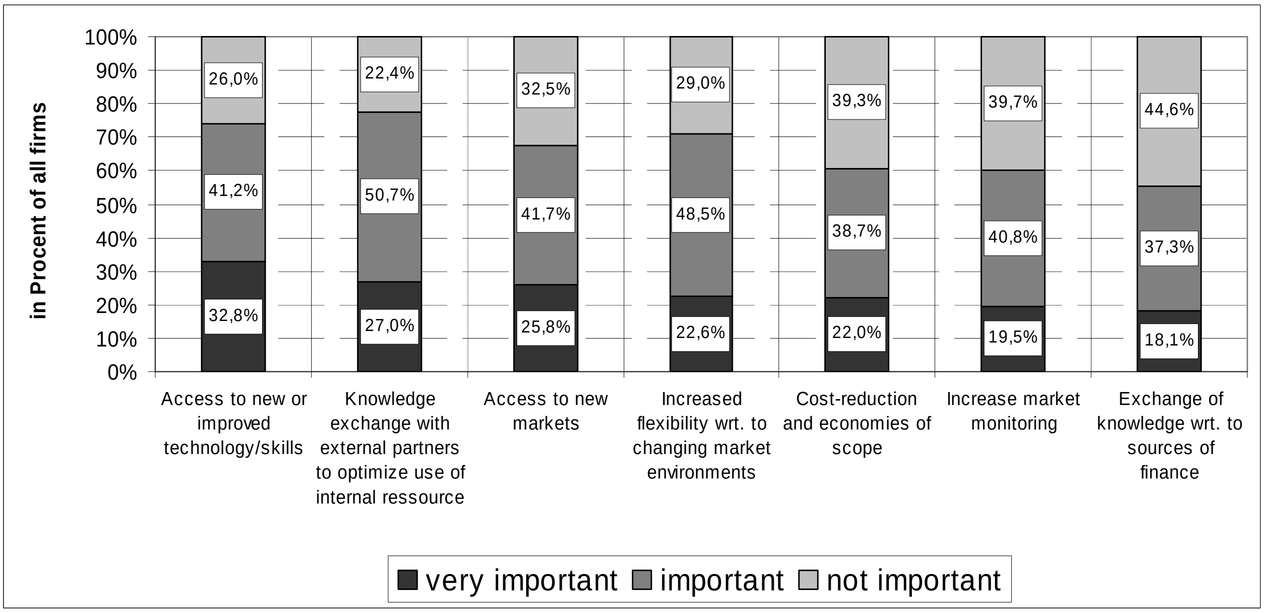
In chapter 2 the motives for co-operation related to knowledge spillovers were reviewed. The generation or prevention of knowledge spillovers are, however not the only motives that firms have to cooperate on R&D and innovation with other actors in the economy. I will discuss additional motives under three headings: strategic motives, motives related to changes in the business environment and framework conditions, and motives related to firm characteristics.[163] The assignment of a motive into a certain category of motives is not always clear-cut as some motives are certainly related to each other and can thus be included in several groups. Of course, a co-operative agreement on R&D and innovation activi-

163 The review will serve as a basis for identifying control variables for the empirical models to be estimated below. It is not intended to be exhaustive and will focus on the empirical evidence on motives and determinants of firms' co-operation activities.

ties with other firms or institutes can be driven by many different motives from all types and groups of motives.

That motives beyond knowledge spillovers are important for analysing the R&D co-operation behaviour of firms is illustrated by the following figure, which is based on a data of more than 8,500 firms in selected service and manufacturing industries from four German Bundesländer.

Figure 7-1 Reasons for R&D Co-operations – Results for Four German Bundesländer



Source: Statistisches Bundesamt, 2004: 17 (translated from German).

Motives and Determinants of R&D Co-operation Related to Strategic Considerations[164]

An overview of what are called “strategic” motives for R&D co-operation has been compiled by Hagedoorn (1993)[165]. The results of his literature review are presented in Table 7-1. Some of the motives in his table can be directly related to knowledge spillovers, like the first set of all three groups of motives listed in the table. The other motives he identifies are by and large, the sharing of cost and risk, the strengthening of the innovation process and gaining access to new markets at home or abroad. In the empirical part of his paper he uses information on co-operative R&D agreements published in newspaper and magazines to show that the motives to cooperate on R&D vary by industry. However, a finding common across all the industries he surveys (manufacturing and services) is that access to complementary knowledge, access to markets and the reduction of the innovation time span are the three most important motives for firms to conduct joined R&D.

164 A basic motive for R&D co-operation is of course to generate financial or strategic benefits (e.g. Stuart, 1998). It is not discussed here, because all activities of profit-oriented firms are usually driven by this motive and not only the R&D co-operation behaviour.

165 Other overviews of the (empirical) evidence on R&D co-operation motives has been compiled by Caloghirou et al. (2003) and Piga and Vivarelli (2003).

Table 7-1 An overview of Motives for (Strategic) Inter-Firm Technology Co-operation[166]

I	**Motives related to basic and applied research and some general characteristics of technological development:**
-	Increased complexity and intersectoral nature of new technologies, cross-fertilization of scientific disciplines and fields of technology, monitoring of evolution of technologies, technological synergies, access to scientific knowledge or to complementary technology
-	Reduction, minimizing and sharing of uncertainty in R&D
-	Reduction and sharing of costs of R&D
II	**Motives related to concrete innovation processes**
-	Capturing of partner's tacit knowledge of technology, technology transfer, technological leapfrogging
-	Shortening of product life cycle, reducing the period between innovation and market introduction
III	**Motives related to market access and search for opportunities**
-	Monitoring of environmental changes and opportunities
-	Internationalization, globalization and entry to foreign markets
-	New products and markets, market entry, expansion of product range

Source: Hagedoorn, 1993: 373 (shortened).

Sakakibara (1997) supports the view that the sharing of costs and risks[167] are two basic motives for co-operation. She argues that firms try to reduce their own project costs by cooperating with external partners. Since expensive projects usually also bear a high risk for the firms undertaking them cost and risk sharing as a

166 Hagedoorn (1993) provides many references for all these motives in the original paper. These will not be included in the review here, which focuses on more recent evidence.

167 See also Banerjee and Lin (2001).

motive for co-operation might be related to each other[168]. The increasing complexity and cost of research projects further enhances the role of these motives (see also Bayona et al., 2001). Tether (2002) found analyzing data from the second Community Innovation Survey (CIS II) that the growing complexity of technological innovations has indeed led to more cooperative behaviour in the UK. His study already points to the second group of motives for co-operation (framework conditions and changing environments), which will be discussed below.

Competition in the product markets is seen a factor influencing the R&D co-operation decision of firms by Negassi (2004). He cites Vickers (1985) to make his point that "R&D alliances are also competitive strategies to gain market share, innovative edge, or to build entry barriers" (Negassi, 2004: 366). He argues that many empirical researchers have overlooked the impact of market share on the R&D co-operative behaviour. The mechanism he proposes is that firms with higher market shares are more attractive co-operation partners than firms with little market share and are thus more often involved in cooperative agreements. He does not find support for this hypothesis in the empirical part for his study and amends his argument: Firms with small market shares will have an incentive to cooperate in order to speed up the growth of their market share. Contrastingly, Link and Bauer (1987) find evidence that market power is the main factor influencing firms' R&D co-operation decision and that the likelihood for co-operating increases with market power.

Hernan et al. (2003) analyse a similar topic. They look at the effect of the concentration of an industry on the R&D co-operation behaviour and find that the – Hirschman-Herfindahl index for four-digit sectors does not significantly influence a firm's participation in research joint ventures. Kaiser and Licht (1998) find no significant impact of the number of competitors in a firms sector on the

168 Contrastingly Cassiman and Veugelers (2002) and Schmidt (2005b) show that cost and risk have opposite effects on the likelihood of firms to cooperate: While risk-sharing has a negative effect, cost-sharing has a positive effect.

decision to cooperate with firms in the same industry, but a significant positive effect for co-operation with firms from other industries.

Miotti and Sachwald (2003) confirms the role of opportunity seeking and market access in a firm's R&D co-operation decision. Their main findings are that technology seeking is the major motive for R&D co-operation with most partners and firms co-operate in R&D in order to be able to access new (foreign) markets. Bayona et al. (2001) in a study of over 1,600 Spanish firms, does not find a significant effect for the R&D co-operation motive market access, though.

Another strategic motive, not mentioned in Hagedoorn (1993) table has been identified by Lhuillery and Galia (2006). One of his conclusions analysing French CIS 1 and CIS 2 data is that "[…] co-operation failures cannot be considered independent from the decision to collaborate in R&D […]" (Lhuillery and Galia, 2006: Abstract). They do not explain the mechanisms behind this argument, but their finding that the characteristics of firms which have a high probability of cooperating are similar to those of firms that have a small probability to fail in innovation activities is some evidence that firms take the potential partners "strength" into account. Their findings should be considered with care, however. They just compare the characteristics of two groups of firms without testing for causality between failure and the likelihood of cooperating.

Motives and Determinants for R&D Co-operation Related to Framework Conditions and Changes in Firms' Business Environment

The increase in technological partnering among firms is very often attributed to changes in the framework conditions for business and innovation activities (e.g. Hagedoorn and Schankenraad, 1989, Rocha, 1999, Chesnais, 1988). These framework conditions include new technological developments, the increasing complexity of technologies, shorter product life-cycles, increased international competition and the rising costs of innovation activities (Ragnitz et al., 2003; Hagedoorn, 2002; Kaiser, 2002a; Caloghirou et al., 2003; Tether, 2002).

Duysters and Hagedoorn (2000) proposes that the above mentioned factors lead to a situation where a single firm cannot "monitor all the technological developments that are important for their core market" (Duysters and Hagedoorn, 2000: 85). They argue that in these situations R&D co-operation is an effective way to monitor a wide range of technological developments, a motive included under the strategic motives by Hagedoorn and related to spillovers. Gilsing and Lemmens, 2005 proposes that in dynamic environments exploration of outside opportunities becomes crucial and that R&D co-operation or networking may be one way to organise the search process. Bayona et al. (2001) propose that the complexity of a technology is a motive for firms to cooperate on R&D and innovation activities. This argument is based on the finding that co-operation is more widespread in industries characterised by complex technologies.

Overby (2005) looks at the R&D co-operation behaviour of two large players ("3", Vodafone) in the market for mobile internet services to analyse the effect of the industry-life cycle on incentives to cooperate. He finds that partner selection criteria change over the industry life-cycle. In the exploratory stage, firms may choose to ally with weak partners, in terms of resource endowments, in the development stage they ally with both weak and strong partners, and in the maturity stage of the industry it seems to be optimal to ally with strong partners.

The framework conditions for cooperative R&D include public support policies adopted by national authorities and the European Union, which have encouraged the formation of co-operations in R&D and innovation projects (see for data on Germany: Fier et al., 2005). Miotti and Sachwald (2003) use data from the French CIS II innovation survey to analyse the impact of public funding and R&D co-operation with different partners. They find a positive effect of R&D subsidies on all types of co-operations except for co-operation with vertically related firms. In contrast Belderbos et al. (2004) find no effect of public funding for horizontal co-operation and a positive effect for vertical and public-private R&D co-operation in their empirical study using CIS I and II data. Abramovsky et al. (2005) confirm the central role of public support for R&D co-operation. They find that the recipients of public support are more likely to cooperate than firms without public support in France, Germany, the UK and Spain. Negassi (2004) shows that if a firm has received public support for its innovation activities it is more likely to cooperate in all but one of their nine different model specifications. Busom and Fernandez-Ribas (2004) find a positive effect of participation in national R&D programs on the likelihood of cooperating in their estimations using data from the Spanish innovation survey of 1999. The effect is particularly strong for public-private partnerships.

Motives and Determinants for R&D Co-operation Related to Firm Characteristics

An example of an empirical study that models the link between R&D co-operation and firm characteristics in addition to knowledge spillovers is Negassi (2004). Using firm level data on French firms he investigates the role of size (measured as total sales), R&D intensity, market share, receipt of public funding and several spillover measures on the total budget firms spend on R&D co-operation. He finds that firms are spending more on R&D co-operation (an indication of their valuation of co-operative agreements) if they are larger and if they have a higher R&D intensity.

Dachs et al. (2004) argue in their literature review that large firms are more likely to have the resources to actively look for partners for their innovation projects and are thus more likely to cooperate than small firms. Large firms also have a higher incentive to cooperate with external partners simply because they focus on their core business and have to acquire complementary knowledge and services from outside their own boundaries (Gerybadze, 2004). If they reduce the number of employees in the course of focusing on their core business, the positive effect of size might become mitigated and not show up in empirical estimations. Fritsch and Lukas (2001) present another argument for the influence of size. They argue that if "there exists a given probability for co-operation per unit of economic activity" (Fritsch and Lukas, 2001: 300) then large firms should be more likely to conduct co-operative R&D than small firms with less economic activity. The majority of empirical studies finds a positive effect of firm size on the likelihood of cooperating in R&D(e.g. Röller et al., 2001, Link and Bauer, 1987 and Cassiman and Veugelers, 2002 (inverse u-shaped)).

Dachs et al. (2004) argue that the export orientation of firms matters for their R&D co-operation decision. They do not find empirical evidence for this hypothesis, however. Busom and Fernandez-Ribas (2004) support this view as they do not find empirical evidence for a link between export intensity, measured as the share of exports over total sales, and the likelihood of cooperating in R&D, however. The mechanism they propose is that exporting firms have access to a larger variety and number of potential co-operation partners (e.g. international firms) than non-exporting firms and are thus more likely to cooperate.

R&D intensity (share of R&D in total turnover or share of R&D employment of total employment), the total amount spend on R&D activities or a dummy variable for continuous R&D activities is usually included in empirical studies on the determinants and motives of R&D co-operative behaviour of firms to control for absorptive capacity (see e.g. Bönte and Keilbach, 2005; Fritsch and Lukas, 2001). In addition to representing a firms ability to source external knowledge these indicators can also been seen as a measure of the need of firms for external knowledge (Fritsch and Lukas, 2001). The empirical evidence on the link between R&D measures and R&D co-operation is mixed, however. While some studies find a positive effect of R&D activities on the likelihood of cooperating on R&D activities (Fritsch and Lukas, 2001; Bönte and Keilbach, 2005 – continuous R&D; Fontana et al., 2005), others do not (Abramovsky et al., 2005 – negative effect for France; Cassiman and Veugelers, 2002 – 2-step results; Rocha, 1999).[169]

As far as the industry of the firm is concerned, Dachs et al. (2004) argue that the industry structure, with respect to intensity of competition, technological in-

169 See Fritsch and Lukas (2001): 301(Footnote 13) for more references.

tensity, and appropriability conditions of the respective industry influences a firm's R&D co-operation decision. These findings point to a fundamental problem of the empirical evidence on the effect of industry on R&D co-operation, i.e. empirical models usually include industry dummies to account for factors that are industry specific, but cannot include separate variables for specific industry characteristics in their model. What the industry dummies measure thus depends on the specific specification of the empirical model[170]. Usually the empirical studies do find an effect of the industry dummies. In the model of Belderbos et al. (2004) for example, the service sector dummy is significant and positive for horizontal and vertical co-operations. Fritsch and Lukas (2001) show that the industry affects the number of R&D co-operations a firm joins. Tether (2002) finds that low technology firms in services are less likely to cooperate than firms from other industry groups. Descriptive statistics from the CIS for the member states of the European Union also show significant differences in the share of firms involved in R&D co-operation in each industry (European Commission, 2004b).

Motives and Determinants for R&D Co-operation with Different Partners

Firms can cooperate with various partners as the overview of different types of R&D partnerships in subsection 2.5.1 has already shown. This has lead some empirical researchers to investigate the motives for specific types of R&D partnerships. Bönte and Keilbach (2005) analyse differences in the motives and determinants of informal versus formal R&D co-operations. Kaiser (2002a) looks at the difference between co-operative agreements with horizontally and vertically related firms. Dachs et al. (2004), Belderbos et al. (2004), Abramovsky et al. (2005) and Cassiman and Veugelers (2002) also investigate the relationship between several co-operation motives and the likelihood of co-operating with customers and suppliers. They go beyond the study by Kaiser (2002a), however, and add co-operation with universities and research

170 The reference category, i.e. the industry dummy left out, is also different for different empirical models, making a comparison across different estimations even harder.

institutions as an additional type of R&D co-operation. The link between industry and science has been at the centre of attention of the studies by Veugelers and Cassiman (2005), Fontana et al. (2005), Fontana et al. (2003), Schartinger et al. (2001) and several others. These later studies do not compare differences in motives for different types of partners, but point to specific skills required and different motives for R&D co-operation with "scientific" partners.

Hagedoorn (1995) classifies the partners for R&D co-operation by industry and shows that leading firms in their industry are more likely to cooperate with external partners from other industries. Overby (2005) looks at the resource endowment of the partners and finds that the motives for co-operating with strongly endowed and weakly endowed partners differ. For co-operation with suppliers and clients Miotti and Sachwald (2003) find: the main motives are "to pool complimentary resources and access more market information" (Miotti and Sachwald, 2003: 1496).

A general conclusion from all these studies is that the importance of a certain motives differs for different types of co-operation. This finding is robust to different types of measurement of the R&D co-operation variable and different econometric specification and methods, ranging from simple OLS regressions to nested logit approaches.

7.2 Estimating the Impact of Knowledge Spillovers on the R&D Co-operation Decision of Firms

The main focus of my analysis is on the impact of spillovers on the R&D co-operation decisions of firms. Just including a variables for knowledge spillovers in the empirical model used to estimate this impact would be to short-sighted, given the large number of motives and determinants for R&D co-operation besides knowledge spillovers. Ideally I should control for all the other motives of R&D co-operation identified in the previous section, due to a lack of data and in order not to make the analysis to complex, I will not include measures of all determinants and motives, but only a selection. The following subsections will provide an overview of the motives and determinants included and their expected effect on the likelihood of cooperating on R&D and innovation activities. The empirical concepts and data used to construct the variables representing each motive or determinant will also be described.

7.2.1 The Model of Cassiman and Veugelers – Benchmark Case[171]

The model of Cassiman and Veugelers (2002) which has inspired many empirical papers on the link between knowledge spillovers and R&D co-operation will serve as the benchmark for my study[172]. It has been chosen as the role-model for the estimation of a benchmark case, with which the findings of my subsequent study can be compared, both for its high profile in the scientific community and because it uses a dataset similar to my own (CIS II), making it easily applicable to new CIS IV data from Germany, which is used to estimate the benchmark model here. Furthermore some of the construct for the variables I will include in my focal model to control for motives for R&D co-operation other than knowl-

171 This subsection largely builds on Schmidt (2005b).

172 The main goal is not to compare our results with those of Cassiman and Veugelers (2002), but to estimate a model with German data, that is set up as the Cassiman and Veugelers (2002) model and compare the results with the results from the model using our own spillover measures.

edge spillovers, will be based on those proposed by Cassiman and Veugelers (2002).

The Setup of the Empirical Model

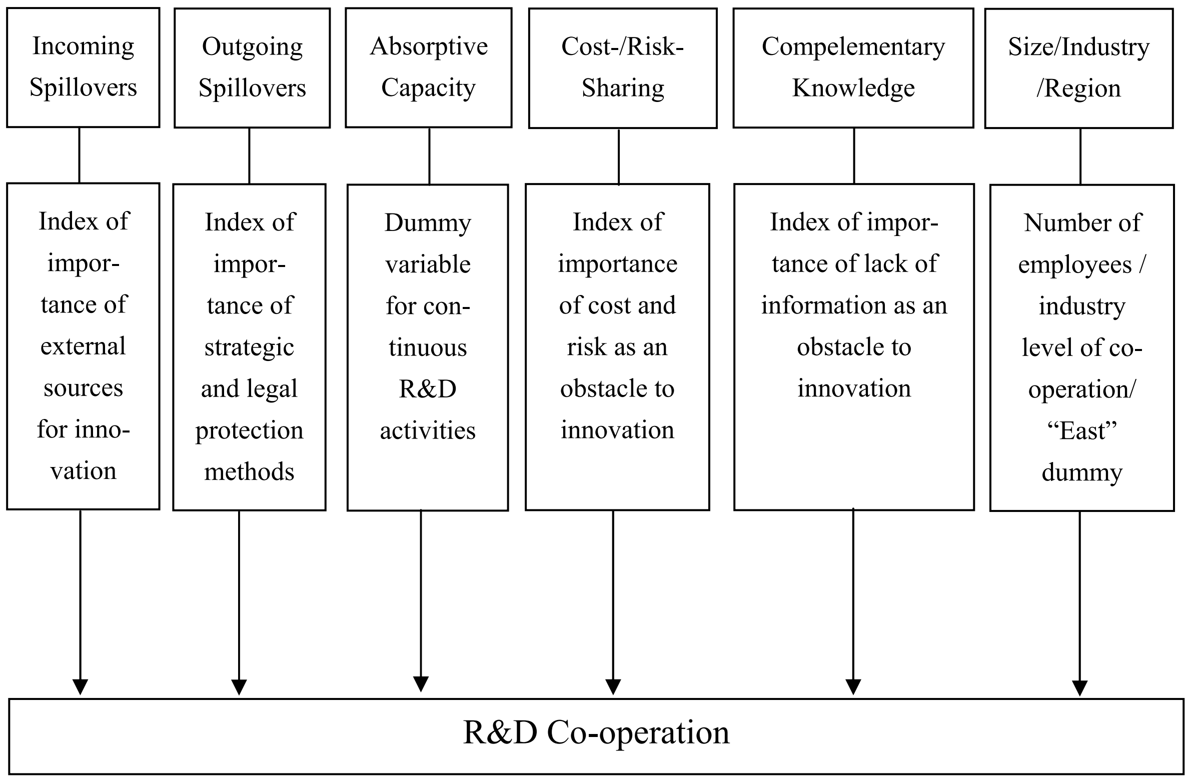
The Cassiman and Veugelers (2002) model cannot be replicated in full, because some of the questions used for the construction of the variables by Cassiman and Veugelers (2002) have changed from CIS II to CIS IV and because of multi-colliniarity between the cost and risk-sharing variable.[173] The main structure, the construction of all the spillover variables and the variables indicating if a firm has cooperated or not is retained, however, despite some shortcoming of the Cassiman and Veugelers (2002) model. Their empirical model can and has been criticized for not adequately representing the industry of the firm in the empirical model, for the choice of instruments for the 2-stage instrumental variable estimation (see below) and for including the variable for legal protection methods at the industry level, rather than at the firm level, like the measure for strategic protection methods.

The following figure provides an overview of the empirical model proposed by Cassiman and Veugelers (2002) to estimate the likelihood that a firm is involved in at least one external R&D co-operation.[174] It includes the type of motive (e.g. cost/risk-sharing) and the indicator used to represent the motive in my empirical estimation on the effect of knowledge spillovers on R&D co-operation.

173 An additional variable (dummy) was included to control for differences in the innovation behaviour of Éast and West German firms. It has been well documented that over a decade after reunification, East and West German firms still differ in their innovation behaviour (see e.g. Rammer et al., 2005a) and innovation strategies (Sofka and Schmidt, 2004). In Table A-12 in the Appendix the way I constructed our measures is compared to that of Cassiman and Veugelers (2002).

174 The exact formulation of the question is given in the appendix. I only considered R&D co-operation with external partners, i.e. suppliers, customers, competitors, commercial laboratories/R&D enterprises, universities, or government or private non-profit research institutes. R&D co-operation within other firms within a firms enterprise group are excluded from the analysis.

Figure 7-2 Potential Factors Influencing a Firm's Decision to have at Least one R&D Co-operation with External Partners



Source: Own illustration.

Elaborating on the blueprint in Figure 7-2, the construction of the variables used in my benchmark model is outlined below.[175]

Knowledge spillovers are represented in this model by three variables describing the importance of external knowledge source for innovation and legal and strategic protection methods for inventions and the innovations. The importance of protection methods is used as an inverse measure of outgoing spillovers since the use of protection methods limits the availability of knowledge outside a firm (see section 6.4.). In more detail:

Incoming Spillovers: The volume of incoming spillovers cannot be measured directly using the CIS IV questionnaire. In order to be able to include incoming spillovers in the model in spite of this, a question in which firms were asked to assess the importance of different sources of information for their innovation activities was used. Firms were given four categories to choose from, ranging from not used (0) to highly important (3). To construct the incoming spillover variable only two of the twelve sources the firms were asked to rate are used, namely professional conferences, meetings and journals as one source and exhibitions and fairs as the other. The scores for these sources are summed up and divided by the maximum sum of scores possible (6) to rescale the firm-specific measure between zero (not used) and one (highly important).

Appropriability: To construct an inverse measure of outgoing spillovers information on the importance of strategic methods to protect innovations and inventions is used. Like the variable for incoming spillovers, this is only a proxy of the level of outgoing spillovers. The question asked the firms to rate the importance of protection methods for innovations, ranging from not used (0) to highly important (3). To obtain the appropriability variable the scores for all the strategic methods (secrecy, complexity of design and lead time) are summed up and divided and the total is divided by the maximum sum possible (9) to rescale the firm-specific measure between zero (not relevant) and one (highly important).

Legal Protection: Additionally, the level of outgoing spillovers is proxied by the level of legal protection, which is constructed according to the method used for appropriability and using formal protection methods (patents, patterns, trademarks, copyrights) instead of strategic methods. The legal protection methods are treated separately since their effect on outgoing spillovers is not as distinct as that of strategic protection methods. Legal protection methods require firms to disclose some of their knowledge and thus generate a special kind of outgoing spillovers (see section 6.4.). This variable was included in the model developed by Cassiman and Veugelers (2002) as an industry-level variable (2digit NACE) by taking the mean of the individual scores in the industry.

Since the spillover measures used by Cassiman and Veugelers (2002) do not incorporate the absorptive capacity of a firm their model includes a dummy vari-

175 For details on the construction of the variables using the German CIS IV data see Table A-12.

able which takes the value one if a firm does R&D continuously, to control for the absorptive capacity of a firm. They follow Cohen and Levinthal (1989), who argue that R&D activities not only generate new knowledge but also enhance a firm's ability to "identify, assimilate and exploit knowledge from the environment" (Cohen and Levinthal, 1989: 569) and thus raises its ability to profit from external sources in general and co-operation in particular.

The motives not directly related to knowledge flows are also investigated in Cassiman and Veugelers (2002) empirical model. The importance of risk and cost as obstacles to innovation activities is a fairly direct measure of the importance of the cost- and risk-sharing motive for R&D co-operation, and is hence part of the empirical model. The more firms are hampered by a lack of finance for innovation activities or by excessive risk involved in potential innovative activities, the more they will be willing to share the risk with others. Complementary knowledge as a motive for R&D co-operation is represented in their empirical model by the importance of the lack of appropriate knowledge as an obstacle to innovation. This is not a direct measure of the need for complementary knowledge it nonetheless reflects the need of firms to get access to knowledge which they themselves do not possess and can thus be used as a proxy.

The size of a firm and its industry are not the same kind of motives as the other motives in their model. They nonetheless influence the decision to cooperate in R&D and are thus included in the model. The size of a firm (measured in terms of the number of employees) should positively influence the likelihood of a firm being involved in at least one R&D co-operation (see section 7.1).

Specific features of certain industries – such as the number of enterprises -- not captured by the other variables in my empirical model are likely to have an influence on the probability of cooperating in R&D as well. If an industry is highly concentrated, for example, there are less potential co-operation partners. Additionally, innovation activities in some industries intrinsically require more external knowledge than others and should thus evince a higher probability of co-operation (for other reasons why the industry might influence the co-operation decision see section 7.1).

Descriptive statistics on the variables constructed using the German CIS IV data reveal that firms involved in R&D co-operations in the years 2002-2004 are significantly different from those that did not cooperate.[176] Cooperating firms are on average more than five times larger than non-cooperating firms (1634 compared to 280 employees). Firms involved in R&D co-operation also assign a higher importance to incoming and outgoing spillovers than non co-operating firms. Among the 534 (31% of the sample) co-operating firms 78% conduct R&D continuously, while only 35% of the non-cooperating firms (69% of the sample) have continuous R&D activities. Access to complementarity is equally important for both types of firms. An interesting insight from the descriptive statistics is that the share of East German firms in the sample of co-operating firms (about 36%) is higher than in the sample of non-cooperating firms (about 30%). An explanation might be that East German firms have a stronger need to cooperate on R&D because they lack the channels and resources to develop innovations on their own. Equally surprising is that co-operating firms assign a significantly higher importance to constraints to their innovation activities than non-cooperating firms. Following the arguments presented for the endogeniety of this variable below, one could have expected that co-operating firms have less problems with respect high costs and high risk of their innovation projects, because they are able to share costs with their research partners.

Based on the discussion above the formal empirical model looks like this:

$$Cooperation_i{*} = \beta' X_i^{coop} + u_i$$

with

$$Cooperation_i = \begin{cases} 1 & if\ Cooperation_i{*} > 0 \\ 0 & otherwise \end{cases}$$

where X_i^{coop} is the column vector representing the variables presented above.

176 See Table A-13 in the Appendix for detailed descriptive statistics.

In this specification all variables are treated as exogenous. As Cassiman and Veugelers (2002), Lopez (2004), Schmidt (2005b) and Abramovsky et al. (2005) have argued, this might not be the case for some of the variables included in the model. Usually the spillover measures, the measures for cost and risk sharing (treated as exogenous in Cassiman and Veugelers (2002) and those for R&D activities are thus treated as endogenous:

If a firm perceives the cost and risk of a planned innovation project to be prohibitively high, it might be inclined to cooperate with another firm in order to overcome these constraints on their innovation activities. However, actually co-operating with external partners also reduces the risk and cost of projects for an individual firm, which indicates that the variable (constraint) may be endogenous.

Similar arguments can be made with respect to the endogeneity of the variables used to capture the importance of external sources of innovation and the importance of strategic protection methods. Both influence the decision to cooperate and are at the same time influenced by the co-operation behaviour of firms. A firm which is co-operating in order to obtain knowledge from external sources is very likely to assign a higher importance to external sources than a non-cooperating firm. The same is true for strategic protection methods for innovation. The perceived importance of strategic protection methods is likely to increase with co-operation, since the firm faces the problem that despite interacting with a partner more closely than without co-operation, the partners should not be able to access knowledge beyond those supposed to be exchanged through the co-operative agreement. Cassiman and Veugelers (2002) also argue in favour of endogenising the importance of strategic protection methods, because this firm-level measure is subject to measurement errors which can be corrected using a two-step procedure.

Besides cost and risk and the spillover measures, the dummy variable for continuous R&D activities is assume to be endogenous, based on evidence from

Veugelers (1997) and Colombo and Gerrone (1996).[177] To take the endogeneity of these variables into account, the simple model has been augmented and a two-step procedure introduced. In the first step the endogenous variables are regressed on all the exogenous variables along with some additional instruments. The instruments used in the first stage are the industry level of all the endogenous variables, the export intensity (exports/turnover) of a firm and its research focus on basic or applied research, measured as the relative importance of knowledge from public institutions compared to knowledge from suppliers and customers.[178]

The predicted values of the endogenous variables calculated from the first step OLS regressions[179] are then used in the second stage regressions in order to find the determinants of R&D co-operation.

Since the independent variable of the 2nd step equation is binary (at least on co-operation Yes-No), the 2nd step was estimated using a probit estimation procedure. According to Greene (1981), the standard errors of the second-stage coefficients would be biased if the two-step method were applied. In order to correct for this bias, the standard errors for the second stage are bootstraped.

The full model for the specification with the endogenous variables takes the following form:

$$Cooperation_i* = \alpha_0 + \alpha_1 \widehat{Spill\_in}_i + \alpha_2 \widehat{Approp}_i + \alpha_3 \widehat{RD\_con}_i + \alpha_4 \widehat{Constraint}_i + \beta' X_i^{coop} + r_i$$

with

$$Cooperation_i = \begin{cases} 1 & if\ Cooperation_i * > 0 \\ 0 & otherwise \end{cases}$$

177 Note that most of the studies propose an effect of co-operation on R&D intensity and R&D budgets not on the longitudinal aspect of R&D activities though.

178 The validity of these instruments can be challenged. Cassiman and Veugelers (2002) argue, however, that "It is unlikely that many of these instruments are truly exogenous. Nevertheless, for the purpose of our investigation (uncovering the relation between co-operation and spillovers), they will be assumed to be exogenous." (Cassiman and Veugelers, 2002: 1174).

179 Angrist, J. and B. Krueger (2001) argue that it is best to use OLS regressions in the first stage even if the dependent variable is binary or censored.

The first-step regression equations:

$$Spill\_in_i = \chi_0 + \chi' Z_i + \delta' X_i^{coop} + v_i$$

$$Approp_i = \lambda_0 + \lambda' Z_i + \sigma' X_i^{coop} + e_i$$

$$RD\_con_i = \eta_0 + \eta' Z_i + \vartheta' X_i^{coop} + k_i$$

$$Constraint_i = \varsigma_0 + \varsigma' Z_i + \tau' X_i^{coop} + l_i$$

where X_i^{coop} is the column vector representing the exogenous explanatory variables of the 2nd step equation. Z_i is the column vector of the instruments used in the first step regressions and $\widehat{Spill\_in}_i, \widehat{Approp}_i, \widehat{RD\_con}_i, \widehat{Constraint}_i$ represent the predicted values calculated from the three first-step OLS regressions for incoming spillovers, appropriability, and continuous R&D activities, respectively.

Results of Estimation of the Cassiman and Veugelers Model for Germany

The results of both the single step and the two-step estimation of the Cassiman and Veugelers (2002) with data from the German part of the Community Innovation survey IV, which contains information on the innovation behaviour of firms in the three year period 2002-2004 are reported in Table 6-2.

Regardless of the estimation procedure applied, the incoming spillover variable is positive and highly significant. This is clear evidence that the R&D co-operation decision of firms is motivated by the need to generate knowledge inflows for their innovation activities. In the two stage estimation I also obtain a positive and significant effect of complementarities. This indicates that firms try to generate knowledge inflows which are complementing their existing in-house knowledge. For the measures of outgoing spillovers, i.e. appropriability and the level of legal protection at the industry level, I obtain mixed results: In the single step procedure appropriability is positive and significant, while it is negative and significant when applying the two stage procedure. Given that the second inverse measure of outgoing spillovers is negative and significant in both cases, I think it is fair to conclude, that the prevention of outgoing spillovers is a motive for R&D co-operation.

Another motive for which I find support in both equations is continuous R&D activities. If interpreted as a measure of absorptive capacity, this indicates that firms which are better able to "identify, assimilate and exploit knowledge from the environment" (Cohen and Levinthal, 1990: 569) are more likely to cooperate, again stressing the fact that knowledge spillovers are the most important drivers of R&D co-operation. The variable for R&D activities can also be interpreted as an indicator of how much value firms place on innovation and R&D activities. At first sight it seems tautological that firms involved in R&D on a continuous basis, are more likely to cooperate in R&D. The opposite could, however, also be the case: The more R&D a firm does in-house the less dependent it becomes on external knowledge since it is able to produce the knowledge needed for its innovation activities itself. My results show that this effect is not very strong or at least it is outweighed by the positive effect of doing R&D on the willingness and ability to work together on R&D activities with external partners. This increased willingness to conduct research with external partners might come from a broader R&D approach or a larger set of technological opportunities the firm sees or actually tries to exploit. That cost and risk sharing are a motive for R&D co-operation is also confirmed.

For all other variables, I cannot provide a clear cut conclusion, since the effects differ between the two empirical methods applied and depend on the endogeniety structure chosen.

Table 7-2 Coefficients of Probit Estimations of the Probability to have at Least one R&D Co-operation between 2002 and 2004

	Simple Probit	**2- Step Procedure**
Incoming Spillovers (I)	0.539 ***	3.621 ***
	(0.157)	(0.966)
Appropriability (I)	0.676 ***	-3.535 ***
	(0.115)	(1.132)
Legal Protection (industry level)	-1.591 **	-1.122 *
	(0.642)	(0.745)
Continuous R&D Activities (I)	0.708 ***	3.851 ***
	(0.082)	(0.565)
Size	-0.194 **	-0.061 ZZ
	(0.097)	(0.145)
Size, squared	0.032 ***	0.019 ZZ
	(0.010)	(0.014)
Constraints (I)	0.452 ***	3.195 ***
	(0.136)	(0.976)
Complementarities	0.187	0.781 ***
	(0.152)	(0.347)
East Germany	0.320 ***	-0.069
	(0.078)	0.099
Industry–level of Co-operation	2.801 ***	0.598
	(0.378)	(0.506)
Constant	-2.307 ***	-5.244 ***
	(0.300)	(0.981)
Observations	1,720	1,720
X^2	407.89	358.46
Loglikelihood	-813.294	-812.124

*** significant at 1%; ** significant at 5%; * significant at 10%

zzz jointly significant at 1%; zz jointly significant at 5%; z jointly significant at 10%

(I) Instrumented in the second stage;
Robust standard errors in parentheses (bootstrapped with 250 draws to correct for bias induced by the two-step procedure).

Source: Own calculations.

7.2.2 Estimating the Impact of Knowledge Spillovers on R&D Co-operation decisions of Firms with the Constructed Spillover Variables

This part of my study deals with the estimation of the link between the spillover measures for realized incoming and outgoing spillovers constructed in the previous chapters and a firm's likelihood of cooperating on R&D. I will not only distinguish between incoming and outgoing spillover, like I have done in the previous section, but also between realized intra-industry and extra-industry incoming spillovers, which is the combination of scientific spillover pools and inter-industry spillover pools. Due to the high correlation between realized scientific incoming spillover and inter-industry spillovers[180] I cannot further differentiate the extra-industry spillovers.

The Setup of the Empirical Model

The structure of the model and the methodology used is very similar to that of Cassiman and Veugelers (2002). I address some of the shortcomings of the Cassiman and Veugelers (2002) model though and will go beyond their model by including addition variables in order to control for a wider range of motives. The data base for the variables other than the spillover measures will be the German CIS IV survey which has been described and mentioned in the previous chapters and sections.

My empirical model is set-up as follows[181]:

The dependent variable is a dummy variable taking the value one if a firm has cooperated with at least one external partner on their innovation activities. [182]

---

180 The correlation coefficient between the two variables is at 0.7041 and highly significant.

181 A detailed description of the construction of the variables included in this model can be found in Table A-12 in the appendix.

182 The exact formulation of the question is given in Table A- 15 the appendix. I only considered R&D co-operation with external partners, i.e. suppliers, customers, competitors, commercial laboratories/R&D enterprises, universities, or government or private non-profit research institutes. R&D co-operation within other firms within a firms enterprise group are excluded from the analysis.

Suppliers, customers, competitors, commercial laboratories/R&D enterprises, universities, or government or private non-profit research institutes are considered as external partners.

The spillover variables included are the realized incoming and outgoing spillover variables constructed in the previous chapters. In addition to that I estimate a model where I spilt up the incoming spillovers into spillovers from a firm's own industry and spillovers from other industries plus spillovers from scientific sources, like research institutes and universities. All my spillover measures are assumed to be exogenous because they are constructed using the past innovation expenditure of firms, which is not influenced by the current co-operation behaviour I want to explain. Since my spillover measures already include the absorptive capacity of the firm, I do not add an additional variable for absorptive capacity, like the R&D intensity or a dummy for continuous R&D activities.

In order to control for motives for R&D co-operation beyond knowledge spillovers, I include a dummy variable which is one if the firm has received any form of financial public support for its innovation activities during the years 2002 to 2004. As the literature review above has shown a positive effect of public support on the likelihood to cooperate can be expected.

While the public support variable belongs into the group of motives related to framework conditions, the number of main competitors a firm has, the importance of cost- and risk as a hampering factor for innovation activities and the need for complementary knowledge belong to the group of strategic motives. The number of main competitors can be taken directly from the Mannheim Innovation Panel survey, which included a question on this topic. It serves as a proxy for the intensity of competition in the firms market. The other two strategic motives for R&D co-operation are taken from a question on hampering factors and are constructed in exactly the same way as in the benchmark model. The variable representing cost- and risk-sharing motives is assumed to be endogenous in this model, for the reasons discussed in the previous subsection.

The group of co-operation motives related to firms' characteristics is represented by five variables. I include the size of the firm measured as the total number of employees both directly (in natural logarithm) and as a squared term, to allow for a non-linear effect of size on the likelihood of cooperating. Another firm characteristic I control for is firms' location in East or West Germany. A major shortcoming of the Cassiman and Veugelers (2002) model is its treatment of the industry. I will address this issue and include dummies for industry groups instead of using the industry-level of R&D co-operation to control for industry differences that are not picked up by the other variables included in the model. Following Dachs et al. (2004) and Busom and Fernandez-Ribas (2004) I also include the export orientation of a firm in my model. Instead of the export intensity, measured as the share of exports of total turnover I use a dummy variable, which is one if the firm had any exports between 2002 and 2004. A final motive related to firm characteristics is firms' age.

Analogous to the benchmark case I use an instrumental variable maximum likelihood probit estimation procedure to control for the endogeneity of the constraint variable. The instruments used in the first step are the average importance of all hampering factors to innovation activities between 2002 and 2004 (except constraints, complementarities and lack of technological information) and the total value of a firm's tangible assets. The first instrument can be interpreted as a measure of uncertainty which influences the level of risk a firm has to take when developing an innovation. The total value of tangible assets is seen as a measure of the financial situation of the firm and should influence the valuation of costs as an obstacle to innovation.[183] In order to control for the endogeniety bias induced by the two step procedure bootstrapped standard errors will be reported.

I will first estimate a model which only distinguishes between realized outgoing and realized incoming spillovers, which are the sum of realized inter-industry, intra-industry and scientific spillovers. This analysis will be supplemented by an estimation where I split-up the realized incoming spillovers into realized intra-industry spillovers and realized extra-industry spillovers, which include realized spillovers from scientific institutions and inter-industry spillovers.

Some Descriptive Statistics[184]

The descriptive statistics for my sample of 556 firms, for which all the variables mentioned above are available[185], provide some interesting insight. A first observation is that the sample is almost evenly split between firms that were involved in at least one R&D co-operation between 2002 and 2004 (45% with R&D co-operation, 55% without). The R&D co-operating firms are thus clearly overrepresented in my sample as the expanded figure for the whole population of enterprises in Germany is at around 24%.

For the realized spillover variables I find significant differences between co-operating and non-cooperating firms, except for outgoing spillovers. Even though the average value for outgoing spillovers is 51.4 for firms involved in R&D co-operation and 28.9 for firms without, this difference is not statistically significant. For all intra- and inter-industry spillovers I find significant differences. In both cases the average values for cooperating firms is almost double that for non-cooperating firms.

For the variables controlling for other motives than knowledge spillovers, I find significant differences for all variables except for the complementarities variable and the other manufacturing industry dummy. Most striking are the differences for funding and the size of the firm: 79.4% of all firms involved in R&D co-

183 Wald-tests with 90%-confidence levels show that the instruments are exogenous for both estimations. Furthermore, the Anderson canonial correlation LR-test confirms that the instruments are valid.

184 More detailed descriptive statistics are provided in Table A-16 in the Appendix.

185 Throughout the empirical part of this study I had to reduce the number of observations. The reasons are manifold and include item-non-response, questions only asked for a subgroup of firms (innovating and co-operating) and the usage of different surveys which are associated with unit-non-response. Because the selection bias, if it existed, were caused by many different reasons an effective control for it cannot be designed.

operation get public funding for their innovation activities. The corresponding figure for non-cooperating firms is 23.1%. The average size of co-operating firms is four times (2,058 employees) that of non-cooperating firms (507 employees). For the distribution across industries I find that the share of high-tech firms from both the service and the manufacturing sector is higher in the group of firms involved in R&D co-operation than in the group of non-cooperating firms.

The only two variables (besides industry dummies) for which I find significant higher values in the group of non-cooperating firms, are the number of main competitors and the age of the firms I investigate. That the co-operating firms are younger on average can be interpreted in the sense that younger firms lack the necessary resources to develop and commercialize innovations on their own and thus cooperate with external partners. The fact that the number of main competitors is higher for non-cooperating firms than for co-operating firms, can be interpreted in light of the literature that proposes a dampening impact of co-operation on competition. The finding should not be over interpreted, however, since descriptive statistics are not able to provide any insight on causality.

To summarize, the descriptive statistics provide further evidence that my expectations about the positive influence of knowledge spillovers on R&D co-operation is warranted.

Results of Instrumental Variable Probit Estimations

The results of the instrumental variable probit estimations (IV-Probit) are reported in Table 7-3 below.

A first striking result is that the variable for outgoing spillovers is insignificant. Contrary to my first hypothesis H1a - "The level of realized outgoing knowledge spillovers has a positive effect on the probability that firms will cooperate on R&D and innovation activities." (page 64) – the level of outgoing spillovers does neither positively nor negatively influence a firm's decision to cooperate on R&D. This is an even more surprising result, given that in the benchmark case, outgoing spillovers had a significant positive influence[186] on the co-operation decision in the two step estimation. Taking everything together, the mixed results in the benchmark case and the insignificance in this model, hypothesis H1a has to be rejected. The amount of knowledge produced by a firm and not protected by patents or secrecy does not seem to play a role in the firm's decision to cooperate with external partners, at least not directly. It may have an indirect influence through its effect on absorptive capacity, which influences the level of realized incoming spillovers. What is more, the amount of knowledge spilling out is a potential incoming spillover for others, which as I will see below influences the co-operation decision positively.[187]

I find support for my hypothesis H1b – "The level of realized incoming knowledge spillovers has a positive effect on the probability that firms will cooperate on R&D and innovation activities." (page 64). In column (1) of Table 7-3 the results for the empirical model with one measure for incoming and outgoing spillovers each, show that incoming spillover have a positive and significant effect on firms' R&D co-operation decisions. This finding is robust to different assumptions about the endogeniety structure, different model specifications and different measures of incoming spillovers, as the benchmark results and the results of the IV-Probit estimation indicate.

Due to the high correlation between realized spillovers from scientific institutes and realized spillovers from firms in other industries I could only include one measure for extra-industry spillovers and not one for inter-industry and scientific knowledge each as originally intended. Nonetheless I am able to extend the existing literature and investigate the difference between spillovers from a firm's own

186 Note that a negative coefficient on the measures of outgoing spillovers in the benchmark case as an indicator of a positive effect of the amount of knowledge spilling out, since they measure the amount of knowledge protected and appropriated by firms.

187 This argument suggests that realized incoming and realized outgoing spillovers are highly correlated. The lag structure chosen and the distinction between potential and realized knowledge spillovers obviously solved this potential problem, as the correlation coefficient between the two measures is insignificant and only -0.0195.

industry versus realized knowledge spillovers from outside sources. I find that extra-industry spillovers are motives for firms to form R&D partnerships, while intra-industry spillovers are not, confirming my second hypothesis – “Realized Incoming knowledge spillovers from different sources influence a firm’s decision to cooperate on R&D and innovation activities differently.” (p. 64).

The insignificance of intra-industry realized knowledge spillovers is particularly surprising. An explanation could be, that two opposing forces are at work which cancel each other out. Firms that realize a lot of incoming spillovers from their own industry might be less likely to cooperate, because they can generate incoming intra-industry knowledge spillovers without having to cooperate and incurring the cost of doing that. This argument builds on the RBV of the firm which proposes that firms cooperate in order to access valuable resources/knowledge held by other firms. According to the classic industrial organisation theory, however, a high level of knowledge spillovers should increase the likelihood of cooperating on R&D, because firms have an incentive to internalize the spillover through co-operation. My findings should not be over interpreted but can be seen as a first indication that both effects are present and in my case offset each other for intra-industry spillovers.

For extra-industry spillovers this is not the case. Here I find the same effect as for the realized incoming spillover variable, i.e. a positive and significant effect on the probability of cooperating in R&D. An explanation could be that the knowledge acquired from sources outside a firm’s own industry is different from knowledge acquired from within the industry. The argument presented above that high spillovers alleviate the willingness to cooperate might not be valid for inter-industry and scientific knowledge. In order to use this external knowledge efficiently it might be cheaper to cooperate than to incorporate it into ones own products or processes without the help of the producer of the knowledge. Cooperating may be a cheap and efficient way to transfer the knowledge from one industry to another if the technological distance between the partners is large.

In the section on absorptive capacity above I have already established that different absorptive capacities are necessary for knowledge from science and firms form other industries. This difference was already taken into account in the construction of the spillover measure, thus the difference between the effects of the two spillover measures cannot exclusively come from the different levels of absorptive capacity.

Table 7-3 Results of Instrumental Variable Probit Estimations on the Determinants of R&D Co-operation between 2002 and 2004

	Model with incoming and outgoing spill-overs (1)	**Model with intra-industry and extra-industry incoming and outgoing spillovers (2)**
Realized *Outgoing* Spillover	-0.00006	-0.00006
	(0.0007)	(0.0003)
Realized *Incoming* Spillovers	0.00003**	
	(0.00001)	
Realized *Intra-Industry* Spillovers		0.00004
		(0.00004)
Realized *Extra-Industry* Spillovers		0.00002**
		(0.000009)
Other Motives:		
Public funding (dummy)	1.271***	1.273***
	(0.165)	(0.163)
Number of main competitors	-0.109	-0.108
	(0.104)	(0.080)
Complementarities	0.050	0.047
	(0.322)	(0.273)
Constraints (I)	1.616***	1.630***
	(0.454)	(0.419)
Exports	0.410**	0.411**
	(0.322)	(0.187)
Size (number of employees)	0.182 ZZZ	0.184 ZZZ
	(0.218)	(0.187)
Size, squared (number of employees)	-0.001 ZZZ	-0.001 ZZZ
	0.020	(0.019)
Age in years	-0.004	-0.004
	(0.005)	(0.003)
East Germany (dummy)	-0.092	-0.094
	(0.151)	(0.174)
Number of observations	586	586
X^2	245.41	293.83
Log Likelihood	-253.652	-251.077

* significant at 10%; ** significant at 5%; *** significant at 1%; ZZZ jointly significant at 1% level;
(I) Instrumented variable;
Bootstrapped Standard Errors in parentheses;
Constant and Six Industry included.

Source: Own calculations.

Only some of the variables controlling for motives beyond knowledge spill-overs are significant: My results highlight the role of public funding as a motive for R&D co-operation. The coefficient is positive and highly significant as ex-pect. This is not surprising as more and more R&D funding programs of the German government and the European Union are directed at collaborative R&D. I also confirm many empirical studies that find that the sharing of costs and risks is a motive for firms to forge R&D partnerships with external partners, a finding consistent with the benchmark case. Furthermore I show that exporting firms are more likely to cooperate than non-exporting firms. These exporting firms seem to try to counter the pressure to develop highly-innovative and complex products and processes for the foreign markets in an ever shorter time, by forming co-operative agreements with external patterns. Finally, the size of a firm has an in-verse U-shaped influence on the R&D co-operation decision in my IV-Probit re-gression. In the benchmark case this influence turns out to be U-shaped. The turning points calculated from the obtained coefficients lay outside of the cover-age of my sample in both cases. For the benchmark case the turning point is at 4.8 employees and for the IV-Probit case at $9*10^{39}$. A scatter plot of the parabola further reveals that the relationship between size and the likelihood of cooperat-ing is almost linear in the interval of my observations for the IV-Probit estima-tion. In summary, the benchmark case and the IV-Probit case confirm that the probability of cooperating increases with firm size.

1

8 Summary and Conclusion

The preceding empirical study has both answered questions on the role of knowledge spillovers in firms' R&D co-operation decisions and raised new questions which should be addressed in future studies. In this chapter I will summarize the main findings of my study and provide suggestions for future research.

The starting point for the analysis was the observation that more and more firms are moving to an innovation strategy that includes R&D and innovation partnerships with a variety of external partners and that access to knowledge is one of the key reasons for this change in strategy. A literature review of both theoretical and empirical work on R&D co-operations underscored this observation. Many researchers from various fields have shown that knowledge spillovers pose an incentive to form R&D co-operations. On the theoretical side, I reviewed the industrial organization literature, the transaction cost literature and the literature ascribed to the resource based view of the firm. Even though they differ in their interpretation of the phenomenon of R&D co-operation among firms, these three strands of literature propose a positive relationship between knowledge spillovers and R&D co-operation. On the empirical side, this positive effect has been confirmed by many studies using the Community Innovation Surveys in different countries and other databases.

These findings lead us to formulate the following three main hypotheses:

H1a: The level of realized outgoing knowledge spillovers has a positive effect on the probability that firms will cooperate on R&D and innovation activities.

H1b: The level of realized incoming knowledge spillovers has a positive effect on the probability that firms will cooperate on R&D and innovation activities.

H2: Realized Incoming knowledge spillovers from different sources influence a firm's decision to cooperate on R&D and innovation activities differently.

In order to test these hypotheses empirically I took two main steps, the construction of realized knowledge spillover pools and the estimation of their impact on firms' R&D co-operation decisions using data on the innovation activities and co-operation behaviour from the Mannheim Innovation Panel surveys of 2001, 2003 and 2005 and information on firms' R&D expenditures from the MIP surveys from 1996 to 2002. Information on the R&D expenditure of industries in Germany comes from the ANBERD database of the OECD.

The first step was to construct adequate measures of realized knowledge spillover pools, which consisted of:

- Construction of the knowledge stock of individual firms, industries and scientific institutions
- Determination of the impact of patents and secrecy on knowledge flows
- Estimation of the level of firms' absorptive capacities

The construction of the knowledge stocks followed given conventions in so far as I took the total amount spent on R&D activities as a proxy for the knowledge generated in an industry. In order to add up the flow of R&D expenditure to a total stock of R&D expenditure I used the perpetual inventory method. I extended the existing literature by using the inverse of the average product life-cycle as the depreciation rate instead of arbitrary assumptions of 10% or 15% depreciation rates.

In order to determine how much of the total knowledge produced by the firm (knowledge stock) is actually available outside the firm's boundaries I tried to determine the influence of patents and secrecy on knowledge spillovers. My hypothesis that both types of protection method hinder knowledge flows was confirmed. An estimation of the actual level of knowledge protection could not be generated, however. In order to be able to proceed with the study anyway, I assumed that the importance of patents and secrecy is an indirect measure for the level of knowledge protected from spilling over to other firms. I further assumed that knowledge generated in public research institutions is not protected from spilling over into the public domain. The products of this exercise were the potential knowledge spillover pools, i.e. the knowledge that is produced which spills out and can potentially be used by other firms in an economy, for a firm's knowledge (outgoing) and intra-industry, inter-industry and scientific knowledge (incoming), respectively.

In order to arrive at the knowledge spillover pools a firm actually uses ("realized incoming spillover pools") I weighted the potential incoming knowledge spillover pools with firms' ability to acquire and make use of external knowledge, i.e. its absorptive capacity. In that part of the study I extended the existing literature by empirically confirming my hypothesis that different types of knowledge require different types of absorptive capacity. As in the case of patents and secrecy, I was faced with the problem of constructing a measure of the level of absorptive capacity. I ended up using the predicted likelihood (based on my multivariate analysis) that a firm has absorptive capacities of a certain type as a proxy, to construct levels of absorptive capacity for three different types of knowledge: knowledge from a firm's own industry, sources outside a firm's own industry and scientific sources.

In the second step of my analysis the realized knowledge spillover pools were included in an empirical model that tries to explain what factors affect the likelihood that a firm will cooperate in R&D and innovation activities and how. Of the three hypotheses above only two could be confirmed, namely hypothesis 1b and 2. I found evidence that incoming spillovers are a main determinant of R&D co-operation among firms and between firms and research institutions. Splitting up the incoming spillovers into knowledge spillovers from a firm's own industry and from other industries I find that only extra-industry spillovers have a positive effect on the likelihood of cooperating in R&D.

Even though I had a wealth of data at hand and extended the existing literature in several directions, I was not able to address all the questions and solve all the problems the research on R&D co-operation and knowledge spillovers has posed.

One of the main limatitions for which this study could be criticised is that I am not able to distinguish between firms that do not want to cooperate and those that are not able to cooperate due to their own specific situation or due to a lack of suitable partners. This issue is not only relevant for the decision to co-operation, but also for the analysis of absorptive capacity and knowledge spillovers in general. To give an example, if the firm is a technology leader at the frontier of its industry, it does not rely on access to knowledge held by other firms in the industry, but rather generates knowledge spillovers to other, less advanced firms. It does not have to use a lot of knowledge spillovers to be successful. My data does not allow us to distinguish between those firms that do not want and those firms that cannot co-operate, future surveys could take this into account. A first step in that direction has already made by the research on networks, where each partner in the network (and its assets and knowledge stocks) is known and can be compared to firms outside the network.

One issue I did not address is the relationship between knowledge flows within the co-operative agreement versus those between the R&D partnership members and non-members or versus knowledge spillovers in an economy in general. A topic related to the discussion of endogenous and exogenous spillovers in the non-tournament literature. For a more detailed analysis of the link between knowledge flows and R&D co-operation this differentiation should be taken into account. A question that has to be answered in this domain is whether R&D co-operation merely helps to internalize spillovers that would have happened anyway or if R&D co-operations lead to additional knowledge spillovers both among members and between member and non-members. Whether the latter additionality existed, is specifically relevant for public policy, as one goal of funding research partnerships is to generate more spillovers than without R&D co-operation. By constructing the realized knowledge spillover pools the way I did above I implicitly focused on knowledge spillovers within an economy without looking at the knowledge transfer between partners of a R&D agreement.

My main approach was to conduct a cross-sectional analysis, with some built-in lag structure, in so far that the knowledge stocks were constructed for the beginning of my observation period. A panel data analysis would have allowed us to look, among other things, at the influence of knowledge spillovers on the lifespan of R&D co-operations.

The findings of my study are, however, not only of interest to academic researchers, but also those working in the world of business may also find them informative. The last section in which I investigate the determinants of R&D co-operation, hold little news for practitioners, because I do not look at the success of R&D co-operation or problems related to stability and costs, topics which would be of interest for managers. Instead I take stock of firms' behaviour.

I can give some practical advice on absorptive capacities, however. I have clearly shown that the stimulation of knowledge transfer among a firm's employees is a prerequisite for absorbing and exploiting external knowledge. What is more, I identify different determinants for different types of absorptive capacity, some of them not related to R&D activities. On these grounds I can suggest that managers should take into account which type of knowledge their firm needs most and set up their knowledge management systems accordingly. Some further implications for practitioners come out of the discussion of patents and secrecy as ways of reducing knowledge flows. I find that the use of patents and secrecy has the strongest impact on the innovation activities within a firm's own industry, but no significant impact in other industries. This gives firms an opportunity to follow a mixed strategy. They are able to protect their knowledge from their competitors in their own industry, while still allowing firms in other industries to use it. These innovation strategies with respect to other industries may help firms to profit from the use of their knowledge in other industries.

I am certain that through knowledge spillovers among economists, practitioners and policymakers and co-operation on academic research and (paper) development the remaining questions will be answered in detail.

Appendix

Question on R&D and Innovation Co-operation from the CIS IV survey:

6.2 During the three years 2002 to 2004, did your enterprise cooperate on any of your innovation activities with other enterprises or institutions? *Innovation co-operation is active participation with other enterprises or non-commercial institutions on innovation activities. Both partners do not need to commercially benefit. Exclude pure contracting out of work with no active co-operation.*

Yes ☐ No ☐

6.3 Please indicate the type of co-operation partner and location *(Tick all that apply)*

Type of co-operation partner	**Germany**	**Other Europe**	**USA**	**Other Countries**
A. Other enterprises within your enterprise group				
B. Suppliers of equipment, materials, components, or software				
C. Clients or customers				
D. Competitors or other enterprises in your sector				
E. Consultants, commercial labs, or private R&D institutes				
F. Universities or other higher education institutions				
G. Government or public research institutes				

Source: Eurostat (2004).

Appendix to Chapter 5 The Construction of the Potential Outgoing Spillover Pools/Knowledge Stocks at the Industry and Firm-Level

Table A-1 Intramural R&D Expenditure in Industry and Services in Billion (current) Euros form 1995 to 2002

NACE	1995	1996	1997	1998	1999	2000	2001	2002
15	187.644	179.317	173.328	170.403	188.667	190.564	238.863	250.979
16	29.655	22.751	16.873	21.332	29.144	29.437	36.898	38.770
17	139.583	145.080	153.388	150.362	173.328	172.792	191.627	188.351
18	14.827	21.980	30.678	29.669	33.745	33.641	37.308	36.670
19	7.158	6.650	6.136	4.545	3.579	3.568	3.957	3.889
20	30.166	27.974	26.076	25.955	26.076	25.898	24.683	21.896
21	78.228	68.543	60.332	69.158	80.273	79.727	75.984	67.405
22	26.076	25.280	24.542	24.428	24.542	24.375	23.231	20.608
23	65.957	69.945	75.671	61.580	47.550	50.000	56.000	50.000
24	4847.047	5078.800	5429.409	5820.035	5694.258	6030.000	5920.000	5940.000
25	393.695	431.459	481.637	432.042	616.107	610.000	612.000	600.000
26	275.586	268.129	265.872	274.564	335.407	410.000	389.000	290.000
27	269.962	270.186	276.097	266.467	259.225	253.834	284.947	277.264
28	386.025	404.507	432.553	469.136	516.916	506.166	568.208	552.887
29	3062.127	3088.631	3190.973	3451.781	3403.159	3380.000	3763.000	3820.000
30	1052.239	846.645	673.371	643.796	633.491	653.351	727.122	704.283
31	1942.398	1367.045	876.866	930.211	1021.050	1053.060	1171.964	1135.152
32	2707.291	3004.036	3276.359	3394.814	3642.443	3756.633	4180.805	4049.484
33	1616.194	1549.299	1499.619	1552.707	1664.766	1716.956	1910.822	1850.803
34	5723.913	6280.709	6991.916	7976.757	9420.042	10530.000	10660.000	11000.000
35	2527.828	2690.326	2918.965	2663.227	2560.550	2800.000	1846.000	2490.000
36	155.433	144.768	136.515	196.459	171.283	175.290	165.444	155.712
37	5.113	4.564	4.090	5.548	4.602	4.710	4.445	4.184
40-41	114.018	102.77	91.521	82.829	106.86	110.000	58.000	60.000
45	74.137	83.341	93.055	90.499	87.942	80.000	54.000	50.000
50-52	33.234	35.791	38.347	84.619	130.891	143.577	156.264	236.213
60-63	187.133	192.463	197.793	304.487	411.181	410.000	822.000	820.000
65-67	27.098	17.384	7.669	10.226	12.782	14.472	16.162	24.431
72	111.973	304.219	496.464	681.041	865.617	860.603	895.878	875.969
73	182.531	300.640	418.748	639.882	861.016	880.000	891.116	871.313
74	388.582	390.116	391.65	419.260	446.869	372.497	462.491	452.213

Source: Own calculation based on OECD (2003) and Stifterverband für die Deutsche Wissenschaft-Wissenschaftsstatistik (2005).

Table A-2 Gross domestic R&D expenditure (GERD) by Government and Higher Education Institutes in Billion (current) Euros from 1995 to 2002 in Germany

Year	1995	1996	1997	1998	1999	2000	2001	2002
GERD	13643.7	13957.5	13949.1	14314.9	14568.2	15019.0	15188.9	15463.0

Source: Own calculation based on OECD (2003).

Appendix to Section 6.4 The Effects of Patents and Secrecy on Knowledge Spillovers

Table A-3 Variables included in the Model on the Relationship between Patents and Secrecy and Knowledge Spillovers

Variable	Type	Construction
Hemm_tech_info	ordered	Variable that takes a value between 0 and 1 according to the following scheme: The lack of information on technology as an obstacle to innovation was not relevant (0), of minor importance (1), important (2), or very important (3).
Pat_ind	Index	Importance of patent protection as a method to protect inventions and innovations, rescaled between 0 (not used) to 1 (highly important). Calculated at the industry level excluding the firm in question.
Pat_sector	Index	Importance of patent protection as a method to protect inventions and innovations, rescaled between 0 (not used) to 1 (highly important). Calculated at the sector level excluding the industry of the firm in question.
Secr_ind	Index	Importance of secrecy as a method to protect inventions and innovations, rescaled between 0 (not used) to 1 (highly important). Calculated at the industry level excluding the firm in question.
Secr_sector	Index	Importance of secrecy as a method to protect inventions and innovations, rescaled between 0 (not used) to 1 (highly important). Calculated at the sector level excluding the industry of the firm in question.
Prot_sector	Index	Importance of secrecy and patents as a method to protect inventions and innovations, rescaled between 0 (not used) to 1 (highly important). Calculated at the sector level excluding the industry of the firm in question.

Variable	Type	Construction
Rel_secr_ind	%	Share of firms indicating that secrecy is more important than patents (industry level).
Rel_pat_ind	%	Share of firms indicating that patents are more important than secrecy (industry level).
Grads	%	Share of employees with higher education in total employees.
R&D_int	%	Share of R&D expenditure in turnover, 2004 (Zero for firms without innovation activities).
R&D_int2	%	Share of R&D expenditure in turnover, 2004, squared (Zero for firms without innovation activities).
R&Dcon	Dummy	One, if firm was engaged in R&D activities continuously.
bed_hemm	Dummy	One, if firm perceived at least one of 13 obstacles to innovation as medium important.
Mneu	Dummy	One, if the firm introduced at least one product innovation that was new to its market between 2002 and 2004.
Pz	Dummy	One, if the firm introduced at least one process innovation between 2002 and 2004.
Lnempl	Log	Natural logarithm of number of employees in 2004.
Lnempl2	Log	Natural logarithm of number of employees in 2004, squared.
East	Dummy	One, if a firm is located in Eastern Germany.
bres_1	Dummy	One, if a firm is from medium-low-tech manufacturing.
bres_1	Dummy	One, if a firm is from high-tech manufacturing.
bres_2	Dummy	One, if a firm is from high-tech services.

Source: Own illustration.

Table A-4 Industries Included in the Model on the Relationship between Patents and Secrecy and Knowledge Spillovers

Name	Label	NACE
Other manufacturing and services	bres_0	10-22; 24 (excl. 244); 29; 31; 34-37 (excl. 353); 40-41; 45; 50-52; 60-67; 70-74; 90; 92
Medium-low-tech manufacturing	bres_1	23; 25-28; 351
High-tech manufacturing	bres_2	244; 30;32; 33; 353
High-tech services	bres_3	64; 72; 73

Source: Own illustration, classification based on the Eurostat and OECD classification for technology and knowledge intensive sectors (Eurostat, 2006).

Table A-5 Additional Descriptive Statistics for the Sample used to Estimate the Effect of Patents and Secrecy on Knowledge Spillovers

Lack of information on technologies is	Number of Observations	Percentage of Total
Very important	64	1.9%
Important	360	10.6%
Somewhat important	1,304	38.3%
Not relevant	1,675	49.2%

Source: Own calculations.

Table A-6 Descriptive Statistics (Means) for the Sample used to Estimate the Effect of Patents and Secrecy on Knowledge Spillovers

	Sample	**Firms without lack of information on technologies**	**Firms with lack of information on technologies**	**T-Test for mean difference**
Observations	3,403	1,675	1,728	
% of total	-	49.2%	50.8%	
Importance of patent protection (industry level)	0.188	0.165	0.210	-7.553
	(0.173)	(0.167)	(0.177)	
Importance of strategic protection (industry level)	0.291	0.268	0.313	-7.963
	(0.165)	(0.161)	(0.166)	
Importance of patent protection (sector level)	0.185	0.181	0.188	-2.038
	(0.100)	(0.096)	(0.099)	
Importance of strategic protection (sector level)	0.286	0.285	0.287	-1.353
	(0.058)	(0.057)	(0.059)	
Share of firms indicating that secrecy > patents (industry level)	0.178	0.169	0.186	-6,844
	(0.072)	(0.073)	(0.072)	
Share of firms indicating that patents > secrecy (industry level)	0.178	0.175	0.180	-3,304
	(0.049)	(0.049)	(0.049)	
Share of employees with higher education (in %)	20.500	20.565	20.436	0.159
	(23.638)	(24.066)	(23.223)	
R&D intensity	0.033	0.026	0.040	-3.127
	(0.126)	(0.106)	(0.143)	
Continuous R&D (dummy)	0.315	0.266	0.363	-6.176
	(0.465)	(0.442)	(0.481)	
Importance of other hampering factors (dummy)	0.833	0.661	0.999	-29.221
	(0.373)	(0.474)	(0.024)	
Market Novelty (dummy)	0.243	0.193	0.292	-6.778
	(0.429)	(0.395)	(0.455)	

	Sample	Firms without lack of information on technologies	Firms with lack of information on technologies	T-Test for mean difference
Process Innovator (dummy)	0.422	0.348	0.494	-7.680
	(0.558)	(0.547)	(0.559)	
Number of Employees	710.304	607.238	810.208	-0.874
	(6787.111)	(6283.552)	(7242.315)	
East Germany (dummy)	0.325	0.357	0.293	3.967
	(0.468)	(0.479)	(0.455)	
Medium-low-tech manufacturing	0.142	0.122	0.161	-3.226
	(0.349)	(0.328)	(0.368)	
High-tech manufacturing	0.088	0.066	0.109	-4.461
	(0.284)	(0.249)	(0.312)	
High-tech services	0.074	0.072	0.075	-0.334
	(0.261)	(0.259)	(0.264)	

Source: Own calculations.

Table A-7 Coefficients of Ordered Probit Estimations of the Effect of Patents and Secrecy on Knowledge Spillovers

	Patents (1)	Secrecy (2)	Patents + Secrecy (3)
Importance of patent protection (industry level)	0.261**		
	(0.149)		
Importance of patent protection (sector level)	0.134		
	(0.236)		
Importance of protection by secrecy (industry level)		0.349**	
		(0.176)	
Importance of protection by secrecy (sector)		0.208	
		(0.396)	
Share of firms indicating that patents > secrecy (industry level)			0.289
			(0.496)
Share of firms indicating that secrecy > patents (industry level)			0.706
			(0.434)
Importance of protection by secrecy + patents (sector level)			0.177

	Patents (1)	Secrecy (2)	Patents + Secrecy (3)
			(0.298)
Share of employees with higher education degree in %	-0.003***	-0.003***	-0.003***
	(0.001)	(0.001)	(0.001)
R&D intensity	0.174	0.176	0.245
	(0.268)	(0.266)	(0.266)
R&D intensity, squared	-0.069	-0.068	-0.084
	(0.105)	(0.104)	(0.106)
Continuous in-house R&D	-0.096*	-0.099*	-0.090*
	(0.055)	(0.055)	(0.054)
Importance of other hampering factors	3.186***	3.184***	3.184***
	(0.315)	(0.315)	(0.315)
Market novelty (dummy)	0.004	0.003	0.006
	(0.052)	(0.052)	(0.052)
Process Innovation (dummy)	0.114***	0.113***	0.110***
	(0.040)	(0.040)	(0.040)
Number of employees, log	0.055	0.054	0.053
	(0.047)	(0.047)	(0.047)
number of employees, log, squared	-0.006	-0.006	-0.005
	(0.004)	(0.004)	(0.004)
East Germany (dummy)	-0.159***	-0.156***	-0.155***
	(0.048)	(0.048)	(0.048)
Medium-low-tech manufacturing	0.114*	0.114*	0.109*
	(0.061)	(0.061)	(0.062)
High-tech manufacturing	0.096	0.065	0.064
	(0.075)	(0.081)	(0.085)
High-tech Services	0.052	0.006	-0.014
	(0.093)	(0.098)	(0.117)
Observations	3,403	3,403	3,403
McKelvey and Zavoina Pseudo R2	0.595	0.595	0.595
X^2	150.99	151.80	151.86
Loglikelihood	-3019.98	-3019.64	-3020.05

* significant at 10%; ** significant at 5%; *** significant at 1%;
Robust Standard Errors in parentheses

Source: Own calculations.

Appendix to Section 6.6 Absorptive Capacity as the Determining Factor of Realized Incoming Knowledge Spillovers

Table A-8 Variables Included in the Empirical Model of the Determinants of Absorptive Capacity

Variable	Type	Construction
Absorp	Dummy	One, if in the three-year period 2000-2002 at least one innovation of a firm was developed because of impulses from at least one of the following sources: customers, suppliers, competitors, universities, research institutions.
Absorp_intra	Dummy	One, if in the three-year period 2000-2002 at least one innovation of a firm was developed and successfully implemented because of impulses from customers, suppliers or competitors from the firm's industry (NACE 2).
Absorp_inter	Dummy	One, if in the three-year period 2000-2002 at least one innovation of a firm was developed and successfully implemented because of impulses from customers or suppliers from industries other than its own (NACE 2).
Absorp_science	Dummy	One, if in the three-year period 2000-2002 at least one innovation of a firm was developed and successfully implemented because of impulses from universities or other public research institutes.
Grads	%	Share of employees with higher education in total employees.
R&D_int	%	Share of R&D expenditure in turnover, 2001
R&D_int2	%	Share of R&D expenditure in turnover, 2001, squared
R&D_int_empl	%	Share of R&D employees in total employees
R&D_int_empl2	%	Share of R&D employees in total employees, squared
R&Dcon	Dummy	One, if firm was engaged in R&D activities continuously
col_infor	Dummy	One, if informal contact among employees were highly important.

Variable	Type	Construction
col_jointstrat	Dummy	One, if joint development of innovation strategies was highly important.
col_opencom	Dummy	One, if open communication of ideas and concepts among departments was highly important.
col_mutsup	Dummy	One, if mutual support of other departments with innovation-related problems was highly important.
col_heads	Dummy	One, if regular meetings of department heads to discuss innovation-related topics were highly important.
col_exchange	Dummy	One, if temporary exchange of personnel between departments for innovation projects was highly important.
col_seminar	Dummy	One, if seminars and workshops for innovation projects involving several departments were highly important.
stim_index	Index	Index based on a question regarding the importance (four-point Likert-scale: "0" not important; "4" highly important") of nine different methods of simulating innovation and knowledge transfer (stim1-stim9), ranging from monetary incentives for leading employees to incentives to develop one's own ideas (full list available upon request). Result of principal component factor analysis suggests a single factor with an Eigenvalue greater than one (5.75). Factor loadings after Varimax rotation rescaled between 0 and 1.
Lnemp	Log	Natural logarithm of number of employees
Lnemp2	Log	Natural logarithm of number of employees, squared
east	Dummy	One, if a firm is located in Eastern Germany.
ind_lt	Dummy	One, if a firm is from a low-tech industry.
ind_mlt	Dummy	One, if a firm is from a medium-low-tech industry.
ind_mht	Dummy	One, if a firm is from a medium-high-tech industry.

Variable	Type	Construction
ind_ht	Dummy	One, if a firm is from a high-tech industry.
serv_lt	Dummy	One, if a firm is from low-tech services.
serv_ht	Dummy	One, if a firm is from high-tech services.

Source: Own illustration.

Table A-9 List of Industry Dummies Included in the Model of the Determinants of Absorptive Capacity

Industry Group	NACE Code
Other manufacturing	40, 41, 45
Low-tech manufacturing	10-22, 36, 37
Medium-low-tech manufacturing	23, 25-28, 351
Medium-high-tech manufacturing	24 (exc. 244), 29, 31, 34, 35 (excl. 353)
High-tech manufacturing	244, 30, 32, 33, 353
Low-tech services (consist of knowledge-intensive market services, knowledge-intensive financial services and other knowledge-intensive services)	50, 51, 52, 55, 60-63, 65-67, 70, 71, 74, 75, 90, 92
High-tech services	64, 72, 73

Note: Only those NACE codes that were present in my sample are listed in the second column.

Source: Own illustration. Classification based on the Eurostat and OECD classification for technology and knowledge intensive sectors (Eurostat, 2006).

Table A-10 Descriptive Statistics for Variables included in the Model of the Determinants of Absorptive Capacity

Definition	Variable	Sample	AC [a]	*Intra*-industry AC [a]	*Inter*-industry AC [a]	Scientific AC [a]
Number of observations		1,650	1,177	575	956	248
% of total			68%	33%	56%	14%
Share of R&D expenditure in turnover, in %	R&D_int	7.46	8.69*	7.70	8.66*	14.80***
		(22.27)	(24.75)	(23.00)	(23.17)	(28.50)
Share of R&D expenditure in turnover, squared	R&D_int2	551.19	687.52	587.58	611.30	1028.27
		(5187.4)	(6004.8)	(5756.2)	(5243.9)	(6371.9)
Share of employees with higher education in total employees, in %	Grads	27.70	29.57*	27.67	29.66*	42.15***
		(26.83)	(27.41)	(25.50)	(27.54)	(29.69)
Continuous R&D activities	R&Dcon	0.53	0.59***	0.60***	0.60***	0.77***
		(0.50)	(0.49)	(0.49)	(0.49)	(0.42)
Number of employees, logarithm	ln_emp	4.59	4.65	4.95***	4.66	4.68
		(1.89)	(1.97)	(2.11)	(1.97)	(2.26)
Number of employees, logarithm, squared	ln_emp2	24.61	25.49*	28.93***	25.58*	26.95*
		(20.52)	(21.96)	(24.78)	(22.03)	(26.95)
Firm located in Eastern Germany	East	0.32	0.34	0.33	0.34	0.33
		(0.47)	(0.47)	(0.47)	(0.47)	(0.47)
Index for importance of methods of stimulating innovation activities and knowledge transfer	stim_index	0.46	0.48***	0.48***	0.48***	0.52***
		(0.23)	(0.22)	(0.22)	(0.22)	(0.21)

Definition	Variable	Sample	AC [a]	*Intra*-industry AC [a]	*Inter*-industry AC [a]	Scientific AC [a]
Informal contact among employees	col_infor	0.47	0.50*	0.51**	0.50*	0.55***
		(0.50)	(0.50)	(0.50)	(0.50)	(0.49)
Open communication of ideas and concepts among departments	col_opencom	0.46	0.49*	0.47	0.48*	0.47
		(0.50)	(0.50)	(0.50)	(0.50)	(0.50)
Joint development of innovation strategies	col_jointstrat	0.32	0.34	0.31	0.35*	0.37
		(0.47)	(0.47)	(0.46)	(0.48)	(0.48)*
Mutual support of other departments with innovation-related problems	col_mutsup	0.43	0.46*	0.41	0.47**	0.46
		(0.50)	(0.50)	(0.49)	(0.50)	(0.50)
Regular meetings of department heads to discuss innovation-related topics	col_heads	0.36	0.37	0.39	0.38	0.36
		(0.48)	(0.48)	(0.48)	(0.49)	(0.48)
Temporary exchange of personnel between departments for innovation projects	col_exchange	0.06	0.06	0.06	0.06	0.10**
		(0.24)	(0.24)	(0.23)	(0.24)	(0.30)
Seminars and workshops for innovation projects involving several departments	col_seminar	0.12	0.13	0.11	0.14	0.21***
		(0.33)	(0.34)	(0.31)	(0.34)	(0.40)

AC: absorptive capacity; means, standard errors in parentheses

[a] Mean is different from the sample mean at * 10%; ** 5%; *** 1%

Source: Own calculations.

Table A-11 Regression Results from Probit (1) and Trivariate Probit (2)-(4) Estimations of the Determinants of Absorptive Capacity

Definition	Variable	AC (1)	*Intra*-industry AC (2)	*Inter*-industry AC (3)	Scientific AC (4)
Number of employees (logarithm)	ln_emp	-0.199**	-0.134*	-0.079	-0.099
		(0.090)	(0.079)	(0.076)	(0.087)
Number of employees, squared (logarithm)	ln_emp2	0.023***	0.021***	0.010	0.012
		(0.008)	(0.007)	(0.007)	(0.007)
Share of employees with higher education in total employees, in %	grads	0.003***	0.001	0.002	0.010***
		(0.002)	(0.002)	(0.002)	(0.002)
Share of R&D expenditure in turnover, in %	R&D_int	0.004	-0.002	0.007*	0.014***
		(0.004)	(0.004)	(0.004)	(0.004)
Share of R&D expenditure in turnover, squared	R&D_int2	-0.00001	0.000005	-0.000028*	-0.00005
		(0.00001)	(0.00001)	(0.000014)	(0.0002)
Continuos R&D activities	R&Dcon	0.306***	0.127*	0.222***	0.451***
		(0.078)	(0.076)	(0.073)	(0.089)
Informal contacts among employees	col_infor	0.159**	0.218***	0.113	0.096
		(0.076)	(0.072)	(0.144)	(0.088)
Open communication of ideas and concepts among departments	col_opencom	0.030	0.102	-0.074	-0.238**
		(0.086)	(0.081)	(0.078)	(0.098)

Definition	Variable	AC (1)	*Intra*-industry AC (2)	*Inter*-industry AC (3)	Scientific AC (4)
Joint development of innovation strategies	col_jointstrat	-0.105	-0.138*	-0.022	-0.050
		(0.085)	(0.080)	(0.080)	(0.100)
Mutual support of other departments with innovation-related problems	col_mutsup	0.090	-0.180**	0.122	-0.089
		(0.084)	(0.079)	(0.077)	(0.096)
Regular meetings of department heads to discuss innovation-related topics	col_heads	-0.010	0.031	-0.032	-0.123
		(0.080)	(0.076)	(0.075)	(0.096)
Temporary exchange of personnel between departments for innovation projects	col_exchange	-0.275*	-0.092	-0.127	0.117
		(0.150)	(0.147)	(0.140)	(0.160)
Seminars and workshops for innovation projects involving several departments	col_seminar	-0.009	-0.341***	0.013	0.243**
		(0.116)	(0.110)	(0.105)	(0.220)
Index for importance of methods of stimulating innovation and knowledge transfer	Stim_index	0.683***	0.293*	0.602***	0.798**
		(0.173)	(0.170)	(0.166)	(0.205)
Firm located in Eastern Germany	east	0.152**	0.154*	0.122*	-0.050
		(0.076)	(0.072)	(0.070)	(0.093)
Low-tech industries	ind_lt	-0.092	0.143	-0.003	-0.124
		(0.245)	(0.225)	(0.078)	(0.291)
Medium-low-tech industries	Ind_mlt	-0.193	-0.315	0.167	-0.183
		(0.239)	(0.222)	(0.205)	(0.288)

Definition	Variable	AC (1)	*Intra*-industry AC (2)	*Inter*-industry AC (3)	Scientific AC (4)
Medium-high-tech industries	Ind_mht	-0.114	0.217	-0.005	-0.120
		(0.237)	(0.215)	(0.201)	(0.275)
High-tech industries	Ind_ht	-0.111	0.038	0.055	-0.092
		(0.248)	(0.226)	(0.211)	(0.282)
Low-tech services	serv_lt	-0.311	-0.177	-0.009	-0.291
		(0.232)	(0.214)	(0.197)	(0.277)
High-tech services	serv_ht	0.008	0.094	0.112	-0.147
		(0.259)	(0.235)	(0.221)	(0.295)
Constant		0.417	-0.540*	-0.305	-1.655
		(0.316)	(0.293)	(0.279)	(0.366)
Observations		1,650		1,650	
X^2		132.73		347.89	
Log-likelihood				-2,663.48	
Aldrich-Nelson Pseudo R^2		0.137		0.231	
Rho			(2,3): 0.27***	(3,4): 0.19***	(2,4)0.11**

* significant at 10%; ** significant at 5%; *** significant at 1%; Robust standard errors in parentheses

AC: exploitive absorptive capacity

Source: Own calculations.

Appendix to Section 7.2 Estimating the Impact of Knowledge Spillovers on the R&D Co-operation

Table A-12 Construction of Variables for the Benchmark Case on the Importance of Knowledge Spillovers for R&D Co-operation

Variable Name	**Construction**	**Cassiman and Veugelers (2002) model**
R&D Co-operation	Indicator variable that takes the value 1 if the firm cooperates on their innovation activities with suppliers, customers, competitors, commercial laboratories/R&D enterprises, universities, or government or private non-profit research institutes between 2001 and 2003.	*No deviations*
Incoming Spillovers	Sum of importance (number between 0 (not used) and 3 (high)) of professional conferences, meetings and journals and of exhibitions and fairs as sources of innovation. Rescaled between 0 (no spillovers) and 1 (maximum spillovers).	Includes the importance of patent applications as a source of innovation.
Legal Protection (industry level)	Mean of Legal Protection at the industry level (NACE 2). Sum of importance (number between 0 (not used) and 3 (high)) of formal protection methods for innovations (patents, copyrights, trademarks, registration of design patterns). Rescaled between 0 (not used) and 1 (highly used).	*No deviation*

Variable Name	Construction	Cassiman and Veugelers (2002) model
Appropriability	Sum of importance (number between 0 (not used) and 3 (high)) of strategic protection methods for innovations (secrecy, complexity of design and lead-time advantage). Rescaled between 0 (not used) and 1 (highly important).	*No deviation*
Constraints	Importance of the following obstacles to innovation process (number between 3 or 4 (high) and 0 (not relevant)): Innovation costs too high; Lack of availability of finance; Excessive perceived economic risks. Rescaled between 0 (not relevant) and 1 (high).	Separate variables for the importance of cost and risk as an obstacle to innovation. Cost: Importance of no suitable financing available, high cost of innovation, payback period too long, innovation cost hard to control as obstacles to innovation. Risk: Importance of high risk as an obstacle to innovation. Treated as exogenous in the CV model.

Variable Name	Construction	Cassiman and Veugelers (2002) model
Complementarities	Importance (number between 0 (not used) and 3 (high)) of lack of information on technology as an obstacle to innovation. Rescaled between 0 (not important) and 1 (very important).	*No deviation*
Size	Natural log of number of employees	Firm Sales in absolute terms
Size^2	Natural log of number of employees, squared	Firm Sales in absolute terms, squared
East	Dummy variable which takes the value 1 if the firm is situated in East Germany	No dummies for region
Export Intensity	Total exports divided by total turnover	*No deviation*
Basicness of R&D	Sum of importance (number between 0 (not used) and 3 (high)) of university and government or private non-profit research institutes as sources of information over sum of importance (number between 0 (not used) and 3 (high)) of suppliers and customers as sources of information	*No deviation*
Industry level of variable	Mean of the variable at the amended 2-digit NACE level	Original NACE 2

Source: Own illustration.

Table A-13 Descriptive Statistics (Means) for the Benchmark Case on the Importance of Knowledge Spillovers for R&D Co-operation

	Sample Mean	**Firms without R&D co-operation between 2001-2003**	**Firms with R&D co-operation between 2001-2003**
Observations	1720	1186	534
% of total	-	69%	31%
Incoming Spillovers	0.485	0.459	0.544***
	(0.239)	(0.238)	(0.231)
Appropriability	0.364	0.286	0.536 ***
	(0.344)	(0.033)	(0.320)
Legal Protection (industry level)	0.203	0.154	0.311***
	(0.255)	(0.233)	(0.269)
Number of employees	701	280	1634***
	(6097)	(1596)	(10629)
Continuous R&D activities	0.485	0.351	0.783***
	(0.500)	(0.477)	(0.413)
Constraints	0.512	0.492	0.556***
	(0.287)	(0.290)	(0.276)
Complementarities	0.745	0.744	0.747
	(0.245)	(0.251)	(0.230)
East Germany	0.316	0.295	0.361***
	(0.465)	(0.456)	(0.481)
Industry-level of R&D co-operation	0.283	0.248	0.361***
	(0.151)	(0.136)	(0.152)

Standard deviation in parenthesis

Mean difference between cooperating and non-cooperating firms is significant at 1% level (***), 5% level (**) or 10% level (*)

Source: Own calculations.

Table A-14 Results for the First Stage OLS Regressions of the Two Stage Probit Estimations of the Probability of Cooperating

	Incoming Spillovers	**Appropri-ability**	**Legal Protection**	**Continu-ous R&D**	**Con-straints**
Incoming Spillovers (industry level)	1.049***	0.272	0.381**	0.501	-0.475*
	(0.227)	(0.306)	(0.214)	(0.411)	(0.253)
Appropriability (industry level)	0.197	0.914***	0.040	0.088	0.304
	(0.203)	(0.269)	(0.186)	(0.370)	(0.235)
Legal Protection (industry level)	0.139	-0.148	0.787***	-0.246	0.062
	(0.119)	(0.167)	(0.117)	(0.234)	(0.141)
Constraints (industry level)	-0.203	0.004	0.075	-0.084	0.876***
	(0.136)	(0.178)	(0.119)	(0.245)	(0.147)
Continuous R&D (industry level)	-0.100	0.042	-0.065	0.834***	-0.167
	(0.109)	(0.159)	(0.113)	(0.212)	(0.124)
Basicness of R&D	0.091***	0.069***	0.062***	0.189***	0.048***
	(0.015)	(0.031)	(0.012)	(0.019)	(0.014)
Export Intensity	0.030	0.196***	0.160***	0.324***	-0.058**
	(0.024)	(0.035)	(0.026)	(0.047)	(0.029)
Number of employees, ln	-0.022*	-0.044**	0.004	0.010	-0.105***
	(0.013)	(0.018)	(0.012)	(0.023)	(0.015)
Number of employees, ln, squared	0.002*	0.007***	0.004**	0.004*	0.008***
	(0.0012)	(0.002)	(0.001)	(0.002)	(0.001)
Complementarities	-0.059**	-0.048	0.018	0.109**	-0.314***
	(0.023)	(0.031)	(0.021)	(0.041)	(0.028)
East Germany	0.033***	-0.034*	-0.039***	0.017	0.001
	(0.013)	(0.018)	(0.011)	(0.024)	(0.015)
Industry-level of R&D co-operation	-0.150	-0.157	-0.089	-0.239	0.061
	(0.110)	(0.169)	(0.118)	(0.224)	(0.123)
Constant	0.123	-0.017	-0.280**	-0.392**	0.751***
	(0.099)	(0.138)	(0.100)	(0.194)	(0.108)
Observations	1,720	1,720	1,720	1,720	1,720
R^2	0.093	0.189	0.284	0.277	0.161

Source: Own Calculations.

Table A-15 Construction of Variables for the Model on Knowledge Spillovers for R&D Co-operation using the Constructed Spillover Measures

Variable Name	Construction
R&D Co-operation	Indicator variable that takes the value 1 if the firm cooperates on their innovation activities with suppliers, customers, competitors, commercial laboratories/R&D enterprises, universities, or government or private non-profit research institutes between 2001 and 2003.
Realized spillovers	Realized spillover variables as constructed in chapters 6.7.
Public funding	Indicator variable that takes the value 1 if a firm has received public funding for its innovation activities from the European Union, national authorities or state authorities.
Number of main competitors	Variable that takes the value 0 if the firm is a monopolist, 1 if it has 1-5 main competitors, 2 if it has 6 to 15 competitors and 3 if it has more than 15 competitors.
Complementarities	Importance (number between 0 (not used) and 3 (high)) of lack of information on technology as an obstacle to innovation. Rescaled between 0 (not important) and 1 (very important).
Constraints	Importance of the following obstacles to innovation process (number between 3 or 4 (high) and 0 (not relevant)): Innovation costs too high; Lack of availability of finance; Excessive perceived economic risks. Rescaled between 0 (not relevant) and 1 (high).

Variable Name	Construction
Constraints_others	Average importance of the following obstacles to innovation organizational problems within the firm, internal oppositions, lack of qualified personel, lack of information on markets, uncertain demand for innovations, regulations and laws, difficulties in finding partners for innovation activeties, market dominated by established firms.Rescaled between 0 (not relevant) and 1 (high). Used as an instrument.
Exports	Dummy variable which takes the value 1 if the firm had any exports between 2001 and 2003.
Size	Natural log of number of employees.
Size^2	Natural log of number of employees, squared.
Age	Age of the firm in years.
East Germany	Dummy variable which takes the value 1 if the firm is situated in East Germany.
Industry dummies	See Table A-9 above.
Tangible assets	Total value of tangible asstes as of 2004 in billion Euros Used as an instrument.
Industry level of variable	Mean of the variable at the amended 2-digit NACE level.

Source: Own illustration.

Table A-16 Descriptive Statistics (Means) of the Sample used for the Model on Knowledge Spillovers for R&D Co-operation using the Constructed Spillover Measures

	Sample Mean	**Firms without R&D co-operation between 2001-2003**	**Firms with R&D co-operation between 2001-2003**
Observations	586	324	262
% of total		55%	45%
Realized Spillovers:			
Outgoing Spillover	38.944	28.896	51.370
	(316.719)	(277.714)	(359.317)
Incoming Spillovers	15,020.400	10,739.350	20,315.770***
	(11,565.02)	(9,184.816)	(12,019.700)
Intra-Industry Spillovers	1,834.826	1,249.155	2,559.090***
	(2,836.626)	(2,068.22)	(3,433.529)
Extra-Industry Spillovers	13,185.580	9,489.192	17,756.680***
	(10,057.48)	(8,117.261)	(10,355.850)
Other Motives:			
Public funding (dummy)	0.483	0.231	0.794***
	(0.500)	(0.422)	(0.405)
Number of main competitors	2.514	2.577	2.435***
	(0.756)	(0.777)	(0.723)
Complementarities	0.260	0.258	0.262
	(0.251)	(0.257)	(0.242)
Constraints	0.515	0.464	0.579***
	(0.284)	(0.285)	(0.271)
Exports	0.778	0.694	0.882***
	(0.416)	(0.461)	(0.324)
Number of employees	1200.805	507.028	2058.760***
	(7147.123)	(3341.107)	(9967.023)
Age in years	23.995	27.725	19.382*
	(85.311)	(112.923)	(22.214)
East Germany (dummy)	0.336	0.284	0.401***
	(0.473)	(0.452)	(0.491)

	Sample Mean	Firms without R&D co-operation between 2001-2003	Firms with R&D co-operation between 2001-2003
Industry dummies:			
Other manufacturing	0.020	0.021	0,019
	(0.142)	(0.146)	(0,137)
Low-tech manufacturing	0.084	0.114	0,046***
	(0.277)	(0.319)	(0,210)
Medium-low-tech manufacturing	0.179	0.210	0,141**
	(0.384)	(0.408)	(0,349)
Med.-high-tech manufacturing	0.188	0.148	0,237***
	(0.391)	(0.356)	(0,426)
High-tech manufacturing	0.166	0.105	0,240***
	(0.372)	(0.307)	(0,428)
Low-tech services	0.225	0.290	0,145***
	(0.418)	(0.456)	(0,353)
High-tech services	0.138	0.111	0,172**
	(0.345)	(0.315)	(0,378)

Standard deviation in parenthesis

Mean difference between cooperating and non-cooperating firms is significant at 1% level (***), 5% level (**) or 10% level (*)

Source: Own calculations.

Table A-17 Results for the First Stage of the Instrumental Variable Probit Estimations of the Model on Knowledge Spillovers for R&D Cooperation using the Constructed Spillover Measures

	Importance of cost and risk sharing as an obstacle to innovation activities (Constraints)	**Importance of cost and risk sharing as an obstacle to innovation activities (Constraints)**
Realized Spillovers:		
Outgoing Spillover	0.000002	0.000001
	(0.000033)	(0.000032)
Incoming Spillovers	0.000003**	
	(0.000001)	
Intra-Industry Spillovers		-0.00001*
		(0.00001)
Extra-Industry Spillovers		0.000004**
		(0.000001)
Other Motives:		
Public funding (dummy)	0.066***	0.061**
	(0.023)	(0.023)
Number of main competitors	0.004	0.003
	(0.013)	(0.013)
Complementarities	-0.084*	-0.087*
	(0.050)	(0.050)
Exports	0.025	0.024
	(0.029)	(0.029)
Size (number of employees), ln	-0.050**	-0.044*
	(0.025)	(0.025)
Size (number of employees), ln, squared	0.002	0.002
	(0.002)	(0.002)
Age in years	0.0001	0.0001
	(0.0001)	(0.0001)
East Germany (dummy)	0.018	0.021
	(0.023)	(0.023)
Instruments:		
Importance of all other motives	0.639***	0.643***
	(0.059)	(0.058)
Value of all tangible assets	0.000002	0.00001
	(0.000008)	(0.00001)

	Importance of cost and risk sharing as an obstacle to innovation activities (Constraints)	Importance of cost and risk sharing as an obstacle to innovation activities (Constraints)
Industry dummies:		
Other manufacturing	-0.178**	-0.242**
	(0.077)	(0.082)
Low-tech manufacturing	0.096**	0.041
	(0.045)	(0.051)
Medium-low-tech manufacturing	0.076**	0.025
	(0.037)	(0.043)
High-tech manufacturing	0.014	-0.022
	(0.034)	(0.037)
Low-tech services	0.040	-0.017
	(0.038)	(0.045)
High-tech services	0.089**	0.023
	(0.038)	(0.047)
Constant	0.331***	0.363
	(0.089)	(0.090)
Observations	586	586

* significant at 10%; ** significant at 5%; *** significant at 1% [188]

Source: Own calculations.

188 Since the whole model is estimated using a maximum likelihood procedure, the quality indicators (X^2 and log-likelihood) are based on both stages and are reported in the table with the second stage results.

Table A-18 Results for the Instrumental Variable Probit Estimations of the Model on Knowledge Spillovers for R&D Co-operation using the Constructed Spillover Measures

	Model with incoming and outgoing spill-overs	**Model with intra-industry and extra-industry incom-ing and outgoing spill-overs**
Realized Spillovers:		
Outgoing Spillover	-0.00006	-0.00006
	(0.0007)	(0.0003)
Incoming Spillovers	0.00003**	
	(0.00001)	
Intra-Industry Spillovers		0.00004
		(0.00004)
Extra-Industry Spillovers		0.00002 **
		(0.000009)
Other Motives:		
Public funding (dummy)	1.271***	1.273***
	(0.165)	(0.163)
Number of main competitors	-0.109	-0.108
	(0.104)	(0.080)
Complementarities	0.050	0.047
	(0.322)	(0.273)
Constraints (I)	1,616***	1.630***
	(0.454)	(0.419)
Exports	0.410**	0.411**
	(0.322)	(0.187)
Size (number of employees), ln	0.182 ZZZ	0.184 ZZZ
	(0.218)	(0.187)
Size (number of employees), ln , squared	-0.001 ZZZ	-0.001 ZZZ
	0.020	(0.019)
Age in years	-0.004	-0.004
	(0.005)	(0.003)
East Germany (dummy)	-0.092	-0.094
	(0.151)	(0.174)

	Model with incoming and outgoing spill-overs	Model with intra-industry and extra-industry incoming and outgoing spill-overs
Industry dummies:		
Other manufacturing	0.891*	0.950*
	(0.485)	(0.539)
Low-tech manufacturing	-0.133	-0.082
	(0.287)	(0.539)
Medium-low-tech manufacturing	-0.041	0.007
	(0.276)	(0.233)
High-tech manufacturing	0.114	0.147
	(0.250)	(0.231)
Low-tech services	0.172	0.224
	(0.250)	(0.226)
High-tech services	0.266	0.326
	(0.279)	(0.231)
Constant	-2.855***	-2.905***
	(0.762)	(0,560)
Observations	586	586
X^2	245.41	293.83
Log Likelihood	-253.652	-251.077

* significant at 10%; ** significant at 5%; *** significant at 1%; [ZZZ] jointly significant at 1% level;
(I) Instrumented variable
Bootstrapped Standard Errors in parentheses.

Source: Own calculations.

Literature

Abramovsky, L.,l E. Kremp, A. Lopez, T. Schmidt and H. Simpson (2005), *Understanding Co-operative R&D activity: Evidence from four European countries,* IFS Working Paper No. 05/23, London.

Acs, Z., L. Anselin and A. Varga (2002), Patents and Innovation Counts as Measures of Regional Production of New Knowledge*, Research Policy* 31 (7), 1069-1085.

Adams, J.D. (1990), Fundamental Stocks of Knowledge and Productivity Growth*, Journal of Political Economy* 98 (41), 673-702.

Adams, J.D. (2006), Learning, Internal Research, and Spillovers: Evidence from a Sample of Industrial R&D Laboratories*, Economics of Innovation and New Technology* 15 (1), 5-36.

Agrawal, A. and R. Henderson (2002), Putting Patents in Context: Exploring Knowledge Transfer from MIT*, Management Science* 48 (1), 44-60.

Almus, M., D. Engel and S. Prantl (2000), The ZEW Foundation Panels and the Mannheim Enterprise Panel (MUP) of the Centre for European Economic Research (ZEW)*, Schmollers Jahrbuch* 120 (2), 301-308.

Angrist, J.D. and A.B. Krueger (2001), Instrumental Variables and the Search for Identification: From Supply and Demand to Natural Experiments*, Journal of Economic Perspectives* 15 (4), 69-85.

Anton, J.J. and D.A. Yao (2004), Little Patents and Big Secrets: Managing Intellectual Property*, RAND Journal of Economics* 35 (1), 1-22.

Arndt, O. and R. Sternberg (2000), Do Manufacturing Firms Profit from Intraregional Innovation Linkages? An Empirical Based Answer*, European Planning Studies* 8 (4), 465-485.

Arora, A. (1997), Patent, Licensing, and Market Structure in Chemicals*, Research Policy* 26 (4-5), 391-403.

Arora, A., M. Ceccagnoli and W.M. Cohen (2005), *R&D and the Patent Premium,* NBER Working Paper No. 9431, Cambridge, Mass.

Arrow, K.J. (1962a), The Economic Implications of Learning by Doing*, The Review of Economic Studies* 29 (3), 155-173.

Arrow, K.J. (1962b), Economic Welfare and the Allocation of Resources for Invention, in: Nelson, R. R. (ed.), *The Rate and Direction of Inventive Activity, Economic and Social Factors*, Princeton University Press, Princeton, 609-625.

Arundel, A. (2001), The Relative Effectiveness of Patents and Secrecy for Appropriation*, Research Policy* 30 (4), 611-624.

Arundel, A. and I. Kabla (1998), What Percentage of Innovations are Patented? Empirical Estimates for European Firms*, Research Policy* 27 (2), 127-141.

Aschhoff, B., T. Doherr, B. Ebersberger, B. Peters, C. Rammer and T. Schmidt (2006), *Innovation in Germany - Results of the German Innovation Survey 2005*, Mannheim.

Aschhoff, B. and T. Schmidt (2006), *Two for the money? Empirical Evidence on the benfits of R&D Co-operation,* ZEW Discussion Paper No. 06-059, Mannheim.

Atallah, G. (2002), Vertical R&D Spillovers, Cooperation, Market Structure, and Innovation*, Economics of Innovation & New Technology* 11 (3), 179-209.

Atallah, G. (2004), *The Protection of Innovations,* CIRANO Scientific Series No. 2, Montréal.

Banerjee, S. and P. Lin (2001), Vertical Research Joint Ventures*, International Journal of Industrial Organization* 19 (1), 285-302.

Barney, J. (1991), Firm Resources and Sustained Competitive Advantage*, Journal of Management* 17 (1), 99-120.

Bartholomaei, M. (2005), *To Know is to be: Three Perspectives on the Codification of Knowledge,* SPRU Electronic Working Paper Series No. 131, Brighton.

Baumol, W.J. (1982), Contestable Markets: An Uprising in the Theory of Industry Structure*, American Economic Review* 72 (1), 1-15.

Baumol, W.J. (1993), *Entrepreneurship, Management and the Structure of Payoffs*, MIT Press, Cambridge, MA.

Bayona, C., T. Gracia-Marco and E. Huerta (2001), Firms' motivation for cooperative R&D: An empirical analysis of Spanish firms, *Research Policy* 30 (8), 1289-1307.

Beath, J., J.A. Poyago-Theotoka and D.L. Ulph (1998), Organizational Design and Information Sharing in a Research Joint Venture with Spillovers, *Bulletin of Economic Research* 50 (1), 47-59.

Becker, C., S. Ekert, K. Blind, R. Bierhals, T. Giebe and T. Grebe (2002), *Effizienzsteigerung bei der FuE-Projektförderung durch wettbewerbliche Vergabeverfahren unter Berücksichtigung des Nachfrageverhaltens der Unternehmen nach Fördermitteln. (Abschlussbericht)*, Gesellschaft für Innovationsforschung und -beratung im Auftrag des BMWA, Berlin.

Becker, W. and J. Peters (2000), *Technological Opportunities, Absorptive Capacities, and Innovation,* Volkswirtschaftliche Diskussionsreihe No. 255, Augsburg.

Belderbos, R., M. Carree, B. Diederen, B. Lokshin and R. Veugelers (2004), Heterogeneity in R&D Cooperation Strategies, *International Journal of Industrial Organization* 22 (8-9), 1237-1263.

Bernstein, J.I. (1988), Costs of Production, Intra- and Interindustry R&D Spillovers: Canadian Evidence, *The Canadian Journal of Economics* 21 (2), 324-347.

Bernstein, J.I. and P. Mohnen (1994), *International R&D Spillovers between U.S. and Japanese R&D Intensive Sectors,* NBER Working Paper No. 4682, Cambridge, MA.

Bernstein, J.I. and I.M. Nadiri (1989), Research and Development and Intra-Industry spillovers: An Empirical Application of Dynamic Duality, *Review of Economic Studies* 56 (2), 249-267.

Bernstein, J.I. and I.M. Nadiri (1991), *Product Demand, Cost of Production, Spillovers, and the Social Rate of Return to R&D,* NBER Working Paper No. 3625, Washington, D.C.

Bessen, J. (2005), Patents and the Diffusion of Technological Information*, Economic Letters* 86 (1), 121-128.

BMBF (2004), *Bundesbericht Forschung 2004*, Bundesministerium für Bildung und Forschung, Berlin.

Bönte, W. and M. Keilbach (2005), Concubinage or Marriage? Informal and Formal Cooperations for Innovation*, International Journal of Industrial Organization* 23 (3-4), 279-302.

Branstetter, L.G. (2001), Are Knowledge Spillovers International or Intranational in Scope?*, Journal of International Economics* 53 (1), 53-80.

Breschi, S., F. Malerba and L. Orsenigo (2000), Technological Regimes and Schumpeterian Patterns of Innovation*, Economic Journal* 110 (463), 388-410.

Brusoni, S., O. Marsili and A. Salter (2002), The role of codified sources of knowledge in innovation: empirical evidence from Dutch manufacturing, *Journal of Evolutionary Economics* 15 (2), 211-231.

Busom, I. and A. Fernandez-Ribas (2004), *Firm Strategies in R&D: Cooperation and Participation in R&D Programs,* Universida Autonoma de Barcelona Working Paper No. 04.05, Barcelona.

Caloghirou, Y., S. Ioannides and N.S. Vonortas (2003), Research Joint Ventures: A Critical Survey of the Theoretical and Empirical Literature*, Journal of Economic Surveys* 17 (4), 541-570.

Caloghirou, Y., I. Kastelli and A. Tsakanikas (2004), Internal capabilities and external knowledge sources: complements or substitutes for innovative performance?*, Technovation* 24 (1), 29-39.

Cameron, G. (1996), *Innovation and Economic Growth,* Centre for Economic Performance Working Paper No. 277, London.

Cantner, U. and A. Meder (2006), *Determinants Influencing the Choice of a Co-operation Partner,* Jenaer Schriften zur Wirtschaftswissenschaft No. 20/2006, Jena.

Cantner, U. and A. Pyka (1998), Absorbing Technological Spillovers: Simulations in an Evolutionary Framework*., Industrial & Corporate Change* 7 (2), 369-397.

Cantwell, J. (1991), The Theory of Technological Competence and its Application to International Production, in: McFetridge, D. (ed.), *Foreign investment, technology and economic growth*, University of Calgary Press, Calgary.

Cassiman, B. and R. Veugelers (2002), R&D Cooperation and Spillovers: Some Empirical Evidence from Belgium*, American Economic Review* 44 (3), 1169-1184.

Chesnais, F. (1988), Technological Co-operation Argeements between Firms*, STI Review* 4, 51-119.

Choi, J.P. (1993), Cooperative R&D with Product Market Competition*, International Journal of Industrial Organization* 11 (4), 553-571.

Cincera, M. (2005), *Firms' Productivity Growth and R&D Spillovers: An Analysis of Alternative Technological Proximity Measures,* CEPR Discussion Paper No. 4894, London.

Cincera, M., L. Kempen, B. von Pottelsberghe, R. Veugelers and C. Villegas (2003), Productivity Growth, R&D and the Role of International Collaborative Agreements: Some Evidence from Belgium Manufacturing Companies*, Brussels Economic Review* 46 (3), 107-140.

Coase, R.H. (1937), The Nature of the Firm*, Economica* 4 (16), 386-405.

Coe, D. and E. Helpman (1995), International R&D Spillovers*, European Economic Review* 39 (5), 859-887.

Cohen, W.M., R. Florida, L. Randazzese and J.P. Walsh (1998), Industry and Academy: Uneasy Partners in the Cause of Technological Advance, in: Teich, A. (ed.), *Challenges to Research Universities*, Brookings Institution Press, Washington, D.C.

Cohen, W.M., A. Goto, A. Nagata, R.R. Nelson and J.P. Walsh (2002), R&D Spillovers, Patents and Incentives to Innovate in Japan and the United States, *Research Policy* 313 (8-9), 1349-1367.

Cohen, W.M. and D.A. Levinthal (1989), Innovation and Learning: The Two Faces of R&D, *Economic Journal* 99 (397), 569-596.

Cohen, W.M. and D.A. Levinthal (1990), Absorptive Capacity: A New Perspective on Learning and Innovation, *Administrative Science Quarterly* 35 (1), 128-152.

Cohen, W.M. and D.A. Levinthal (1994), Fortune Favors the Prepared Firm, *Management Science* 40 (2), 227-251.

Cohen, W.M., R.R. Nelson and J.P. Walsh (2000), *Protecting Their Intellectual Assets: Appropriability Conditions and Why U.S. Manufacturing Firms Patent (or Not),* NBER Working Paper No. 7552, Washington.

Cohen, W.M. and J.P. Walsh (2000), *R&D spillovers, appropriability and R&D intensity: a survey based approach*, Economic Assessment Office.

Colombo, M.G. and P. Gerrone (1996), Technological Cooperative Agreements and Firm's R&D Intensity. A Note on Causality Relations, *Research Policy* 25 (6), 923-932.

Cowan, R., P.A. David and D. Foray (2000), The explicit economics of knowledge codification and tacitness., *Industrial and Corporate Change* 9 (2), 211-254.

Dachs, B., B. Ebersberger and A. Pyka (2004), *Why do Firms Co-operate for Innovation? A Comparison of Austrian and Finnish CIS 3 Results,* Volkswirtschaftliche Diskussionsreihe der Uni Augsburg No. 255, Augsburg.

Daghfous, A. (2004), Absorptive Capacity and the Implementation of Knowledge-Intensive Best Practices, *Advanced Management Journal* 69 (2), 21-27.

Dasgupta, P. and J. Stiglitz (1980), Industry Structure and the Nature of Innovative Activity, *Economic Journal* 90 (358), 266-293.

D'Aspremont, C. and A. Jacquemin (1988), Cooperative and Noncooperative R&D in Duopoly with Spillovers, *American Economic Review* 78 (5), 1133-1137.

D'Aspremont, C. and A. Jacquemin (1990), Cooperative and Noncooperative R&D in Duopoly with Spillovers: Eratum, *American Economic Review* 80 (3), 641-642.

David, P.A. (2003), *The Economic Logic of "Open Science" and the Balance between Private Property Rights and the Public Domain in Scientific Data and Information: A Primer,* Stanford Institute for Economic Policy Research Discussion Paper No. 02-30, Stanford.

De Bondt, R. (1996), Spillovers and Innovation Activities, *International Journal of Industrial Organization* 15 (1), 1-28.

De Bondt, R. and I. Henriques (1995), Strategic Investment with Asymmetric Spillovers, *The Canadian Journal of Economics* 28 (3), 656-674.

De Bondt, R., P. Slaets and B. Cassiman (1992), The Degree of Spillovers and the Number of Rivals for Maximum Effective R&D, *International Journal of Industrial Organization* 10 (1), 35-54.

De Bondt, R. and R. Veugelers (1991), Strategic Investment with Spillovers, *European Journal of Political Economy* 7 (7), 345-366.

Dickson, K., H.L. Smith and S.L. Smith (1991), Bridge over Troubled Waters? Problems and Opportunities in Interfirm Research Collaboration, *Technology Analysis & Strategic Management* 3 (2), 143-156.

Drejer, I. and B.H. Jorgensen (2005), The Dynamic Creation of Knowledge-Analysing Public-Private Collaborations, *Technovation* 25 (2), 83-94.

Dussauge, P., B. Garrette and W. Mitchell (2000), Learing From Competing Partners: Outcomes and duration of Scale and Link Alliances in Europe, North America and Asia, *Strategic Management Journal* 21 (2), 99-126.

Duysters, G. and J. Hagedoorn (2000), Core Competences and Company Performance in the World-Wide Computer Industry, *Journal of High Technology Management Research* 11 (1), 75-91.

European Commission (1993), *Council Regulation (EEC) N° 696/1993 of 15 March 1993, OJ N° L76 of the 3 March on the statistical units for the observation and analysis of the production system in the Community*, Brussels.

European Commission (2004a), *Council Regulation (EEC) N° 1450/2004 of 13 August 2004 implementing Decision No 1608/2003/EC of the European Parliament and the Council concerning the production and development of Community statistics on innovation*, Brussels.

European Commission (2004b), *Innovation in Europe - Results for the EU, Iceland and Norway (Data 1998-2001)*, Theme 9 Science and Technology, Luxemburg.

Eurostat (2004), *The Fourth Community Innovation Survey (CIS IV) - The Harmonised Survey Questionnaire*, Luxemburg.

Eurostat (2006), *Technology and Knowledge-Intensive Sectors* (Source: http://europa.eu.int/estatref/info/sdds/en/hrst/hrst_sectors.htm), downloaded: July 19th, 2006.

Felder, J., D. Harhoff, G. Licht, E. Nerlinger and H. Stahl (1994), *Innovationsverhalten der deutschen Wirtschaft. Ergebnisse der Innovationserhebung 1993*, ZEW Dokumentation 94-01, Vol. 94-01, Baden-Baden.

Fier, A., B. Aschhoff and H. Löhlein (2005), *Measuring Additionality of Government Financing of Business R&D - Methodological Approaches and Findings in Germany*, Bericht an das Bundesministerium für Bildung und Forschung (BMBF), Mannheim.

Fontana, R., A. Geuna and M. Matt (2006), Firm Size and Openness: The Driving Forces of University-Industry Collaboration, in: Caloghirou, A., B. Constantelou and N.S. Vonortas (eds.), *Knowledge Flows in European Industry*, Routledge, London, 181-209.

Fontana, R., A. Geuna and M. Matt (2005), *Factors Affecting University-Industry R&D Collaboration: The Importance of Screening and Signalling,* Document de travail No. 2005-07, Strassburg.

Frenz, M., J. Michie and C. Oughton (2004), *Co-operation, Innovation and Firm's Absorptive Capacity,* Working Paper, Birmingham.

Fritsch, M. and G. Franke (2004), Innovation, Regional Knowledge Spillovers and R&D Cooperation*, Research Policy* 33 (2), 245-255.

Fritsch, M. and R. Lukas (2001), Who Cooperates on R&D?*, Research Policy* 30 (2), 297-312.

Gallini, N.T. (2002), The Economics of Patents: Lessons from Recent U.S. Patent Reform*, Journal of Economic Perspectives* 16 (2), 131-155.

Geroski, P. (1995), Do Spillovers Undermine the Incentive to Innovate?, in: Dorwick, S. (ed.), *Economic Approaches to Innovation*, Edgar Elgar Publishing, Vermont, 76-97.

Geroski, P., S. Machini and J. Van Reenen (1993), The Profitability of Innovating Firms*, RAND Journal of Economics* 24 (2), 198-211.

Gerybadze, A. (2004), Management von Kooperationen, in: Barske, H., A. Gerybadze, L. Hünninghausen and T. Sommerlatte (eds.), *Digitalen Fachbibliothek "Innovationsmanagement"*, Symposium Publishing GmbH, Düsseldorf.

Gilsing, V. and C. Lemmens (2005), *Strategic Alliance Networks and Innovation: a Deterministic and Voluntaristic View Combined,* Eindhoven Centre for Innovation Studies Working Paper No. 05.02, Eindhoven.

Glasgow, G. (2001), Mixed Logit Models for Multiparty Elections*, Political Analysis* 9 (2), 116-136.

Google Scholar (2006), *Search Results for "D'Aspremont and Jacquemine" at* http://scholar.google.com/ (Source: Google Scholar), downloaded: February 1st, 2006.

Goto, A. and K. Suzuki (1989), R&D Capital, Rate of Return on R&D Investment and Spillover of R&D in Japanese Manufacturing Industries, *Review of Economics and Statistics* 71 (4), 555-564.

Gottschalk, S. and G. Licht (2003), Innovation und Netzwerke, in: Janz, N. and G. Licht (eds.), *Innovationsforschung heute*, Baden-Baden.

Gradwell, T. (2003), Outsourcing Knowledge Creation: Don't Give the Game Away, *Specialty Chemicals* 23 (8), 24-25.

Greene, W.H. (1981), Sample Selection Bias as a Specification Error: A comment, *Econometrica* 49 (3), 795-798.

Greene, W.H. (2003), *Econometric Analysis*, Prentice Hall, New York.

Greunz, L. (2003), Geographically and Technologically Mediated Knowledge Spillovers between European Regions, *Annals of Regional Science* 37 (4), 657-680.

Griffith, R., R. Harrison and J. Van Reenen (2006), How Special is the Special Relationship? Using The Impact of US R&D spillovers on UK Firms as a Test of Technology Sourcing, *American Economic Review* 96 (5), 1839-1875.

Griliches, Z. (1979a), Issues in Assessing the Contribution of Research and Development to Productivity Growth, *Bell Journal of Economics* 10 (1), 92-116.

Griliches, Z. (1979b), ssues in Assessing the Contribution of Research and Development to Productivity Growth, *Bell Journal of Economics* 10 (1), 92-116.

Griliches, Z. (1990), Patent Statistics as Economic Indicators: A Survey, *Journal of Economic Literature* 28 (4), 1661-1707.

Griliches, Z. (1992), The Search for R&D Spillovers, *Scandinavian Journal of Economics* 94 (Supplement), 29-47.

Griliches, Z. (1994), Productivity, R&D, and the Date Constraint, *American Economic Review* 84 (1), 1-23.

Griliches, Z. and J. Mairesse (1984), Productivity and R&D at the Firm Level, in: Griliches, Z. (ed.), *R&D, Patents and Productivity*, University of Chicago Press, Chicago.

Grosser, T. (2005), Neuer Stoff, neue Hoffnung - Bei Technischen Textilien sind deutsche Hersteller Weltspitze, *Handelsblatt*, Issue: May 9, 2005.

Grossman, G.M. and C. Shapiro (1987), Dynamic R&D Competition, *The Economic Journal* 97 (386), 372-387.

Grünfeld, L.A. (2003), Meet me Halfway but don't Rush: Absorptive Capacity and Strategic R&D Investment Revisited, *International Journal of Industrial Organization* 21 (8), 1091-1109.

Hagedoorn, J. (1993), Understanding the Rationale of Strategic Technology Partnering: Interorganizational Modes of Cooperation and Sectoral Differences, *Strategic Management Journal* 14 (5), 371-385.

Hagedoorn, J. (1995), A Note on International Market Leaders and Networks of Strategic Technology Partnering, *Strategic Management Journal* 16 (3), 241-250.

Hagedoorn, J. (2002), Inter-firm R&D Partnership: An Overview of Major Trends and Patterns since 1960, *Research Policy* 31 (4), 477-492.

Hagedoorn, J., A.N. Link and N.S. Vonortas (2000), Research Partnerships, *Research Policy* 29 (4-5), 567-586.

Hagedoorn, J. and Schankenraad (1989), Strategic Partnering and Technological Cooperation, in: Dankenbaar, B., J. Groenewegen and H. Schenk (eds.), *Perspectives in Industrial Economics*, Kluwer Academic Publishers, Dordrecht, 171-191.

Hajivassiliou, V.A., D.L. McFadden and P. Ruud (1996), Simulation of Multivariate Normal Rectangle Probabilities and Their Derivatives: Theoretical and Computational Results, *Journal of Econometrics* 72 (1-2), 85-134.

Hall, B. and J. Mairesse (1995), Exploring the Relationship between R&D and Productivity in French Manufacturing Firms*, Journal of Econometrics* 65 (1), 263-294.

Hamel, G. (1991), Competition for Competence and Inter-Partner Learning within International Strategic Alliances*, Strategic Management Journal* 12 (Summer Special Issue), 83-103.

Hanusch, H. and U. Cantner (1993), Neuere Ansätze der Innovationstheorie und der Theorie des technischen Wanndels - Konsequenzen für eine Industrie- und Technologiepolitik, in: Meyer-Krahmer, F. (ed.), *Innovationsökonomie und Technologiepolitik - Forschungsansätze und politische Konsequenzen*, Physica Verlag, Heidelberg, 11-46.

Harabi, N. (1995), Appropriability of Technological Innovations - An Empirical Analysis*, Research Policy* 24 (6), 981-992.

Harabi, N. (1997), Channels of R&D Spillovers: An Empirical Investigation of Swiss firms.*, Technovation* 17 (11/12), 627-635.

Hennart, J.-F. (1988), A Transaction Costs Theory of Equity Joint Ventures*, Strategic Management Journal* 9 (4), 361-374.

Hernan, R., P.L. Marin and G. Siotis (2003), An Empirical Evaluation of the Determinants of Research Joint Venture Formation*, The Journal of Industrial Economics* 51 (1), 75-89.

Hinloopen, J. (1997), Subsidizing Cooperative and Noncooperative R&D in Duopoly with Spillovers*, Journal of Economics* 66 (2), 151-175.

Hussinger, K. (2006), Is Silence Golden? Patents versus Secrecy at the Firm Level*, Economics of Innovation and New Technology* 15 (6), forthcoming.

Inkmann, J. (2000), *Horizontal and Vertical R&D Cooperation,* CoFE-Discussion Paper No. 00-02, Konstanz.

Inkmann, J. and W. Pohlmeier (1995), *R&D Spillovers, Technological Distance and Innovation Success,* University of Konstanz, mimeo.

Jaffe, A.B. (1986), Technological Opportunity and Spillovers of R&D: Evidence from Firm's Patent, Profits, and Market Value*, American Economic Review* 76 (5), 984-1001.

Jaffe, A.B. (1988), Demand and Supply Influences in R&D Intensity and Productivity Growth*, Review of Economics and Statistics* 70 (3), 431-437.

Jaffe, A.B. (1996), *Economic Analysis of Research Spillovers - Implications for the Advanced Technology Program. A Report Prepared for the Advanced Technology Program*, Brandeis University and NBER, Washington.

Jaffe, A.B. and M. Trajtenberg (1999), International Knowledge Flows: Evidence from Patent Citations*, Economics of Innovation & New Technology* 8 (1/2), 105-137.

Jaffe, A.B., M. Trajtenberg and R. Henderson (1993), Geographic Localization of Knowledge Spillovers as Evidenced by Patent Citations*, The Quarterly Journal of Economics* 108 (3), 577-599.

Janz, N., G. Ebling, S. Gottschalk and H. Niggemann (2001), The Mannheim Innovation Panels (MIP and MIP-S) of the Centre for European Economic Research (ZEW)*, Journal of Applied Social Science Studies* 121 (1), 123-129.

Janz, N., G. Ebling, S. Gottschalk and B. Peters (2002), Die Mannheimer Innovationspanels*, Allgemeines Statistisches Archiv* 86 (2), 189-201.

Janz, N., G. Ebling, S. Gottschalk, B. Peters and T. Schmidt (2003), Die Mannheimer Innovationspanels: Datenerhebung und Nutzung, in: Janz, N. and G. Licht (eds.), *Innovationsforschung heute*, Nomos, Baden-Baden, 9-16.

Janz, N. and G. Licht (2003), *Innovationsforschung heute*, ZEW Wirtschaftsanalysen, Vol. Bd. 63, Baden-Baden.

Jones, O. and M. Craven (2001), *Absorptive Capacity and New Organisational Capabilities: A TCS Case Study,* Manchester Metropolitan University Business School Working Paper Series No. 01/02, Manchester.

Kaiser, U. (2000), *Research Cooperation and Research Expenditures with Endogenous Spillovers: Theory and Microeconometric Evidence for the German Service Sector,* ZEW Discussion Paper No. 00-25, Mannheim.

Kaiser, U. (2002a), An Empirical Test of Models Explaining Research Expenditures and Research Cooperation: Evidence for the German Service Sector, *International Journal of Industrial Organization* 20 (6), 747-774.

Kaiser, U. (2002b), Measuring Knowledge Spillovers in Manufacturing and Services: An Empirical Assessment of Alternative Approaches, *Research Policy* 31 (1), 125-44.

Kaiser, U. and G. Licht (1998), *R&D Cooperation and R&D Intensity: Theory and Micro–Econometric Evidence for German Manufacturing Industries,* ZEW Discussion Paper No. 98-32, Mannheim.

Kamien, M.I., E. Muller and I. Zang (1992), Research Joint Ventures and R&D Cartels, *American Economic Review* 82 (5), 1293-1306.

Kamien, M.I. and I. Zang (2000), Meet me Halfway: Research Joint Ventures and Absorptive Capacity, *International Journal of Industrial Organization* 18 (7), 995-1012.

Katsoulacos, Y. and D. Ulph (1990), R&D Rivalry Under Product Differentiation, *Journal of Economic Literature* 28 (1), 1-31.

Katsoulacos, Y. and D. Ulph (1997), Technology Policy: A Selective Review with Emphasis on European Policy and the Role of RJVs, in: Poyago-Theotoky, J. A. (ed.), *Competition, Cooperation, Research and Develepement: The Economics of Research Joint Ventures*, Macmillan Press, London, 13-38.

Katsoulacos, Y. and D. Ulph (1998), Endogenous Spillovers and the performance of Research Joint Ventures, *Journal of Industrial Economics* 46 (3), 333-357.

Katz, M.L. (1986), An Analysis of Cooperative Research and Development, *RAND Journal of Economics* 17 (4), 527-543.

Keller, W. (2002), Geographical Localization of International Technology Diffusion, *American Economic Review* 92 (1), 120-140.

Kennedy, P. (1998), *A Guide to Econometrics*, MIT Press, Cambridge, USA.

Kesteloot, K. and R. Veugelers (1994), Stable R&D Cooperation with Spillovers, *Journal of Economics and Management Strategy* 4 (4), 651-672.

Killing, J.P. (1988), Understanding Alliances: The Role of Task and Organizational Complexity, in: Farok, J., P. Contractor and P. Lorange (eds.), *Cooperative Strategies in International Business*, Lexington Books, Lexington, MA.

Kogut, B. (1988), Joint Ventures: Theoretical and Empirical Perspectives, *Strategic Management Journal* 9 (4), 319-332.

Kogut, R. and U. Zander (1992), Knowledge of the Firm, Combinative Capabilities and the Replication of Technology, *Organization Science* 33 (3), 383-397.

König, H. and G. Licht (1995), Patents, R&D and Innovation, Evidence from the Mannheim Innovation Panel, *ifo Studien* 41, 521-543.

König, H., G. Licht and M. Staat (1994), F&E-Kooperationen und Innovationsaktivität, in: Gahlen, B., H. Hesse and H. J. Ramser (eds.), *Schriftenreihe des wirtschaftswissenschaftlichen Seminars Ottobeuren Band 23*, Tübingen, 219-242.

Krugman, P. (1991), *Geography and Trade*, MIT Press, Cambridge, MA.

Kultti, K., T. Takalo and J. Toikka (2002), *Secrecy vs. Patenting,* University of Helsinki Working Paper No. 7552, Helsinki.

Lane, P.J., B. Koka and S. Pathak (2002), A Thematic Analysis and Critical Assessment of Absorptive Capacity Research, *Academy of Management Proceedings*, M1.

Lane, P.J. and M. Lubatkin (1998), Relative Absorptive Capacity and Inter-Organizational Learning, *Strategic Management Journal* 19 (5), 461-477.

Laursen, K. and A. Salter (2005), *My Precious - The Role of Appropriability Strategies in Shaping Innovation Performance,* DRUID Working Paper No. 05-02, Frederiksberg, Denmark.

Leahy, D. and J.P. Neary (1997), Public Policy Towards R&D in Oligopolistic Industries*, American Economic Review* 87 (4), 642-662.

Leahy, D. and J.P. Neary (2004), *Absorptive Capacity, R&D Spillovers and Public Policy,* CEPR Discussion Papers No. 4171, London.

Lenox, M. and A. King (2004), Prospects for Developing Absorptive Capacity through Internal Information Provision*, Strategic Management Journal* 25 (4), 331-345.

Levin, R.C., A.K. Klevorick, R.R. Nelson and S.G. Winter (1987), *Appropriating the Returns from Industrial Research and Development,* Brookings Paper on Economic Activity No. 3, Washington.

Levin, R.C. and P.C. Reiss (1984), Test of a Schumpeterian Model of R&D and Market Structure, in: Griliches, Z. (ed.), *R&D, Patents, and Productivity*, Chicago University Press, Chicago, 538-556.

Levin, R.C. and P.C. Reiss (1988), Cost-Reducing and Demand-Creating R&D with Spillovers*, RAND Journal of Economics* 19 (4), 538-556.

Lhuillery, S. and F. Galia (2006), *The R&D Kiss of Death: Empirical Evidence on Failed Cooperation,* CEMI-Rreport No. 2006-005, Lausanne.

Liebeskind, J.P. (1997), Keeping Organizational Secrets: Protective Institutional Mechanisms and their Costs*, Industrial and Corporate Change* 6 (3), 623-663.

Lim, K. (2004), *The Many Faces of Absorptive Capacity: Spillovers of Copper Interconnect Technology for Semiconductor Chips,* MIT Sloan School of Management No. 4110, Cambridge, MA.

Link, A.N. and L.L. Bauer (1987), An Economic Analysis of Co-operative Research*, Technovation* 6, 247-260.

Link, A.N. and L.L. Bauer (1989), *Cooperative R&D in U.S. manufacturing*, Lexington Books, Lexington.

Lopez, A. (2004), *Determinants for R&D Cooperation: Evidence from Spanish manufacturing firms,* mimeo, Madrid.

Los, B. and B. Verspagen (2000), R&D Spillovers and Productivity: Evidence from U.S. manufacturing microdata*, Empirical Economics* 25 (1), 127-148.

Lundvall, B.-A. (1988), Innovation as an Interactive Process: From User-Producer Interaction to the National System of Innovation, in: Soete, L. (ed.), *Technological Change and Economic Theory*, Pinter Publishers, London, 349-369.

Mahnke, V., T. Pedersen and M. Venzin (2005), The Impact of Knowledge Management on MNC Subsidiary Performance: The Role of Absorptive Capacity*, Journal of International Business* (forthcoming).

Malchup, F. and E. Penrose (1950), The Patent Controversy in the Nineteenth Century*, The Journal of Economic History* 10 (1), 1-29.

Mansfield, E. (1998), Academic Research and Industrial Innovation: An Update of Empirical Findings*, Research Policy* 26 (7-8), 773-776.

Mansfield, E., M. Schwartz and S. Wagner (1981), Imitation Costs And Patents: An Empirical Study*, The Economic Journal* 91, 907-918.

Mariti, P. and R.H. Smiley (1983), Co-operative Agreements and the Organization of Industry*, Journal of Industrial Economics* 31 (4), 437-451.

Markiewicz, K.R. (2003), *University Patenting and the Rate of Knowledge Exploitation,* Academy of Management Best Papers and Proceedings, August 2003, Seattle, USA.

Marshall, A. (1920), *Principle of Economics*, Macmillan, London.

Martin, S. (2002), Spillovers, Appropriability, and R&D*, Journal of Economics* 75 (1), 1-32.

Maurseth, P.B. and B. Verspagen (2002), Knowledge Spillovers in Europe: A Patent Citations Analysis*, Scandinavian Journal of Economics* 104 (4), 531-545.

Miotti, L. and F. Sachwald (2003), Cooperative R&D: Why and with Whom? An Integrated Framework Analysis, *Research Policy* 32 (8), 1481-1499.

Mohnen, P., I.M. Nadiri and I. Prucha (1986), R&D, Production Structure and Productivity Growth in the US, Japanese and German Manufacturing Sectors, *European Economic Review* 30 (4), 749-772.

Monjon, S. and P. Waelbroeck (2003), Assessing Spillovers from Universities to firms: Evidence from French firm-level data, *International Journal of Industrial Organization* 21 (9), 1255-1270.

Motta, M. (1992), Cooperative R&D and Vertical product differentiation, *International Journal of Industrial Organization* 10 (4), 643-661.

Mowery, D., J.E. Oxley and B.S. Silverman (1998), Technological Overlap and Interfirm Cooperation: Implications for the Resource-Based View of the Firm, *Research Policy* 27 (5), 507-523.

Mowery, D.C. and J.E. Oxley (1995), Inward Technology Transfer and Competitiveness: The Role of National Innovation Systems, *Cambridge Journal of Economics* 19, 67-93.

Mukherjee, A., W. Mitchell and F.B. Talbot (2000), The Impact of New Manufacturing Requirements on Production Line Capacity and Quality at a Focused Factory, *Journal of Operations Management* 18, 139-168.

Nadiri, I.M. (1993), *Innovations and Technological Spillovers,* NBER Working Paper No. 4423, Cambridge, MA.

Narula, R. (2004), *Understanding Absorptive Capacity in an "Innovation System" Context: Consequences for Economic and Employment Growth,* MERIT-Infonomics Research Memorandum series No. 3, Maastricht.

Negassi, S. (2004), R&D co-operation and innovation a microeconometric study on French firms, *Research Policy* 33 (3), 365-384.

Nelson, R. (1989), What is Private and what is Public about Technology?, *Science, Technology & Human Values* 14 (3), 229-241.

Nelson, R.R. (1959), The Simple Economics of Basic Scientific Research, *Journal of Political Economy* 67 (3), 297-306.

Nelson, R.R. and E.N. Wolff (1997), Factors behind Cross-Industry Differences in Technological Progress*, Structural Change and Economic Dynamics* 8 (2), 205-220.

Nonaka, I. and H. Takeuchi (1995), *The knowledge-creating company*, Oxford University Press, New York.

OECD (1996), *Technological Cooperation Agreements between Firms: Some Initial Data and Analysis*, Paris.

OECD (2003), *The OECD Research and Development Expenditure in Industry database, 1987-2001*, Paris.

OECD and Eurostat (1997), *Oslo Manual - Proposed Guidelines for Collecting and Interpreting Technological Innovation Data*, Paris.

OECD and Eurostat (2005), *Oslo Manual - Proposed Guidelines for Collecting and Interpreting Technological Innovation Data - 3rd Edition*, Paris.

Oltra, M.J. and M. Flor (2003), The Impact of Technological Opportunities and Innovative Capabilities on Firms' Output Innovation*, Creativity & Innovation Management* 12 (3), 137.

Orlando, M.J. (2004), Measuring spillovers from industrial R&D: On the importance of geographic and technological proximity*, RAND Journal of Economics* 35 (4), 777-786.

Overby, M.L. (2005), *Partner Selection Criteria in Strategic Alliances: When to Ally with Weak Partners,* DRUID Working Paper No. 05-07, Copenhagen.

Penrose, E. (1959), *The Theory of the Growth of the Firm*, Blackwell, Oxford.

Peri, G. (2005), Determinants of Knowledge Flows and their Effect on Innovation*, The Review of Economics and Statistics* 87 (2), 308-322.

Peters, M.A. (2003), Education Policy in the Age of Knowledge Capitalism*, Policy Futures in Education* 1 (2), 361-380.

Philips (2006a), *Beethoven's Ninth Symphony of Greater Importance than Technology* (Source: http://www.research.philips.com/newscenter/dossier/optrec/beethoven.html), downloaded: July 19th, 2006.

Philips (2006b), *The Inventor of the CD* (Source: http://www.research.philips.com/newscenter/dossier/optrec/index.html), downloaded: July 19th, 2006.

Piga, C. and M. Vivarelli (2003), Sample Selection in Estimating the Determinants of Cooperative R&D*, Applied Economics Letters* 10 (4), 243-246.

Pisano, G.P. (1990), The R&D Boundaries of the Firm: An Empirical Analysis*, Administrative Science Quarterly* 35 (1), 153-176.

Polanyi, M. (1967), *The tacit dimension*, Doubleday & Co., Garden City, NY.

Porter, M.E. and S. Stern (2000), *Measuring the "Ideas" Production Function: Evidence From International Patent Output,* NBER Working Paper Series No. 7891, Washington, D.C.

Poyago-Theotoky, J. (1995), Equilibrium and Optimal Size of a Research Joint Venture in an Oligopoly with Spillovers*, Journal of Industrial Economics* 43 (2), 209-226.

Prahalad, C.K. and G. Hamel (1990), The Core Competence of the Corporation*, Harvard Business Review* 68 (3), 79-91.

Qiu, L.D. and Z. Tao (1998), Policy on International R&D Cooperation: Subsidy or Tax? - Implications for Competition and Antitrust*, European Economic Review* 42 (9), 1727-1750.

Ragnitz, J., D. Czarnitzki, D. Engel, T. Hagen, G. Licht, A. Spermann and A. Spielkamp (2003), *Zweiter Fortschrittsbericht wirtschaftswissenschaftlicher Institute über die wirtschaftliche Entwicklung in Ostdeutschland,* Sonderheft Institut für Wirtschaftsforschung Halle No. 7/2003, Halle.

Rammer, C. (2003), The Chemical Industry as Driver for Innovation in Other Industries, in: Dröscher, M., G. Festel and M. Jager (eds.), *The Power of Innovations, How Innovations can Electricize the Chemical Industry*, Aachen, 50-66.

Rammer, C., B. Aschhoff, T. Doherr, B. Peters and T. Schmidt (2005a), *Innovationsverhalten der deutschen Wirtschaft - Indikatorenbericht zur Innovationserhebung 2004,* ZEW / Infas, Mannheim.

Rammer, C., E. Müller, D. Heger, B. Aschhoff, V. Zimmermann and F. Reize (2005b), Innovationspotentiale und -hemmnisse unterschiedlicher Gruppen von KMU., *Schwerpunktstudie zur technologischen Leistungsfähigkeit Deutschlands im Auftrag des bmb+f*, ZEW Mannheim and KFW-Bankengruppe, Mannheim and Frankfurt/Main.

Rammer, C., B. Peters, T. Schmidt, B. Aschhoff, T. Doherr and H. Niggemann (2005c), *Innovationen in Deutschland - Ergebnisse der Innovationserhebung 2003 in der deutschen Wirtschaft*, ZEW Wirtschaftsanalysen Band 78, Nomos Verlagsgesellschaft, Baden-Baden.

Rammer, C., B. Peters, T. Schmidt and T. Doherr (2004), *Innovationsverhalten der deutschen Wirtschaft - Indikatorenbericht zur Innovationserhebung 2003*, ZEW Mannheim, Mannheim.

Reinganum, J.F. (1981), Dynamic Games of Innovation*, Journal of Economic Theory* 25 (1), 21-41.

Reinganum, J.F. (1989), The Timing of Innovation: Research, Development, and Diffusion, in: Schmalensee, R. and R. D. Willig (eds.), *Handbook of Industrial Organization - Volume 1*, North-Holland, New York, 849-908.

Richardson, G.B. (1972), The Organisation of Industry*, The Economic Journal* 82 (327), 883-896.

Rocha, F. (1999), Inter-firm technological Cooperation: Effects of absorptive capacity, firm-size and specialization*, Economics of Innovation & New Technology* 8 (3), 253.

Romer, P.M. (1986), Increasing Returns and Long-Run Growth*, Journal of Political Economy* 94 (5), 1002-1036.

Romer, P.M. (1990), Endogenous Technological Change*, Journal of Political Economy* 98 (5), 71-102.

Rosen, H.S. (2002), *Public Finance*, McGraw-Hill, New York.

Rosenkranz, S. (1995), Innovation and Cooperation under Vertical Product Differentiation*, International Journal of Industrial Organization* 13 (1), 1-22.

Rothwell, R. and M. Dodgson (1991), External linkages and innovation in small and medium-sized enterprises, *R&D Management* 21, 125-137.

Rouvinen, P. (2002), Characteristics of Product and Process Innovators: Some Evidence from the Finnish Innovation Survey, *Applied Economics Letters* 9 (9), 575-580.

Ruff, L.E. (1969), Research and Technological Progress in a Cournot Economy, *Journal of Economic Theory* 1 (4), 397-415.

Sakakibara, M. (1997), Heterogeneity of Firm Capabilities and Cooperative Research and Development: An Empirical Examination of Motives, *Strategic Management Journal* 18 (6), 143-165.

Samuelson, P.A. (1954), The Pure Theory of Public Expenditure, *The Review of Economics and Statistics* 36 (4), 387-389.

Schartinger, D., A. Schibany and H. Gassler (2001), Interactive Relations between Universities and Firms: Empirical Evidence for Austria, *Journal of Technology Transfer* 26 (3), 255-68.

Schmidt, T. (2004), *ZEW Branchenreport Innovationen,* ZEW Branchenreport Innovationen No. 1-22, Mannheim.

Schmidt, T. (2005a), *Absorptive Capacity - One Size Fits All? A Firm-level Analysis of Absorptive Capacity for Different Kinds of Knowledge,* ZEW Discussion Paper No. 05-72, Mannheim.

Schmidt, T. (2005b), *Knowledge Flows and R&D Co-operation: Firm-Level Evidence from Germany,* ZEW Discussion Paper No. 5-22, Mannheim.

Schmidt, T. (2006), *An Empirical Analysis of the Effects of Patents and Secrecy on Knowledge Spillovers,* ZEW Discusssion Paper No. 06-048, Mannheim.

Schmidt, T., B. Aschhoff, T. Doherr, S. Gottschalk, H. Löhlein, B. Peters and C. Rammer (2005), Das Mannheimer Innovationspanel (MIP): Innovationsaktivitäten der deutschen Wirtschaft, in: Ellendorfer, I. and U. Fahl (eds.), *Ansätze zur Modellierung von Innovationen in der Energiewirtschaft*, BWMA and IER Hohenheim, Bonn, 31-38.

Siebert, R. (1996), *The Impact of Research Joint Ventures on Firm Performance: An Empirical Assessment,* WZB Discussion Paper No. FS IV 96-3, Berlin.

Simpson, D.R. and N.S. Vonortas (1994), Cournot Equilibrium with Imperfectly Appropriable R&D*, Journal of Industrial Economics* 42 (1), 79-92.

Smith, W., E. Graversen, B. Damm and J. Overgaard (2001), *International Research Cooperation, Spillovers and Competition,* The Danish Institute for Studies in Research and Policy Working Paper No. 2001/1, Aarhus.

Sofka, W. and T. Schmidt (2004), *I Like The Way You Move: An Empirical Investigation into the Mechanisms Behind First Mover and Follower Strategies,* ZEW Discussion Paper No. 04-87, Mannheim.

Spence, M. (1984), Cost Reduction, Competition, and Industry Performance*, Econometrica* 52 (1), 101-121.

Statistisches Bundesamt (2004), *Ad Hoc Befragung über Unternehmenskooperationen - Eine Pilotstudie im Auftrag von Eurostat Berichtsjahr 2003*, Statistisches Bundesamt, Wiesbaden.

Steurs, G. (1995), Inter-Industry R&D Spillovers: What Difference do they Make?*, International Journal of Industrial Organization* 13, 249-276.

Stewart, M.B. (1983), Noncooperative Oligopoly and Pre-emptive Innovation Without Winner-Take-All*, The Quarterly Journal of Economics* 98 (4), 681-694.

Stifterverband für die Deutsche Wissenschaft-Wissenschaftsstatistik (2005), *FuE-Info 1/2005*, Essen.

Stiglitz, J.E. (1999a), Knowledge as a Global Public Good, in: Stern, M. A. (ed.), *Global Public Goods*, Oxford University Press, Oxford, NY, 308-325.

Stiglitz, J.E. (1999b), *Public Policy for a Knowledge Economy,* Speech at the Department of Trade and Industry and CEPR on January 27, 1999, London, UK.

Stock, G.N., N.P. Greis and W.A. Fischer (2001), Absorptive Capacity and New Product Development*, Journal of High Technology Management Research* 12 (1), 77.

Stuart, T.E. (1998), Network Positions and Propensity to Collaborate: An Investigation of Stratigic Alliance Formation in a High-Technology Industry, *Administrative Science Quarterly* 43 (3), 668-698.

Suzumura, K. (1992), Cooperative and Noncooperative R&D in an Oligopoly with Spillovers, *American Economic Review* 82 (5), 1307-1320.

Teece, D.J. (1986), Profiting from Technological Innovation: Implications for Integration, Collaboration, Licensing and Public Policy, *Research Policy* 15 (6), 285-305.

Teece, D.J. (1992), Competition, Cooperation, and Innovation: Organizational Arrangements for Regimes of Rapid Technological Progress, *Journal of Economic Behaviour and Organization* 18 (1), 1-30.

Terleckyj, N.E. (1974), *Effects of R&D on the Productivity Growth of Industries: An Explanatory Study*, National Planning Association, National Planing Association, Washington, D.C.

Tether, B. (2002), Who Co-operates for Innovation, and Why: An Empirical Analysis, *Research Policy* 31 (6), 947-967.

Tsang, E.W.K. (2000), Transaction Cost and Resource-based Explanations of Joint Ventures: A Comparison and Synthesis, *Organizational Studies* 21 (1), 215-242.

Van Den Bosch, F.A.J., R. Van Wijk and H.W. Volberda (2003), Absorptive Capacity: Antecedents, Models, and Outcomes., *Blackwell Handbook of Organizational Learning & Knowledge Management*, 278-301.

Van Den Bosch, F.A.J., H.W. Volberda and M. De Boer (1999), Coevolution of Firm Absorptive Capacity and Knowledge Environment: Organizational Forms and Combinative Capabilities., *Organization Science: A Journal of the Institute of Management Sciences* 10 (5), 551.

Veugelers, R. (1997), Internal R&D Expenditures and External Technology Sourcing, *Research Policy* 26 (3), 303-315.

Veugelers, R. (1998), Collaboration in R&D: An Assessment of Theoretical and Empirical Findings, *De Economist* 146 (3), 419-443.

Veugelers, R. and B. Cassiman (2005), R&D Cooperation between Firms and Universities. Some Empirical Evidence from Belgian Manufacturing, *International Journal of Industrial Organization* 23 (5/6), 355-379.

Veugelers, R. and R. de Bondt (1992), Cooperative Innovative Activities, in: Antonelli, C. (ed.), *The Economics of Information Networks*, North Holland, Amsterdam.

Veugelers, R. and D.B. Koen (1999), *Access to External Knowledge: An Empirical Analysis of Alliances as Spillover Channel,* mimeo

Vickers, J. (1985), Pre-emptive Patenting, Joint Ventures and the Persistance of Oligopoly, *International Journal of Industrial Organization* 3 (3), 261-273.

Vinding, A.L. (2000), *Absorptive Capacity and Innovation performance: A human capital approach.,* Department of Business Studies-DRUID/IKE Group, Aalborg University, Denmark.

Von Graevenitz, G. (2004), *Spillovers Reconsidered: How Optimal R&D Subsidies Depend on the Spillover Process,* mimeo

Von Hippel, E. (1988), *The Sources of Innovation*, Oxford University Press, New York.

Vonortas, N.S. (1994), Inter-firm Cooperation with Imperfectly Appropriable Research, *International Journal of Industrial Organization* 12 (3), 413-435.

Welsch, H., J. Liao and M. Stoica (2001), *Absorptive capacity and firm responsiveness: An empirical investigation of growth-oriented firms.,* Procceedings of: 2nd USASBE/SBIDA Conference, An Entrepreneurial Odyssey, Orlando, USA.

Wernerfelt, B. (1984), A Resource-Based View of the Firm, *Strategic Management Journal* 5 (2), 171-180.

Wiethaus, L. (2005), Cooperation or Competition in R&D when Innovation and Absorption are Costly, *Economics of Innovation and New Technology*, forthcoming.

Williamson, O.E. (1967), Hierarchical control and the optimum firm size, *Journal of Political Economy* 75 (2), 123-138.

Williamson, O.E. (1975), *Markets and Hierarchies: Analysis and Antitrust Implications*, The Free Press, New York.

Williamson, O.E. (1985), *The Economic Institutions of Capitalism: Firms, Markets Relational Contracting*, The Free Press, New York.

Williamson, O.E. (1988), The Logic of Economic Organization, *Journal of Law, Economics, and Organization* 4 (1), 65-93.

Williamson, O.E. (1991), Comparative Economic Organisation: The Analysis of Discrete Structural Alternatives, *Administrative Science Quarterly* 36 (2), 269-296.

Wölfl, A. (1998), *Spillover Effects - An Incentive to Cooperate in R&D?,* IWH Discussion Paper No. 79, Halle.

Yi, S.-S. and H. Shin (2000), Endogenous formation of research coalitions with spillovers, *International Journal of Industrial Organization* 18 (2), 229-256.

Zahra, S.A. and G. George (2002), Absorptive Capacity: A Review and Reconceptualization, and Extension, *Academy of Management Review* 27 (2), 185-203.

Ziss, S. (1994), Strategic R&D with Spillovers, Collusion and Welfare, *Journal of Industrial Economics* 17 (4), 375-393.

Erklärung gemäß § 4 Abs. 1 Pkt. 3 PromO:

Hiermit erkläre ich,

1. dass mir die geltende Promotionsordnung bekannt ist;

2. dass ich die Dissertation selbst angefertigt und alle von mir benutzten Hilfsmittel und Quellen in meiner Arbeit angegeben habe;

3. dass ich bei der Auswahl und Auswertung des Materials sowie bei der Herstellung des Manuskriptes keine fremde Hilfe in Anspruch genommen habe;

4. dass ich nicht die Hilfe eines Promotionsberaters in Anspruch genommen habe und dass Dritte weder unmittelbar noch mittelbar geldwerte Leistungen von mir für Arbeiten erhalten haben, die im Zusammenhang mit dem Inhalt der vorgelegten Dissertation stehen;

5. dass ich die Dissertation noch nicht als Prüfungsarbeit für eine staatliche oder andere wissenschaftliche Prüfung eingereicht habe;

dass ich nicht die gleiche, eine in wesentlichen Teilen ähnliche oder eine andere Abhandlung bei einer anderen Hochschule bzw. anderen Fakultät als Dissertation eingereicht habe.

Mannheim, den ----------------------------

(Tobias Schmidt)

Tabellarischer Lebenslauf des Autors

Dipl.oec. Tobias Schmidt, M.A. (WSU)

Wupperstraße 15

68167 Mannheim

Tel: 0621 – 397 405 4

Fax: 0621 – 123 542 35

E-Mail: Schmidt@zew.de

P e r s ö n l i c h e A n g a b e n

Staatsangehörigkeit:	Deutsch
Geburtsdatum:	9. August 1975
Geburtsort:	Erlangen
Familienstand:	Verheiratet, Eine Tochter

A u s b i l d u n g

Aug 2004 -	**Friedrich Schiller Universität Jena** Externer Doktorand am Lehrstuhl von Prof. Dr. Uwe Cantner
Sep 1999 - Mai 2000	**Wayne State University (WSU)** Detroit, Michigan, USA *Abschluss: Master of Arts in Economics (GPA: 3,79 ≈ Note: 1,3)*
Okt 1996 - Mär 2002	**Universität Augsburg** Schwerpunkte: Innovationsökonomik und Wirtschaftsinformatik Abschluss: Diplomökonom (Note: 1,33)
Sep 1986 - Jun 1995	**Simon-Marius-Gymnasium Gunzenhausen** *Abschluss: Abitur (Note:2,1)*

Stipendien und Auszeichnungen

Nov 2002	**Diplomarbeitspreis der PCI Augsburg GmbH**
Jan 2000 - Dez 2000	**Heilsbronner Stipendienfonds**
Sep 1999 - Apr 2000	**DAAD Auslandsstudium**
Apr 1998 - Sep 2001	**Rheinstahlstiftung**

Berufserfahrung

Okt 2001 -	**Zentrum für Europäische Wirtschaftsforschung (ZEW)** Mannheim *Abteilung: Industrieökonomik und Internationale Unternehmensführung*
Feb 2001 - Apr 2001	**HypoVereinsbank AG** München *Praktikum in der Abteilung Volkswirtschaft*
Aug 1998 - Okt 1998	**LOCO s.r.o.** Trenčin, Slowakei *Praktikum*

Laufende und abgeschlossene Projekte

Aug 2006	**Gemeinschaftliche Innovationserhebung 2006: Anwendung der 3. Auflage des Oslo Manuals (2005) auf den CIS – eine explorative Untersuchung**
Jun 2005 –	**Zur technologischen Leistungsfähigkeit der deutschen Umweltwirtschaft im internationalen Vergleich**
Okt 2002 –	**Indikatorenbericht zur technologischen Leistungsfähigkeit Deutschlands**
Okt 2001 –	**Mannheimer Innovationspanel: Innovationsaktivitäten der deutschen Wirtschaft**
Jun 2004 – Nov 2004	**Eignung von Strukturindikatoren als Instrument zur Bewertung der ökonomischen Performance der EU-Mitgliedstaaten**
Nov 2003 – Dez 2004	**Innovation und Beschäftigung in Europäischen Unternehmen (IEEF)**
Sep 2003 – Sep 2003	**Innovationsaktivitäten niedersächsischer Unternehmen 1999-2001**

Mär 2001 – Dez 2003	**Dritte Innovationserhebung in der Europäischen Gemeinschaft (CIS 3)**

B e r a t e n d e T ä t i g k e i t e n u n d M i t g l i e d s c h a f t e n

Projektbezogene Tätigkeiten:

Jan 2007 –	**Mitglied der "National Experts on Science and Technology Indicators Group (NESTI)"** OECD
Feb 2006 –	**Mitglied der "Task Force for the Preparation of the Community Innovation Survey 2006"** Eurostat
Nov 2003 – Jun 2005	**Mitglied der "Oslo Manual Revision Task Force"** OECD/Eurostat
Nov 2003 – Mai 2005	**Mitglied der "Task Force for the Preparation of the 4th Community Innovation Survey (CIS IV)"** Eurostat
Nov 2003 –	**Mitglied der "Working Party on Science, Technology and Innovation (STI) Statistics"** Eurostat

Wissenschaftliche Tätigkeiten:

Mai 2007	**Referee für "R&D Management Journal"**
Feb 2007	**Referee für die Academy of International Business (AIB) Konferenz, Indianapolis, 2007**
Dez 2006	**Referee für „Research Policy"**
Jun 2006	**Referee für "Technovation"**
Feb 2006	**Referee für die Academy of International Business (AIB) Konferenz, Peking, 2006**
Dez 2005	**Referee für "Applied Economics Journal"**
Mai 2005 – Dez 2005	**Mitglied der Canadian Economic Association (CEA)**

Forschungsaufenthalte

Nov 2006 – Dez 2006	**Instituto Superior Técnico, IN+, Centre for Innovation, Technology and Policy Research** Empirische Analysen zu internationalen Kooperationen mit portugiesischen und deutschen Innovationsdaten Lissabon, Portugal
Sep 2006 – Nov 2006	**Statistics Canada** Empirische Analysen zu Kooperationsmotiven mit kanadischen Innovationsdaten Ottawa, Kanada

---

Fremdsprachen und Computerkenntnisse

Fremdsprachen:

Englisch
Verhandlungssicher

Spanisch
Grundlagen

Software:

STATA
Expertenwissen

Microsoft Office
Expertenwissen

Ehrenamtliches Engagement

Sep 2003 – Sep 2006	**Leiter der EC Jugendgruppe in Mannheim-Feudenheim** Ortsgruppe des Deutschen Jugendverbands "Entschieden für Christus" (EC) e.V.
Sep 2000	**Volunteer im „Pavillon der Hoffnung“ (EXPO 2000)** Pavillon der Hoffnung e.V.
Aug 1997 – Aug 2001	**Leiter der EC Jugendgruppe in Wassertrüdingen** Ortsgruppe des Deutschen Jugendverbands "Entschieden für Christus" (EC) e.V.

Mannheim, den

____

(Tobias Schmidt)