Technological Change and Interindustrial Linkages

Introducing Knowledge Flows in Input-Output Studies

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by

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Preface

This thesis has been underway since my enrollment as a phd student at the IKE Group in February 1996. There is no doubt that the past three and a half years have been a great learning experience. In particular the DISKO project has been very influential, and I draw on results of this project (published in Drejer, 1998) in several chapters. But also the different networks, which my relation to the IKE Group automatically introduced me to, have provided very important inputs to my work. The most important of these networks have been the ones related to the ETIC Doctoral Training Programme and the DRUID research unit, both being characterised by the ability to combine a high level of scientific interaction with a very nice social environment, always making ETIC and DRUID events something worth looking forward to.

I owe thanks to all my colleagues for making my phd enrollment a fruitful and happy (admittedly also sometimes a very frustrating) time. Special thanks go to my supervisor Esben Sloth Andersen, who has contributed with important new angles to my work; to the main driving force behind the IKE Group, Bengt-Åke Lundvall, who has given me the opportunity to be involved in several interesting projects, not least the DISKO project, while I have been working with the IKE Group; and to Christian DeBresson (UQAM) for taking me under his wings during my stay at University of Quebec in Montreal (UQAM) in 1997 - and for inviting me to meet the recently deceased Wassily Leontief, who has a central position in my work, in New York in April 1997. During my involvement in the DISKO project, Anker Lund Vinding, Lars L. Schmidt, Birgitte Hansen and Lone Nielsen were of excellent - primarily computational - assistance. The advisory board of the DISKO project contributed with useful comments on the design and findings of the project.

A particular word of gratitude goes to my phd colleagues, not least Keld Laursen and Frank Skov Kristensen, who have also been my co-authors in different settings. Keld also has the responsibility of introducing me to the IKE Group in 1991, while we were both still MA students, through offering me to join him as a co-worker in the process of editing what became the 1992-book on *National Systems of Innovation*. Jesper Lindgaard Christensen has provided valuable comments during the process, in particular in relation to the DISKO related work, and the work

Chapter 1: Introduction

The first step is to get an idea. That is not at all hard to do. The tricky part is to get a <u>good</u> idea (Varian, 1997).

1.1 The theoretical starting points

The subject of this thesis is interindustry relations studied from a knowledge and technology perspective.[1] The work places itself between two main research traditions. The first tradition is the 'input-output tradition' initiated by Wassily Leontief in the 1930's and 40's, while the second tradition was initiated by Joseph Schumpeter with his *Theory of Economic Development* originally published in German in 1911 (translated into English in 1934). I label this the 'technological change research tradition'.

The main theoretical question to be dealt with is *whether it is possible bridge the apparently large gap between the two above mentioned research traditions.*

One the one hand the Leontief tradition admittedly emphasises the importance of technology and technological change, but it works within a rather rigid, inherently static framework that only allows for a mechanistic perception of technology. Wassily Leontief started out as a student of the Russian balance of payment in 1925 (Leontief, 1925), but already in 1928 he introduced his notion of *The Economy as a Circular Flow* (Leontief, 1928; for an English translation see Leontief, 1991, with an introduction by Paul A. Samuelson). The relation between technology and economy is discussed already in the first paragraph of *The Economy as a Circular Flow*:

> *It is astonishing that in spite of all other disagreements, theorists of different persuasions seem to agree on one issue: that the separation between technology and the economy is an essential*

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[1]   The concepts 'knowledge' and 'technology ' are closely related, technology being perceived as a subelement of knowledge, i.e. technology is here defined as knowledge about technical processes and products.

precondition for economic theorizing. [...] For us, on the contrary, both 'technical' and 'economic' facts are established data which are used as a point of departure for further analysis (Leontief, 1991, p. 181).[2]

Leontief's notion of technology is often reduced to the coefficients expressing the input and output relations between industries, and in the Leontief framework the emphasis on structure has led to a neglect of a dynamic perception of technology (i.e. there is only room for a mechanistic technological change).

On the other hand there is a strong large emphasis on technological change, but little emphasis on structure, in the Schumpeterian tradition. Schumpeter is widely accepted as the father of evolutionary economics (see e.g. Hodgson, 1993). Schumpeter's major intellectual challenge was the explanation of economic development as driven by technological change (innovation). Just like Leontief, Schumpeter had a long productive life with a continuous development of his ideas about what were the major driving forces in economics. In Schumpeter's case this led scholars to make a distinction between the ideas of the young Schumpeter ("Schumpeter Mark I") and the older Schumpeter ("Schumpeter Mark II"), the major contrast between Mark I and Mark II being the importance ascribed to the individual (heroic) entrepreneur as opposed to the research departments within large companies (intrapreneurship).[3]

Schumpeter defines development as initiated from within the economic system (Schumpeter, 1934, p. 63). Development is a spontaneous, discontinuous change continuously disturbing equilibrium. The point of equilibrium will always be moving, and even though equilibrium is always an attractor, it will never be reached because of its continuously changing position. This is the mechanism through which technological change is driving economic development. The technology focus takes its point of departure in radical and unpredictable innovation, resulting

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[2] The original 1928-article on *Die Wirtschaft als Kreislauf* was translated (and abridged quite considerably) for the journal on *Structural Change and Economic Dynamics* in 1991. [...] indicates a passage that has been omitted in the translation.

[3] Langlois (1987) points out that the conflicting views on the role of the individual heroic entrepreneur can actually be found throughout all Schumpeter's work, so let me just compromise here by stating that there is a larger focus on the importance of the individual entrepreneur in Schumpeter's earlier works, while the role of large research labs is more in focus in the later works.

in what appears as a quite general or diffuse theory of endogenous technological change.

1.2   Approaching a set of research questions

The existence of a gap between the two research traditions has not been neglected on any of the two sides, and different attempts have been made to develop unifying frameworks. From the input-output tradition the most important contributions are those of Anne P. Carter, who works with both the upstream and downstream benefits of innovation (Carter, 1990) and with concepts such as 'metainvestment'[4] (Carter, 1994), and of Luigi Pasinetti, who analyses structural change and economic growth in models characterised by vertically integrated input-output sectors. Important contributions within the Schumpeterian tradition are to be found in Dahmén's development blocks as expressions of the dynamics of interrelations, Rosenberg's study of technological interdependence in the American economy, and Lundvall's user-producer framework for studying innovation. Although he can hardly be characterised as belonging to the Schumpeterian tradition, Schmookler has also contributed to a synthesis between the Schumpeterian and Leontief tradition through his considerations of the importance of progressive customers in product development. Another important contribution to establishing a conceptual bridge is found in development economics, with Hirschman's introduction of the linkage concept in the context of economic development.

The above mentioned scholars have tried to combine structure and technological innovation in different ways. Although the literature appears to be fragmented and not fully developed, several results have been produced in the last decades, which could motivate a new attempt to create a synthesis between the traditions of Leontief and Schumpeter. The synthesis presented in this thesis will be empirically founded, and can be combined under the notions of knowledge flows and knowledge linkages. The empirical orientation is based on the perception that theory without data is facing rapidly decreasing returns to scale. This is especially obvious when attempting to combine two areas of research with many opposing assumptions. Therefore the main emphasis is on preparing the ground for theoretical research and at the same time to suggest fruitful empirical investigations.

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[4]   Metainvestment is defined as investment in change in Carter (1994).

As a consequence of the above mentioned emphasis, the empirical research questions are mainly methodologically oriented, stemming from the major question: *how can the synthesis between the theoretical Leontief and Schumpeter traditions be incorporated in empirical measures of industrial interdependence*? Further, *what are the necessary empirical requirements for measuring technological linkages - and how is such a measure related to traditional input-output based measures*?

Finally a group of research questions are centred around the possible empirical results. These questions concern the identification of major technological interindustry relations: *what are the most important knowledge sources and receivers*? *What characterises these groups of industries*? *Can the empirical measures contribute to the understanding of user-producer relations*? And last but not least, *how can linkage measures be used in international comparative work*? In the present thesis we choose to answer the last question form a qualitative and quantitative perspective respectively, addressing the question first of *whether the mapping of linkages can contribute to the understanding of institutional differences between national systems of innovation*; and second, *how the existence of linkages affect the economic characteristics of a country, here expressed by export specialisation?*

Summing up, the research questions can be grouped into 3 main sets each at different levels:

Level 1:   What are the theoretical and conceptual requirements for building a bridge between the input-output (Leontief) and technological change (Schumpeter) research traditions?

Level 2:   What are the methodological requirements for creating a synthesis between the input-output and technological change traditions in empirical measures of industrial interdependence?

Level 3:   How does the empirical mapping and measurement of linkages contribute to characterising an economic system?

Below I will give an overview of how these questions are attempted to be answered in the subsequent chapters.

1.3   An overview of the structure and content

As illustrated above, the present work will approach industrial interdependence or linkages from different angles.[5] The thesis is primarily empirical, focussing on methods for identifying and interpreting technological interindustry relations. This is reflected in the fact that the theoretical and methodological starting point discussed in part I of the thesis also is closely related to empirical analysis. This is in accordance with Leontief, who throughout his very long career kept on insisting that theoretical and empirical work should go hand in hand:

> *The engine of economic theory has reached, in the last twenty years, a high degree of internal perfection and has been turning over with much sound and fury. If the advance of economics as an empirical science is still rather slow and uncertain, the lack of sustained contact between the wheels of theory and the hard facts of reality is mainly to blame* (Leontief, 1953, p. 4).

The theoretical foundation for the study of technological interdependence and the role of interdependence in technological development has been quite weak, which probably is characteristic for an emerging scientific field - and the attempt to endogenise technological change in interindustry relations must be characterised as being still in its infancy.

The present thesis does not claim to bring neither input-output nor innovation theory much further. Rather the contribution lies in the link it establishes between interdependence studies, as expressed in traditional input-output theory, and contemporary studies of the role of interdependence in technological change. This link has been largely ignored, based on the inherently static nature of input-output analysis. Just as Leontief's 'dynamic' input-output analysis was only a more complex method for comparative statics than traditional static input-output analysis, the present analysis remains static. But my claim is that the static analysis is helpful in

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[5]   The two concepts are largely used interchangeably, with 'linkages' having a bias towards a reference to input-output based calculations of industrial interdependencies.

identifying the most dynamic areas in economic space by pointing to areas combining intense economic transactions with a high knowledge level.

The thesis is divided into three main analytical parts, and a fourth part with a conclusion and a policy perspective on the linkage approach: part I, consisting of chapters 2 and 3, offers the theoretical and methodological starting point, while part II, consisting of chapters 4 and 5, presents empirical applications of linkage studies based on Danish data. The nationally oriented empirical chapters of part II are supplemented by chapters 6 and 7 in part III, which apply the linkage analysis to international comparisons. This division into parts largely reflects the levels of the research questions presented in the previous section.

Part I presents the 'playing field' for the analysis by introducing some slight alterations of traditional input-output and linkage expressions, which make it possible to include explicitly the role pf technology and knowledge into the analysis. Thus the theoretical and methodological considerations of part I serve as a foundation for the empirical work of part II and III, and constitutes the general reference point of the following chapters. Additionally, part I provides an overview of the history of economic thought in relation to interdependency studies.

Chapter 2 offers a discussion of the relation between the traditional input-output framework and contemporary interdependence studies, and is thus mainly related to the research question at level 1. In chapter 2 it is claimed that the theoretical considerations behind traditional input-output analysis - as static as they may be - actually can be used as the starting point for the analysis of technological linkages. This is based on a common perception among the two traditions of the economy as an interrelated system where the development of one industry cannot be understood in isolation from its surroundings in terms of e.g. suppliers and users.[6] An important "glue" between the classical interdependence literature and the more contemporary literature, focussing on an endogenous explanation of technological development, is Pasinetti's work on structural change and economic growth, which ascribes an important role to technology, but nonetheless does not abandon the assumption that technology is exogenous. The chapter ends up with relating

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[6]   The focus will be on vertical rather than horisontal linkages here, i.e. the role of competitors will not be analysed.

the non-formalised theoretical considerations of the importance of interdependence in technological development, forwarded by e.g. Rosenberg and Lundvall, to the traditional input-output scheme, claiming that the key to a common understanding is an extended interpretation of input-output coefficients.

Chapter 3 creates the bridge between chapter 2 and chapter 4 by starting out with a survey of input-output based measures of linkages in the spirit of Rasmussen and Hirschman, and ending up with a proposal on how to include technology into these measures. Hirschman, who must be given credit for the widespread fame of the linkage concept, is primarily a development economist. Chapter 3 illustrates that the Rasmussen specifications of Hirschmanian backward and forward linkages are actually best suited for the analysis of primitive input-output tables with a large fraction of empty cells, which is contrary to advanced economic systems characterised by a high degree of integration, expressed by many relations between industries (i.e. no or only very few empty cells). Part I ends up with the conclusion in chapter 3, that a simple expansion of linkage specifications of the Hirschman-Rasmussen type by including different knowledge indicators in the linkage specifications is rather primitive, and this modification of the traditional linkage measures is not a satisfactory method to increase our knowledge of key knowledge industries in advanced economic systems. Thus other methods are called for in order to understand potential dynamic interindustry relations. Accordingly, part II attempts to identify these methods and measures.

In chapter 4 the rigid calculation of linkage indicators classifying industries according to an average linkage value is abandoned, and the focus is shifted toward linkages as sources of knowledge inputs at the industry level. Chapter 4 introduces the concept of 'indirect' knowledge, expressing knowledge acquired through purchased inputs to the production process. Two related and supplementary methods for analysing knowledge intensive linkages are used, based on the same basic calculations but leading to a quantitative and graphical representation of linkages respectively: the first method is an estimation of the 'value' of embodied knowledge, while the second is a graph theoretically inspired method for mapping the (quantitatively) most important knowledge intensive linkages between knowledge sources and receivers respectively. The main contribution of chapter 4 is first, that it presents the combination of different methods for

measuring linkages, and second, that it develops the methods by introducing a broadened range of indicators to be applied in an analysis of this kind. The chapter rests on the assumption that knowledge can be embodied in goods and services, i.e. the knowledge accumulated in an end-product (be it a consumption or investment good or service) is the 'result' of the knowledge used in the production at the different intermediate production steps in the vertical production chain. The accumulation of knowledge in an end-product differs from the accumulation of knowledge in the economic system as such, since the second type contributes to the total stock of knowledge in the system, while the first type (product accumulated knowledge) does not in a narrow sense increase the total knowledge stock of the economic system. But through the diffusion and broadening of the area of application of the given knowledge stock, it can be perceived as increasing the total knowledge intensity of production.

Chapter 4 applies three different knowledge indicators: R&D expenses, patenting activity and formal training of employees, in order to provide a nuanced image of knowledge intensive and 'extensive' industries respectively. This leads to the identification of business services as one of the knowledge intensive industries. The primary knowledge receivers are non-business services and the food industry, while the primary knowledge sources are industries like machinery, business services, iron and metal and construction. The most knowledge intensive industry of all is the medical/pharmaceutical industry, but this industry does not play a major role as a knowledge source. In other words, the analysis shows that the most important knowledge sources are not necessarily the most knowledge intensive industries. This is an important point in relation to policy initiatives aimed at increasing the knowledge diffusion and use of knowledge in general in the economic system.

As mentioned above, the methodological contributions of chapter 4 concerns the value from combining different indicators and methods in the knowledge linkage analysis. But chapter 4 rests heavily on the embodied knowledge assumption, and the methods applied are not capable of capturing knowledge linkages which are not based on economic transactions. Thus chapter 5 is an important supplement to chapter 4, as it analyses interindustry knowledge linkages based on survey data on product innovation flows. Also, in chapter 5, the rigid perception of knowledge as a stock that can be diffused throughout the economic system is abandoned, and the attention

is turned towards the interactive aspect of the innovative process, focussing on the diffusion of product innovations as well as on the contribution by users to the innovative process.

The first aim of chapter 5 is to analyse the extent to which the input-output based linkages identified in chapter 4 can be supported by interindustry flows of product innovations. In general, most of the linkages from chapter 4 can be found in one form or another in chapter 5. But a number of new linkages/flows are also identified, which is interpreted as an expression of economic relations in general leading to innovative relations, while innovative relations do not necessarily lead to economic relations to any notable extent. The similarity of knowledge bases can be one explanation of this phenomenon, based on the claim that industries that are not closely economically related can have some common features in knowledge bases.

As mentioned above, chapter 5 also looks at the external inputs to the innovative process. The pattern of the product innovation flows and the oppositely directed 'information flows', as the inputs to the innovative process are labelled, leads us to the generalisation that two main types of innovation (knowledge) sources can be identified: i) source industries that supply firms in many different industries with product innovations. This type of sources are characterised as 'generic knowledge sources'. These industries do not in general get a lot of inputs to the innovative process from firms in their user industries. ii) the other type of sources has its receivers of product innovations concentrated in one or a few industries. In these cases firms in the user industries are often providing inputs to the innovative process in the supplier industries; this is labelled a 'true interdependence' (of the Lundvall kind) between innovative producers and their users.

When analysing knowledge intensities and embodied knowledge flows, it is impossible to ignore issues related to the construction and use of indicators. Knowledge is a complex phenomenon which cannot be measured in a simple way, rather my claim would be that knowledge cannot be measured directly at all. We thus have to depend on indicators that supply us with an admittedly incomplete image of the knowledge applied in e.g. a specific production process. The best thing to do in a situation like this is to avoid building the analysis on one indicator only. When including several different indicators, each expressing different features of a complex phenomenon, the risk of misrepresenting the true feature of the phenomenon is reduced. The indicators used in the

present analysis - R&D expenses, patenting activity, the formal education of employees, as well as innovative activity - are biassed towards formal knowledge creation, while informal knowledge creation is somewhat less represented, except perhaps through the innovation data. But, nonetheless, they provide a more complete picture of the knowledge intensities at the industry level than what is most often presented in analyses applying one single indicator.

In part II the analysis is confined to Danish data. In part III the international perspective is introduced applying OECD data. The purpose of widening the scope of analysis in chapter 6 is to explore the applicability of the method of mapping interindustry interdependencies through directed graphs in comparative studies. This underlines that the major aim of the present work is not to study the Danish economic system, rather the aim is to study methods for identifying linkages, primarily exemplifying with the case of Denmark, as there is a wide access of data on the Danish system. Thus I have been able to study the effect of using different indicators and methods in the Danish case. In the comparative analysis in chapter 6 only one knowledge indicator is used (R&D expenses). In relation to the research questions, part II (chapters 4-5) mainly relates to the question at level 2, while part III (chapters 6-7) mainly refers to level 3.

A systemic view pervades the chapters of part II, analysing the different aspects of linkages in the Danish economy, and the national system of innovation approach is implicit in all the empirical chapters. In chapter 6, the linkage discussion is explicitly placed in a national system of innovation framework. In this chapter, the R&D based linkages in four major OECD countries are compared from the national innovation system perspective. In chapter 4 it is demonstrated that input-output based knowledge linkages are quite stable over time. Chapter 6 goes one step further by arguing that the knowledge linkages are deeply rooted in the historical process of industrialisation. Current positions of strength can be explained by looking back in history at the creation of e.g. institutions, incentives and 'external chocks'. Patterns of interdependence reflect the national positions of strength, both with regards to major knowledge sources as well as to the extent of the interconnectedness (as e.g. exemplified by a densely connected Japanese electronics related cluster). The guiding assumption behind the analysis of chapter 6 is that the institutional factors characterising a national system of innovation are mirrored in the major knowledge based linkages at the industry level. In particular, the chapter relates the historical building of institutions - both

formal and informal - to the present day structure of industrial interdependence in relation to knowledge diffusion and creation.

As mentioned above, the major aim of the present work is to contribute with methodological insights on interindustry studies. Thus the work has a strong descriptive bias, focussing on mapping interindustry linkages. The mapping of technological linkages is found to increase the understanding of the underlying structures of the economic system in question, as exemplified by the comparative analysis in chapter 6. And discussing methodological aspects of how to map linkages is a necessary exercise which precedes analyses of another important issue: the effect of linkages in a broader context. The assumption underlying this entire work is that interdependence is an economic feature which cannot be ignored as the relations to other entities are a central aspect of what defines an economic unit, no matter what level of analysis is chosen. And I argue that interdependence is a major factor behind technological development and innovation. Thus it should be expected that linkages affect a wide range of economic features.

Chapter 6 illustrates that the way technologies have developed seems to have influenced the clustering of relations today. This is illustrated by the case of Germany where industrial chemicals have played a major role in the process of industrialisation, and where industrial chemicals remain today a major knowledge source connecting the entire system. Opposed to this structure is Japan, the United States and United Kingdom, where industrialisation primarily took off in electronics and transport related areas, and where we today find electronics and transport related industries to exist in a cluster which is not integrated with the chemicals related industries to the same extent as is the case for Germany. Thus this kind of linkage analysis, superficial as it is, can actually illustrate some fundamental differences between institutional set-ups in different systems of innovation. Furthermore, chapter 6 indicates that there is a relation between the industries which are heavily integrated into the system through knowledge linkages, and the industries in which a country is export specialised.

Following the results of chapter 6, chapter 7 takes a first step into analysing the economic effect of linkages by exploring the relation between linkages and export specialisation. One could argue that other relations would be of more interest, e.g. the relations between linkages and performance

as expressed by productivity. But measuring productivity is an increasingly complex matter, as the awareness of the problems with defining and measuring the appropriate inputs and outputs are increasing. It is assumed that the industries in which a nation is export specialised are primarily industries in which the nation has an international stronghold. What is analysed is then the relation between the extent of (technology weighted) linkages to users and suppliers of an industry, and the export specialisation (international position of strength) of this industry, assuming that an extensive number of linkages to technologically sophisticated users and suppliers, all other things being equal, should improve the international strength of the industry.

Since both user and suppliers are assumed to influence the technological sophistication of an industry, chapter 7 analyses the statistical relation between both backward and forward linkages and export specialisation. Apart from Hirschman's general linkage effects, which do not explicitly concern international competitiveness, a further theoretical foundation for expecting such a relation can be found in the work of the Swedish economist Staffan Burenstam Linder, who introduced the concept of a 'home-market-effect'. The 'home-market effect' assumption is based on the idea that especially the development of new or changed products must take place in close connection with the market, and thus if an entrepreneur decides to direct a product for the export market only, he would lack the close access to the crucial information that, in accordance with Lundvall's user-producer relations, must be exchanged between producers and their consumers. Since the 'home-market-effect' is not assumed to be of equal importance in all types of products, the statistically estimated relations are allowed to differ according to their innovative characteristics as established by Pavitt (1984). Linder's analysis is extended by not only analysing the importance of home-demand (forward linkages), but also advanced suppliers (backward linkages). The sophistication of users and suppliers is measured by patenting activity in this chapter.

The analysis of chapter 7 shows that linkages are significantly related to export specialisation for scale intensive and specialised supplier industries, while no significant relation can be found for supplier dominated and science based industries.

The concluding part IV of the thesis does not only summarise the preceding chapters and reflect

on the three levels of questions presented above, it also offers some reflections on political implications of linkage studies in chapter 9. The by now well known cluster approach, which ascribes its world fame to the work of Porter in the early 1990's, is the guiding point of the discussion in chapter 9. Technology is not an explicit factor in cluster studies of the Porter type, rather the criteria for being a dynamic cluster is international competitiveness. Porter-type cluster studies are included in this last part of the thesis since they have played an important role in introducing the linkage concept in a policy perspective, and, as such, have contributed to turning an increased attention towards the systemic - interdependent - nature of economies. But there is a call for alternative measures of linkages in advanced economic systems. It is proposed that the need is primarily for a move towards a more dynamic expression of linkages and clusters. A promising approach is to follow in the footsteps of Dahmén, who focussed on clusters based on a systemic view. Clusters are in this context complexes of industrial interrelations that can be perceived as factors stimulating economic development through different push and pull effects as well as more indirectly by creating a stimulating environment (in geographical as well as economic space) in the lines of Marshallian external economies.

Let me finally turn to the limitations of the thesis. I criticise the Leontief framework for being to static in its nature, and for being unable to deal with technology in other than a very mechanistic way. The ideal is a dynamic analysis, but given the nature of the data sources in the present analysis, a dynamic analysis is not possible, and thus we have to make do with a comparative static analysis. But different types of comparative statics exist, and one way to distinguish the present analysis from other types of analyses could be to relate to the concepts of static versus dynamic efficiency as introduced by Dosi et al. (1990). 'Static' efficiency is related to allocation while 'dynamic' efficiency is related to innovative and demand dynamism (Dosi et al., 1990, p. 269). The Leontief framework is basically characterised by static efficiency, while the technological change framework is related to dynamic efficiency. And through introducing technology and innovation into the linkage specifications, the synthesis which I present is also related to dynamic efficiency even though the analysis is still static in its basic nature.

I by no means claim to solve the many problems arising in the process of creating a synthesis between the economics of technological change and input-output economics, but by the mainly

empirical approach presented in the following chapters represent a strategy which, I hope, may bring the process a small step further, acknowledging that a lot of work still remains to be done.

Part I: The Theoretical and Methodological Starting Point

This introductory part of the dissertation deals with the theoretical foundation of studies of technological linkages. The role of linkages to users and suppliers as a major factor in the process of knowledge creation and technological development is coming increasingly more into focus within the field of economics of technological change. But the theoretical framework for studying interdependence appears to be fragmented and unstructured. Chapter 2 has the modest aim of revealing which basic economic structures are implicitly underlying the analyses of technological interdependence. The input-output framework can, if we stick to treating the equilibrium assumption as a book-keeping principle, be used as a starting point for introducing technological interdependence into the system. In its aim to develop a more coherent framework for studying interdependence with respect to technological development and innovation in an economic system, the chapter puts Leontief's input-output scheme into the same overall framework as Schmookler's primarily demand-side driven considerations regarding the combination of user wants and producer knowledge, Rosenberg's more supply-side oriented empirically founded analysis of the importance of interdependence in technological development, and Lundvall's user-producer interaction. It is argued that these are all important steps on the way from the basically static input-output system to a more dynamic understanding of the role of interdependence in technological development.

Chapter 3 proceeds with a survey of the traditional linkage literature and succeeding attempts to develop measures of interindustrial linkages. The chapter ends up with an application of a range of the measures on contemporary Danish data, as well as some exploratory work on including technology into linkage measures. The purpose of the chapter is twofold: first to illustrate the empirical and theoretical starting point of linkage studies with a major emphasis on the contribution of Albert O. Hirschman, who primarily was focussed on developing countries, but also provided some general insights regarding economic structures; second to empirically compare different specifications of linkage measures, as well as to evaluate the quality and applicability of the different measures.

Chapter 2: Theoretical considerations of interdependence - a historical overview from static structures to incorporated technological change

Long-term economic growth is primarily the result of the growth of technological knowledge - the increase in knowledge about useful goods and how to produce them [....]. Since each industry buys inputs (products) from other industries, the production technology of the former consists to a large extent of the product technologies of the latter[1].
(Schmookler, 1966, p. 196).

2.1   Introduction

This chapter demonstrates that the study of interindustry relations by no means is a new thing. It also shows that elements of a common conceptual framework can be detected between traditional input-output interindustry studies, and contemporary studies by the followers of Schumpeter of the role of interdependence in technological development. Some major differences can be identified as well though, in particular in relation to the positioning within an overall theoretical framework.

Leontief was a major driving force in the process of recognizing the importance of interindustrial interdependence, bringing back to life the notion of the economy as a circular system (Leontief, 1928/1991), which was first presented by Quesnay in his *Tableau Economique* (1766/1973). With his study of qualitative input and output relations in the economic system of the United States (1936) Leontief attempted to create a Tableau Economique for the United States for the year 1919. Whereas Quesnay's Tableau Economique supported and served to illustrate the Physiocratic perception of all value stemming out of land, Leontief's major aim with his first construction of a Tableau Economique was to supply an empirical background for the study of the interdependence between the different parts of the national (American) economy on the basis of the theory of general economic equilibrium, which was developed by Walras more than a century after Quesnay's first presentation of the Tableau Economique.

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[1]   Product technology = the knowledge used in creating products
Production technology = the knowledge used in producing products (Schmookler, 1966, p. 88).

Leontief went on to study the *structure* of the American economy (1941;1953), and structural analysis has been a major field of application of the input-output technique. The issue to be dealt with here is the role played by Leontief as the starting point of interindustry analysis in the 20th century, starting with studies of static structures and ending up with studies of the relation between industrial interdependence and technological change carried out within the Schumpeterian tradition.

The starting point of section 2.2 is the classical static Leontief system, which was later developed in an attempt to study dynamics by introducing a time perspective through including investment effects. This is followed by an analysis of the contributions of Pasinetti in relation to the study of the *consequences* of technological change. The Leontief and Pasinetti approaches share the common feature of exogenous technological change. Attempts to endogenise technological change are presented in section 2.3, starting out with Dahmén's development blocks and Schmookler's considerations of the importance of user competences in technological development. The section then moves on to Rosenberg's considerations of the role of technological interdependence. Through proposing a simple extension of the dynamic input-output scheme by making technical coefficients dependent on knowledge in both own sector and related sectors, a formal representation of Rosenberg's main ideas is attempted. Also section 2.3 discusses technological interdependence at the micro level, still maintaining a relation to the input-output framework. Finally, the chapter is wrapped up in a discussion of the importance of a coherent theoretical framework for studying technological interdependence, as well as reflections on the present state of this framework.

2.2. The classical interdependence literature

2.2.1 *Theoretical considerations of interdependence - the Leontief scheme*

The fact that an economy is an interdependent system has been acknowledged for centuries and it is the foundation of almost all economic theorizing, including the entire general equilibrium framework. But it was not until Leontief presented his input-output framework that we were able to study the functioning of this interdependence in a more detailed manner.

Leontief takes the general equilibrium theory as his point of departure by turning the attention to the principal merits of this theory, which is making it possible to take account of the highly complex network of interrelations which transmits the impulses of any local primary change into the remotest corners of the economic system. But he at the same time points to the problem of the static nature of this theory:

> *The general, and at the same time dynamic, type of analysis still remains an unwritten chapter of economic theory, the claims of innumerable "model-builders" notwithstanding. [....] The [...] theoretical approach, based on the combination of the complexities of a general interdependent system with the simplifying assumptions of static analysis, constitutes the background of this investigation* (Leontief, 1941, p. 33).

Thus Leontief (1941) in *The Structure of American Economy* presents a scheme of 'general interdependence', which as a first step, is described under the assumption of stationary equilibrium. The technical setup of each industry in the economic system is described by a series of as many homogeneous linear equations as there are separate cost factors involved (Leontief, 1941, pp. 34-37).

Leontief's scheme implies a formal rejection of the marginal productivity theory since the marginal productivity of any factor equals zero: the output will not increase unless the inputs of all the other factors are also increased according to their respective coefficients of production. Put in another way, the production function used by Leontief excludes technical substitutability of factors within the framework of any given production process.[2]

An important distinction when dealing with industrial interdependence is between *industry* and

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[2]

    Leontief claims that this assumption does not imply a severe break with the logic of factor substitution: In theoretical discussions 'factors of production' are still in most cases reduced to land, labour and capital, although there in some cases also is a distinction between consumers' and producers' goods industries. Thus when the concept of technical substitution and the law of variable proportions is applied to aggregated industries in a more realistic economic system, they have as their main function the concealment of the non-homogeneous character of conventional industrial classification. Leontief claims that many cases of so-called factor substitution can be traced back to simple interindustrial shifts, without any reference to variable factor combinations within separate strictly defined industrial setups (Leontief, 1941, pp. 39-40).

commodity. Leontief defines the *efficiency* of the commodity, k, as composed by the productivity of industry k and the productivity of commodity k. The productivity of an industry k refers to the productivity related to *producing* commodity k, while the productivity of commodity k refers to all the industries *using* commodity k: if all industries applying commodity k as an input have reduced the amount of the commodity required in the production of any other commodity, then the productivity of commodity k has increased. If the productivity of the industry and the commodity were to change proportionally but in opposite directions, then the efficiency of the commodity would remain unchanged from the perspective of the total economy (Leontief, 1941, p. 64). This distinction is somewhat related to the spillover discussion regarding the problem of determining whether productivity gains in a given industry can be ascribed to the industry itself or to the industry's supplying industries. It is especially related to problems with so-called rent spillovers where the productivity or quality gains in the supplying industry are not entirely expressed in the price of the product from this industry. It should be noted that Leontief never engaged in the spillover discussion though, but in present day input-output analysis it is a substantial research area (for some of the more recent contributions to the spillover discussion within the field of input-output economics see e.g. Bernstein, 1997; Los, 1998; Verspagen and De Loo, 1998; Wolff and Nadiri, 1993).

The role of the equilibrium assumption

The general equilibrium theory defines and stratifies the basic types of economic phenomena and describe their mutual interrelationships in such a general form that only few, if any, operational propositions concerning measurable properties of specific economic systems can actually be derived from them (Leontief, 1954, p. 41).

What the general equilibrium theory shows is that the magnitudes of the outputs, the inputs and the prices of all commodities and services in principle can be derived from three sets of data: 1) the supply of primary factors of production; 2) the production functions reflecting the technological possibilities of the economy; and 3) the consumption functions describing the basic structural characteristics of the households of the economy.

The empirical input-output approach is focussed on collecting data reflecting the basic structural

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relationships of the economy concerned. All the other operational properties of the input-output approach are then derived deductively through computations on the primary empirical data into appropriate theoretical general equilibrium formulas (Leontief, 1954, p. 44).

The notion of general equilibrium as applied by Leontief plays different roles for the analysis of input-output structures depending on the focus of the study. If the aim is to determine prices in the system, then the general equilibrium assumption is of crucial importance. From the point of view of Schumpeterian economics of technological change the notion of general equilibrium has some disturbing features: this particular field of economics has its main emphasis on the dynamics of economic systems, on how they are always evolving and never reach a resting point. The fact that general equilibrium theory in its basic form treats tastes, technology and resources as constant, non-economic factors does not fit well into this framework. We are still far from a coherent theoretical framework of 'economics of technological change' or 'evolutionary economics', which is the main label usually applied to this field of economics. This is not to claim that important theoretical contributions have not been made within this field (the most distinguished example being Nelson and Winter, 1982), but we are still far from a general theory in the same sense as the general equilibrium theory. And maybe we will never reach such a general theory, simply because those days are over, where it is believed that it is possible to have a general model for describing the main rules of this very complex - an in many ways unpredictable - system called 'an economy'.

Leontief's choice of a stationary equilibrium as the starting point of the description of the theoretical scheme for studying interdependence is guided by his wish to carry out an empirical study of interrelations among different parts of a national economy as revealed through covariations of prices, outputs, investments, and incomes. His inquiry is in his own words a compromise between unrestricted generalities of purely theoretical reasoning and the practical limitations of empirical fact finding (Leontief, 1941, pp. 3-4). In particular we are today still facing the problem that the entire input-output framework is based on the assumption that the economic system we are studying is in an equilibrium position. In a book-keeping sense it might be an equilibrium, but a general equilibrium in the sense of a market clearing equilibrium is far from the assumptions behind economics of technological change.

2.2.2   Introducing technology in the input-output scheme

Leontief's main contribution to economics lies in the development of a tool and analytical framework for studying the economic importance of relations between industries. Leontief sees these relations as reflections of the structure of the technology of the economic system in question (Leontief, 1951), but what this chapter aims to do is to extend this rather narrow perception of technology to embrace the use of knowledge in the production process.

Leontief has on several occasions underlined the importance of technology, often linking it to the problem of unemployment (see e.g. Leontief and Duchin, 1986), and to economic change in general:

> *Among the many factors that have promoted economic change, I believe that technology or, rather, change in technology is the most prominent. […] [S]cience very quickly leads to change in technology, and […] change in technology is the driving force of development* (Leontief in Carter, 1996b, p. 315 and p. 318).

Technology in a Leontief input-output framework is represented by 'technical coefficients' which express average values, partly by referring to groups of industries (a certain degree of aggregation is unavoidable) with different cost structures, partly by referring to whole series of techniques applied simultaneously in each line of production reaching from the oldest technique which is still applied to the most recent technique which has just been introduced in the most modern production units (Leontief, 1953, p. 23).

The ways that technical coefficients[3] have been used in analysing the structure of economic systems - the most famous examples being Leontief's study of the structure of the American economy 1919-1939 (Leontief, 1941), and the follow-up analysis by Carter of structural changes in the American economy during the period 1939-1959 (Carter, 1970) - are characterised by being essentially static in nature.

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[3]   Punzo (Goodwin and Punzo, 1987, p. 182) points to the ambiguous nature of the coefficients which at the same time are exchange and production coefficients.

According to Leontief economic change can theoretically be explained either as a structural change or a dynamic process. If economic change is perceived as a structural change then the variation on the dependent variables is related to underlying changes in some of the fundamental data of the system. This way of perceiving change is purely static. If, on the other hand, economic change is perceived as a dynamic process, then the axioms of change are perceived as given, i.e. they are inherent in the structure of the mechanism of determination. Thus change is an inherent element in the economic system. It should be stressed that the difference between the two perceptions is purely theoretical and does not refer to different empirical situations (Leontief, 1953, p. 17). Leontief defines structural change as a change in the structural matrix of an economic system (the matrix of technical coefficients), and systems with different structural matrices are by definition structurally different (Leontief, 1953, p. 19). Carter follows Leontief's definition of structural change as change in technical coefficients. But Carter points to one important factor creating uncertainty: no matter how disaggregated the sectoring, there will always be structural changes which are due to changes in 'production technology', and changes which are due to changes in the 'product mix' of the sector. This is due to the previously mentioned average feature of technical coefficients (Carter, 1970, p. 8).

Another problem in relation to traditional economic theory is the clear-cut distinction between *substitution*[4] (i.e. movement along a given production function) and *technological change* (i.e. changes in the production function). Since a given input-output structure only describes one single combination of inputs, without any alternatives, both substitution and technological change will lead to changes in input-output structures (Carter, 1970, pp. 10-11). In relation to the production function in should be noted that strictly speaking the system cannot be given a technological interpretation unless we add the hypothesis that it is in fact a (partial) realization of the production functions. Furthermore a technological description of a system using the structural matrix lacks a large number of coordinates referring to all inputs that go through the market only at irregular intervals, e.g. fixed capital, goods installed in productive units, goods in process, stocks of intermediate goods etc. (Punzo in Goodwin and Punzo, 1987, pp. 180-181). Finally there is the fundamental problem with the perception of the production function building on the assumption that either the producer has the capabilities to run an activity according to a given production

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[4]   Substitution is, as illustrated in page 19, excluded in the production function proposed by Leontief.

function or he does not, i.e. the production set, expressed by a production function, is taken as given without considering changes over time (Nelson and Winter, 1982, pp. 60-61). This is just to point to some of the theoretical and methodological problems in the input-output approach.

In relation to technological change as expressed by invention and innovation, invention in itself does not affect input-output coefficients, but innovation and diffusion does, and thus changes in input-output coefficients subsume long- and short-run substitution along with innovation and diffusion of new techniques (Carter, 1970, p. 217). Thus alternative means are necessary in order to use input-output relations in analysing technological interdependence as opposed to purely economic interdependence. Section 2.2.3 below will go further into the way Leontief attempts to include technological change more directly into the input-output framework, but before turning to that a brief introduction to how Carter has dealt with knowledge is in order. The measurement problem expressed by the discrepancy between traditional economic measures of input and output and the knowledge based economy, whose performance these inputs and outputs represent, has been a central issue in some of the more recent work of Carter (1996a). One important new input is 'metainvestment', i.e. investment in change itself (Carter, 1994). Metainvestment includes conventional R&D as well as costs for building markets and supply networks for procuring new inputs, implementing new processes, learning and managing the sequence of effecting change. Carter calls for new models and new variables, implying a need for new measures, in order to study an economic system geared to change, but does not propose how this is to be done within the limits of an input-output setting, and thus section 2.2.3 below will return to developments within the narrow input-output framwork.

2.2.3 'Dynamic' input-output analysis

Different attempts to dynamize the input-output approach have been presented. The first was Leontief's dynamic inverse[5] which introduced capacity expansion and the corresponding investment processes explicitly into the system. (Leontief, 1970/1977, p. 50). This implies that

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[5] Theoretically Leontief relates the dynamic inverse to Quesnay's 'productive advances', Marx' 'process of expanded reproduction' and Böhm-Bawerk's 'roundabout production' (Leontief, 1970/1977, pp. 70-71).

part of what has been included as an exogenous element in final demand, i.e. investment in the form of annual additions to the stock of fixed and working capital used by the productive sectors, is now included in the functional expression that determines the growth in sectoral output. Whereas the basic static input-output system can be represented by the expression:

$$\mathbf{x} - \mathbf{A}\mathbf{x} = \mathbf{c},$$

the dynamic system is represented by:

$$\mathbf{x}_t - \mathbf{A}_t\, \mathbf{x}_t - \mathbf{B}_{t+1}\, (\mathbf{x}_{t+1} - \mathbf{x}_t\,) = \mathbf{c}_t$$

where $\mathbf{x}_t$ is a column vector of sectoral outputs produced in year t by the n sectors;
$\mathbf{A}_t\, \mathbf{x}_t$ represents the input requirements of all n industries in year t;
$\mathbf{B}_{t+1}\, (\mathbf{x}_{t+1} - \mathbf{x}_t\,)$ represents the investment requirements, i.e. the additions to the production stock that would permit all n industries to expand their capacity of outputs from year t to year $t+1$ from the volume x_t to x_{t+1}. The subscript $t+1$ attached to matrix $\mathbf{B}$ refers to year of use, not year of production;
$\mathbf{c}_t$ is a column vector of deliveries to final demand (Leontief, 1970/1977, p. 51).

As illustrated by the equation, the capital goods produced in year t are assumed to be installed and put into operation in the next year, $t+1$. The time subscripts attached to the structural matrices allows for using different sets of flow and capital coefficients for different years, thus incorporating technological change into the dynamic system (ibid.).

The trick is then to construct a system of linear equations of the above type, with one equation for each year, and thus creating a system of interlocked balance equations describing the development of a given economic system over a period of time:

$$
\begin{bmatrix}
1-A_{-m}+B_{-m+1} & -B_{-m+1} & .. & .. & .. & .. \\
.. & 1-A_{-m+1}+B_{-m+2} & -B_{-m+2} & .. & .. & .. \\
.. & .. & .. & .. & .. & .. \\
.. & .. & .. & 1-A_{-2}+B_{-1} & -B_{-1} & .. \\
.. & .. & .. & .. & 1-A_{-1}+B_{0} & -B_{0} \\
.. & .. & .. & .. & .. & 1-A_{0}
\end{bmatrix}
\begin{bmatrix}
x_{-m} \\
x_{-m-1} \\
... \\
x_{-2} \\
x_{-1} \\
x_{0}
\end{bmatrix}
=
\begin{bmatrix}
c_{-m} \\
c_{-m+1} \\
... \\
c_{-2} \\
c_{-1} \\
c_{0}
\end{bmatrix}
$$

The solution of this system determines the sequence of annual total sectoral outputs that would enable the economy to yield the sequence of final annual deliveries described by the array of column vectors entered on the right hand side, which express the deliveries to final demand.

The system is solved by subsequently substituting the solutions of an equation into the previous equation, i.e. starting by substituting the solution of the last equation into the equation next to the last and thus proceeding stepwise through the whole set of equations until we reach the first equation. When this process is completed, we end up with a set of equations expressing the unknown **x**'s (sectoral outputs) in terms of a given set of **c**'s (deliveries to final demand). The vector of **c**'s is premultiplied by the square matrix which is the result of the substitution process. This square matrix is the *dynamic inverse* (Leontief, 1970/1977, p. 52), and the term 'dynamic' thus refers to the introduction of time into the system.

Leontief applied the method of the dynamic inverse in an analysis of the structural properties of the American economy in the years 1947 and 1958. The missing years were filled out using the assumption that the shift of technology from 1947 to 1958 occurred gradually over the intervening years (Leontief, 1970/1977, p. 56). One important contribution of the dynamic inverse is the illustration of sectoral differences with regards to time horizons. The time shape of the elements of the dynamic inverse that governs direct and indirect requirements varies from industry to industry, stressing that while the output of one particular industry for a given year might primarily depend on the composition and the level of final demand for the same year, the output of another industry might reflect deliveries to final demand several years later (Leontief, 1970/1977, p. 65).

The technological change dealt with in the dynamic inverse is purely exogenous. Thus the method shares a common feature with the method for introducing technological change in an input-output framework presented in another seminal work: Pasinetti (1980;1981).

2.3 Pasinetti's vertically integrated sectors: structural change and economic growth

Pasinetti, who is inspired by Sraffa's (1960) model of production, used the input-output approach in an analysis of growth and structural change. In *Structural Change and Economic Growth* a dynamic model of production, fulfilling - without necessarily leading to - the conditions of full employment, is presented (Pasinetti, 1981). Pasinetti's model represent an important extension of the traditional Leontief scheme by turning the attention towards the effects of technological change.

In the Pasinetti universe all production inputs can be reduced to either inputs of labour or to services from stocks of capital goods (Pasinetti, 1981, p. 29), i.e. all production processes are considered to be vertically integrated. In Pasinetti's scheme Man represents the central focus (Pasinetti, 1981, p. 23), which will secure continuos technical development since - as long as the intellectual abilities of mankind do not deteriorate - technical progress is an inherent characteristic of human history.

Vertically integrated sectors are, rather than being related to industries, related to final goods. In relation to the analysis of technological development, vertically integrated sectors have their primary advantage in their ability to take into account the fact that obsolete capital is replaced by new capital of another quality. During a period with technical development any comparison of capital at different points of time will loose its relevance in relation to a dynamical analysis, if capital is expressed in terms of ordinary physical units. But if the capital is expressed in units of productive capacity then the relation between capital measured in different points of time maintains its relevance, even though the composition of the capital stock has changed. Obsolete capital will in a situation like this be considered as replaced if the economic system at the end of each period of production has the same productive capacity as in the initial situation (Pasinetti, 1980, p. 42).

Pasinetti applies the system in which all processes of production are vertically integrated in a dynamical analysis of a system with growth as a consequence of an increasing population and of technical change respectively. It is assumed that the increase in population is exogenously given and constant (Pasinetti, 1981, p. 51), and the technical rate of development is assumed to be constant over time in each sector, i.e. the productivity increases with a constant rate but at different rates in each sector (Pasinetti, 1981, pp. 81-82). The assumption regarding the constant rate of growth in productivity is not crucial for the results of the analysis, and it is only included for simplifying reasons.

If there is technical change then each technical coefficient will decrease with its own rate over time. This implies among other things that the structure of employment will change, with a tendency of generating unemployment unless there is a corresponding tendency for an increase in the coefficients of demand.[6] If the system is to maintain an equilibrium growth path (i.e. growth with full employment) it is necessary that the per capita income is constantly increasing (Pasinetti, 1981, pp. 219ff). It is also necessary that the workforce is so flexible and mobile as to make it possible to move labour between sectors. The price structure must also necessarily be subject to continuous change if the technical rate of development varies between sectors. If the relative prices remain constant from one period to another, while there are different rates of technical progress in the different sectors, it implies that a cumulative distortion of the price system will take place. In a situation like this there will no longer be a 'natural' relation between production costs and prices. Thus the structure of demand must change according to economic growth.[7] When the productivity increases then the per capita income will raise and the increasing demand will concentrate on a shifting set of goods (cf. Engel's Law). This implies that the rate of change in demand for each product will be subject to a continuous change, and it will most often differ from the rate of change of demand for any other good. Punzo (in Goodwin and Punzo, 1987, p. 198) describes the role of the final demand as a dynamical stabilizer, which cannot in general

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[6]

It is apparent that Pasinetti shares a common interest with Leontief in this focus on the relation between technological development and unemployment.

[7]

It should be noted that Pasinetti's point of departure is a situation with full employment. Growth can either be a consequence of technical progress or a growing workforce.

follow a steady expansion path. Each sector's actual production will thus follow its own path with a non-stable rate of growth. This can cause problems for the individual unit of production since it is facing an unstable demand for its product, and thus it will face problems with the long-term planning of the production. This is in contrast with a basic assumption in neoclassical economics: the existence of perfect information and the absence of uncertainty.

Pasinetti claims that there is no natural mechanism which guarantees that the economic system will tend to develop along an equilibrium growth path. Thus there is a need of a deliberate public policy which regulates the economic system in order to avoid severe fluctuations in the business cycle (Pasinetti, 1981, pp. 237-8)[8], and the firms will have to engage actively in the process of maintaining an increasing demand that can ensure full employment.[9]

Pasinetti has with his model captured many of the factors a traditional (neo-classical) economic model cannot explain. Pasinetti takes as his point of departure the fact that we are living in a period of time with rapid changes and the basic purpose of his model is to explain the implications of this for a unspecified economic system. How an actual system might react depends on the institutional setup and the way this affects the basic mechanisms.

According to Pasinetti there is not, at any given point of time, any logical difference between his approach with vertically integrated sectors and a more traditional input-output analysis. It is basically the same issues that are treated applying two different methods of classification: the coefficients of production in a vertically integrated model are a linear combination of the coefficients of production (the 'technical' coefficients) in the corresponding input-output model. Thus it is possible to pass from one model to the other by an algebraical re-arrangement,

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[8]   Thus Pasinetti is perceived as a neo-Keynesian.

[9]

        Four ways in which a pattern of steady growth can be aimed at are proposed:

- try to utilise the existing physical appliances, personnel, organisational and financial structure, technical know-how, etc. to enter new fields of production where demand is expanding, or to introduce entirely new products;
- keep a reservoir, or backlog, of ideas about new products and new investment products, in order to smooth out prospective difficulties and ensure a potentially steady expansion;
- try to manipulate consumers' decisions through advertising;
- find out new outlets abroad or directly develop new markets abroad (Pasinetti, 1981, p. 224).

corresponding to a process of solving a system of linear equations (Pasinetti, 1981, p. 111). The 'bridge' between the two methods is the inverse matrix.

Also from an empirical point of view there is a great resemblance between the method applied in Pasinetti's dynamic vertically integrated sectors, and the method applied in a static input-output analysis (Pasinetti, 1981, p. 109). Both methods build on coefficients that express actual results of production. The technical coefficients of the input-output analysis and the coefficients of production in the vertically integrated sectors are both the result of a choice made from a larger set of possibilities - all alternative possibilities that were not chosen are irrelevant in both cases. The coefficients in both methods are to be perceived as expressions of physical, observable quantities.

The two methods do not share their perception of the process of production though. The traditional input-output approach deals with the directly observable interindustry transactions, while the relations in the vertically integrated system are perceived as part of an ongoing process - this process reaches its completion only when the product comes out as a final commodity (consumption or investment good) (Pasinetti, 1981, p. 110).

But as mentioned in the introduction to the Pasinetti scheme, traditional input-output analysis (applying the dynamic inverse) and Pasinetti's vertically integrated sectors also share the common feature that technology is exogenously given.[10] The incorporation of technical change is at the core of the present chapter, and thus the next section will turn to attempts to include technology as an endogenous factor in the economic system.

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[10]

    Thus Pasinetti's attempt to explain the relation between structural change and growth is contrary to a main strand in the so-called endogenous growth theory. In this theory technology is made endogenous by including a technology producing sector where technology (design) is assumed to grow exponentially for a given research effort (among the first significant contributions within this scheme were Romer, 1986; Romer, 1990; Grossman and Helpman, 1991a). Thus, technology and innovation within this scheme is a result of deliberate activities in the business units (Fagerberg, 1992b). However, the way new growth theory includes technological linkages, which primarily is through international spillovers (Grossman and Helpman, 1991b), differs substantially (spillovers being characterised by being unintentional from the perspective of the 'supplier') from the interdependence approach dealt with here, and thus we will not devote further effort to this string of theory in the present context.

2.4   Towards an endogenous explanation of technological development

One way to increase the understanding of the importance of interdependence for technological development, and not just assess the *effects* of technological change, is to analyse the endogenous evolution of the technical coefficients. In the previous section the technological change did not *depend on* the relations/linkages, but rather *influenced* the structural relations. This section will deal with attempts to explain technological development as inseparably related to industrial interdependence.

Dahmén's development blocks are one starting point. A development block refers to a sequence of complementarities which by way of a series of structural tensions, i.e. disequilibria, may result in a balanced development situation (Dahmén, 1988, p. 5).[11] A development block is related to structural tension, which is illustrated by an example that also shows the importance of backward and forward linkages (see chapter 3 as well as Hirschman, 1958). The example is taken from the British textile industry in the 1730's: the introduction of the flying shuttle in the process of weaving cloth led to an acute shortage of yarn. This induced a number of inventions and innovations in spinning (i.e. we are here dealing with the effect of a backward linkage from the weaving industry). But the innovativeness in the spinning industry made the weaving industry fall behind until it came up with the mechanical loom (which thus was the result of a forward linkage from spinning). Thus until a balanced situation was reached between the spinning and weaving industry through the introduction of the mechanical loom a series of structural tensions between the two industries had been at play (Dahmén, 1988, p. 5, note 3). But the development potential had to exist for the structural tension to lead to a dynamic development process, i.e. structural tension does not in itself create a development block.

Dahmén poses a critique of the input-output framework by stating that:

> *A complex of interindustrial interrelations is easy to understand and is also possible to identify,*

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[11]   Dahmén's 1988-article on *'Development Blocks' in Industrial Economics* draws on his doctoral thesis from 1950 (published in English in 1970), i.e. the concept of development blocks was originally introduced around the same time as some of Leontief's major contributions. I have chosen to use the 1988 article in the present chapter, since it presents a much more structured introduction to development blocks.

*e.g. by input-output schemes, **when viewed as a set of static interrelations**. But by the use of neoclassical eyeglasses one is likely to miss a point which is crucial, namely the **dynamics** of the interrelations* (Dahmén, 1988, p. 7).

Dahmén goes on by stating that the analysis of the processes whereby interrelations evolve through time, by looking at how and why decisions are taken at micro levels is the most promising way to study Schumpeterian dynamics.[12] I still argue though, that input-output interrelations at the macro/meso level can increase our understanding of industrial dynamics at the meso and macro level.[13]

A relation between innovative capabilities of producers and the progressiveness of their users that is not unlike the structural tension between producer and user capabilities dealt with by Dahmén (as exemplified by the British textile industry) is pointed out by Schmookler:

> *the greater part of the output of most industries is sold to other industries […]. For this reason, contrasts between the "progressiveness" of the former with the "un-progressiveness" of the latter are likely to be misleading. The ability of the former to market new products depends precisely on the "progressiveness" of their customers* (Schmookler, 1966, p. 174).

Schmookler goes on by stating that

> *The high degree of interdependence of the industries in a modern economy may mean that the net genuine superiority in the improvement possibilities of one industry's total technology over another's may easily be less than one might infer from simple interindustry differences in, say, the ratio of each industry's patents to its value added, because the best way to improve an industry's technology is often to improve the inputs it buys from other industries* (Schmookler, 1966, p. 175).

At first glance there does not seem to be that great a difference between the way Schmookler stresses the importance of interdependence for technological development, and the way the

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[12]   For a further discussion of Dahmén's perception of Schumpeterian dynamics see Dahmén (1986).

[13]   Section 2.4.1 will deal with some aspects of the micro level.

interdependence is analysed in a traditional input-output framework. But what distinguishes Schmookler from a traditional input-output way of thinking is the emphasis his puts on the role of the user for technological development. In a traditional input-output framework the user only plays a role in relation to the amount he or she uses, as well as in relation to the forward linkages the user has in the production chain. In Schmookler's universe the *competence* of the user is an important factor in determining the ability of the former to market new products. But on the other hand the argument that "*the best way to improve an industry's technology is often to improve the inputs it buys from other industries*" can be directly linked to Leontief's above mentioned distinction between the productivity of an industry and the productivity of a commodity, recalling that the productivity of a commodity refers to all the industries using the commodity. Thus it is primarily in relation to the user competences that Schmookler's ideas are distinguished from what can be incorporated in a traditional input-output framework, and as such express some similarities with Dahmén's approach.

The underlying reason for Dahmén studying development blocks is the understanding and explanation of growth. Also the contributions from the input-output tradition, represented by Carter and Pasinetti, have had a strong focus on growth. A corresponding contribution from the technological change tradition is Rosenberg's 'Technological interdependence in the American economy' (Rosenberg, 1982b), in which the explanation of the long term growth of the American economy is the analytical starting point. Rosenberg's focus is on the importance of technology and innovations, and the article has a very strong empirical foundation. But soon it becomes apparent that much of what Rosenberg is discussing is closely related to what in Leontief's universe is labelled *the efficiency of a commodity*: how the productivity of an industry and/or the productivity of a commodity in some cases have had major impacts on the development and growth of the entire American economy. An example of a productivity increase in an industry with a major effect on the whole system is the railroad sector. Rosenberg refers to a study illustrating an extremely large productivity growth in the railroad sector between 1870 and 1910 (Rosenberg, 1982b, p. 69). This increased efficiency of the 'transportation commodity', through a productivity increase in the transportation industry, had significant influences on all of the American economy, but in particular agriculture, since regional specialisation now became economically viable. Rosenberg generalises this feature by stating that

Input-output information enables us to predict that cost-reducing technological changes in some sectors are likely to have wider-range repercussions than similar changes in other sectors. It highlights the pervasiveness of cost reductions in such sectors as transportation, energy, services, and communications, and makes it possible to identify and assess the relative significance of such cost reductions in different sectors of the economy (Rosenberg, 1982b, p. 73).

Even though Rosenberg focusses on the impact of cost reductions rather than changes in the final demand, the kinds of sectors he is aiming at are closely related to the key sectors identified within the input-output based linkage literature (see chapter 3 and Hirschman, 1958; Hirschman, 1977; Rasmussen, 1957). And the concept of key sectors is important in order to understand which *types* of industries are likely to be most influential as upstream or downstream industries. In general an industry which is centrally placed in the economy, i.e. it has many linkages to both users and suppliers, is most likely to have a large effect on the economic system as such through its linkages, while it is more difficult to characterise the industries which play a large role for a single or few industries through the quality of the inputs they supply or through their own input requirements. This discussion will be touched upon in greater detail in chapter 3.

Returning to Rosenberg, he acknowledges the usefulness of input-output analysis in breaking open the

"black box" in which the primary factors of production, capital, and labour are somehow transformed into a flow of final output, [and input-output analysis] *displays a wealth of information on the sectoral flow of intermediate inputs. The technique makes it possible to study the process of technological change by examining changing intermediate input requirements* (Rosenberg, 1982b, p. 71).

Input-output analysis helps understand the structural interdependence of the economic system and how this changes over time, by providing coefficients that express the interindustry flows of goods and services in a quantitative way.

But Rosenberg goes one step further by stating that not only has technological development in

one sector important repercussions throughout the economic system via its price and efficiency, but technological development in one sector of the economy has become increasingly dependent upon technological change in other sectors. Thus when it comes to achieving a high rate of productivity, industries are increasingly dependent upon skills and resources external to, and perhaps totally unfamiliar to, themselves (Rosenberg, 1982b, p. 73). It is this kind of technological interdependence - which is both related to input-output based interdependence stemming from the flow of intermediate goods and services, as well as related to a more diffuse and hard to measure interdependence encompassing e.g. technologies which are either complementary or can be perceived as generic - which constitutes the endogenous element in the technological change. The technical coefficients expressing the relations between industries thus change endogenously since they are determined by factors internal to the system: they are among others a function of the skills and resources in the surrounding industries which are relevant to the industry in question. In any economic model it is necessary that the number of endogenous (unknown) elements equals the number of equations in the model. In the input-output system final demand as well as technical coefficients are exogenous, while the sectoral outputs are the only endogenous elements. If we make the development of the technical coefficients endogenous, then we cannot express the features of the system in one equation only, thus we have to include an extra equation. Let us turn once more to the dynamic input-output model set up by Leontief:

$$\mathbf{x}_t - \mathbf{A}_t \, \mathbf{x}_t - \mathbf{B}_{t+1} \, (\mathbf{x}_{t+1} - \mathbf{x}_t \,) = \mathbf{c}_t$$

The endogenisation implies that $\mathbf{A}_t$ is a function of e.g. a skill matrix $\mathbf{D}_t$: $\mathbf{A}_t = f(\mathbf{D}_t)$, but since this skill matrix is again dependent of the relations between the industries, this expression is in fact too simple to capture the dynamic interaction. The equation can be developed in a simple way by assuming that the elements of the matrix $\mathbf{A}_t$, $\mathbf{a}_{ij,t}$, are a function of the skills, or more general, of the knowledge, in own industry as well as the knowledge levels in the 'collaboration'[14] industries. Thus the elements of $\mathbf{A}_t$ are determined as:

$$\mathbf{a}_{ij,t+1} = f(\mathbf{H}_{j,t}, \, \mathbf{F}_{ji,t}, \, \mathbf{B}_{ij,t})$$

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[14]

Collaboration is used in a very broad meaning here, simply expressing exchange of goods and services between industries.

This equation states that the coefficients expressing flows from sector i to sector j at time $t+1$, $\mathbf{a}_{ij,t+1}$, are determined by the knowledge level in industry j in the previous time period t ($\mathbf{H}_{j,t}$), the knowledge level in the forward linkage industries at time t ($\mathbf{F}_{ji,t}$), as well as the knowledge level in the backward linkage industries at time t ($\mathbf{B}_{ij,t}$). A time lag is introduced by making the technical coefficients being determined by the knowledge levels in the previous time period.

Empirically $\mathbf{F}_{ji,t}$ can be measured as $[\mathbf{x}_{ji,t}/\mathbf{X}_{j,t}]\mathbf{H}_{i,t}$, i.e. the output coefficient weighted by the knowledge level in the user industry. This expression implies that both the (quantitative) intensity of the relation, as well as the knowledge level in the collaboration industry has influence on the value of $\mathbf{F}$.

Likewise $\mathbf{B}_{ij,t}$ can be measured as $[\mathbf{x}_{ij,t}/\mathbf{X}_{j,t}]\mathbf{H}_{i,t}$, i.e. the input coefficient weighted by the knowledge level in the supplying industry.[15]

A further specification can be made by making $\mathbf{H}$ depend on knowledge creating activities like R&D investments or the like, or a choice can be made of simply applying R&D as an expression of knowledge, as is done in subsequent chapters.

2.4.1 Technological interdependence at the micro level

Of course other strategies have been chosen in the process of including technical development more directly in the system. One example is Andersen (1997), who proposes an evolutionary economic micro foundation to Pasinetti's scheme of the structural economic dynamics of a pure labour economy by introducing a R&D intensity rule for each firm, stating that in each time period the firm will spend a certain fraction of its labour on R&D (Andersen, 1997, p. 6). Probability distributions for firm productivity as well as innovative results are applied in the specification of the features of the model. Since Andersen's model is a development of the Pasinetti scheme, the use of labour and the question of employment is central. The endogenous development of the labour coefficients reveals that the long-run consequence of productivity growth in a multi-

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[15]   This entire exercise of course implies that we are able to measure knowledge. For the sake of the argument I will at this point assume that this is possible. In subsequent chapters I will go further into the discussion of how to estimate knowledge levels at the industry level.

sectoral economy is technological unemployment unless new consumption goods are produced to a sufficient degree (Andersen, 1997, p. 14). But Andersen's model is primarily a simulation model which again analyses the *consequences* of endogenous technological development on the need of production inputs (in this case labour), as opposed to the above suggested attempt to describe how the knowledge and technological development in one industry is linked to the knowledge and technological development in related industries.

Some much less formally structured micro based considerations of the role of interdependence in technological development are presented in Lundvall (1985). Lundvall, in his own words, leans heavily on Rosenberg (1982a) in the development of his arguments regarding the user-producer perspective to innovation. Lundvall regards innovation as the result of collisions between technical opportunity and user needs (Lundvall, 1985, p. 3). This is in line with Schmookler. The user competences, just as in Schmookler, are an important factor. Competent users are of crucial importance for leading the innovations in a satisfactory direction where the innovations are not only influenced by the competencies of the producers, but also meet the requirements of the users. Lundvall points to a number of cases in Denmark, in particular exemplified by the case of dairy processing plants, where the plants, due to lack of competences among the users, were more capital intensive, more inflexible, and more highly automated, than what corresponded to the cost effective solutions and the needs of the users (Lundvall, 1985, p. 33; Lundvall et al., 1984). The competences of the users are thus an important driving force in determining the direction of the trajectory of innovations within a given technological field.

This interdependence and the user-producer relations presented by Lundvall are strongly related to backward and forward linkages as discussed in the following chapter (discussing Hirschman, 1958), since these linkages act as strong restraints upon the firms' opportunities: the linkages set up the borders inside which user-producer relations can develop, and the opening up of new channels of information and the development of new codes which cross these borders set up by the existing backward and forward linkages will involve investment costs and an increasing uncertainty compared to relations kept within the well-known frame.

A basic assumption behind Lundvall's argument is that innovative activities are carried out in units engaged in production. Production is a routine process which results in a fairly regular flow of

goods and services from producers to users. This is the kind of flows that can be observed in an input-output table, as they describe the production linkages between users and producers. Innovation, on the other hand, is the result of a search process with much less regularity in outcome. Production and innovation are interdependent processes influencing and shaping each other: information obtained through production, and the regular flow of goods and services, feeds the innovative process, and innovation reshapes production and the regular flow of these goods and services (Lundvall, 1985, p. 5).

Lundvall's arguments are primarily developed in relation to professional users, i.e. users acting within the formal part of the economy, while the specific characteristics of final consumers are ignored. This is also the case in the present chapter. But whereas Lundvall deals with interaction between organisations, this chapter primarily has dealt with interindustrial interaction and interdependence. A combination of these two approaches is proposed by Lundvall (1985, p. 71) in his reference to Pavitt's taxonomy (Pavitt, 1984). Pavitt's well known article, where he sets out to pave the way towards a taxonomy and a theory of sectoral patterns of technical change, combines empirical evidence from 2000 significant postwar innovations in Britain with theoretical considerations of the characteristics of innovative processes. The first characteristic is that technical change is largely a cumulative process specific to firms. What a firm can realistically try to do technically in the future is strongly conditioned by what it has been able to do technically in the past. The second characteristic is that sectors vary in the relative importance of product and process innovation, in sources of process technology, and in the size and patterns of technological diversification of innovative firms. But nonetheless some regularities emerge, and these regularities are captured in the proposed taxonomy. Different principal activities of firms generate different technological trajectories, which can be grouped into three categories: *supplier dominated*, *science based* and *production intensive*. This last group can further be divided into *scale intensive* firms and *specialised suppliers*, so we end up with four main categories of firms, which are guided by sectoral differences in sources of technology, users' needs and means of appropriating innovative benefits (Pavitt, 1984, p. 353).

Whereas Pavitt's taxonomy can be perceived as the technological equivalent of an input-output table (Pavitt, 1984, p. 345), it might seem somewhat more difficult to place Lundvall in the input-output framework. If we take the dual role of the input-output coefficients mentioned by Punzo

(Goodwin and Punzo, 1987, p. 182) - they are at the same time exchange and production coefficients - into consideration, the task becomes somewhat easier. By focussing on innovative activities as they are carried out in units engaged in production, and on how innovations subsequently reshape the production and thus the regular flow of goods and services from producers to users, Lundvall primarily perceives the input-output coefficients as *exchange coefficients* expressing the flows of goods and services. The role as production (technical) coefficient is only implicit in Lundvall's argument. Regarding the degree to which the evolution of the technical coefficients is endogenous, it is thus necessary to devote a little more time to the discussion of the character of these coefficients in Lundvall's user-producer framework. In the initial situation the coefficients express the flows of goods and services between users and producers in relation to the total production, and are as such equivalent to an ordinary input-output coefficient. The relation between production and innovation can in a very simplified manner be expressed by this figure:

Search process

Production ← Innovation
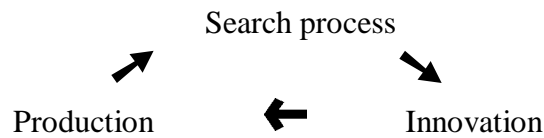
Figure 2.1: The simplified relation between production and innovation

Expressed formally we once again have an expression of the type $\mathbf{A}_t = f(\mathbf{D}_t)$ where $\mathbf{D}_t$ is now innovation, or the search process leading to innovation, rather than skills/knowledge as was the case with Rosenberg, i.e. the evolution of the technical coefficients is also endogenous in Lundvall's case.

The goods and service exchange relations between users and producers can be expressed as a function of the search processes carried out in relation to the production:

$\mathbf{a}_{ij,t+1}=f(\mathbf{S}_{j,t})$, where $\mathbf{S}_{j,t}$ is the search process carried out in industry *j* at time *t*.

The search process in industry *j* can further be expressed as a function of the industry's relations (linkages) to other industries as well as the technological level of the industry:

$$\mathbf{S}_{j,t}=f(\mathbf{F}_{ji,t}, \mathbf{B}_{ij,t}, \mathbf{H}_{j,t}),$$

thus we can end up with a relation of the same type as in the Rosenberg case. The attempt to incorporate technological change is in accordance with the concept of *National System of Innovation* applied by Lundvall and others (see Edquist, 1997; Lundvall, 1992b; Nelson, 1993) which aims at explaining the innovative characteristics and capabilities through the institutional set-up and the intrinsic features of the economic system. One aspect of a national system of innovation is not captured in this equation though: the institutional set-up and the historical context. Nelson and Winter (1982, pp. 171-173) argue that modelling a firm's search for superior techniques by taking input coefficients[16] (or changes in these) as the objects of change suppresses one of three important aspects of the search process: the contingent character of the search process, i.e. the fact that search takes place in a specific context. The two other important aspects are the irreversibility of the search process, and the uncertainty attached to the process. When input coefficients are used for modelling search, the model loses contact with the fact that a search for new techniques involves questions of improved machine design, work arrangement, etc. And answers to such questions are generated by processes external to the firm. It could be argued though, that to the extent that the backward and forward linkages, as it is the case in the expression above, takes the knowledge level of the collaboration partners into consideration, some of these external processes are partly taken into account. However, the model in the current form does not take factors like the institutional setup and path dependence into account.

2.5   Conclusions

This chapter has given an historical overview of theoretical considerations of interindustry relations, illustrating the link between the static structures of the original Leontief input-output scheme and recent (Schumpeterian) attempts to include technological interdependence (technological linkages) as important explanatory factors for economic (and technological) development. Despite this link there is a lack of theoretical considerations and references to

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[16]

When Nelson and Winter deal with input coefficients as objects for search, they focus on the price of inputs. In the present context the focus is on the knowledge associated with the inputs (and outputs), i.e. it is the knowledge relations that are assumed to be influential rather than the price inducement mechanisms.

classical discussions in much of the interdependence literature. The recent interdependence literature can be divided into two main, strongly interrelated, strings: an empirically focussed string analysing actual effects and structures of interdependence in the innovative or technological process (e.g. Rosenberg, Pavitt); and a conceptually focussed string which primarily operates within the National System of Innovation framework, represented by Lundvall in the present context.

As the focus on the importance of interdependence increases, the need for a coherent theoretical framework for studying technological interdependence becomes more obvious. As stated in section 2.2 we will probably never reach an evolutionary theory or a theory of technological change with has the same wide applicability as the general equilibrium theory, because the general equilibrium theory treats those factors which are of special interest in economics of technological change - tastes, technology, resources - as constant, non-economic factors. It is evident that a theory which is attempted to have a very general applicability necessarily must be restrictive in the number of factors it can include.

Thus this chapter has a more modest aim of revealing which basic economic structures are implicitly underlying the analyses of technological interdependence. To a large extent the input-output framework - if we stick to treating the equilibrium assumption as a bookkeeping principle - can be used as a starting point for introducing technological interdependence into the system. This technological interdependence is introduced through the addition of a further interpretation of the input-output coefficients. Now they are not just expressing exchange and production but also - through the weighting by a knowledge variable - *direct exposure to external knowledge* (via suppliers and users), which functions as an important input to the technological development process. This attempt to get closer to an endogenous explanation of technological development through the interpretation of input-output coefficients as expressions of direct exposure to external knowledge will be applied in different settings in the following chapters, and it is as such a cornerstone in the thesis.

Chapter 3: Input-Output Based Measures of Interindustry Linkages Revisited - A Survey and Discussion

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..ongoing activities because of their characteristics, push or, more modestly, invite some operators to take up new activities. Whenever that is the case, a linkage exists between the ongoing and the new activity (Hirschman, 1977, p. 80)

3.1   Introduction

While the focus of the present chapter was a purely theoretical discussion attempting to create a synthesis between the input-output and technological change traditions, this chapter will go further into a theoretical discussion of the linkage concept as it was originally proposed by Hirschman. The discussion will be supported by some empirical illustrations. The linkages dealt with in this chapter are of a traditional input-output type, in their original form based on demand stimulating effects only, classifying industries based on index values. The linkages discussed in the present chapter do not reveal which industries are more or less related to each other through linkages, this is a question which is to be dealt with in subsequent chapters.

Interindustry linkages have been studied since the late 1950's with the purpose of identifying 'key industries' that are central for economic development. The present chapter gives an overview of different specifications of linkage measures followed by an assessment of the empirical strengths and weaknesses of the different measures. The chapter ends up with a discussion of the value of the linkage measures in analysing modern economic systems, as well as with a discussion of the possibilities of incorporating indicators of technology in the classical linkage measures, acknowledging the increasing focus on technological linkages in contemporary economics.

The classical linkage literature can be viewed as the first attempts to measure the 'pattern' of industrial interdependence. The classical linkage literature was not particularly concerned with the relation between interdependence on the one side and technological development and technology diffusion on the other, which has gained much interest in the recent years (see e.g. Leoncini et al., 1996; Los and Verspagen, 1996; Schnabl, 1994; Schnabl, 1995; Verspagen, 1997), but was solely

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focussed on demand and supply effects, searching for the industries which had the maximal effects on the total system through their demand and supply relations with other industries. This should be seen in the light of the prevailing economic conditions at that time: after World War II Keynesian demand-stimulating policies were dominating the agenda, thus making it a natural task for linkage studies to have as their main aim the identification of industries likely to have the most widespread demand stimulating effects (key industries).

The following section (section 3.2) presents the Hirschman linkage concept and discusses different attempts to measure these linkages, taking Rasmussen's (1957) indices of dispersion as the point of departure, but also introducing attempts to refine the Rasmussen indices. In section 3.3 an empirical comparison of the different measures is carried out applying Danish input-output data as a basis for a discussion of the qualities of the different measures. This is followed by an attempt to include technology in the traditional measures (section 3.4). Finally section 3.5 sums up and draws conclusions on both the merits of the measures and their applicability in analysing advanced economic systems.

3.2   Introducing the classical linkage concept

Backward and forward linkages were first presented by Hirschman (1958).[1] The linkage concept is generalised to the observation that ongoing activities 'induce' agents to take up new activities. This effect expresses a linkage between the ongoing and the new activity (Hirschman, 1977, p. 80).

Backward linkage effects are related to derived demand, i.e. the provision of input for a given activity. Forward linkage effects are related to output utilisation, i.e. the outputs from a given activity will induce attempts to use this output as inputs in some new activities (Hirschman, 1958, p. 100).

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[1]

Hirschman was primarily a development economist with a particular interest in Latin American countries. *The Strategy of Economic Development* (1958), which introduced the backward and forward linkage concepts, was thus founded on experiences gained as an official advisor and private consultant in Columbia in the first half of the 1950's (Hirschman, 1986a). But the economics developed in *Strategy* turned out to have a general applicability.

The total linkage effect for an industry i is defined as TL=$\Sigma x_i p_{ij}$, with x_i being the net outputs of industry i, and p_{ij} being the probability that each of the industries j will be set up as a consequence of the establishment of industry i.

For backward linkages the probability can be interpreted as the ratio of annual inputs required from industry i, denoted y, over the minimum economic size, in terms of annual productive capacity, of firms that would produce these outputs, z (i.e. p=y/z) (Hirschman, 1958, p. 101).

For forward linkages the probability is not easily defined, since the size of the market for the industries that might be established as the consequence of forward linkages does not depend on their suppliers. The probability is related to the importance of the products of industry i as inputs into the production of the output of the 'to-be-linked' industry. If these inputs are a very small fraction of the industry's eventual output, then their domestic availability is not likely to be an important factor in calling forth that industry.

3.2.1 Attempting to measure linkages

The *Rasmussen dispersion indices*, which were presented in the Danish economist P. Nørregaard Rasmussen's 1955/1957 doctoral thesis *Studies in Inter-Sectoral Relations*, have later become widely used as measures of Hirschmanian linkages, despite the fact that Rasmussen's thesis was published before the publication of Hirschman's *Interdependence and Industrialization* in 1958. Actually Rasmussen's thesis was primarily concerned with the effects of price changes on interindustry relations as expressed by 'terms of trade', but it is for the development of the index of the 'power of dispersion' of an industry as a means of identifying key industries that Rasmussen has gained his fame. The index describes the relative extent to which an increase in final demand for the products of a given industry is dispersed throughout the total system of industries. The power of dispersion index is defined as

$$\Sigma_i U_{ij} = \frac{\dfrac{1}{n}\, \Sigma_i B_{ij}}{\dfrac{1}{n^2}\, \Sigma_i \Sigma_j B_{ij}}$$

where *n* is the number of industries, and $\Sigma_i \mathbf{B}_{ij}$ is the sum of the column elements in the Leontief inverse matrix $\mathbf{B}=(\mathbf{I}-\mathbf{A})^{-1}$, which can be interpreted as the total increase in output from the whole system of industries needed to cope with an increase in the final demand for the products of industry *j* by one unit (Rasmussen, 1957, pp. 133-134). This index has been widely applied as a measure of backward linkages.

A supplementary index describing the extent to which the system of industries draws upon a given industry - an index of the 'sensitivity of dispersion' - is also presented by Rasmussen. The sensitivity of dispersion index measures the increase in the production of industry *i*, driven by a unit increase in the final demand for all industries in the system. This index is defined as

$$\Sigma_j U_{ij} = \frac{\dfrac{1}{n}\,\Sigma_j \boldsymbol{B}_{ij}}{\dfrac{1}{n^2}\,\Sigma_i\Sigma_j \boldsymbol{B}_{ij}}$$

where $\Sigma_j \mathbf{B}_{ij}$ is the sum of the row elements, which is interpreted as the increase in output in industry *i* needed in order to cope with a unit increase in the final demand for the product of each industry. The sensitivity of dispersion index has been interpreted as a measure of forward linkages.

An industry with a high power of dispersion (and a relatively small value of a standard deviation index, indicating that the industry draws evenly on the total system of industries) has the features of a 'key industry', since it would hand over a relatively large share of the increase of final demand for its products to the system of industries in general.

The interdependence measured by the Rasmussen indices is restricted to demand pull and supply push effects of changes in final demand. The indices are an expression of the way that input and output relations diffuse demand changes for the final products of a given industry *j* to other industries in the economic system, as the amount on inputs they provide to the directly affected industry *j* are dependent on the final demand for the products produced by industry *j*. Thus what is studied here is the *systemic character of an economy*: no unit - firm or industry - exists in isolation from the other units in the system.

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The definition of a linkage effect is closely related to the discussion of how an input-output system emerges. This can be illustrated by the way Hirschman presents Rasmussen's index of 'power of dispersion' as a measure of backward linkages based on a *mental experiment,* assuming for every industry in turn that the country's development started with just that industry, so that all the industry's sales to and purchases from other domestic industries are imagined to have developed as a sequel to the foundation of the industry in question (Hirschman, 1958, p. 105). Thus 'true' Hirschmanian linkages are only at play in the process of *development* of an input-output system, where new industries emerge as a result of the linkage effects. The sequential development of an input-output system presented by Hirschman has - at least theoretically - some radically different implications as opposed to perceptions of the input-output system as either emerging out of a 'Big Bang' or alternatively as having always existed (which is the way the system is often treated by statisticians). A Hirschmanian system is in theory always developing as long as the effects are at play, and thus this is a dynamic system which is continuously evolving.[2] The existing industries provide the incentives and driving forces for the development/expansion of the system through their activities, or rather through the input demands as well as output production stemming from these activities, which would imply that economic systems with a high degree of interrelatedness and strong causal linkage effects are more dynamic than a system with few causal linkages due to few incentive driving activities in the existing industries.[3]

Due to this causal effect which influences, or rather creates, the setup of an economic (input-output) system, linkages and interdependence cannot be used interchangeably in a Hirschman setting, since the industry which shows the highest degree of interdependence could very well have been set up last, thus providing that maximum interdependence is quite compatible with complete absence of active (causal) linkage effects (Hirschman, 1958, p. 105). The way that the linkage concept most often is used in input-output analysis is interchangeable with interdependence though, but that is basically due to a misuse of Hirschman's original concept:

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[2]

I am grateful to Esben Sloth Andersen for pointing to the importance of different perceptions of the emergence of input-output systems.

[3]

'Authentic' Hirschmanian linkages could in fact be perceived as induced innovations: Hirschman is talking about 'new activities' emerging as the consequence of the demand and supply effects of ongoing activities.

input-output analysis is by nature synchronic, where as linkage effects need time to unfold. [....] This basic difference has bedevilled various ingenious attempts at comprehensive, cross-section measurement of linkage effects and thereby "testing the linkage hypothesis". The more illuminating uses of the concept are perhaps to be found in a number of historically oriented studies which paid close attention to the sequence of development in individual countries (Hirschman, 1977, pp. 70-71).

Hirschman suspects that the reason for the success of the linkage concept in particular in development economics is to be found in the *apparent* intimate tie with input-output analysis, which is seen as a representative of the technical corpus of economic knowledge. But Hirschman claims that even though linkages seem easy to make operational, this draws on a misconception of the true character of linkages (Hirschman, 1977, p. 70).

One element that illustrates this is the fact that backward and forward linkages are not automatic: it is not just the relation between the market size and the economic size of a plant (i.e. the ratio y/z) that will trigger the private or public entrepreneurship needed to take up the opportunities for linkage investments. Variables such as technological 'strangeness' or 'alienness' of the new economic activities in relation to the ongoing ones, as well as obstacles in the form of the need of large amounts of capital due to scale requirements and the lack of marketing access and knowledge are also at work (Hirschman, 1977, p. 77-78). These factors are somewhat parallel to the concepts of 'absorptive capacity' (Cohen and Levinthal, 1990) or 'technological relevance' (Fikkert, 1997) in the spillover literature: a certain degree of technological closeness is necessary for the linkage to have an actual effect.

The elaborations on the linkage concept above clearly illustrate that the linkages which Hirschman had in mind are much more complex than what can be captured in a simple input-output index. But most of the attempts that have been made to make the linkage concept more operational have developed the Rasmussen indices without being truly capable of capturing the causality and probability incorporated in the Hirschmanian linkage concept. And while an input-output table cannot reveal which additional industrial branches are likely to be created in the wake of industrial investment in a given product line in a country setting out to industrialise, Hirschman does acknowledge that once a country has a fairly broad industrial base, where the expansion of a given

industry leads primarily to the expansion of existing industries rather than the creation of new industries, then the measurement of linkage effects on the basis of input-output tables becomes more meaningful (Hirschman, 1986b, pp. 58-59).

3.2.2   *Refinements of the linkage measure*

A central problem of making linkages of the Hirschman type operational is presented in Jones (1976). Jones points to the fact that in an input-output framework sales of industry *A* to industry *B* are recorded as industry *A*'s forward linkages and industry *B*'s backward linkages, but only one of these can be effective in a causal Hirschman sense. Each industry's backward linkage is equivalent to a weighted sum of the forward linkages of its supplier industries, while each forward linkage is a weighted sum of the user's backward linkages (Jones, 1976, p. 329). As a consequence of this, for an economy as a whole the backward linkages equal the forward linkages (both weighted by the value of output), implicating that at the system level the total linkages are precisely the double of the maximum causal ('Hirschmanian') potential. For an industry though, where upstream and downstream linkages are expected to differ, the total linkages represent the maximum potential causal linkages.

The relation between input-output dependencies and pure Hirschmanian linkages is summarised as follows by Jones:

*   Interdependence is a necessary, but not sufficient, condition for linkage effects. High interdependence thus suggests potential linkages which could be further examined for causality, e.g. through case studies;
*   Even when a linkage is inoperative in the *causal* sense, it may still have *economic importance* (Jones, 1976, p. 324).

Interdependence in an input-output framework can only be identified with linkages if the linkage concept is broadened to include 'permissive and inoperative linkages', i.e. sectoral interdependencies which are not 'crucial' in the sense that one industry has induced the existence of the other, as well as 'true' Hirschmanian causal linkages (Jones, 1976, p. 325).

Jones also questions the use of Rasmussen's index of sensitivity of dispersion as a measure of forward linkages, arguing that there is not much economic sense in exploring what happens to an industry if all industries, no matter their size, are to expand their output by an identical unit increase. Instead Jones proposes the use of the *output inverse* matrix, as opposed to the Leontief *input inverse* matrix as a meaningful measure of forward linkages. The output inverse is calculated from output coefficients (x_{ij}/X_i),[4] and contains elements expressing the increase in output of an industry *j* required to utilize the increased output brought about by a unit of primary input into an industry *i*.

Even though Jones claims that he describes how to measure Hirchmanian linkages, what he in fact is doing is refining the *Rasmussen* indices. This is due to the fact that pure Hirschmanian linkages, as correctly pointed out by Jones in the introduction to his paper, *cannot* be measured by the use of coefficient matrices alone. At most it can be argued that the Rasmussen-type indices are *proxies* of Hirschmanian linkages (as suggested by Hirschman himself), disregarding the qualitative factors that also play an important role in the establishment of causal linkages.

An attempt to make up for some of the deficiencies of the linkage measures based on coefficient matrices is presented in Cuello et al. (1992), who incorporate information from outside the Leontief inverse matrix in order to obtain a more accurate measure of the economy wide importance of key industries.[5] Cuello et al. use the original Rasmussen definition as the starting point in calculation both types of indices, i.e. also in the case of the forward linkage measure is the Leontief inverse based on *input* coefficients used.

Cuello et al. reformulate the traditional linkage approach by including a vector of parameters which is used in weighing the coefficients in the Leontief inverse matrix. Two different vectors are used in the analysis: the relative importance of final demand $(\alpha_i = y_i / \Sigma \ y_i)$; and the importance of total sectoral output $(\beta_i = \{\Sigma_j \ [x_{ij} + y_{ij}]\}/\{\Sigma_{ij} \ [x_{ij} + y_{ij}]\})$.

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[4]   The matrices of output coefficients and input coefficients share the same diagonal since $X_i = X'_j$

[5]

      Dietzenbacher (1992) also presents an alternative method, the so-called eigenvector method, for measuring linkages. As the logic behind this linkage measure is somewhat different than the measures presented here, which are straightforward developments of the Rasmussen measures, I will not go further into the eigenvector method here.

The backward (U_{wj}) and forward (U_{wi}) linkages are now calculated as:

$$U_{wj} = \frac{\frac{1}{n}\Sigma_i w_i b_{ij}}{\frac{1}{n^2}\Sigma_{ij} w_i b_{ij}}$$

$$U_{wi} = \frac{\frac{1}{n}\Sigma_j w_j b_{ij}}{\frac{1}{n^2}\Sigma_{ij} w_j b_{ij}}$$

with w being the chosen weight (either α or β) and b_{ij} being the elements of the Leontief inverse (**B**).

Cuello et al. also deal with the problem of measuring the likelihood of the linkages - a problem that has remained unsolved since McGilvray (1977) criticised the notion of a 'vector of probability'. McGilvray's critique concerns the weights used as probability measures: a common way of calculating the probability for backward linkages is using actual final demands or output. This means that the measures of the linkage will reflect the actual or *ex post* linkages in the economy, rather than the *ex ante* or potential linkages created by a concentrated development of certain key industries. While linkage measures based on the *ex post* level and pattern of production may be useful in summarising the interdependence of industries at the current level of development, McGilvray claims that they are not necessarily very useful in the context of the type of growth sequence envisaged by Hirschman (McGilvray, 1977, p. 53).

Cuello et al. try to solve this problem by introducing assumptions on the statistical distribution of the indices in order to calculate their likelihood. In an empirical[6] test the likelihood of the approaches including weights in general showed to be greater than the likelihood of the traditional approaches which do not use weights. But Cuello's likelihood tests of the weighted linkages do not solve the core of the problem raised by McGilvray: how to find an *ex ante* probability measure. Instead Cuello et al. test the 'quality' of the chosen *ex post* possibility weight.

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[6]   Using input-output data from Washington State (USA), 1963-72.

The present chapter does not attempt to solve the problem of finding a more appropriate measure of true Hirschmanian linkages in an input-output framework since, as pointed to by Hirschman himself, other more qualitative methods are called for to fulfill this task. I am thus in the present context content with being able to estimate possible linkage effects in order to identify industries of economic importance, acknowledging the fact that there might not have been a causal effect at play. In order to be able to go further into a discussion of the appropriateness of the different measures from an empirical point of view, the next section is devoted to an empirical comparison of the measures, applying Danish input-output data.

3.3   An empirical comparison of linkage measures - identifying key industries

This section will compare the different measures presented in section 3.2 from an empirical perspective. The data applied are Danish input-output tables for the years 1966, 1979 and 1992. The data are in their standard form classified according to a 117 industry aggregation based on the United Nations' ISIC-1968 classification standard, but I have chosen to present results at a 22 industry level which is also used in subsequent chapters. Results based on the 117 industry aggregation are presented in appendix A. The availability of input-output tables as far back as the mid-1960's allows for an analysis of the stability of the linkage measures, as well as for an evaluation of the informational value of the identification of the so-called key industries.

3.3.1   The stability of linkage indices over time

As table 3.1 illustrates, the linkage indices are very stable even over considerable time periods (illustrated in the dark grey cells). The correlation between the Rasmussen backward linkages in the 13 year interval 1966-1979 is 0.7, while it is 0.6 for the subsequent 13-year interval 1979-1992. Between 1966 and 1992 the correlation is also 0.6. A similar pattern is found for the Cuello α backward linkage, while the correlation between time periods is even stronger for the β backward linkage .[7]

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[7]   α and β should range between 0 and 1, and sum up to 1. In the case of the Danish matrices the second feature is fulfilled, but due to the fact that final demand in the Danish input-output tables includes changes in stocks, which can be negative for some industries, the weight can in fact have a value less than 0. The linkages were calculated both including and excluding changes in stock, with no changes in the ranking of the sectors according to their index value.

Table 3.1: Pearson correlations between linkage measures for the years 1966, 1979 and 1992#

	Rasm. BL,'66	Rasm. BL,'79	Rasm. BL,'92	C-α BL,'66	C-α BL,'79	C-α BL,'92	C-β BL,'66	C-β BL,'79	C-β BL,'92	Rasm. FL,'66	Rasm. FL,'79	Rasm. FL,'92	Jones FL,'66	Jones FL,'79	Jones FL,'92
Rasm.BL,'66	1														
Rasm.BL,'79	.723**	1													
Rasm.BL,'92	.639**	.637**	1												
C-α BL, '66	-.275	-.174	-.127	1											
C-α BL, '79	-.591**	-.526*	-.353	.782**	1										
C-α BL, '92	-.634**	-.598**	-.403	.644**	.938**	1									
C-β BL, '66	-.267	-.153	-.109	.908**	.634**	.457*	1								
C-β BL, '79	-.378	-.307	-.208	.797**	.618**	.453*	.960**	1							
C-β BL, '92	-.474 *	-.408	-.314	.750**	.598**	.481*	.913**	.979**	1						
Rasm.FL,'66	-.149	-.102	-.103	.387	.204	.136	.696**	.789**	.790**	1					
Rasm.FL,'79	-.294	-.293	-.195	.329	.217	.166	.638**	.781**	.821**	.949**	1				
Rasm.FL,'92	-.413	-.363	-.352	.319	.312	.284	.544**	.703**	.765**	.759**	.829**	1			
Jones FL,'66	.586**	.434*	.303	-.021	-.345	-.376	.127	.114	.092	.468*	.364	.188	1		
Jones FL,'79	.349	.351	.120	.139	-.281	-.322	.293	.284	.297	.507*	.441*	.404	.802**	1	
Jones FL,'92	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.

** Correlation is significant at the 0.01 level

 * Correlation is significant at the 0.05 level

 # Cuello forward linkages are not shown in the table as they equal Cuello backward linkages.

Also the forward linkages are very stable over time with the Rasmussen forward linkages (sensitivity of dispersion) being slightly more stable than the Jones linkages. This observation might be due to outputs varying more than inputs industry wide over time.[8] The Cuello forward linkages are equal to the backward linkages because of the large influence of the weights compared to the very narrow range of the unweighted measures around unity. Thus the Cuello forward linkages are excluded from any further analysis.

Even though it is a well-known fact that input-output structures are very stable, the above results are remarkably strong, considering the changes which the Danish economy has undergone during the 26-year period covered by the tables. This could indicate that the measures are not very suitable for time series analysis, at least not in advanced countries with a developed interindustrial structure. Furthermore the identification of new key industries is limited by the prevailing industry classification principle, which even at the level of detail in the appendix table implies that if new key areas of the economy are grouped together with stagnating/declining areas, then it is not possible to identify these areas in an input-output framework.

3.3.2 Correlations between different linkage measures - does the specification make a difference?

As described in section 3.2.1 Cuello et al. introduce weights into the Rasmussen linkage measures in order to obtain a 'more accurate' measure of the economy wide importance of key industries. The purpose is to develop an index which is more able to capture the spread of the multiplier (demand stimulating) impact of key industries (Cuello et al., 1992, pp. 285-286).

This section will explore whether the Cuello indices are in fact significantly different from the Rasmussen index. Again only the Cuello backward linkages are included as the forward linkages do not differ from the backward ones.

As table 3.1 shows, the Cuello backward linkage measures, both in the α and β specification,

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[8] The Jones linkage value for 1992 is constant with a value of 1 for all sectors, i.e. no correlation can be calculated including this year.

differ considerably from the Rasmussen backward linkage (power of dispersion) measure. The difference between the α and β specifications is moderate (light grey cells), thus it is primarily the choice between a Rasmussen and a Cuello backward linkage specification that makes a notable difference.

The choice of backward linkage measure depends on the purpose of the analysis: the Rasmussen index does not take the size of industry into consideration in calculating the linkage effects, i.e. this is a 'pure' measure of the extent of interrelatedness of industries distinguishing which industries have a larger multiplier than others. Thus this specification can be of value in an analysis of the extent to which industries draw more, respectively less, than average on the system of industries, but when it comes to the application of the concept of key industries for policy[9] purposes the inclusion of a measure of the size of the industry becomes relevant, which leads to the application of the Cuello specification. The α weight seems most appropriate since final demand is more easily manipulated through policy measures than total production.

Jones (1976) characterised the Rasmussen forward linkage measure (sensitivity of dispersion) as being 'not a very fruitful specification' (Jones, 1976, p. 327). The criticism relates to Rasmussen's index as an expression of the effect for a single industry of an increase in the expansion of output by all industries by an identical unit - no matter the size of the industry. Jones finds this an unlikely situation, and instead proposes to utilize the *output* inverse matrix in the calculation of the index. The row sums of the output inverse show the increase in total output of the system, required to utilize the increased output from an initial unit of primary input into industry i (Jones, 1976, p. 328).

However, as illustrated in table 3.1, the Jones forward linkages do not appear to differ empirically as much from the Rasmussen specification of forward linkages as was the case with the backward linkages measured by Rasmussen and Cuello et al. respectively, with the correlation between the two measures being around 0.5.

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[9]   'Policy' in this chapter is primarily used in the sense 'Keynesian policy', as the linkage measure was originally developed from the perspective of Keynesian policy thinking (cf. the introduction to this chapter).

It seems that Jones' modification of the forward linkage measure is more in line with the original idea behind a forward linkage: a linkage related to the output utilisation. The Rasmussen index of sensitivity of dispersion seems more artificial in the sense that it does not provide much useful information for assessing the linkage effect of a given industry. In that sense the Jones specification provides more (policy) relevant information since it expresses the increase in output of an industry j required to utilize the increased output brought about by an initial unit of primary input into an industry i, thus it expresses the need for production expansion necessary to fully utilize output increases in intermediary industries.

3.3.3 Key industries in Denmark

The above sub-sections have been dealing with the features of the linkage measures. But what is really interesting from an applied economics perspective is which industries are identified as key industries in the Danish economy.

At the disaggregated level of industry classification illustrated in appendix A, several industries are identified as key industries in the Danish economy. The more aggregated analysis presented here provides a more 'manageable' result, but it should be kept in mind that the higher the level of aggregation, the more information is hidden.

Applying the Rasmussen linkage measures, key backward linked industries are mainly to be found in traditional low tech industries with production principles determined by economies of scale (see left columns of table 3.2), while key forward linked industries are to be found in services and public utilities as well as raw materials/other manufacturing.

Recapturing the definition of a key backward linked industry (i.e. an industry with a power of distribution index larger than 1) it is an industry that pulls (through input requirements) more than average on the whole system of industries in its production. A key forward linked industry is an industry which experiences an above average production effect from a general increase in demand in the system, i.e. the system of industries pulls more than average on this type of industry. Thus it makes sense that it is general input industries like services as well as raw materials that are the

types of industries which are most effected by general increases in demand.

Table 3.2: Key industries in Denmark

	Rasmussen						Cuello BL						Jones FL	
	BL			FL			α			β				
	'66	'79	'92	'66	'79	'92	'66	'79	'92	'66	'79	'92	'66	'79
Food etc.	x	x		x			x			x	x	x		
Textiles, leather etc.		x	x											
Chemical raw mat.	x												x	x
Pharmaceuticals	x													
Rubber and plastics	x	x		x									x	x
Other chemical ind.	x		x										x	
Non-metallic mineral prod.	x	x	x											
Iron and metal ind.	x	x		x	x					x			x	x
Agricultural mach.	x													
Other machinery														
Telecom. incl. radio/TV														
Other electronics	x	x											x	
Shipbuilding														
Transport equipment	x	x												
Instruments	x													
Construction							x	x	x	x	x	x		
Wholesale and retail trade				x	x	x	x	x	x	x	x	x		
Public utilities (heating, electricity etc.)				x	x	x				x	x	x	x	
Business services					x	x					x	x	x	x
Other services							x	x	x	x	x	x		
Primary sectors and manufacturing n.e.c.				x	x	x	x	x	x	x	x	x	x	x
Public services							x	x	x					

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The industries with above average forward linkage values can in the Rasmussen specification be regarded as the industries that are most strongly affected by a general expansion in the production by the whole system of industries. Thus from a policy perspective these industries are not as interesting as the backward linked industries which influence the rest of the system through the multiplier effect. Rather the forward linked industries are those industries that are most influenced by the backward linkages.

Even though the Rasmussen indices, as shown in section 3.3.1, are very stable over time, the range of the backward linkage index values is very narrow, ranging from 0.9999995 to 1.0000006 in 1966, and narrowed in even more in 1992 from 0.9999999 to 1.0000001, i.e. the differences in the linkage indices are very small. The primary reason for this very narrow range of the index is - somewhat paradoxically - to be found in the quality of the input-output tables, as well as in the high degree of interrelatedness in the Danish economy, which implies that practically no cells in the input-output matrix are empty. The original indices calculated by Rasmussen were based on the Danish 1947 input-output matrix which had 293 empty cells out of a total of 441 cells (a 21x21 matrix). In this case the power of dispersion (backward linkage) index ranged from 0.85 to 1.24 - if only two decimals were to be applied in the present calculations all index values would equal 1. Thus it seems that the Rasmussen indices only really makes sense as a tool for identifying key industries in the cases of incomplete input-output matrixes with several empty cells, while their use is very limited in case of advanced matrices with no or very few empty cells.[10] Thus even though the indices are stable over time, i.e. it is largely the same industries that are identified as key industries at different points of time, their power as key industries is not very strong.

Let us instead turn the attention to the Cuello indices which were developed with the aim of obtaining a more accurate measure of the economy wide importance of key industries by incorporating information from outside the Leontief inverse matrix. As in section 3.3.1 and 3.3.2, two different versions of the backward and forward indices are calculated: an α index using the relative importance of final demand ($\alpha_i = y_i / \Sigma \, y_i$) as a weight in calculating the coefficients in the Leontief inverse matrix, and a β index using the importance of total sectoral output ($\beta_i = \{\Sigma_j$

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[10]   This is the case even at a very disaggregated level, at the 117 industry level, the range of the backward linkage index is 0.999989-1.0000042 in 1966, narrowing in to 0.9999998-1.0000007 in 1992.

$[x_{ij}+y_{ij}]\}/\{\Sigma_{ij} [x_{ij}+y_{ij}]\})$ in the weighing procedure. As section 3.2. showed, the α and β linkages are rather closely correlated since final demand is used in calculating both weights. The Cuello indices do not identify key industries based only on their linkages to other industries in the economic system, but also based on the size of the industry according to deliverances to final demand (α) or total sectoral output (β). Thus when applying the Cuello measures we end up with a group of industries which are quantitatively large and/or have large demand stimulating effects through their backward linkages.

Construction, wholesale and retail trade, other services as well as primary sectors and other manufacturing are key industries in all periods applying both the α and β specification. These industries are large in volume, both in terms of final demand and in terms of total sectoral output. Food is only a key industry in 1966 applying the α specification, while it is a key industry in all periods applying the β specification, indicating the large role played by intermediate inputs from this industry. The opposite situation is to be observed for public services, which is only a key industry from the final demand perspective. Public utilities and business services (except in 1966) are key industries applying the total sectoral output specification, once again illustrating the large role played by intermediate output from these industries. In general the Cuello specification serves to illustrate the importance of the non-manufacturing section of the Danish economic system in terms of production volume, as opposed to the Rasmussen (BL) index, which illustrates the degree of interconnectedness in the manufacturing section of the system.

Let us finally turn to the Jones forward linkages. As described in section 3.2.2, Jones uses the output coefficient matrix in calculating forward linkages, instead of the input coefficient matrix as is done in Rasmussen's specification. Thus Jones' forward linkages are somewhat more relevant from a policy perspective since they measure the full capacity production required as inputs increase for a given industry.

The values of Jones index are to be found within an even more narrow range than the Rasmussen index, from 0.9999997 to 1.0000006 in 1996, 0.9999999-1.0000001 in 1979, and reaching the constant value of 1 for all industries in 1992. Thus the increase in total output of the system, required to utilize the increased output from an initial unit of primary input into a given industry,

becomes still more evenly distributed on the total system.[11] Key forward linked industries in 1966 and 1979 are chemical raw materials, rubber and plastics, iron and metal industries, business services as well as primary sectors and other manufacturing, i.e. primarily scale intensive industries and services. In 1966 also other chemical industry, other electronics and public utilities are key industries. Since the Jones key industries are expected to be the typical intermediate industries, it might be expected that more specialised supplier industries were found to be key industries. Even at the more disaggregated level this is not the case though, the major part of the Jones FL industries are to be found in scale intensive and supplier dominated industries. But when you take a closer look it makes sense that industries with products of a wide applicability, like chemical raw materials, rubber and plastics, iron and metal as well as services, play a major role as input suppliers.

Summing up, this section has showed that the measurement specification applied makes a considerable difference for the characterization of an economy applying linkage indices. Thus results of such an analysis should be interpreted with caution, and the indices cannot be used as indicators that can stand alone, rather they should only be applied in a broader context. Before going further into the discussion of the values of the different linkage measures, the final analytical part of this chapter attempts to develop the linkage measure in order to be able to include a more dynamic potential of the interrelatedness between industries in an economic system than the above described indices.

3.4   Measuring technological linkages

As mentioned in the introduction, the present chapter also attempts to incorporate technology indicators into the classical linkage measures. It is assumed that linkages involving technology or knowledge intensive industries are likely to be more dynamic than 'ordinary' linkages since knowledge is a key factor in economic development. A very simple way of incorporating technology is by applying the basic Cuello expression (again only backward linkages are to be dealt with):

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[11]   At the 117 industry aggregation an uneven effect on the system can still be found, but this is evened out in the aggregation.

$$U_{wj} = \frac{\frac{1}{n}\Sigma_i w_i b_{ij}}{\frac{1}{n^2}\Sigma_{ij} w_i b_{ij}}$$

but instead of using the α and β weights, a number of technology or knowledge weights, γ, δ and λ are introduced. Thus instead of weighting the linkages according to their production volume, the knowledge level in the linked industry is used as a weight. The industries identified through applying these linkages are industries which have above average (demand stimulating) backward linkages and/or a high knowledge level, i.e. they can be perceived as key (knowledge intensive) user industries through the combination of the extent of their demand as well as through their knowledge level.

γ is expressed as the fraction of employees with a degree in engineering or natural sciences (from advanced studies, either short, medium or long), in the following chapters labelled 'technical

Table 3.3: Pearson correlations between the knowledge weighted backward linkage measures (γ, δ and λ) and the 'traditional' backward linkage measures

	γ, 1979	γ, 1992	δ, 1979	δ, 1991	λ, 1979	λ, 1991
γ, 1979	1					
γ, 1992	.950**	1				
δ, 1979	.629**	.645**	1			
δ, 1991	.654**	.589**	.836**	1		
λ, 1979	.379	.345	.310	.147	1	
λ, 1991	.402	.383	.376	.195	.989**	1
Rasmussen 1979	-.042	-.004	.023	-.233	-.050	-.041
Rasmussen 1992	-.155	-.097	.045	-.271	-.197	-.191
α, 1979	-.500*	-.498*	-.371	-.300	-.031	-.070
α, 1992	-.399	-.412	-.412	.298	.039	-.010
β, 1979	-.466*	-.479*	-.257	-.086	-.207	-249.
β, 1992	-.377	-.408	-.247	-.008	-.206	-.254

** Correlation is significant at the 0.01 level
 *Correlation is significant at the 0.05 level

employment', δ is expressed as the industry's R&D expenses, and λ as the number of patent grants[12]. The data are at present only available for the period 1980-1991/1992, thus the data on formal education from 1980 are combined with 1979 input-output data. The different weights have each their own characteristic as a knowledge indicator: R&D is a measure of the input effort in relation to knowledge creation; patent grants is a measure of output from the knowledge creation process; while the fraction of employees with a degree in engineering or natural sciences is an overall - and somewhat abstract - measure of the general technical knowledge 'level' in each industry.

Table 3.3 shows that the knowledge weighted measures do not correlate significantly with either of the other backward linkage measures (with the exception of some negative correlations with the Cuello measures). There is a quite high correlation between the γ and δ weighted measures (i.e. between the education and R&D weighted measures), while the λ weighted measure (patenting) does not correlate significantly with any other measure. The γ, δ and λ weighted measures show the same stability over time as all the other measures.

Turning to the actual key industries identified applying the knowledge weighted measures (table 3.4) the most striking difference as compared to the measures presented in section 3.3 is that industries like other machinery, telecommunications and other electronics are identified as key industries (all by at least 2 of the 3 specifications). In particular telecommunications and electronics are amongst the dynamic core of knowledge based industries. The λ (patent) weighted measure is restricted to identifying key industries amongst manufacturing industries and construction, while the γ and δ weighted measures, just like the Cuello α and β measures, also identify business services as a key industry.

Whether the knowledge weights are more useful than the other specifications of the linkage measure depends on the purpose of the analysis. As the overall purpose of the thesis is to analyse the importance of technological interindustry linkages the knowledge weights are found to be a useful modification of the Cuello specification, although it is acknowledged that a linkage analysis

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[12]   US patent data, i.e. Danish firms' patenting in the United States. The US patent data are chosen at the expense of European patent data (EPO) based on the assumption that the American patenting market represents a higher degree of technological novelty.

Table 3.4: Key industries in Denmark applying knowledge weights

	Edu, BL (γ)		R&D, BL (δ)		Patents, BL (λ)	
	'79	'92	'79	'91*	'79	'92
Food etc.			x			
Textiles, leather etc.						
Chemical raw mat.	x	x	x		x	x
Pharmaceuticals	x	x	x	x		x
Rubber and plastics						
Other chemical ind.	x	x				
Non-metallic mineral prod.						
Iron and metal ind.					x	x
Agricultural mach.						
Other machinery	x	x	x	x	x	x
Telecom. incl. radio/TV	x	x	x	x		x
Other electronics	x	x			x	x
Shipbuilding						
Transport equipment						
Instruments	x	x	x	x	x	x
Construction	x	x			x	x
Wholesale and retail trade				x		
Public utilities (heating, electricity etc.)						
Business services	x	x	x	x		
Other services						
Primary sectors and manufacturing n.e.c.						
Public services						

of this sort cannot stand alone as an expression of nodal industries in an economic system. What has been achieved in this chapter nonetheless is a critical overview of different linkage measures, illustrating different drawbacks as well as advantages of various specifications. The next concluding section will elaborate further on this.

3.5   Conclusions

This chapter has attempted to revive and bring forward the discussion of the use of input-output based linkages in the analysis of economic systems, taking a discussion of the linkage concept, both in its original theoretical form as presented by Hirschman, as well as in its empirical form as expressed by different input-output related measures, as the point of departure.

The empirical measures presented were the Rasmussen power of dispersion (backward linkages) and sensitivity of dispersion (forward linkages) indices, the Jones forward linkage applying the output coefficient matrix instead of the input coefficient matrix, and the Cuello backward and forward linkages introducing weights into the specification. The two weights used by Cuello were an α and a β weight respectively. The α weight is the relative importance of final demand while the β weight is the importance of total sectoral output. Finally three new weights, γ, δ and λ are introduced. γ, δ and λ are different knowledge indicators, applying the fraction of employees with a technical or natural science degree, R&D expenses and patent grants respectively.

A Hirschman linkage effect is in its original formulation an effect of an ongoing activity, i.e. the ongoing activity invites operators to take up new activities, either through an output utilisation effect (forward linkage) or an input requirement effect (backward linkage). In the case of a developed country with a broad industrial base, the linkage effect is primarily an expansion of the linked activities rather than the creation of new activities, in this case expressed as industries. Thus in developed countries the input-output approach for identifying linkages is more appropriate than in the case of industrializing countries where the purpose is to analyse the emergence of new industries. In developed countries the linkage effects could be reduced to demand stimulating (backward) linkages or production requirement (forward) linkages. Thus in this respect the Rasmussen power of dispersion index is an appropriate measure of backward linkages. But the Rasmussen specification has the problem of leading to index values very close to unity for all industries in the case of a developed, quite interrelated economic system like the Danish. Thus the Rasmussen specification turns out to be more appropriate in the case of economic systems which are represented by input-output matrices with several blank cells expressing lack of interdependence, in order to lead to a clear-cut distinction between the 'key industries' and less linked industries. Thus also respecting Hirschman's original linkage concept, keeping in mind that

Hirschman has a strong focus of the policy perspective, it seems appropriate to follow Cuello et al. in changing the linkage specification in order to also take the size of the industry into account when calculating the indices for developed countries. A very small industry with an above average backward linkage index is hardly very interesting as a 'key industry' for the economic system thus making the combination of linkage effect and size an important development of the linkage measure.

The introduction of weights makes the separation between forward and backward linkages impossible though, since the weight plays a very large role in calculating the index. Also the forward linkage measure does not have the same value from a policy perspective as the backward linkage which has a straightforward interpretation as a demand stimulating industry. If a forward linkage measure is to be applied, the Jones specification is to be preferred relative to the Rasmussen sensitivity of dispersion index, as the Jones index expresses the increase in output of an industry required to utilize the increased output brought about by an initial unit of primary output into another industry with which the first industry is linked as a user. The Rasmussen sensitivity of dispersion index simply expresses the effect for a single industry of an increase in the expansion of output by all industries by an identical unit. This does not have much in common with a forward linkage as presented by Hirschman.

The chapter ends up with the introduction of a new weight to be applied in a Cuello type specification of a backward linkage: the knowledge indicator weights γ, δ and λ. The purpose of introducing these knowledge weights is to introduce a more dynamical dimension into the linkage specification, as knowledge is assumed to be a prerequisite for economic development. Thus if the linkage is to express a development potential, as was Hirschman's primary intent, these weights seem more appropriate than size related weights like the α and β weights originally introduced by Cuello et al. But most important of all the chapter has illustrated that linkage measures and their related key industries should be interpreted with caution, and can only be used as a very first step in the study of patterns of interindustry linkages. And if the intent to attempt to create a synthesis between traditional input-output economics and economics of technological change a linkage measure based on ranking indices alone is insufficient. Part II will thus expand the linkage discussion and introduce alternative, and I argue, more informative linkage measures.

Appendix A: Backward and forward linkages in Denmark, 1966, 1979 and 1992 (based on 117 industry aggregation)

	Backward linkage measures											Forward linkage measures					
	POD	POD	POD	α	α	α	β	β	β	γ	γ	SOD	SOD	SOD	Jones	Jones	Jones
	66	79	92	66	79	92	66	79	92	79	92	66	79	92	66	79	92
1 Agriculture				x	x	x	x	x	x			x	x	x			
3 Fur farming etc.			x			x											
5 Forestry, logging																x	
6 Fishing							x	x	x			x	x		x	x	x
7 Extr. coal, oil, gas	x								x	x	x						
8 Other mining	x	x													x	x	x
9 Slaught. of pigs and cattle				x	x		x	x				x	x				
10 Poultry killing etc.	x	x	x														
11 Dairies				x			x	x				x	x				
12 Cheese, cond. milk	x					x											
13 Ice cream mfr.	x	x	x														
14 Proc. of fruits and veget.	x	x															
15 Proc. of fish	x																
16 Oil mills			x				x	x		x	x	x	x	x	x	x	x
17 Margarine mfr.	x	x	x													x	
18 Fish meal mfr.	x	x	x														
19 Grain mill prods.	x	x	x				x	x				x	x		x	x	x
20 Bread factories	x	x	x														
21 Cake factories	x	x															
23 Sugar factories, refin.	x	x			x		x	x	x	x	x	x		x	x	x	x
25 Mfr. of food prods n.e.c.	x	x														x	
26 Mfr. of animal feeds	x	x	x									x			x	x	x
27 Dist and blending spirits	x	x	x							x	x					x	x
28 Breweries											x						

	Backward linkage measures											Forward linkage measures					
	POD	POD	POD	α	α	α	β	β	β	γ	γ	SOD	SOD	SOD	Jones	Jones	Jones
	66	79	92	66	79	92	66	79	92	79	92	66	79	92	66	79	92
30 Spinning, weaving (text)							x	x				x				x	
31 Made-up textile goods	x															x	
33 Cordage, rope and twine	x	x	x														x
34 Mfr. of wearing apparel				x													
35 Leather, leather prods.	x	x	x									x			x	x	x
36 Mfr. of footwear	x	x	x														
37 Wood prods excl. furnit.						x	x		x								
38 Wooden furniture, etc.						x											
39 Pulp, paper, paperboard		x	x				x					x			x	x	x
40 Paper containers, wallp.							x	x	x			x	x	x	x	x	x
41 Reprod and comp. serv.	x	x											x		x	x	x
42 Book printing							x	x	x			x	x	x	x	x	x
43 Offset printing	x						x	x	x			x	x	x	x	x	x
44 Other printing	x	x							x			x			x	x	x
45 Bookbinding	x	x	x												x	x	x
46 Newspapers							x	x				x	x			x	
47 Book and art publishing	x	x	x														
48 Magazine publishing	x	x	x													x	
49 Other publishing	x	x	x													x	
50 Basic ind. Chemicals										x	x						
51 Fertilizers and pesticides			x							x	x						
52 Basic plastic materials	x							x			x		x		x	x	
53 Paints and varnishes										x	x	x				x	
54 Drugs and medicines										x	x						

	Backward linkage measures												Forward linkage measures					
	POD	POD	POD	α	α	α	β	β	β	γ	γ		SOD	SOD	SOD	Jones	Jones	Jones
	66	79	92	66	79	92	66	79	92	79	92		66	79	92	66	79	92
55 Soap and cosmetics		x																
56 Chemical products n.e.c.	x	x			x					x	x					x	x	x
57 Petroleum refineries						x	x	x	x	x	x		x	x		x		
58 Asphalt, roofing mat.		x								x	x							
59 Tyre and tube industries	x	x	x													x		x
60 Rubber products n.e.c.										x	x		x			x		
61 Plastic products n.e.c.							x	x			x		x	x	x	x	x	
62 Earthenware and pottery	x	x	x															
63 Glass and glass products	x	x														x	x	x
64 Structural clay products		x	x															
65 Cement, lime, plaster										x	x					x	x	
66 Concrete prods & stone cut.										x	x							
67 Non-metallic mineral products										x	x							
68 Iron and steel works	x									x	x					x		
69 Iron and steel casting	x	x	x													x		
70 Non-fer. metal works	x	x	x				x	x		x	x		x	x		x	x	x
71 Non-fer. metal casting	x	x	x								x					x	x	
72 Mfr. of metal furniture	x	x									x							
73 Structural metal prods									x	x	x							
74 Metal cans, containers							x			x	x		x			x	x	x
75 Other fabricated prods					x		x	x	x	x	x		x	x	x			
76 Agricultural machinery					x					x	x							
77 Industrial machinery					x					x	x							

	Backward linkage measures											Forward linkage measures					
	POD	POD	POD	α	α	α	β	β	β	γ	γ	SOD	SOD	SOD	Jones	Jones	Jones
	66	79	92	66	79	92	66	79	92	79	92	66	79	92	66	79	92
78 Repair of machinery							x	x	x				x	x		x	
79 Household machinery	x	x								x	x						
80 Refrigerators, accessories				x	x	x	x	x	x	x	x	x	x	x			
81 Mfr. of telecom. equip.					x					x	x						
82 Electrical home appl.	x	x	x							x	x						
83 Accumulators, batteries	x	x	x							x				x	x	x	x
84 Other electrical supplies							x	x	x	x	x	x	x				
85 Ship building and repair				x	x	x	x		x	x	x						
86 Railroad, auto equip.				x	x	x				x	x						
87 Cycles, mopeds, etc.	x	x	x								x						
88 Prof. and measur. equip.					x	x				x	x						
89 Mfr. of jewellery, etc.		x	x														
90 Toys,sporting goods,etc.						x											
91 Electric light and power							x	x	x	x	x	x	x	x	x		
92 Gas mfr. and distr.	x	x								x	x						
93 Steam and hot water sup										x	x						
94 Water works and supply	x	x	x							x	x						
95 Construction				x	x	x	x	x	x	x	x	x	x	x			
96 Wholesale trade				x	x	x	x	x	x	x	x	x	x	x			
97 Retail trade				x	x	x					x						
98 Restaurants and hotels								x									
99 Railway and bus transp.								x									
100 Other land transports							x	x	x			x	x	x			

	Backward linkage measures											Forward linkage measures					
	POD	POD	POD	α	α	α	β	β	β	γ	γ	SOD	SOD	SOD	Jones	Jones	Jones
	66	79	92	66	79	92	66	79	92	79	92	66	79	92	66	79	92
101 Water transport				x	x	x						x					
102 Serv. to water transport		x															
103 Air transport								x	x								
104 Serv. allied to transport							x	x	x			x	x	x	x	x	
105 Communication							x	x	x			x	x	x			
106 Financial institutions				x	x	x	x	x	x								
108 Dwellings				x	x	x											
109 Business services						x	x	x	x	x	x	x	x	x			
113 Rep. of motor vehicles							x	x	x			x	x	x			
114 Household services								x	x				x	x			
117 Prod. of gov. services				x	x	x	x	x	x				x				

Part II: Extending the Linkage Concept - The Danish Case as an Illustration of Linkage Mapping Exercises

Part I discussed the elements relating the input-output and technological change research traditions, reaching the conclusion that an extended interpretation of the input-output coefficients as expressions of direct exposure to external knowledge and technology was an important step in combining the two research traditions. Also part I concluded that traditional, index based linkage measures are insufficient as expressions of technology linkages.

In order to deal with this insufficiency, part II extends the linkage concept and presents different empirical applications of linkage studies with the major focus on mapping linkages. The purpose of part II is to illustrate different methods for identifying technological interindustry linkages, as well as different ways of interpreting the linkages, their background and their implications.

The chapters in this part (chapters 4 and 5) are devoted to the analysis of the Danish economy. Chapter 4 investigates technological interdependencies at the industry level in Denmark, during the period 1980-1992. The chapter introduces the concepts 'direct' and 'indirect' technology, the indirect technology being acquired through economic transactions as they appear in an input-output scheme. In other words this chapter deals with flows of technology embodied in goods and services only. The first part of the chapter seeks to measure the quantitative extent of technology flows in Denmark, while the second part applies a graph theoretical model for mapping the major technological relations in Denmark. A range of different technology indicators are used in order to get a broad picture of technological relations in Denmark.

In chapter 5 technological linkages are expressed as flows of product innovations. Data from the Danish part of the first European Community Innovation Survey are applied in the analysis. The chapter primarily serves as a supplement to chapter 4, contributing to the discussion of the validity of the embodied technology hypothesis. But the innovation survey data also allow us to explore the extent to which innovation is an interactive process, as the survey does not only cover the flows of product innovations between firms in different industries, but also includes a question on the active participation of firms in other industries in the innovative process. Thus it is possible

to distinguish between different types of relations between industries depending on whether the industries are closely related by innovative activities and thus are 'truly interdependent', or whether the supplying industry more has the character of a generic technology source, and thus is not closely related to firms in the receiving industry.

Viewed together chapter 4 and 5 deal with different methods and indicators for identifying technological interindustry linkages. This exercise is relevant as a methodological contribution to the discussion of how to analyse the structure of national innovation systems, as well as an empirical contribution to the study of the Danish economy as an interdependent system.

Chapter 4: Linkages as sources of indirect knowledge inputs[1]

> *.. even though only a few industries are research-intensive, the interindustry flow of new materials, components, and equipment may generate widespread product improvement and cost reduction throughout the economy. (...) Industrial purchasers of such producer goods experienced considerable product and process improvement without necessarily undertaking any research expenditure of their own* (Rosenberg, 1982b, p. 76).

4.1   Introduction

Two new types of related linkages will be introduced in this chapter. The first type of linkage is an extension of the knowledge weighted linkage measures presented in chapter 3, but here the linkages are used for calculating the 'effect' of the linkages through the introduction of the concept 'indirect' knowledge. Instead of identifying the industries which have the quantitatively most important linkages through an index value, this chapter calculates the 'size' of the indirect knowledge. The second type of linkage introduced in the present chapter is a graphical representation of linkages expressed as embodied knowledge flows between industries that are knowledge sources and knowledge receivers respectively. The knowledge flows are mainly seen as one-way relations from producer to user in this chapter. Chapter 5 will draw on innovation survey data in order to include the role of the user in the innovative process.

The technological linkages are mapped for Denmark in 1979 and 1991. The analysis uses the three knowledge indicators presented in chapter 3: R&D expenses, patenting and employees with a degree in technical or natural sciences (referred to as 'technical employees').[2]

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[1]   The chapter draws on results from module 4 of the DISKO project (The Danish Innovation System in a Comparative Perspective), supported by the Danish Business Development Council. A preliminary version of the chapter was presented at the *12th International Conference on Input-Output Techniques*, New York, 18-22 May 1998 (see Drejer, 1998b).

[2]   For an assessment of the strengths and weaknesses of different quantitative measures of technological activities see Pavitt and Patel (1988).

4.2 The importance of technological interdependence

The present chapter, as does the entire thesis (see chapter 1), deals with knowledge and technology in a somewhat synonymous way, but with the distinction that technology is defined as knowledge about scientific and technical processes, i.e. technology is a sub-element of knowledge.

Knowledge is a prerequisite for innovation. Kline & Rosenberg stress the importance of accumulated knowledge in the innovative process. Knowledge is defined as the stock part of science, while research is the flow part, which creates new knowledge to add to the accumulated knowledge of the system (Kline and Rosenberg, 1986). It is the use of accumulated knowledge that is essential to modern innovation, not as much in the initiating step, as in the whole process of innovation ('central-chain-of-innovation' in the terms of Kline & Rosenberg).

Knowledge in the Kline and Rosenberg sense is accumulated in the system. But in a more narrow sense, knowledge can also be accumulated in a given end-product. When knowledge is used in the production of a product a, this knowledge will be embodied in product a. If the product a is used as an input further down in the production system, the embodied knowledge will flow through the system. Even though the user of product a does not acquire the total amount of knowledge embodied in the product, he or she will make use of/build upon the knowledge in the further processing of product a into product b. The knowledge embodied in product b will be the accumulation of knowledge used in industry A (the industry that produces product a) and in industry B (the industry producing product b). The amount of knowledge embodied in an end-product will, according to this line of thought, consist of the knowledge accumulated through the process of production.

The accumulation of knowledge in a product differs from the knowledge accumulation described by Kline & Rosenberg in dimension - the stock of knowledge in the Kline & Rosenberg sense is the continuous accumulation of knowledge over time *in the whole system*, while the knowledge accumulated in a given end-product is accumulated through a process or flow *through the system*. The accumulation of knowledge in an end-product does not in a narrow sense contribute to the accumulated stock of knowledge in the system, but since it broadens the area of application of the

existing stock of knowledge, it can be perceived as increasing the knowledge intensity of the production. And it is this knowledge intensity that is in focus in this chapter.

Knowledge flows are important aspects of knowledge diffusion, which is one of the central elements in describing a national system of innovation (Lundvall, 1992a, p. 2). An analysis of knowledge flows is not only of academic interest, it also has important policy implications: a thorough mapping of knowledge flows that uncovers major sources for the spread of knowledge in the economic system can point out which industries have a widespread effect on the whole system through the diffusion of knowledge in the economic system as a result of transactions between industries.

Moving to methodological considerations, Marengo and Sterlacchini (1989) examine two families of methodologies for quantifying patterns of technological change among sectors. The first group of methodologies uses input-output analysis based on vertically integrated sectors in a focus on embodied (indirect) technology transfers. The second methodology has as its main contribution Scherer's (1982a; 1982b; 1984) study of direct technology flows focussing on disembodied technology transfers. Marengo and Sterlacchini point to the need of an integrated approach that combines direct and indirect methodologies in the analysis of technology transfers for at least 3 reasons:

i)   embodied and disembodied transfers are strictly connected as parts of one process of innovation and diffusion;

ii)   the processes take place through a sequence of stages: indirect transfer is likely to be - at least partly - fed by direct transfer, and indirect transfer often follows direct transfer at a later stage of the diffusion process;

iii) the overall accordance of the empirical results obtained by different methods suggests that combined procedures are likely to yield empirically relevant results (Marengo and Sterlacchini, 1989, p. 12).

The methods applied in this and the following chapter supplement each other as the input-output based method presented in this chapter strictly deals with embodied transfers, while the innovation survey presented in chapter 5 has a broader view where also the interactive element of innovation

and diffusion is included.

4.2.1 The difference between technological interdependence and spillovers

An analysis of technological interdependence can - somewhat mistakenly - be perceived as a spillover analysis. Spillovers are basically externalities occurring when the actions performed by an entity affects another entity in a positive or negative way without a full compensation being payed for this effect.[3]

According to Langlois and Robertson (1996, p. 11-12), spillovers can take three forms:

1)   Spillovers may result from increases in *consumer surplus* if buyers do not have to pay for the full benefit that they receive from an innovation embodied in a good or service they have purchased.

2)   Spillovers may result from *competitors* of the innovator acquiring the new knowledge at less than the full costs of R&D, which the originator had to pay.

3)   Spillovers may result from firms in *other industries* acquiring the knowledge at less than full costs of R&D.

Los and Verspagen (1996), following Griliches (1979), distinguish between pure knowledge spillovers and rent spillovers. Rent spillovers are obtained through the purchase of innovated products, and corresponds to the first type of spillovers in the Langlois and Robertson definition above. According to Los and Verspagen, rent spillovers are not true spillovers, since they largely are due to a 'mis-measurement', in the sense that conventional price index systems are not able to account for quality changes, making price increases, which could be due to improved efficiency, be interpreted as inflation. Knowledge spillovers on the other hand are not embodied in traded goods and this type of spillovers do not, according to Los and Verspagen, occur in relation to market transactions. In stead pure knowledge spillovers occur when information is exchanged during conferences, when an R&D engineer moves from one firm to another, or when a patent is

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[3]   Empirically the methods for identifying technological interdependencies and spillovers are often identical.

disclosed (Los and Verspagen, 1996, p. 4).

Spillovers of the above kind have been argued to prohibit 'efficiency' due to the fact that investment returns are not fully appropriable, resulting in a situation where markets provide an insufficient incentive for the investment in knowledge (e.g. Grossman and Helpman, 1994).[4]

Somewhat in line with Los and Verspagen, Eliasson (1996) states that spillovers mainly occur through the movement of people and the formation of integrated complexes of consultants and subcontractors. Even though Eliasson is convinced that spillovers are true micro market phenomena, he does acknowledge that they can be established econometrically on macro data (Eliasson, 1996, p. 126). Eliasson does not distinguish between technology diffusion and spillovers: the main idea behind his argument is that competence blocks of advanced firms operate as 'technical universities' and 'research institutes' which *unintentionally* provide free education and research services to other agents in the market. The competence that diffuses from competence blocks is both economic and technological, and it only diffuses under market circumstances characterised by competition - and the spillover/diffusion is dependent on the *local receiver competence*[5] (Eliasson, 1996, p. 125-8).

Eliasson's lack of distinction between spillover and diffusion is problematic in the present context, as the main difference between interdependence and diffusion on one side, and spillovers on the other, is that spillovers are unintentional.[6] The knowledge flows dealt with in this chapter, and the industrial interdependencies which are represented by these flows, are not perceived as the unintentional outcome of market imperfections. They are rather perceived as a necessary condition for a successful technological and economic development.

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[4] In relation to the Langlois' definition, this would primarily be the case in relation to the second type of spillovers, which involves competitors.

[5] This is what is referred to as absorptive capacity by Cohen and Levinthal (1990).

[6] The unorthodox perception that spillover generation can be intended can be found, see e.g. Grupp (1996) who defines technological spillovers as sharing of knowledge with other bodies performing R&D without reimbursement.

4.2.2 *Previous studies of technological interdependencies*

Scherer (1982b), Pavitt (1984) and DeBresson (1994) are examples of previous attempts to measure technology flows between industries using different types of empirical data.

Scherer (1982b) analysed inter-industrial technology flows in the United States matching industrial invention patents and the R&D expenditures supporting activities that gave rise to the inventions. Scherer's main aim was to analyse the effect of R&D on productivity growth by distinguishing between sectors of production and sectors of use, finding that productivity growth in fact comes from *used R&D* rather than from *product R&D* at its point of origin. Scherer's analysis applied survey data, and the sample used for analysing the technology flows did not characterise total industrial technology flow relations since smaller companies were excluded from the sample.

At the same time as Scherer was carrying out his work on constructing technology flow matrices, Pavitt (1984), as briefly mentioned in chapter 2, analysed sectorial differences in innovative activity and innovative characteristics in the United Kingdom.[7] Using information on 2000 significant innovations and on innovating firms in Britain from 1945 to 1979, Pavitt developed a taxonomy separating industrial firms into four categories: Supplier dominated firms (agriculture, housing, private services, traditional manufacture), scale-intensive firms (bulk materials, assembly), specialised suppliers (machinery, instruments) and science based firms (electronics, chemicals). Each category has special innovative characteristics. Sources of the main knowledge inputs into the innovations were identified by asking sectoral experts and the innovating firms to identify the type of institution that provided up to the three most important inputs into each innovation. Pavitt finds that the information on the sectors of production of innovations and on the sectors of use provides what can be considered as the technological equivalent of an input-output table: it shows intersectoral patterns of production and sale of goods in intersectoral transfers of technology. Further Pavitt illustrates that the major technological flows in relation to significant innovations are from science based firms to supplier dominated firms, to scale intensive

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[7]

Scherer (1982a), actually refers to a SPRU working paper by Pavitt (1982) which was a forerunner to the now well-known 1984 article on 'Sectoral Patterns of Technical Change: Towards a Taxonomy and a Theory'.

firms as well as to specialised suppliers; from specialised suppliers to science based firms and to scale intensive firms; and from scale intensive firms to specialised suppliers and to supplier dominated firms.[8] Pavitt's method has a limitation similar to one of the limitations of Scherer's analysis: the analysis is not representative of the total economic system of interrelations. In Pavitt's case the analysis is limited to technological relations related to what has ex post proven to be significant innovations.

The method used by DeBresson (1994) for collecting information on innovation sources and users can in many respects be compared to the method used by Pavitt. By use of a survey of 24.000 Italian production firms, DeBresson constructs an innovative activity matrix, based on the most innovative part of the respondents' identification of their most important innovation, as well as the typical user-industry for this innovation. The analysis shows that the innovative activity is concentrated in a small part of the economic space, and that the Italian system of innovation is asymmetric in the sense that the most important users are most often to be found in another part of economic space than the most important suppliers. The Italian analysis is compared to a similar analysis of China and France in DeBresson and Hu (1996). The method applied by DeBresson will be discussed further in chapter 5.

4.3   Direct vs. indirect knowledge

As mentioned in the previous section, knowledge flows can affect the knowledge intensity of the producing units in the economy. Normally the knowledge intensity of an industry refers to the knowledge creating activities within that industry only. Following this the industries with the highest and lowest knowledge intensities respectively in Denmark can be illustrated as in table 4.1.

All knowledge indicators point towards the medical industry, instruments, and telecommunication equipment as members of the 'Top 5' of knowledge intensive industries. Other electronics is identified as a knowledge intensive industry according to the R&D and employment indicators, and the R&D indicator also points towards machinery. The employment indicator identifies business services as the most knowledge intensive industry of all. Finally, the patent indicator

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[8]   See chapter 7 for a figure describing the linkages between the four Pavitt sectors.

Table 4.1: Knowledge intensities in high and low knowledge intensity industries in Denmark, 1991

Tech. employment/ Total employment	R&D/ Production	Patents/ Production#
High knowledge intensity		
Business services (14.0%)	Medical (15.1%)	Instruments (19.0%)
Telecom. equipment (12.7%)	Instruments (9.3%)	Chemical raw materials (8.0%)
Instruments (11.2%)	Telecom. equipment (8.1%)	Telecom. equipment (7.0%)
Other electronics (9.3%)	Machinery (2.8%)	Medical (6.7%)
Medical (8.2%)	Other electronics (2.3%)	Agricultural mach. (5.8%)
Low knowledge intensity		
Textiles (0.62%)	Other services (0.073%)	n.a
Food (1.1%)	Construction (0.075%)	n.a
Other services (1.2%)	Public utilities (0.18%)	n.a
Trade (1.5%)	Textiles (0.19%)	n.a
Public utilities (2.1%)	Trade (0.31%)	n.a

Production is measured in 10,000s in order to make the patenting intensity comparable with the two other intensities. Low intensity industries are not identified applying the patent indicator, as patent data are only available for manufacturing industries.

Source: Background calculations for Drejer (1998a) carried out by Lone Nielsen and Birgitte Hansen in relation to the DISKO project.

places chemical raw materials and agricultural machinery among the five most knowledge intensive industries in Denmark in 1991. Based on a combination of all three indicators the medical industry, instruments, telecommunication equipment, other electronics and business services are characterised as the five most knowledge intensive industries in Denmark. Business services are included even though it is only classified as a knowledge intensive industry according to the employment indicator, since it is the industry with the highest intensity of technical employees. The education indicator is emphasised since it does not have a sectoral bias to the same extent as the two other indicators.[9] Regarding patents, industries (or technological fields) have very

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[9]   Pavitt and Patel (1988, p. 36) indirectly support this view in their description of technology as largely being generated through full-time or part time technological activities (design, development, production engineering) - activities that depend on the employee qualifications - rather than through R&D activities. Pavitt and Patel perceive R&D and patenting as being related to invention, innovation and diffusion rather than technological activities as such.

different propensities to patent (Pavitt and Patel, 1988)[10], while the R&D indicator is biassed towards industries with an over-representation of large firms, both because large firms have a clearer distinction between production and R&D activities as compared to small firms, and due to the way that R&D statistics are collected in Denmark, with small firms' R&D activities not being registered at the industry level.

The industries with the lowest knowledge intensities are other services, textiles, trade and public utilities, both applying the R&D and employment indicator, while the R&D indicator also places construction among the five industries with the lowest knowledge intensities. The employment indicator also points towards the food industry.

As mentioned in the introduction to this section, the ranking in table 4.1 does not take acquired knowledge into account when classifying industries according to their knowledge intensities. Mapping the knowledge relations between 'knowledge sources' and 'knowledge receivers', as well as estimating the quantitative importance of knowledge acquired through embodied knowledge flows between industries, applying the case of Denmark, is the major aim of this chapter.

4.3.1 A minimal flow model of embodied knowledge flows

Schnabl (1994; 1995) presents an input-output based method for analysing interdependences/linkages in an economic system: the minimal flow analysis (MFA).[11] Innovative expenditures weighted by input-output coefficients expressing the economic interdependence between industries are used as expressions of embodied technology flows between industries. I.e. it is assumed that the embodied technology flows are proportional to the innovative expenditures in the innovating industries, as well as to the quantitative extent of the flows of intermediate goods and services between the user and producer industries. The advantage of this method is that it

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[10]   And further, patent data are not available for service industries.

[11]   Other examples of minimal flow analysis can be found in Torre (1992), who decomposes input-output matrices into quasi-autonomous subsets - the so-called 'filieres' - that characterise the internal structure of the productive system; and in Cassetti (1995) who uses minimal flow analysis to study international interindustry linkages.

captures the combined effect of innovative activities and the structure of the production system in which these activities are transported through intermediate commodity flows from their sources to their final use.

The model identifies embodied technology flows whether these flows are the result of a direct link from one industry to another (e.g. if the paper industry supplies packing material to the food industry) or the flows are indirect via other industries in the system (e.g. if the above mentioned deliverance is supplied through a wholesaler or a similar agent in the wholesale or retail sector). Thus the method is related to the Rasmussen family of linkage measures presented in chapter 3. This implies that the technology flows are 'screened' for possible intermediate links between the observed industries, and thus it is not possible to distinguish direct from indirect deliverances. But opposed to the Rasmussen type linkage specifications, this is a graphical presentation where a minimum value for entries in a transaction matrix is selected (hence the name 'minimal flow analysis'). All values exceeding this value are set equal to 1, while all other entries are assigned the value 0, i.e. making the analysis qualitative. In Schnabl (1995) the method is used to analyse the characteristics of interindustrial technology flows for a national innovation system (Germany 1980-1986). Different technology indicators can be included in the analysis in order to cover different areas of the 'innovative landscape'. A comparison of the production structure of the German system of innovation in 1980 and in 1986 shows a very stable structure without major changes in the industry structure between the two years.

An analysis of embodied knowledge flows applying input-output data implies that the sectors of utilization of the knowledge carried out by an industry are proportionally the same as the sectors of utilization of goods and services in input-output tables. As pointed out by Archibugi (1988, p. 273) there is no real certainty that the knowledge flows[12] of an industry have the same direction as the industry's products. But, as Archibugi also states, even though the analysis of knowledge flows might only provide indications, these indications are still valuable in the absence of a definite proof regarding flows between sectors.

Another problem is that a traditional input-output model, which is a 'snap-shot' of a system in a

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[12] Archibugi deals with R&D flows only.

given time, will not be able to embrace all the dynamic elements at play in a national system of innovation. But by introducing knowledge flows to the input-output system, it is the intention to show a snap-shot of the system which indicates some technological relations between the sectors in the system - and thereby supply the input-output model with an angle, which is related to dynamic efficiency as discussed in chapter 1.

The analysis of knowledge flows in Denmark uses a slightly moderated version of Schnabl's model. Also, in stead of using innovative expenditures, the three previously mentioned knowledge indicators are used: R&D expenditures, patenting and employees with a technical or science degree. For a technical description of the model see appendix B.

The flow charts based on the minimal flow model are related to the concepts of direct and indirect technology presented in Papaconstantinou et al. (1996) in their analysis of embodied technology diffusion in 10 OECD countries[13] in the 1970's and 1980's. Just as the minimal flow analysis of technological relations, the OECD analysis builds on the assumption that knowledge or technology, in this case represented by R&D expenses, developed within a firm in a given industry is not only beneficial to the firm and industry itself, but also to users of input from the developing firm/industry. The knowledge embodied in the product or service of a given firm or industry, is thus the sum of the firm/industry's own knowledge generating activities and the knowledge generating activities embodied in the production inputs received from other firms/industries. The main principle behind this thinking is illustrated in figure 4.1.

The graphs based on the minimal flow model are constructed for Denmark for the years 1979 and 1991.[14] Since the model is calculated in current prices, the filter values cannot be set equal for the two years. The resulting structure will vary according to the filter value chosen, thus making it

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[13]   The G7 countries (USA, Japan, Great Britain, Germany, France, Italy and Canada) as well as Australia, the Netherlands and Denmark.

[14]   The combination of several knowledge indicators puts severe limitations on the data availability. Educational statistics are only available for the period 1980-1992; while R&D data is only available for odd years, and only in current prices. It is also the combination of indicators that determines the level of aggregation. As the structure of education and employment is relatively stable, the 1980 education matrix is used in combination with the 1979 input-output matrix.

Figure 4.1: Internally developed vs. externally acquired (embodied) knowledge
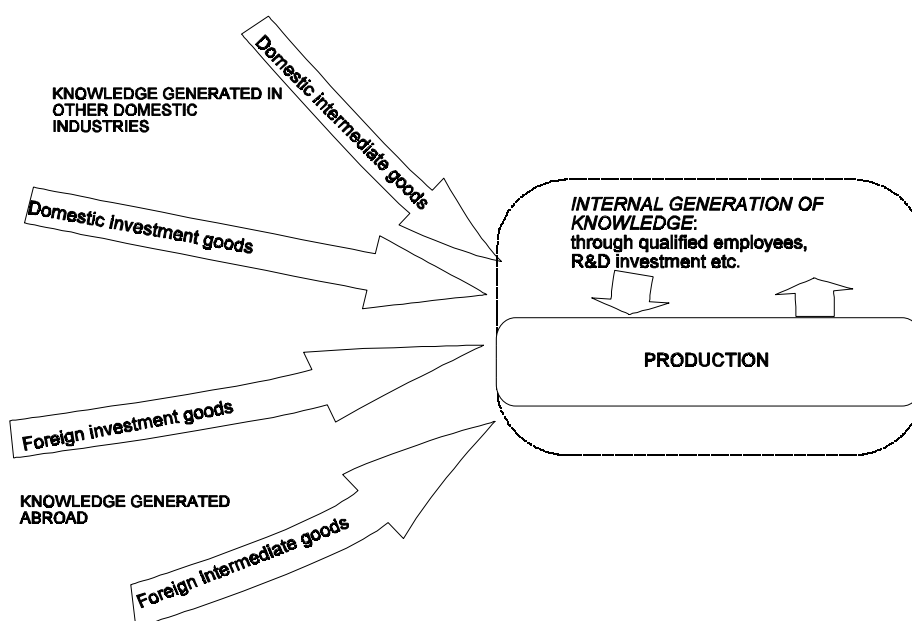
crucial to examine different filter values. There will always be a trade-off between the 'depth' of the analysis including a large number of relations (a low filter value), and finding a structural picture which will give an easily conceivable overview of the main technological relations in the economic system (a high filter value) (Schnabl, 1995). In the present analysis the structural overview of the system has been favoured at the expense of detail in the analysis. The filter values are chosen in such a manner that approximately the same number of industries and the same number of linkages occur in the two comparable years.[15] This implies that the focus is on changes in the relations between industries, e.g. a shift from knowledge receiver to knowledge source, and not on the development in the degree of systemic interaction. In an international perspective, the degree of systemic interaction is very high in Denmark with a well developed net of trade relations between industries.

Not just the high filter values, but also the high level of aggregation used in the analysis implies that many relations are excluded from the analysis. The number of industry groups used in the analysis is 22, thus ignoring a number of relations between industries included in the same industry

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[15]   The filter values have been checked for stability, making sure that the patterns of the graphs are robust, i.e. they do not change if the filter values are changed marginally.

group (intraindustry relations are not included in the analysis).

It is only the largest knowledge sources and the quantitatively most important users that are included in the graphs. The industries listed in the bottom left corner of figures 4.2-4.4 are described as not being part of the representative flows of the system, but they are part of the overall system of flows of goods and services in the economic system, albeit with values that are below the preset filter value.

4.3.2   Embodied knowledge flows in Denmark 1979 and 1991

Due to the lack of information on intermediate flows of goods and services which links information on source country and industry for a given receiver industry, the analysis only includes national relations.[16] This implies that an analysis which includes import relations either must build on the assumption that the level and structure of knowledge is the same in the source country as in Denmark, or, a little more sophisticated, on a pre-determined assumption about the country-composition for a given source industry's deliverances to a receiving industry. Both types of assumptions ascribes a large uncertainty to the outcome of the analysis, and thus the international relations are excluded from the present analysis. But nonetheless it should be kept in mind, that due to the fact that Denmark is a small open economy, imported inputs to the production play a significant role in most industries, construction being one of the only exceptions.[17] This implies that a lacking importance of some industries as knowledge sources can be due to *Danish* firms in these industries being relatively unimportant knowledge sources. The industries can still be important international knowledge sources even though they do not play an important role in the *nationally bounded* innovation system.

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[16]   Information on import is on the one hand available in the form of imported amount specified on industry and country of origin without any information about which industries might use the imported goods or services as production input, on the other as input-output tables, where source and receiver industries are identified, but there is no link to source country.

[17]   Based on a method where the R&D embodied in imported intermediate inputs is a weighted sum of foreign sectoral R&D intensities, where the weights are the intermediate demand of an industry from each other industry multiplied by the import share of that industry by trading partner country (i.e. the most sophisticated of the above mentioned methods), Papaconstantinou et al. (1996) find that imports are more important as sources of acquired technology than domestic inputs in Denmark, as well as in two other small countries, Canada and the Netherlands.

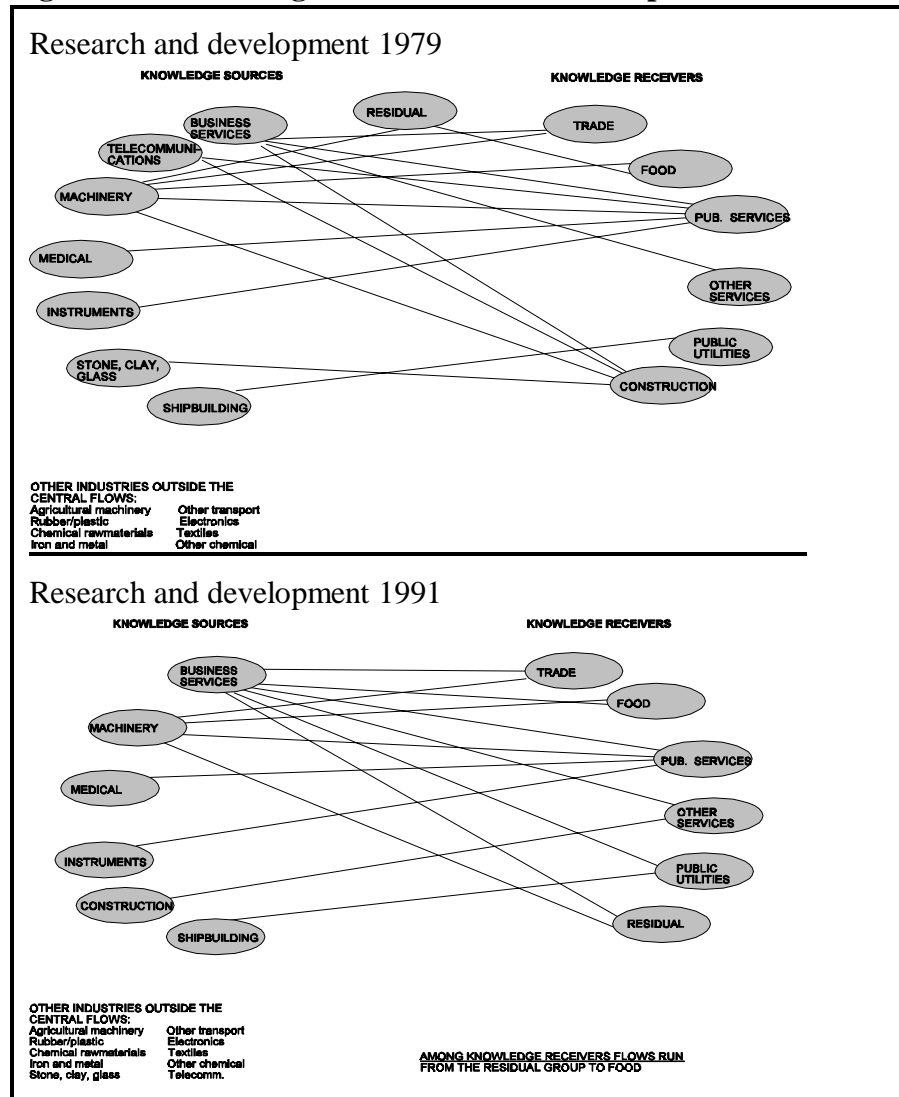## Figure 4.2: Knowledge flows based on R&D expenditures

Research and development 1979

KNOWLEDGE SOURCES   KNOWLEDGE RECEIVERS

RESIDUAL   TRADE

BUSINESS SERVICES   FOOD

TELECOMMUNI-CATIONS   PUB. SERVICES

MACHINERY

MEDICAL   OTHER SERVICES

INSTRUMENTS   PUBLIC UTILITIES

STONE, CLAY, GLASS   CONSTRUCTION

SHIPBUILDING

OTHER INDUSTRIES OUTSIDE THE
CENTRAL FLOWS:
Agricultural machinery   Other transport
Rubber/plastic   Electronics
Chemical rawmaterials   Textiles
Iron and metal   Other chemical

Research and development 1991

KNOWLEDGE SOURCES   KNOWLEDGE RECEIVERS

BUSINESS SERVICES   TRADE

FOOD

MACHINERY   PUB. SERVICES

MEDICAL   OTHER SERVICES

INSTRUMENTS   PUBLIC UTILITIES

CONSTRUCTION   RESIDUAL

SHIPBUILDING

OTHER INDUSTRIES OUTSIDE THE
CENTRAL FLOWS:
Agricultural machinery   Other transport
Rubber/plastic   Electronics
Chemical rawmaterials   Textiles
Iron and metal   Other chemical
Stone, clay, glass   Telecomm.

AMONG KNOWLEDGE RECEIVERS FLOWS RUN
FROM THE RESIDUAL GROUP TO FOOD

Figure 4.3: Knowledge flows based on patents

Patents 1979

KNOWLEDGE SOURCES   KNOWLEDGE RECEIVERS

CHEMICAL RAW MATERIALS   TRADE

FOOD

IRON AND METAL   CONSTRUCTION

PUB. SERVICES

MACHINERY   RESIDUAL

INSTRUMENTS   PUBLIC UTILITIES

STONE, CLAY, GLASS

OTHER INDUSTRIES OUTSIDE THE
CENTRAL FLOWS:
Agricultural machinery   Textiles
Rubber/plastic   Other chemical
Electronics   Shipbuilding
Business services   Other transport
Telecommunications   Medical
Other services

Patents 1991

AMONG KNOWLEDGE SOURCES FLOWS RUN
FROM IRON AND METAL TO MACHINERY

KNOWLEDGE SOURCES   KNOWLEDGE RECEIVERS

CHEMICAL RAW MATERIAL   TRADE

FOOD

IRON AND METAL   PUB. SERVICES

TRANSPORT   RESIDUAL

MACHINERY   PUBLIC UTILITIES

INSTRUMENTS   OTHER SERVICES

OTHER INDUSTRIES OUTSIDE THE
CENTRAL FLOWS:
Agricultural machinery   Textiles
Rubber/plastic   Other chemical
Stone, clay, glass   Electronics
Shipbuilding   Medical
Business services   Construction
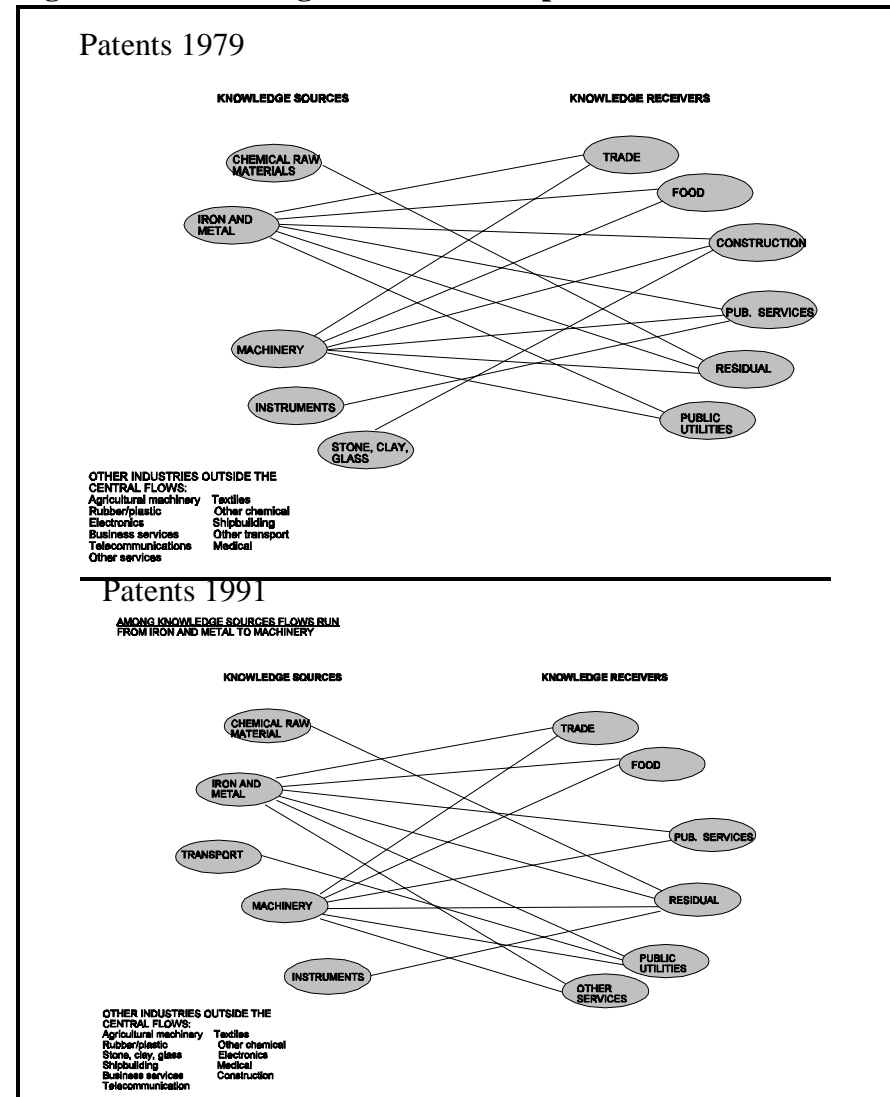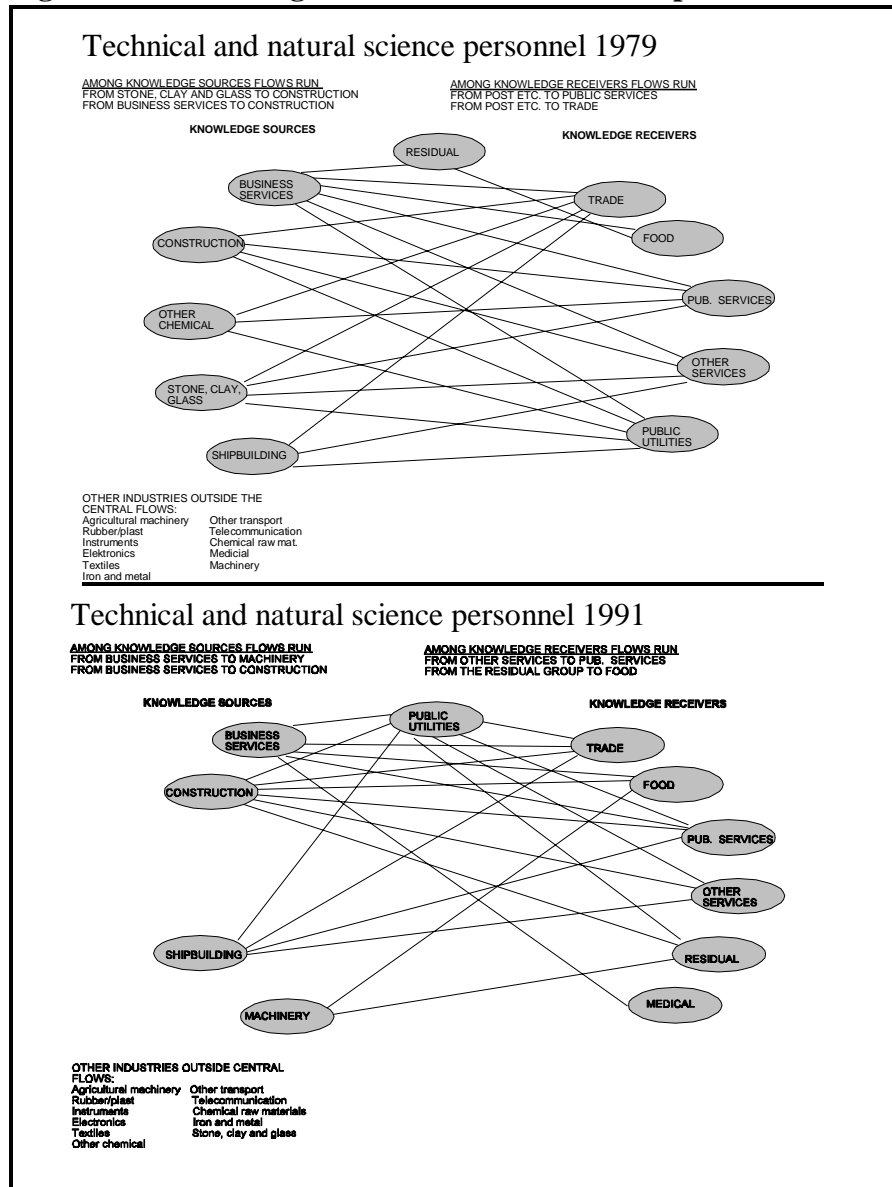Telecommunication

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Figure 4.4: Knowledge flows based on tech.-nat. personnel

Industries included in the analysis:

Manufacturing:

1. Food and beverages
2. Textiles, clothing and leather
3. Chemical raw materials
4. Medical industry
5. Rubber and plastic
6. Other chemical industry
7. Stone, clay and glass products
8. Iron and metal industry
9. Manufacture of agricultural machinery
10. Machinery
11. Telecommunications and radio/television
12. Other electronics
13. Shipbuilding
14. Transport equipment
15. Instruments

Other industries:

16. Construction
17. Trade
18. Public utilities: Post/telecommunication services/transport services/-electricity/gas/water
19. Business services
20. Other services
21. Residual: agriculture, fishery, extraction of raw materials. Wood and furniture, paper and graphical industry, other manufacturing
22. Public services

The graphs are to be read from left to right, with the lines being uni-directional. I.e. the industries at the left of the graph are knowledge sources, while the industries at the right are knowledge receivers. There are no bilateral relations at the filter values used in the present analysis.

When comparing the flows from the three indicators (figures 4.2-4.4) several features are worth noticing. First the graphs show that the overall picture of the knowledge flows between industries is fairly stable regardless of indicator. There are a number of common features regardless of whether patent grants, R&D expenses or educational statistics are used. One of these common features is that food, as the only manufacturing industry, is a recurring knowledge receiver. This confirms previous findings of the food industry relying to a large extent on technology carried out in other industries (e.g. Christensen et al., 1996). Service industries such as trade, public services as well as other services are also recurring knowledge receivers.

Combining all three indicators, machinery and business services stands out as general sources of knowledge, since both industries are identified as major sources from two out of three indicators. Other important sources, which are only identified from one indicator, are iron and metal (patents) as well as construction (education).

As mentioned above the group of users is wider and more stable: food, trade, public services, the residual group, public utilities as well as other services are identified as knowledge receivers regardless of indicator. This indicates that knowledge production is more concentrated than knowledge use.

This difference in concentration can also be illustrated by a calculation of the distribution of the direct and indirect knowledge intensities in the industries, based on the method presented in Papaconstantinou et al. (1996) mentioned above (following the basic idea illustrated in figure 4.1). A vector of total knowledge intensities can be calculated as:

$$\frac{K}{X} \, (I - A)^{-1}$$

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with K being the knowledge indicator, e.g. R&D, and X being the total production,[18] thus K/X is the direct knowledge intensity. $(I-A)^{-1}$ is the Leontief inverse introduced in chapter 2. As the Leontief inverse matrix expresses the direct and indirect production necessary in order to deliver one unit to final demand from each industry in the system, it is possible to calculate the knowledge contribution from each industry. The indirect knowledge intensity can thus be calculated as the total intensity minus the direct intensity:

$$\frac{K}{X} \, (I{-}A)^{-1} \; - \; \frac{K}{X}$$

The direct knowledge intensities (based on R&D expenses) varied between 0.07 percent and 15 percent in Denmark in 1991, while the intensities of R&D received through intermediate inputs varied between 0.3 and 2.5 percent.[19] In other words research and development in Denmark is primarily carried out in a few knowledge intensive industries from where it is diffused and used throughout the economic system.

The importance of indirect knowledge in knowledge intensive industries and low intensity industries respectively can also be expressed by the ratio of indirect to total (direct + indirect) knowledge, as illustrated in table 4.2, where the most knowledge intensive industries are included, as well as the industries in the low intensity group which are the recurring receivers of embodied knowledge.[20]

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[18]   In the case of the technical employee indicator, K is number of technical employees, while X is total employment. For patents K is the number of Danish patents granted in the US during the five year period leading up to the basis year (the five year period is applied in order to even out fluctuations in patenting), while X is of the total production measured in units of 10.000 (as in table 4.1). The only difference between the measures of X in the case of R&D and patents is the changed scale for patents. This is introduced in order to make the intensities comparable, despite the number of patent grants being very low compared the pecuniary measure of R&D activity.

[19]   Based on calculations carried out by Lone Nielsen and Birgitte Hansen, presented in (Drejer, 1998a, p. 42).

[20]   In order to be able to compare business services with the other knowledge intensive industries in table 4.2 an 'artificial' direct patenting intensity has been calculated. The calculation is very simple, based on the conservative assumption that the fraction of patent grants in business services to total number of patent grants (for the entire economy) equals the fraction of the production volume of business services to the total production volume of the economy.

Depending on whether the focus is on the employment indicator or the R&D indicator, the indirect knowledge accounts for between 57 and 80 percent, or 53 and 93 percent of the total knowledge in the low intensity industries. The choice of indicator makes a considerable difference, as e.g. indirect R&D accounts for 93 percent of the total knowledge within construction, while the indirect knowledge input from technical employees only accounts for 57 percent of the total knowledge input from technical employees within this industry.[21] The high importance of indirect knowledge occurs despite of the fact that the low intensity industries only receive relatively few goods and services from the knowledge intensive industries, i.e. even a small knowledge flow towards the low intensity industries plays a large role when compared to the total knowledge intensity in these industries.

Table 4.2: Indirect knowledge/total knowledge, in high and low knowledge intensity industries respectively, Denmark 1991.

	Indirect tech.empl./ total tech.empl.	Indirect R&D/ total R&D	Indirect patents/ total patents #
Low knowledge intensity			
Textiles and clothing	80%	74%	n.a.
Construction	57%	93%	n.a.
Trade	57%	53%	n.a.
Other services	70%	85%	n.a.
Public utilities	57%	71%	n.a.
Food	71%	61%	n.a.
High knowledge intensity			
Medical industry	31%	14%	30%
Instruments	32%	19%	19%
Telecom. equipment	33%	24%	37%
Other electronics	37%	42%	41%
Business services	18%	22%	38%

Intensities are not calculated based on the patent indicator for the low intensity industries, as these industries do not patent at all, or have a negligible patenting activity .

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[21]   Construction has a quite high fraction of technical employees, but a very low direct R&D intensity.

For the high knowledge intensity industries the fraction of indirect knowledge varies between 18 and 37 percent for technical employees, between 14 and 42 percent for R&D, and between 19 and 41 percent for patenting. Regardless of indicator, other electronics is the knowledge intense industry with the highest importance of indirect knowledge. Both within the group of high knowledge intensity industries, and within the group of low intensity industries, the technical employee indicator has the lowest dispersion, while the dispersion is considerably larger for the R&D intensities.

4.3.3   Characterising the Danish economy

The above analysis has revealed a number of characteristics of the Danish economy. The first characteristic worth some attention concerns the food industry. This industry has been dominating in the Danish economy for a long time, both in terms of volume of production and export. It is basically a low knowledge industry, but the industry is to a large extent an important user of production inputs from knowledge intensive industries, i.e. we are dealing with an industry which has an absorptive capacity for using inputs containing embodied knowledge.

The second characteristic concerns the service industries. The Danish service industries are, with the exception of business services, low knowledge industries (at least judging from the presently available knowledge indicators), but the services are, just as the food industry, intensive receivers of embodied knowledge. I.e. a flow of embodied knowledge from a few industries to a broad range of service industries is observed.

If the focus is turned towards the knowledge sources, two very different industries are found to be the most important sources of embodied knowledge diffusion in the Danish economy: on the one hand the role of business services confirms that knowledge intensive services not just within the last few years, but for a quite some years, have played a central role as a knowledge source, not just for manufacturing but also for other services. And on the other hand machinery, which is a traditional manufacturing industry, still plays an important role as a knowledge source. Although analysed from a different perspective, this is in accordance with the findings of Pavitt (1984), where machinery is a classical specialised supplier industry. Also the analysis shows, by the example of machinery as compared to e.g. instruments and the medical industry, that it is not

necessarily the most knowledge intensive industries, which are the most important sources of embodied knowledge flows.

4.4   Conclusions

The aim of this chapter was to analyse the structure and quantitative importance of acquired knowledge at the industry level. The methods for identifying interindustry knowledge flows have been expanded upon by introducing a number of knowledge indicators instead of relying solely on one indicator.

Input-output based analyses of knowledge flows were applied since they have a large advantage in the possibilities they provide for comparing structures over time. The analysis showed that there is a high degree of industrial interdependence in the Danish economy. A complex web of relations illustrates that looking at the most knowledge intensive industries isolated from the rest of the economy is too simplistic an approach as it will not reveal which industries are central to the utilisation and diffusion of knowledge in the economic and technological system.

A few methodological findings should be emphasised. First, the high degree of stability of the relations between the two years analysed is an important result. Few major shifts are observed between 1979 and 1991, which confirms the results found by Schnabl in his analysis of Germany. Second, analyses building on input-output data combined with different knowledge indicators have as their main advantage the possibility of comparing structures over time. But the weakness in only capturing the fraction of interindustrial knowledge flows which are embodied in goods and services cannot be ignored. Third, the assumption that the embodied knowledge from an industry is evenly distributed on all products flowing from this industry is questionable.

Thus the following chapter will look at actual product innovation flows between industries in order to get a more complete image of the interindustrial knowledge relations in the Danish economic system.

Appendix B: The model for the graph theoretical minimal flow analysis

The following model is a modified version of the model presented in Schnabl (1994; 1995).

The model starts with a Leontief system, where the total production equals the direct and indirect intermediate flows of goods and services (as expressed in the Leontief inverse) multiplied by final demand. This expresses the total production requirement for producing for the actual final demand:

$$X=(I-A)^{-1}\langle y\rangle, \quad \langle\ \rangle \text{ expresses the diagonalisation of a vector.}$$

This system is 'normalised' by pre-multiplying by the inverse of the diagonalised vector for final output, thus making all rows summing to 1. Thus we now have relative requirements:

$$S=\langle x\rangle^{-1}(I-A)^{-1}\langle y\rangle.$$

Knowledge or technology is now introduced through the diagonalised vector $\langle tek\rangle$. This step weights the production requirements by the technology levels in the delivering industries:

$$X_{tek}=\langle tek\rangle\langle x\rangle^{-1}(I-A)^{-1}\langle y\rangle.$$

Since $(I-A)^{-1}$ by definition equals

$$I+A+A^2+A^3.....$$

the X_{tek} equation can be expressed by the following section of equations:

$$X_{1,tek}=\langle tek\rangle\langle x\rangle^{-1}A\langle y\rangle.$$
$$X_{2,tek}=\langle tek\rangle\langle x\rangle^{-1}A^2\langle y\rangle$$

etc.

In order to make the system binary, and thus allowing for the use of graph theoretic methods, the values of the $X_{n,tek}$ matrices, which express the direct technology deliverances, are 'filtered' through a preset minimal value, thus making cells with a value less than the minimal value equal 0, while cells with a value equal to or larger than the minimal value are given the value 1. Thus a new matrix W_{tek} is created, with cells having the values 0 or 1.

W_{tek} is used for calculating a 'dependence' or 'reachability' matrix, D:

$$D=\#(W+W^2+W^3+W^4+ \ ... \ +W^{n-1}),$$

where # expresses boolean summation, and n is the number of industries in the system.

D is used in calculating a 'connection' matrix, C:

$$c_{ij}=d_{ij}+[d_{ij} \ d_{ji}]+k_{ij},$$

where $k_{ij}=1$ if there is a relation, regardless of direction, between the industries i and j, or else $k_{ij}=0$.

K is calculated as

$$K= \#[(I+I') + (W+W') + (W+W')^2+ (W+W')^3+ (W+W')^4+.....],$$

where the summation of the transposed W matrix (W') and W 'dissolves' the direction in the relation between industries i and j by making the sum matrix (W+W') symmetric.

The elements of C can take the values 0, 1, 2 or 3 (see e.g. Harary et al., 1965):

$c_{ij}= 0$: no relation between i and j.
$c_{ij} = 1$: there is a weak relation between i and j, in the sense that i and j both are

connected to a 3rd industry, but there are no flows, neither direct nor indirect, between i and j.

$c_{ij} = 2$: there is a one-way-relation from i to j. The direction from i to j is the result of the multiplication d_{ij} d_{ji}.

$c_{ij} = 3$: a bilateral relation between i and j exists, i.e. the relation is both from i to j and from j to i.

The C matrix is used for calculating centrality coefficients, defined as the sum of the rows divided by the sums of the columns. The centrality coefficients reveal whether the industry in question is a technology source (more outflows than inflows) or a technology receiver (more inflows than outflows). Using the coefficients to decide the position of the industries in the graph and the values of the cells to decide whether there is a relation between two industries, and if so, whether this relation is one-way or bilateral, a directed graph of the embodied technology flows between industries is constructed.

Chapter 5: Interdependence in innovative activity matrices[1]

> *One of the most important achievements of contemporary economics is the constant creation of new knowledge. Yet economic theory is still focussing on the problems central to a past epoch: universal scarcity. Economic analysis is still largely focused on the best management of scarce resources, what the economists have termed the **optimal allocation of factors**. Yet the process which characterizes today's economy is the **creation of new factors*** (DeBresson, 1996, p. xxiii).

5.1   Introduction

In this chapter the linkage concept is expanded once more. More specifically the chapter looks at innovative linkages, viewing innovation as an interactive process based on mutual dependence between innovation suppliers and users (as introduced in chapter 2). The chapter has two main aims. The first aim is to supplement the analysis in chapter 4 of technological interdependencies based on input-output statistics with an analysis of innovative interdependencies, as they were expressed in the Danish part of the European Community Innovation Survey. The second aim is to identify different types of innovative clusters, based on different types of linkages.

The most noticeable difference in relation to the linkage concepts dealt with in the previous chapters is that the role of the user as a source of input to the innovative process is introduced in this chapter, thus the linkage concept introduced here has more dimensions than a pure input-output linkage.

The first step of the chapter compares the patterns of product innovation flows with the input-output based flows of chapter 4. This is done in order to assess the 'credibility' of the input-output based analysis, through examining the extent to which there is an overlap between embodied knowledge flows and observed product innovation flows. Thus this part assesses the embodied knowledge hypothesis.

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[1]   Just as chapter 4, this chapter draws on results from the DISKO project, supported by the Danish Business Development Council.

The second step studies innovative clusters. Ongoing work on identifying technological and innovative clusters at the industry level is applying a variety of methods, resulting in different types of clusters. Here the focus will be on survey based analyses of innovation flows.

5.2   Introducing innovative activity matrices

The construction of innovative activity matrices is developed by DeBresson (see e.g. DeBresson 1996; DeBresson et al., 1994). DeBresson aims at identifying where new knowledge is being developed in economic space, and for this a method for 'identifying the locus of learning and the creation of new techno-economic knowledge' is presented (DeBresson, 1996, p. 15). Innovative activity matrices are inspired by input-output matrices, but instead of measuring flows of goods and services, the cells in the matrix express a flow of product innovations at the industry level. DeBresson perceives an innovative activity (or interaction) matrix as a reflection of an increase in the partners' knowledge (DeBresson, 1996, p. 69):

> *An innovative interaction between a supplier and a user is an indicator of an increment in their level of technological knowledge, and is therefore an output indicator of a process of learning and knowledge creation* (DeBresson, 1996, p. 70).

The increase in knowledge is a central factor distinguishing an innovative activity matrix from an input-output matrix. The exchange and sharing of new knowledge will not deplete a business unit's own knowledge fund, it might in fact even increase it (cf. the critique of applying a spillover view on technological interdependence introduced in chapter 4).

Innovative activity matrices are constructed for Canada, China and Italy, based on extensive survey data, in DeBresson (1996). Further a matrix is estimated for France. In the Canadian, Chinese and Italian cases the surveys had uncovered interindustrial flows of production innovations through asking the innovators to identify the industrial affiliation of the major users of their product innovations. In the French case data of this sort were not available, and thus an innovative activity matrix was estimated based on input-output data combined with data on innovative activity in the supplying sectors (DeBresson, 1996, pp. 393-395).

One of DeBresson's theses is that innovative activity tends to cluster in the areas of economic space where 'normal' economic activity is most dense, i.e. where intermediate flows between industries are most numerous. For this purpose matrices estimated partly on the basis of input-output matrices are not very useful. Thus an analysis of innovative interdependence rests on the availability of extensive survey data on innovative interdependencies. In the Danish case, data from the first European Community Innovation Survey (C.I.S.), carried out in 1993 and covering innovative activity during the period 1990-1992, are used.[2]

The Community Innovation Survey is in principal an internationally comparable innovation survey based on the Oslo Manual (OECDb, 1992), which builds on the experiences of a range of innovation surveys carried out within the last three decades. One of the earliest surveys of innovation was the one carried out in relation to the project SAPPHO (Scientific Activity Predictor from Patterns with Heuristic Origins), which compared innovative successes and failures within chemical processes and scientific instruments in the early 1970's (Rothwell et al., 1974). Much in accordance with what has been argued here, the SAPPHO project found that the factors most important to innovative success are related to determining, monitoring and meeting user needs. Many of the successful firms interacted with a representative sample of potential customers throughout the development process in order to achieve this understanding of user needs. The SAPPHO project was followed by the data collection for the database on significant innovations in Britain at SPRU-Science and Technology Policy Research, documented in Townsend et al. (1981), which among other were the background data for Pavitt's Taxonomy (1984). Townsend et al. inspired a Canadian innovation survey documented in DeBresson and Murray (1984). Italy carried out its first compulsory innovation survey in 1986-87, a survey which was designed especially to construct an innovative activity matrix, and France carried out an extensive survey of innovation in 1991 (DeBresson, 1996). Innovation surveys have also been carried out in Germany by the Ifo (Information und Forschung) Institute, and data from these surveys have e.g. been applied by Schnabl (1995) in the analysis mentioned in chapter 4.

None of the surveys mentioned above were aimed at collecting internationally comparable results. The Community Innovation Survey is the first attempt to carry out the same survey in a number

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[2]   The data are weighted in order to be representative of the industries included in the analysis.
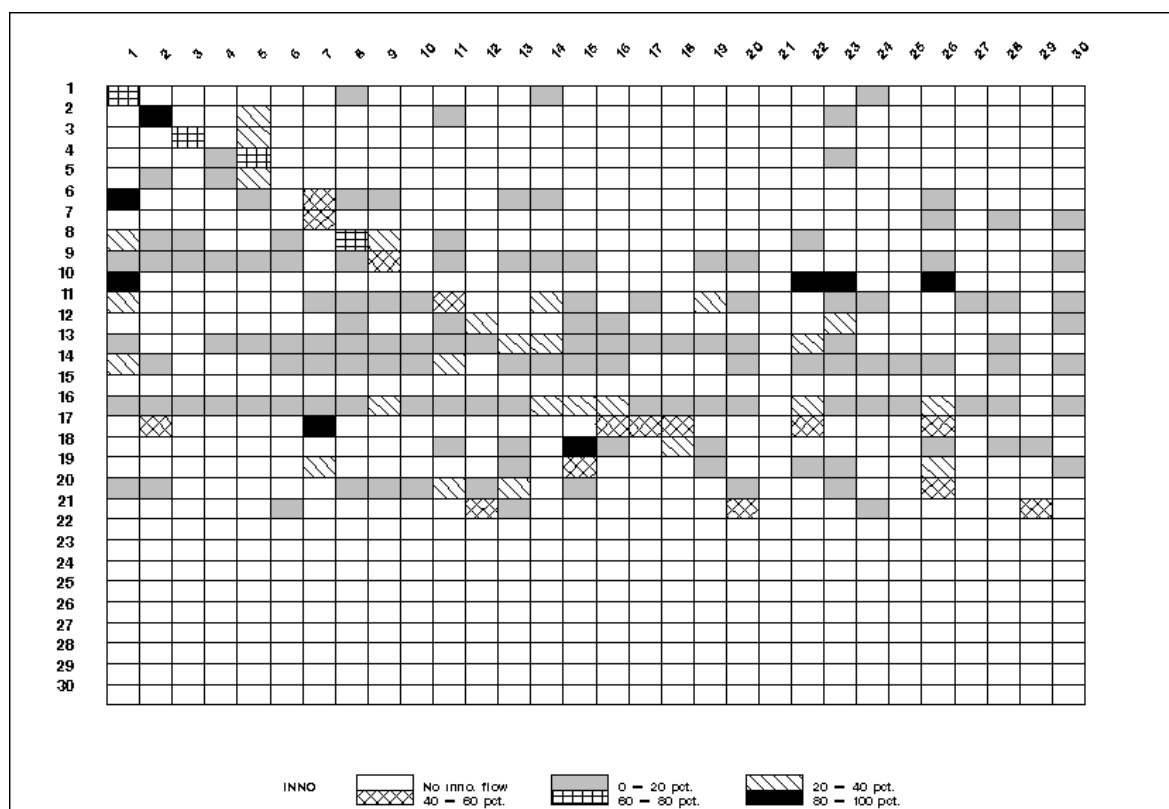
of countries at the same time, in order to provide internationally comparable data on innovative activities. The first survey carried out in 1993 was only a partial success in this respect, as national differences in sampling, formulation of questions and the collection of data put severe restrictions on international comparisons (Archibugi et al., 1994; DeBresson et al., 1998). The second Community Innovation Survey carried out in 1997/98 has not yet been evaluated but it seems that the harmonised collection of innovative data is still in its infancy.

In the Danish C.I.S. survey, which covered the manufacturing industries, the questionnaire included supplementary questions[3] on the supply of product innovations in the form of means of production, raw materials or intermediary goods to main user industries. On the basis of this information a matrix of innovation flows - an innovative activity matrix - can be constructed.

The innovation flows are measured as the fraction of firms in an industry that identify firms in their own or other industries as important users of the firms' product innovations. The Danish C.I.S. data also provides information on inputs to the innovative process, expressed as active participation of firms in other industries in the innovative development process. Thus the innovative activity matrix is supplemented with an information matrix. The information flows are measured as the fraction of firms in an industry that identify firms in another industry as active participants in the innovative process. The innovation and information flow matrices for Denmark for the period 1990-1992 are shown in figures 5.1 and 5.2. In figure 5.1 the rows are the innovation suppliers while the columns are the innovation receivers. The different patterns in the cells express the intensities of the flows (the percentages refer to the fraction of firms engaged in the transactions). The dimensions have been reversed in figure 5.2 (through transposing the matrix), i.e. the rows are receivers of information, while the columns are sources. This reversion has been made in order to make it easier to combine the information of figure 5.1 and figure 5.2. The matrices show that intraindustry relations (the diagonal) are a predominant phenomenon, both with regards to innovation flows and inputs to the innovative process.

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[3]   I.e. questions that were not part of the standardised international questionnaire. Thus the international C.I.S. does not allow for the construction of innovative activity matrices.
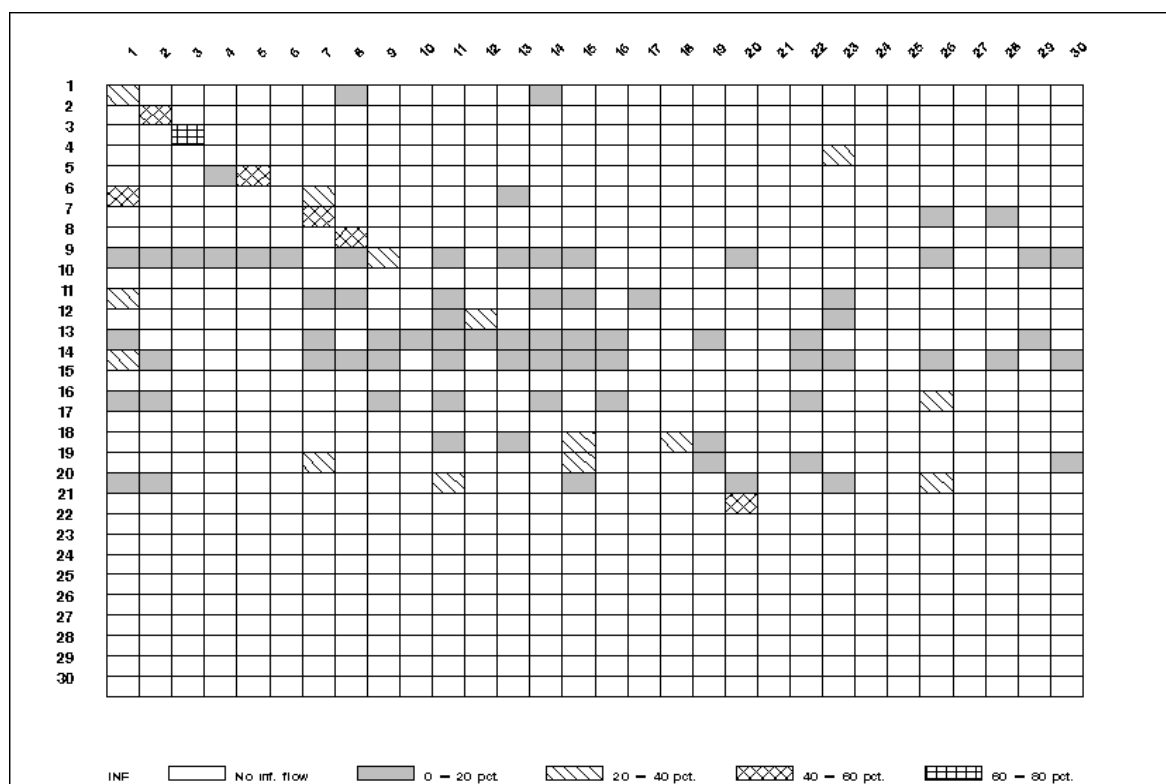
Figure 5.1: Innovation flows in Denmark, 1990-1992

1. Food	11. Rubber and plastic	21. Raw materials/other manufacturing
2. Textile and clothing	12. Stone, clay and glass	22. Public utilities
3. Leather	13. Iron and metal industry	23. Construction
4. Wood	14. Machinery	24. Trade and repair
5. Furniture	15. Electronics	25. Hotels and restaurants
6. Paper	16. Electrical machinery and apparatus	26. Transport services etc.
7. Graphical industry	17. Office machinery and computers	27. Finance and insurance
8. Pharmaceutical ind.	18. Telecommunication equipment	28. Public adm., defence etc.
9. Chemical industry	19. Instruments	29. Education
10. Mineral oil	20. Transport (manufacture)	30. Health and welfare institutions

Industries 15 and 22-30 are only included as users, no. 21 is only included as supplier.

Figure 5.2: Information flows (active participation in the innovative development process) in Denmark, 1990-1992

1. Food	11. Rubber and plastic	21. Raw materials/other manufacturing
2. Textile and clothing	12. Stone, clay and glass	22. Public utilities
3. Leather	13. Iron and metal industry	23. Construction
4. Wood	14. Machinery	24. Trade and repair
5. Furniture	15. Electronics	25. Hotels and restaurants
6. Paper	16. Electrical machinery and apparatus	26. Transport services etc.
7. Graphical industry	17. Office machinery and computers	27. Finance and insurance
8. Pharmaceutical ind.	18. Telecommunication equipment	28. Public adm., defence etc.
9. Chemical industry	19. Instruments	29. Education
10. Mineral oil	20. Transport (manufacture)	30. Health and welfare institutions

Industries 15 and 22-30 are only included as users, no. 21 is only included as supplier.

The industries which have their users of product innovations dispersed on the largest number of industries are the chemical industry, the iron and metal industry, machinery as well as electrical machinery and apparatus. These industries, with the exception of electrical machinery and apparatus, also receive input to their innovative process from firms in a considerable number of different industries. The following sections will go further into the details of the interindustry relations.

5.3   Mapping flows of product innovations

The innovation survey data serve two purposes in this chapter: firstly it is possible to check whether the hypothesis that embodied technology flows estimated from input-output analysis can be used as an approximation of technological (innovative) interdependencies between industries, can find support in product innovation flow data. Secondly, the survey allows for an analysis of the extent to which the flows are one-way from supplier to user, and to which extent we are dealing with a dependence which is two-way between supplier and receiver of the product innovation - i.e. it is possible to come closer to an answer to the question of the truly interdependent nature of technological development and innovative processes raised in chapter 2.

In order to be able to compare the innovation flows to the embodied knowledge flows identified in chapter 4, some central information is extracted from figures 5.1 and 5.2 and presented in directed graphs. The graphs in figures 5.3 and 5.4 are to be read in the same way as the graphs in figures 4.2-4.4. The level of aggregation and industry classification differs slightly from the classification used in chapter 4. This is due to differences in the classification codes used in the input-output tables (ISIC related classification) and the Community Innovation Survey (NACE classification). Thus it is not possible to compare in a one-to-one manner, neither is it possible to calculate statistical correlations between the two types of matrices.
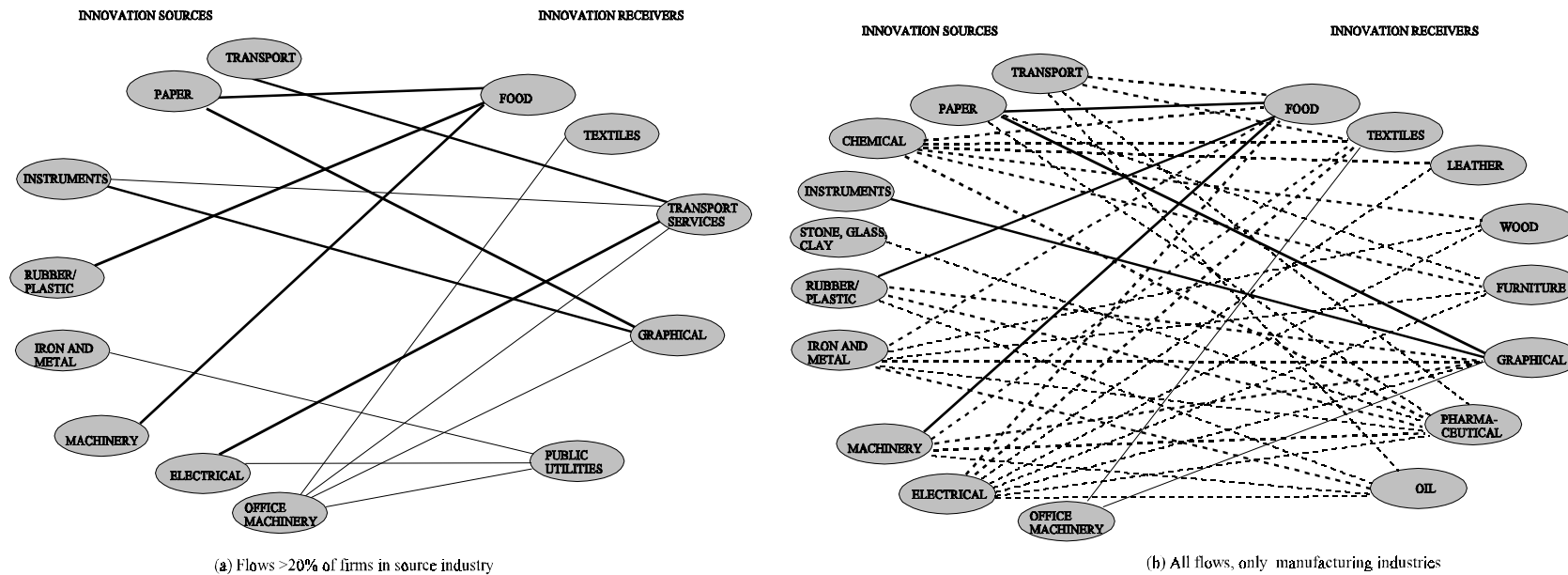
Figures 5.3 (a) and 5.3 (b) show the product innovation flows between industries in Denmark during the period 1990-1992. When comparing the innovation flows to the embodied knowledge flows identified in chapter 4, there is a serious limitation in the lacking coverage of services in the

innovation survey, implying among others that the importance of business services as a knowledge source pointed out in chapter 4 cannot be examined further. Figure 5.3 (a) only shows the flows including more than 20 percent of firms in the source industry. This figure shows a quite different picture of the technological interindustry relations than do figures 4.2-4.4. Some similarities can be found though: the role of machinery as a general knowledge source is confirmed (machinery is here split up into two: office machinery,[4] and (other) machinery), with some of the same receivers: food, public utilities and transport services (which was included in public services in chapter 4). New receivers compared to the embodied knowledge flows are textiles and the graphical industry. On the source side a number of newcomers occur: transport, paper, and rubber and plastics. Instruments and iron and metal were also identified as knowledge sources in chapter 4, instruments by both the R&D and patenting indicator, and iron and metal by the patent indicator only, but their users are not the same as in chapter 4, and thus figure 5.3 (a) does not support the findings of chapter 4 in this case. What figure 5.3 (a) does show is, that in several cases we are faced with 'true' interdependence between firms in different industries, in the sense that the innovation sources receive input to the innovative process from firms in the user industries (marked by the bold lines).

If we now turn the attention to figure 5.3 (b), where all product innovation flows (also flows including less than 20 percent of the firms in the source industry) are illustrated, a quite complex picture emerges. In order to reduce the complexity of figure 5.3 (b) the service industries are excluded, as they only are covered as users in the survey, and thus by definition will be placed in the receiver group. The product innovation flows from manufacturing to non-manufacturing industries are illustrated in appendix C, which confirms that low knowledge services are major knowledge receivers. Regarding flows between manufacturing industries in many cases it is only possible to support the findings of chapter 4 in an indirect way, as the classification applied in chapter 4 caused manufacturing industries like e.g. wood and furniture as well as the paper and graphical industry to be part of a residual group also including primary sectors and manufacturing n.e.c. In chapter 4 the residual group of industries receives embodied knowledge flows from machinery, chemical raw materials, iron and metal, instruments as well as business services.

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[4]   Part of the office machinery sector in the NACE classification is also to be found in the ISIC sectors telecommunications and instruments.

Figure 5.3: Innovation flows, major flows and complete network

INNOVATION SOURCES   INNOVATION RECEIVERS

(a) Flows >20% of firms in source industry

INNOVATION SOURCES   INNOVATION RECEIVERS

(b) All flows, only manufacturing industries

Signature:
Full line: more than 20% of the firms in the source industry have supplied product innovations to firms in the receiver industry.
Broken line: between 0 and 20% of the firms in the source industry have supplied product innovations to firms in the receiver industry.
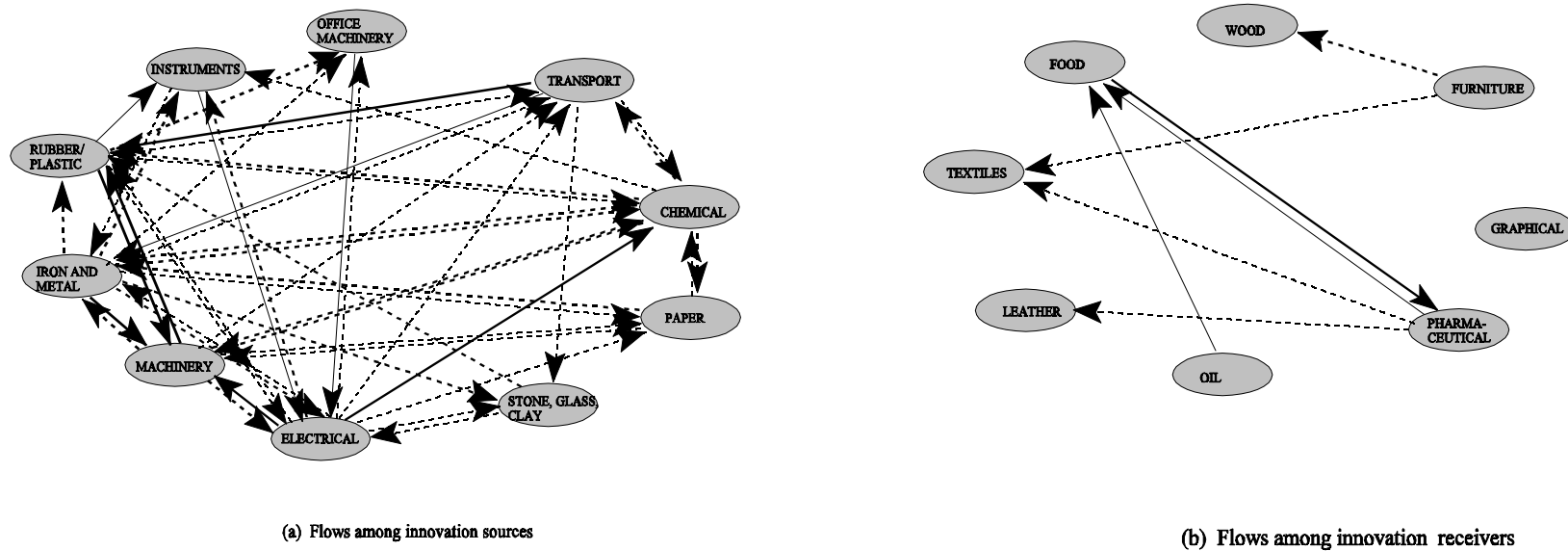Bold line: firms in the receiving industry have supplied information to the innovation process.

The figure to the left - figure 5.3 (a) - only shows the flows that exceed 20% of the firms in the source industry. This illustrates the overall structure in the relations.
The figure to the right - figure 5.3 (b) - also includes the flows that involve less than 20% of the firms in the source industries. In order to reduce the complexity of figure 5.3 (b), service industries are left out here.
Flows among industries in the source group as well as flows among the receiver industries are not shown in figure 5.3, but are instead illustrated separately in figure 5.4.

Figure 5.4: Innovation and information flows between innovation sources, and between innovation receivers

(a) Flows among innovation sources

(b) Flows among innovation receivers

Signature:
Full line: more than 20% of the firms in the source industry have supplied product innovations to firms in the receiver industry.
Broken line: Between 0 and 20% of the firms in the source industry have supplied product innovations to firms in the receiver industry.
Bold line: firms in the receiving industry have supplied information to the innovation process.

As opposed to figure 5.3 (and the figures in chapter 4), flows do not run from left to right in figure 5.4. Instead the direction of the innovation flows is indicated through arrows.

Figure 5.3 (b) shows that both the chemical industry, iron and metal and electrical machinery and apparatus supply product innovations to both the wood and the furniture industries; and both instruments, iron and metal and machinery supply product innovations to the graphical industry.

The paper industry turns out to be an innovation source for both food and the graphics industries, as well as furniture and the pharmaceutical industry. In the case of food and pharmaceuticals the innovation is most likely to be related to packaging which is of increasing importance in relation to improving and prolonging the freshness of products.

In general almost all of the embodied knowledge flows between knowledge sources and knowledge receivers identified in figures 4.2-4.4 can be confirmed in figure 5.3 - if not in figure 5.3. (a) showing the most dense relations, then in figure 5.3 (b) including all product innovation flows. An exception is of course the relations involving services and construction which were not covered as respondents in the innovation survey.

The most important general supplier of product innovations is electrical machinery and apparatus. No electronics related industry is included in the central knowledge flows with any of the knowledge indicators used in chapter 4, i.e. the importance of this industry is completely ignored when using the input-output based method. Thus an analysis of technological or knowledge interdependence which is solely based on the input-output method would miss what seems to be the most important supplier of generic knowledge in the Danish economy.

Figure 5.4 illustrates the flows among innovation sources - figure 5.4 (a) - and innovation receivers - figure 5.4 (b) - respectively. The figure shows that the innovation sources have a well developed net of relations amongst each other. In most cases the relations are two-way both in the sense that receivers supply information to the innovation process (illustrated by bold lines), and in the sense that most of the relations are of the type where the industries are sources for each other, e.g. machinery is both an innovation source for rubber and plastic and an innovation receiver from this industry.

The industries in the receiver group are much less related through innovation flows than the innovation sources. A strong relationship is found between the food industry and the

pharmaceutical industry. The isolation of the medical/pharmaceutical industry is not as outspoken when looking at innovation flows as was the case with the embodied flows. But the isolation is obvious when looking at information flows - or rather lack of these - to the pharmaceutical industry. And also it is paradoxical that the knowledge intensive pharmaceutical industry is placed among the innovation receivers rather than among the innovation sources. The isolation of the industry is probably due to the knowledge base of the pharmaceutical industry being relatively specific to this industry with relatively few overlaps to other industries except the food industry.

The innovation survey data both supports some findings from the input-output analysis, and reveals some features which were not captured by the input-output data. In particular the survey based data illustrates that when it comes to technological and innovative relations between industries, we are often faced with relations that express a true *inter*dependence where source and receiver are mutually dependent.

Another important finding when comparing the input-output based flows to the innovation flows is that economic relations, as expressed by flows of intermediate goods and services, seem to be followed by flows of innovations. This is illustrated in the way that the innovation flows in most cases support the findings from the minimal flow analysis. But the fact the innovation flows also to a large extent appear between industries without extensive trade relations also illustrates that we are faced with a one-way causality from exchange of goods and services to innovation flows, but with no apparent causality from innovation flows to a considerable economic exchange.[5] A possible explanation of this observation is that two industries might have overlapping technology bases and thus can be related through an innovative cooperation even though they are not closely related in an economic sense.

The analysis also indirectly supports the point raised by Marengo and Sterlacchini, referred to in chapter 4, that embodied and disembodied knowledge transfers are connected in the process of innovation and diffusion: is has been illustrated that a relation exists between on the one side

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[5]   Regarding production and *invention* rather that innovation, Schmookler (1962) claimed that the causality neither ran from production to invention nor vice versa, but rather they moved in parallel way and were closely correlated. Schmookler partly explained this by the simple fact that to the degree that inventions are made by either the producers or users of a commodity, more money will be available for invention when the industry's sales are high than when they are low.

knowledge embodied in general flows of goods and services, and on the other knowledge embodied in product innovations as well as knowledge inputs to the innovative process. This finding illustrates the benefits from combining different methods.

The next section will explore the innovation data further in relation to the analysis of chapter 4, focussing on the nature of the interdependence with the aim of identifying different types of innovative clusters.

5.4   Innovative Clusters

The applied definition of a cluster rests on the assumption put forward in DeBresson (1996): firms in innovative industries cannot innovate alone, they need supplier industries for new components and user industries for new applications and requirements. This section will look at clusters defined on the basis of the way industries are interdependent in the processes of both developing and diffusing innovations.

DeBresson (1996, p. 149) points out that even the 'father of innovation theory', Joseph Schumpeter argued that innovative activity clusters in economic space by stating that innovations are not distributed evenly in the economic system at random, but rather they tend to be concentrated in or around certain sectors (Schumpeter, 1939, p. 100-101).[6]

DeBresson operates with several types of space, in particular an abstract economic space constituted by the supply and demand of different goods, and represented by the web of supplier-user relationships in an input-output matrix, and a technical space represented by a techno-functional classification of patents. Distances in economic space are determined on the basis of linkages, i.e. two industries that are connected by forward or backward linkages are economically

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[6]   Schumpeter also argues that innovation cluster in time, which is used as an explanation of economic booms and following recessions (Schumpeter, 1927). That innovation clusters in time is not supported by innovation surveys, like e.g. the C.I.S. The surveys on the contrary report that innovative firms tend to carry out innovative activity at a continuous basis. But where the surveys apply a very broad innovation concept, Schumpeter deals with radical innovations, so it is not obvious that there is a contradiction between the two. But Schumpeter's (Mark I) perception of an innovator (the entrepreneur) as an extraordinary - heroic - person, who innovates alone, is contradicted by the survey that show innovation as an interactive process.

closer than industries that are not connected in this way. The same principle applies for technical space. Distances in the discontinuous technological space are measured with patent subclasses: industries that patent in the same subclasses are technologically closer than those that do not patent in the same subclass (DeBresson, 1996, pp. 151-2). Without looking at patenting activities, it was argued in the previous section that a reason for the food and pharmaceutical industries to be closely related through innovation and information flows could be the overlapping technology bases, which could also have been expressed as technological proximity.

DeBresson's definition of an innovative cluster mainly refers to the economic space:

> *economic agents (or industries) that are at the nodes of most diverse information are most likely to recombine factors for use in a new way - to innovate (…). As a result, innovative activities will cluster in industries that have the most different backward and forward linkages* (DeBresson, 1996, pp. 162-163).

In other words, DeBresson defines an innovative cluster as a concentration of innovative activities in industries that are very integrated in the economic system through backward and forward linkages. A graphic way to illustrate this is through the triangularisation of an input-output matrix. If DeBresson's proposition is true, then the innovative activity will be concentrated in the industries in the left-hand corner of the triangularised matrix. Even though the previous section, combined with the results if chapter 4, gave some support to this view, the definition of an innovative cluster applied in this chapter differs from DeBresson's definition in its focus on the interactive element of the innovative process. The information on the industrial affiliation of active participants in the innovative process allows for this focus.

From the innovation and information matrices presented in section 5.2, two types of innovative clusters of industries can be identified in Denmark:

• single-industry clusters each consisting of an industry which is a general supplier of product innovations to a broad range of receiver industries. This type of industry-cluster is important for the diffusion of knowledge in the economic system as they are suppliers

of what can be labelled 'generic technologies'[7] which are of general use in the economic system;

• clusters consisting of industries which are intensive suppliers to a single or few receiver(s) as well as these industries' main receivers. These supplier and receiver industries are examples of innovative user-producer relations, in which the role of the users is often crucial for the innovative outcome (cf. Lundvall, 1985). Thus in this second type of cluster a close relation between the supplier and receiver industries is assumed in the innovative process.

As pointed out in the previous section, manufacturing of electrical machinery and apparatus is one general supplier of innovations, supplying close to all other sectors in the system. Machinery, the iron and metal industry, rubber and plastic as well as the chemical industry (excl. pharmaceuticals) are also general suppliers of innovations. The main characteristic of these industries is that the

Figure 5.5: Innovation and information relations between firms in the electrical machinery and apparatus industry and firms in other industries
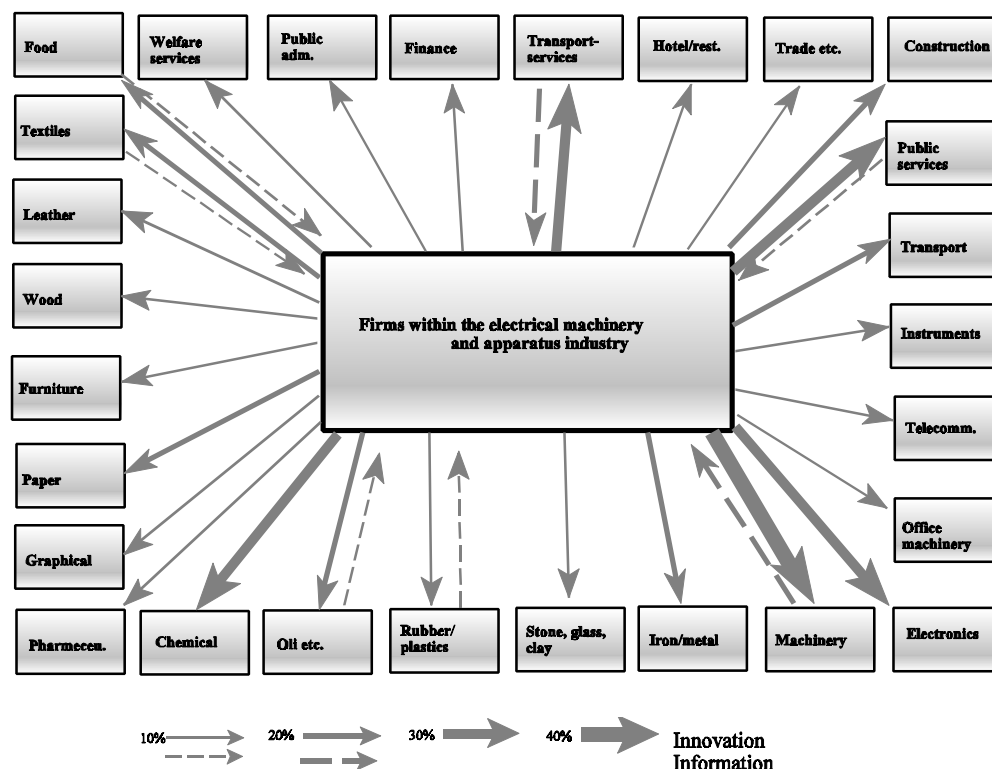
percentage of firms in each industry supplying product innovations to firms within a single industry is relatively low, which could indicate a high degree of specialisation regarding user groups between the firms within each general supplier industry.[8] Also only a few of the receiving industries (especially for what concerns the electrical machinery and apparatus industry) are reported to be information sources in relation to the innovative process. The web of relations surrounding these types of industries is illustrated by the electrical machinery and apparatus industry in figure 5.5, where full lines represent product innovation flows, and broken lines represent information flows/inputs to the innovative process.

As a contrast to these general supplier industries a number of industries with a high intensity of innovation flows to few other industries are identified. When the innovation and information matrices are combined, among others indications of innovative clusters between paper (innovation supplier) and food (user and information source) are identified; also clusters between paper (innovation supplier) and the graphical industry (user and information source), and between telecommunications (innovation supplier) and electronics (user and information source) are identified.

The example of a user-producer relationship between the paper and food industries show that 80 percent of the firms in the paper industry have supplied product innovations to the food industry during the period analysed. During the same time period 50 percent of the firms in the paper industry identify firms in the food industry as active participants in the innovative process. Another example of such an user-producer relation is between telecommunications and electronics: 90 percent of the firms in the telecommunications industry have supplied product innovations to the electronics industry during the period 1990-1992. At the same time 40 percent of the telecommunication firms identify firms in the electronics industry as active participants in the

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[8]   As pointed out by Peter Maskell at the DRUID winter conference, Middelfart, 1998, where some of these results were presented, this could actually also indicate that it is a very heterogeneous industry, or as Rosenberg would formulate it, the industry concept applied is outmoded.

Figure 5.6: Innovation and information relations between firms in the food and paper industries
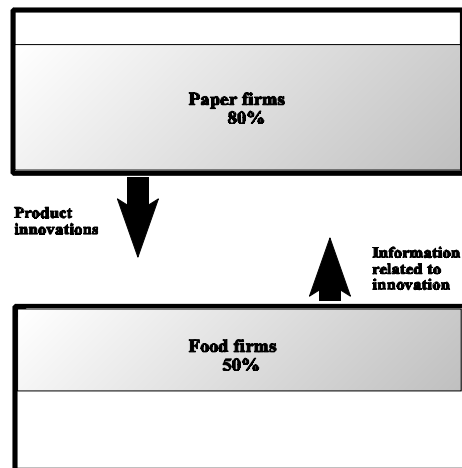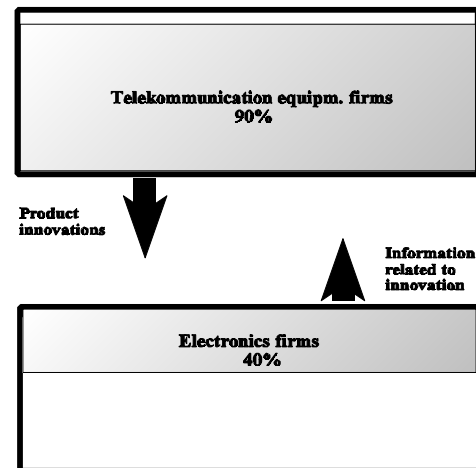
Figure 5.7: Innovation and information relations between firms in the telecommunication and electronics industries

developing process.[9] Figures 5.6 and 5.7 illustrate the extent of the relations in the two clusters.

Telecommunications and electronics are two knowledge intensive industries with overlapping technological competencies explaining the high degree of innovative interdependence between the two industries.[10] But innovative clusters can also exist between two relatively low knowledge industries, like the food and paper industry. As mentioned earlier, the dependence of the food industry on innovations (in packaging) from the paper industry was also found by Christensen et al. (1996).

Examples of industries, like the mineral oil industry, which are major suppliers of innovations to firms in a single or few industries, without any apparent information flow relations between the two groups are also found. This observation indicates that innovation being an interactive process

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[9]   While the relation between telecommunication and electronics could not be captured in the I-O analysis in chapter 4, the relation between paper and food, at least indirectly, could be seen from the graphs based on both R&D expenses and technical and science personnel, since the paper industry is included in the residual group of industries.

[10]   The survey did not cover firm in the electronics industry as respondents, but only firms in electrical machinery and apparatus, i.e. it is not possible to check the extent of innovation flows from firms in the electronics industry to firms in the telecommunications industry, nor is it possible to check the corresponding information flows.

is by no means a rule without exceptions.

5.5   Conclusions

This chapter has illustrated that technological linkages between firms in different industries have no simple explanation.

Some support could be found for the assumption that technological relations tend to cluster in areas with extensive economic relations. But on the other hand innovative relations also often appear between industries which are not closely economically linked. Thus both of the two types of space introduced by DeBresson seem to be of importance to the existence of technological linkages: proximity in economic space can explain some technological relations, while others are assumed to be based on technological proximity or overlapping knowledge bases. This chapter does not claim to provide a full explanation of this phenomenon though. Rather we have only scratched the surface.

The chapter gives empirical support to the proposition from some strands of innovation theory, that innovative activity is an interactive process. Active participation in the innovative process from the user side is most outspoken in the case of industries which are 'specialised' in supplying product innovations to firms in one single or few industries, but also in the case of more 'generic' technology sources some user involvement is reported.

In relation to the cluster discussion this chapter has introduced two types of clusters, which differ with regards to their extent of and relations to users. The main element characterising a cluster, namely the linkages that connect the different elements, is maintained in the case of the user-producer cluster, although a more dynamic element has been included in the interdependence - the innovative process. But single-industry innovative clusters, which are characterised by being important innovation sources for the entire economy, are also introduced. These types of industries are important in relation to understanding the forces driving technology development and diffusion in the economic system.

Appendix C: Flows of product innovations to firms in non-manufacturing industries
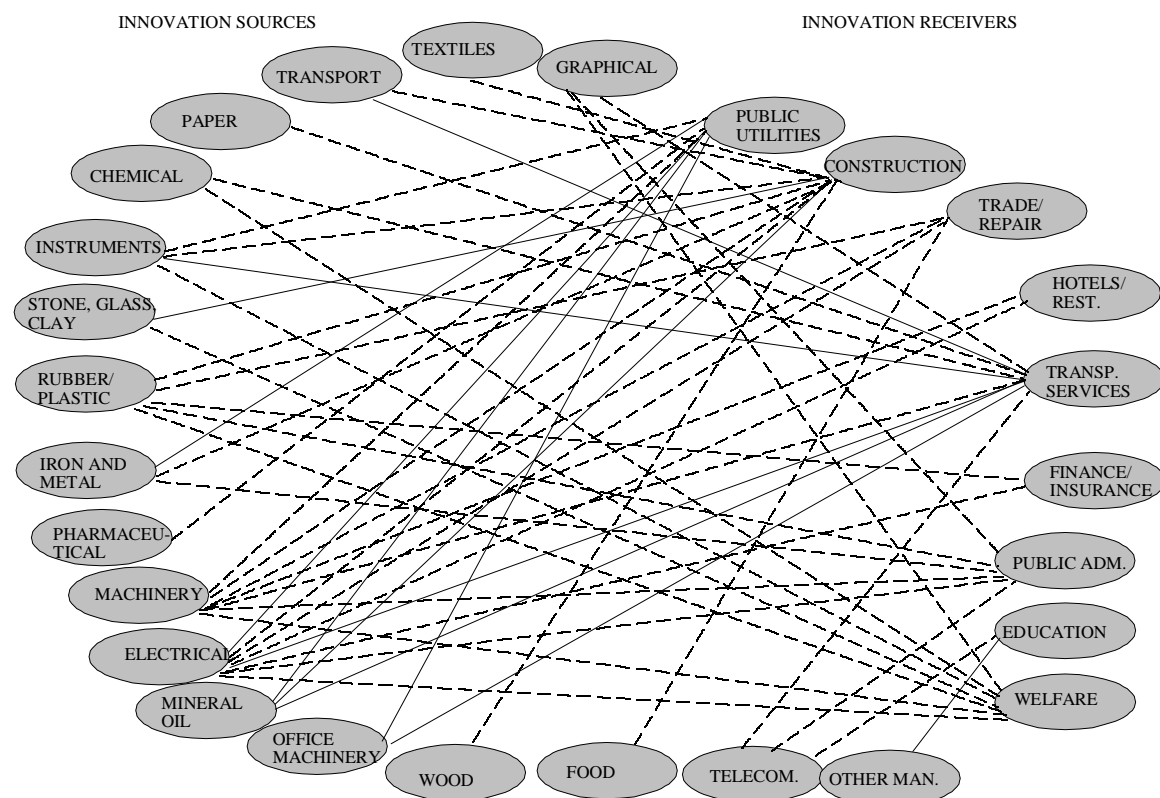
INNOVATION SOURCES INNOVATION RECEIVERS

Signature:

Full line: more than 20% of the firms in the source industry have supplied product innovations to firms in the receiver industry.

Broken line: between 0 and 20% of the firms in the source industry have supplied product innovations to firms in the receiver industry.

Flows run from left to right.

Part III: Applying Linkages in International Analyses

Part III broadens the focus of linkage studies from a single country perspective to international analyses. Chapter 6 reapplies the input-output based graph theoretical model from chapter 4, but the focus is now moved from the methodological aspect to the analysis of national systems of innovation. The aspect of 'history matters' in the emergence of dominating economic structure is the centre of analysis. From the national system of innovation perspective chapter 6 compares the structure of interindustrial linkages in four major OECD countries: Germany, Great Britain, Japan and the United States, and relates the structure of each country to its history of industrialisation. The chapter demonstrates the existence of two dominating main structures of interdependence in the countries analysed, but the major message is the national systems of innovation continue to differ to such an extent that some of these differences are visible even in a model which is only able to capture some broad structures of interdependence in the system.

Chapter 7 moves on to the analysis of the extent to which interindustry linkages are related to the structures of export specialisation. The hypothesis behind the analysis is that backward and forward linkages to competent (here measured as technologically advanced from the perspective of patenting) users and suppliers are beneficial from an international competitive point of view, and thus countries tend to be export specialised in industries that are linked to 'competent' user and supplier industries. Even though export specialisation is a relative measure of the characteristics of the composition of exports, and as such cannot be perceived as a performance measure in the traditional sense, it is in this chapter attempted to measure some concrete effects of linkages, the previous chapters being devoted to *mapping* linkages. The chapter seeks to establish a statistical relation between linkages and export specialisation. Since it is not assumed that linkages are of equal importance in all industries, the chapter distinguishes between four major groups of industries according to Pavitt's (1984) taxonomy.

Thus part III broadens the linkage analyses by looking at differences between countries with regards to linkage structures in chapter 6, and differences in the effect of linkages between industries in chapter 7.

Chapter 6: Comparing Patterns of Industrial Interdependence in National Systems of Innovation - a study of Germany, Great Britain, Japan and the United States

..it is assumed that learning is predominantly an interactive and, therefore, a socially embedded process which cannot be understood without taking into consideration its institutional and cultural context. Specifically, it is assumed that the historical establishment and development of the modern nation state was a necessary prerequisite for the acceleration of the process of learning which propelled the process of industrialisation, in the last centuries (Lundvall, 1992a, p. 1)

6.1   Introduction

The previous chapters have dealt with technological interdependence in the Danish economy only. In this chapter the focus is broadened to a comparison of four major OECD countries: Germany, Great Britain, Japan and the United States. The chapter sets out to compare the structure of technological interdependencies between industries as they are expressed by embodied R&D flows in the four countries. The national system of innovation approach is used as the point of departure, and the major aim is to analyse the extent to which the differences in structure of interdependence can be explained by some underlying characteristics of each individual innovation system. In particular the extent to which 'history matters' for the current structure of a national system is emphasised.

The chapter shows that a relatively simple graphical representation of major relations in a national system of innovation can illustrate some fundamental differences between systems, which cannot be revealed from e.g. economic key figures. Such economic key figures or indicators for the four countries analysed are presented in appendix D. I claim that an input-output based graph theoretical model is a relatively simple way, by applying quantitative data, to illustrate some qualitative differences between national innovation systems.

Of course each country cannot be done justice at the limited space available here, but the admittedly superficial stories of the development of each of the four systems serves to illustrate

the major point of this chapter: that differences in the industrial development of each country, and the institutional factors influencing this development, results in differences in the overall structural relations of the national systems of innovation.

A national system of innovation is constituted by the institutions and economic structures affecting the rate and direction of technological change in the society, including not only the system of technology diffusion and the R&D system, but also institutions and factors determining how technology affects productivity and economic growth (Edquist and Lundvall, 1993, p. 267). Even though knowledge and technology gets diffused through several other channels than embodied R&D flows, I find that the identification of these flows is an important first step in understanding the structure of a national system of innovation. An analysis of embodied R&D flows that uncovers major sources for the spread of technology in the economic system can, as illustrated in previous chapters, point out sectors which have a widespread effect on the whole system through the diffusion of technology as a result of transactions between industries. But also the patterns of interdependence might help in understanding the importance of the historical background for the present setup of the system, claiming that the current structure of the systems is largely dependent on their past history of industrialisation.

As R&D is only a proxy of the input effort to a technology creation and development process, and furthermore technology itself is only a subset of knowledge, the analysis in the present chapter is limited to the study of a reasonably well defined corner of the total knowledge interdependence and diffusion system within a national system of innovation. It should be kept in mind that knowledge gets diffused through several channels of which many are informal and difficult - if not impossible - to measure.

The relations studied are, like in the previous chapters, national only since the focus is on intra-country relations trying to compare *national* differences in the way the *national* economies are structured. This of course does not imply that international relations are not crucial in understanding and explaining technological development in advanced open economies, especially since some industries are more internationally oriented than others. But a national system of innovation is characterised by historical specificity and a multiplicity of institutional configurations which affect its outcomes, and although globalization can change the nature of a national system

of innovation substantially by e.g. adding new international linkages and by making the systems more interactive, it is unlikely that globalization will eliminate national or local specificities completely (Saviotti, 1997, pp. 195-196).

The analysis of the characteristics of each national system of innovation to be found in this chapter, among other sources draws on the empirical analysis of national areas of strength and weakness in Porter (1990), since these national analyses are very rich in empirical and historical detail. And although Porter does not deal with the innovation system concept, but focusses on explaining and analysing the competitive advantages and disadvantages of nations, there is a large degree of overlap between the two approaches, at least when it comes to analysing dynamic and competitive characteristics of nation countries.

The analysis is related to the analysis presented in Düring and Schnabl (1998) which compares structural changes in Germany, Japan and the United States between 1980 and 1990. Even though Düring and Schnabl claim to compare national systems of innovation, they put almost no emphasis on the inherent structures and institutional setups determining the observed development, thus the major similarity between this chapter and Düring and Schnabl's approach lies in the model applied.

6.2   Why study national systems of innovation?

Lundvall (1998) answers the question 'why study national systems of innovation' by pointing to the importance of understanding different styles of innovation, and differences in how new knowledge is created, distributed and used for establishing a theoretical basis for the analysis of national systems of innovation.

Innovation and learning are cornerstones in the national system of innovation approach. But the way that innovative activity is carried out, and the way learning - which in the national system of innovation approach is perceived as 'interactive learning' - takes place in a system is affected by institutions. Both formal institutions and informal institutions perceived as norms, routines, habits etc. are important. Some of the types of informal institutions pointed to by Lundvall (1998, p. 409) as especially important in the context of learning and innovation are:

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i)   The 'time horizon' of agents: the Anglo-Saxon systems are characterised by a shorter time horizon in corporate governance than the Japanese and German systems, which are known for working with a quite long time horizon in investment decisions.

ii) The role of 'trust': the German and Japanese systems are perceived as being more trust oriented in business matters than the Anglo-Saxon systems (see e.g. DeBresson et al., 1998).

iii) The way that 'authority' is expressed: the expression of 'authority' in industrial relations affects the capability to learn. Here Lundvall points to Polyani's (1966) proposition that the learning of new skills typically takes place in the context of a master-apprenticeship relationship where a mixture of trust and authority is necessary in order for learning to take place efficiently. The learning capabilities of Asian countries, here represented by Japan, in certain areas are suggested to be rooted in the special kinds of authority relations in these countries (Lundvall, 1998).

It is of course not possible to study the functioning of these different types of informal institutions in an analysis of the aggregated type that performed here. But it is worth remembering that these underlying factors might help explain the development leading to the current structure.

Patel and Pavitt (1993) also deal with the institutional influence on the setup of national systems of innovation, but Patel and Pavitt primarily deal with formal institutions in the form of business firms, universities and other training institutions as well as government. Thus they define a national system of innovation as :

> *the national institutions, their incentive structures and their competencies, that determine the rate and direction of technological learning (or the volume and composition of change-generating activities) in a country* (Patel and Pavitt, 1993, pp. 5-6).

The kinds of institutions in mind are mentioned above. The incentive structure among other things involve government support for basic research, but Patel and Pavitt also point to possible disincentives regarding investment in competence enhancement in the form of mobility of employees (making the return of firm-based training uncertain), and the relation between competition and imitation. As will be illustrated below, differences in institutions, in particular

higher education institutions, as well as in incentive structures influencing e.g. military oriented research, have had a considerable influence on the observed differences in the structural setup of national systems of innovation.

6.3 Methodological considerations

R&D expenses are used as a proxy of technology in the present chapter. The use of R&D expenses represents a very narrow perception of technology. R&D is one input factor to a technological creation process; a process that is in fact too complex to describe using one single factor only. Chapter 4 and 5 illustrated that the combination of different knowledge and technology indicators, including both input and output indicators, is an important step in defining 'knowledge intensive industries'. However, due to restrictions in form of data availability, it has not been possible to combine several indicators in the present chapter, and thus the limitations in just looking at one indicator of knowledge creating/technological activity should be kept in mind.

The OECD STAN databases, which among other consists of data covering industrial R&D expenditures and input-output relations, provide new opportunities to comparative analysis of technology transfers. The analysis by Papaconstantinou et al. (1996) mentioned in chapter 4, as well as a follow-up analysis by Sakurai et al. (1996), used the STAN input-output matrices and ANBERD data on R&D expenses as the foundation of their analysis of the diffusion of R&D and industrial performance (productivity) in the manufacturing industry in 10 OECD-countries.

The present chapter is not going to deal with the productivity issue, but will concentrate on identifying the patterns of technological interdependencies within the four major OECD countries, applying the same data sets as Papaconstantinou and Sakurai. The main feature distinguishing the present chapter from most previous studies of interdependence is the explicit claim that *history matters*. Thus the structure of each national system is related to the national history of industrial development.

The model applied is the graph theoretical model presented in chapter 4 (see appendix B for the technical description of the model) which transforms the input-output system to a minimal flow system where only flows exceeding a preset value will be included. As in previous chapters flows

go from left to right (except when they are marked with an arrow). Bold lines express bilateral relations.

The graphs are constructed for Germany, Great Britain, Japan and the United States for the year 1990. All values are calculated in US dollars, but the filter values are scaled according to the total business sector R&D expenses in each country, i.e. the filter value for the United States is approximately 1.5 times as large as the filter value for Japan, since the R&D expenditures in the United States are approximately 1.5 times as large as the Japanese R&D expenditures.

6.4 Exploring differences in structures of industrial interdependence in national systems of innovation

The four countries that are at focus in this chapter might at the surface look similar from an overall industrial point of view. If one e.g. look at the main economic indicators of the four countries in appendix D, food, motor vehicles and non-electrical machinery are found to be among the five most important industries from a production volume point of view in all countries. Food and non-electrical machinery are among the five largest employment industries in all countries. Concerning R&D efforts communication equipment and motor vehicles are among the five most important industries in all countries. The export specialisation indicator is the only one where the similarities between countries are not too obvious, although some common features also appear here. The United States distinguishes itself from the other three countries by being most strongly export specialised in high-tech industries only: aerospace, office machines and computers, instruments, communication equipment and semiconductors as well as industrial chemicals. The most R&D spending industries among the five industries in which Germany is most strongly export specialised are motor vehicles, industrial chemicals and non-electrical machinery, the two other industries on the 'export specialisation Top 5' being fabricated metal products, and electrical machinery. Britain is most strongly export specialised the R&D intensive aerospace industry, followed by other manufacturing industries. On the following places another research intensive industry appears: pharmaceuticals; as well as office machines and computers, and instruments. Japan is most strongly export specialised in transport industries (shipbuilding and other transport) followed by communication equipment, office machines and instruments.

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Despite the similarities in economic indicators, the four countries have gone through quite different development processes. Great Britain was the dominant industrial nation in the 19th century, but have since lost its World leadership. The United States took over that leadership in the 20th century, and in particular in the post World War II-period the American economy flourished. Both the German and Japanese economic systems were severely struck by their defeat in the Second World War, but they both managed to rebuild their nations very fast to become major economic powers. But their foundations for rebuilding - apart from being subject to both American restrictions and support - were very different. Thus the four systems differ considerably in the formal and informal institutions guiding economic behaviour, in the economic structures determining technological change, and in the historical development leading to the current structures, in other words they represent four very different national systems of innovation. What is attempted carried out in this section is a analysis of whether, and if so, how these differences are expressed in the structure of interindustrial technological linkages.

6.4.1 Germany

Porter (1990, p. 356) sums up the remarkable success of the post-war German industrial strategy by stating that no country in the world, including Japan, exhibits the breath and depth of industries with strong international positions as Germany.

Figure 6.1 illustrates a system with industrial chemicals being a dominant industry which appears to be a general technology source for the entire system, including industries in the 'transport and machinery cluster'. Furthermore it is worth noticing the bilateral relations in the 'transport and machinery cluster' consisting of non-electrical machinery, electrical machinery and motor vehicles.[1]

The background for the dominating position of chemicals in Germany can be found in the 19th century. Many of the German competitive positions were created by the turn of the century,[2]

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[1] Figure 6.1 confirms all the relations found for Germany in 1990 by Düring and Schnabl (1998), but more relations are included in figure 6.1 than in the Düring-Schnabl graphs. I ascribe this to a larger filter value applied by Düring and Schnabl.

[2] Historical continuity is very outspoken in Germany - despite of the destruction during the World Wars - also at the firm level. This is illustrated by the fact that 19 of the 25 largest firms in 1989 were

where Germany was characterised by a close connection between universities, *Technische Hochschulen* and industrial firms. With the universities and the Technische Hochschulen Germany had established a sophisticated system for education in scientific, technical and commercial matters, reaching from elementary school to doctoral level (Keck, 1993, p. 122). This system has had a significant influence on the structure of the German system as we know it today.

The first major science based industry in Germany was the beet-sugar industry which became a major exporter in the late 19th century. In addition to chemical research the industry had a base in agricultural research. Important lines of business in the chemical industry also supplied inputs to the textile industry (in particular bleaching and dyeing). Germany's largest chemical companies BASF, Hoechts and Bayer were all founded in the 1860's, and were at the time main producers of synthetic dyes (Keck, 1993, pp. 125-126). Porter actually perceives the pressure from factor *dis*advantages as a major factor behind the success of the German chemical industry, as the lack of available raw materials stimulated breakthroughs in synthetic materials (Porter, 1990, p. 371).

A feature of strength in the German chemical industry is the tendency to integrate backwards into production of basic chemicals and intermediates. In general German firms has prospered from

Figure 6.1: R&D linkages in Germany, 1990
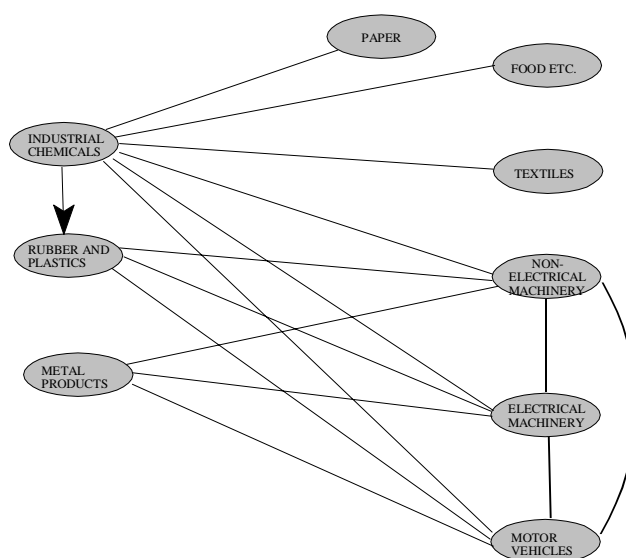
founded before 1913. These firms were mainly to be found in the fields of chemicals, vehicles, electricity, energy, steel, and machinery (Keck, 1993, p. 136).

taking advantage of economies of scope, which also meant that the primary focus was on process innovation rather than product innovation (Murmann and Landau, 1998, p. 31).

The dominance of the chemical industry in Germany was so strong that during the interwar years, German industrial power became synonymous with IG Farbenindustrie Actiegesellschaft, which was a result of the merger of the major German chemical companies in 1925 (IG included contemporary giants such as Hoechts, BASF and Bayer) (Murmann and Landau, 1998, pp. 49-50).

The German chemical industry did not suffer as much as could have been expected after the end of the Second World War, even though the Allies confiscated know-how, trademarks and patents from German industry as a part of the policy of making public all information from the enemy. Germany's 'luck' was that the end of WWII coincided with a shift from coal-based technology in chemicals to petrochemicals. Thus most of the information obtained by the Allies soon became obsolete as the technological frontier in chemicals moved in a direction new to all parties. Restrictions on chemical production and research were soon removed, as it became obvious that a reversal of the German economic decline required allowing German chemical firms to produce again - as chemicals were perceived as 'the lifeblood' of a modern economy (Murmann and Landau, 1998, pp. 60-61). Germany has since experienced a decline in competitive advantages, and the dominance of the chemical industry in Germany is not very outspoken when looking at the economic indicators of appendix D. But from figure 6.1 it is apparent that industrial chemicals still have a central position in the German system of technological relations. Industrial chemicals, together with rubber and plastics, is the source of embodied R&D for a broad range of industries including paper, food, textiles, electrical and non-electrical machinery as well as motor vehicles. In other words the main bulk of embodied R&D flows run from industries in a main group related to chemistry towards industries related to electronics and metal processing.

Moving in to the non-chemical part of German industry, metal products is also a technology source, but only to industries in the electrical-transport section of the system. The mining and metal processing industries have their offspring in the mining schools which trained generations of administrators and managers in the 18th and 19th centuries, leading to an effective transfer of technology from abroad as well as to graduates pioneering in new processes (Keck, 1993, p. 127). Porter (1990) also points to metals, metalworking and associated machinery as well as construction of metallurgical plants as another major field of strength in Germany. This field is

closely related to transportation equipment. The motor vehicles industry, electrical machinery and non-electrical machinery are all related through bi-lateral relations, i.e. these industries are both sources to and receivers of technology from each other. Düring and Schnabl (1998) characterise a bilateral connection of two industries as a 'growth dipole' with respect to interchanged innovations, as the innovation growth of one industry is seen as stimulating an additional growth of the other industry, which is then reflected back to the first one. Thus Düring and Schnabl see the bilateral linkages (in their case a bilateral relation is only identified between electrical machinery/apparatus and motor vehicles) as 'the dynamic source of the economy' (Düring and Schnabl, 1998, p. 9). However I find that the identification of innovative dynamics might be reading too much into the data, but do acknowledge that the highly integrated machinery-motor vehicles cluster is a notable characteristic of the German system of innovation, illustrating the other important position of relative strength in Germany besides the industrial chemical industry. Judged from figure 6.1 the machinery and transportation (motor vehicles) industries are in fact also closely related to the industrial chemicals industry. As will be illustrated below, Germany is the only one of the analysed systems with a chemical industry so deeply integrated in the web of industrial interdependence in the national innovation system.

Germany also shows a lack of industrial strength in some areas. The service industries as well as electronic products, computers and semiconductors etc. are weak spots in the German system (Porter, 1990, p. 367), despite the fact that German firms devote a major part of their R&D expenses to some of these fields (see appendix D).

Summing up on the characteristics of the German system of innovation, skills and technology has played an important role for the present characteristics of the system, in particular characterised by the strong position in the R&D intensive chemicals industry. Thus the influence of the institutional set-up most notably expressed by the educational system cannot be neglected. But Germany seems to be better at improving performance and staying ahead in traditional areas of specialisation than at moving in to new fields of growth (such as computers). This is underlined in figure 6.1 by the fact that Germany is the only of the four countries analysed which has not one single electronics, communications or computer related industry as a source of embodied R&D flows. A proposed explanation for this is that while Germany's strength has been built on upgrading advantages by raising the quality of human and technical resources, these advantages in human skills through an outstanding quality of education seem to have eroded in the past

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decades. Thus the German system now appears to be structured mainly around 'old' positions of strength, which might prove to be a vulnerable position in the long run.

6.4.2   Great Britain

As opposed to the German system, Britain has experienced a long period of relative decline in economic power from a 19th century position of dominance. While the German industries are praised for their depth, British clusters are described as 'shallow', i.e. the vertical strength which is seen in e.g. the German chemical and related industries is missing in Britain's major industries. An exception is services, which is a British success sector. But Britain lacks competitive advantage in several areas, most notably telecommunication equipment, consumer electronics, most transport equipment, mechanically based consumer goods as well as machinery (Porter, 1990, pp. 484-494).

Figure 6.2 of the main R&D linkages in the British system of innovation shows a system which is split up into two distinct clusters: a chemicals related clusters with industrial chemicals and pharmaceuticals as sources of knowledge for a range of low-tech industries; and an electronics related cluster with electrical machinery and communication equipment being sources for the, from a R&D perspective, major industries office machinery and aerospace, as well as non-electrical machinery and motor vehicles.

The main successful industries are chemicals, pharmaceuticals and computers. The success in chemicals and pharmaceuticals can be explained partly by a heavy investment in R&D (see appendix D), partly by the establishment of strong linkages to university (Porter, 1990, p. 498;Walker, 1993, p. 180).

Britain started out by being leading in the electrical and mechanical area, while the position of strength in chemicals and pharmaceuticals came later. For most of the 18th and 19th century the British innovation system[3] was generating revolutionary changes in techniques of energy and material transformation (the coal, iron and steam nexus), in the organisation of production (the

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3   von Tunzelmann (1995, p. 138) argues that any reference to national systems of innovation before well into the 19th century is premature since this was the time that nation-states as we know them today were coming into existence. Britain is an exception from this as the union between Scotland and England in to Great Britain was realised in the early 18th century.

Figure 6.2: R&D linkages in Great Britain, 1990
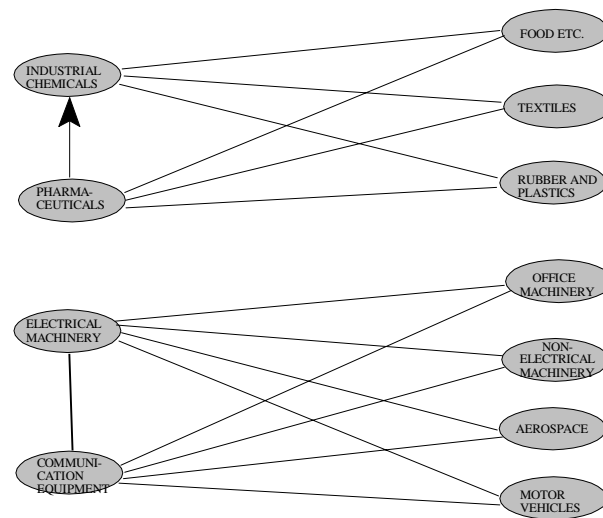
factory system), and in transportation (railways and steam ships). These industries have all declined in importance and have now lost their world dominance (Walker, 1993, pp. 187-188).

The relatively poor performance of engineering related industries has among other been blamed on the defence procurement which has absorbed a large proportion of high technology engineering resources, a position which is also supported by Porter (1990, p. 498). The effect of defence procurement for the technological development does not always have to be negative though, as is illustrated in the cases of Japan and the United States below. The proposed reasons for the negative effects of the involvement in defence markets in Great Britain are a small spinoff into the civil sector, and that the defence involvement has influenced the 'style' of technological activity (product rather than process innovation) (Walker, 1993, p. 177). Another straightforward explanation for the decline in engineering related industries is the lack of an educational strategy in engineering, since Great Britain has a comparatively poor quality of especially vocational training and secondary level education (Mason, et al., 1992).

The development of a 'cluster' around industrial chemicals and pharmaceuticals cannot be dated as far back as the 'engineering cluster'. Food, which is among the receiver industries in this cluster, has played a considerable role in the world market as Britain is home to some of the worlds largest food, drink and tobacco companies with origins in the 18th and 19th century (Walker, 1993, p. 161). The chemical and pharmaceutical industries appear to be somewhat

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newer. But as a consequence of the demand created by the industrial revolution (by industries such as textiles, glass, steel etc.) Britain was in fact the home of the largest chemical industry in the world in the middle of the 19th century. The German chemical industry outperformed the British around the turn of the century through German investments in both manufacturing, marketing, and management, allowing for reaping cost advantages from both economies of scale and economies of scope. Also the large German investments in R&D, which resulted in an continuous stream of new or superior products and processes, were causing Britain to fall back (Murmann & Landau, 1988, pp. 28-30). The above mentioned German education system was one of the factors allowing these investments.[4] But during WWI British firms were very close to catching up with German firms, since chemicals played an important role in the warfare (poisonous gasses), and the British government induced the creation of an infrastructure for interaction among science, industry, and government, which had been missing previously, but turned out to be very beneficial for the industry. Also the transfer of know-how from Germany to Britain during and after the First World War played a crucial role for the technological catch-up in chemicals (Murmann & Landau, 1998, pp. 46-47). The British chemical industry never reached the same overwhelming importance for the national industrial society as was the case in Germany, but in recent years an effort in the area of higher education has made the British level of science of world class (Murmann & Landau, 1998, pp. 63-64).

A reason for lack of linkages between the two main clusters in the British industry could be the above mentioned lack of synchrony in the development of the clusters. Britain now possesses some of the world's leading chemicals and pharmaceuticals firms, probably due to these industries being closely linked to science, a field in which Great Britain has a considerably stronger position than in electronics and related industries (Walker, 1993, p. 180). Thus figure 6.2 underlines the uneven development of the two main areas of British industry.

Wrapping up, it is characteristic for Britain that the major role in the world economy is maintained in manufacturing industries which are typically 'science-based' (cf. Pavitt, 1984). The success has been less in engineering-based industries where R&D needs to be much more 'development' than 'research' (von Tunzelmann, 1995, p. 186). A reason for this in the institutional set-up can partly

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[4]   The German education system actually produced too many highly qualified scientists which allowed for a British import of talented chemical engineers from Germany.

be found in the relatively low-priority in the British education system to engineering related education. The chemicals related industries have benefited from linkages to science, and the educational strategy has been inspired by the successful German system. Thus the two main clusters in the British innovation system are the result of two different strategies: in the chemical cluster a deliberate strategy inspired by the German success story; and in the engineering cluster a lack of sufficient initiatives strengthening the basic competencies needed to keep in pace with the world leaders.

6.4.3   Japan

As mentioned in the introduction to this section, Japan shares the impressive success after the destruction in World War II with Germany, but it is claimed that unlike Germany, Japan did not have a strong historical position in areas such as chemicals and machinery to rebuild on (Porter, 1990, p. 384). Nevertheless the considerable competitive strength gained by Japan in consumer electronics, office machines, electronic components and computing equipment, transport equipment and related machinery, as well as steel and fabricated metal products is based on the existence of a strong heavy industry dating back to the 19th century.

Figure 6.3 of the relations in the Japanese system of innovation has some similarity to figure 6.2 for Britain, i.e. two distinct 'clusters' are at play in the Japanese system of innovation. But the electronics related cluster includes more industries and is more dominating compared to the chemical cluster.[5]

The five industries in which Japan are most strongly export specialised are other transport, shipbuilding, communication equipment and semiconductors, office machines and computers, and instruments (see appendix D). The dominance of electronics and transport related industries in Japan can partly be explained by the role of the Japanese military in the previous century. In terms of industrial composition, food processing and textile were the largest industries in the late 19th century, but then metal, machinery, chemicals and other heavy industries began to grow fast.

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[5]   Düring and Schnabl (1998) find chemicals to have a much more central role as a technology source in Japan than what is the case in the present analysis - also to industries in the electrical-transportation cluster. One explanation for this difference could be that Düring and Schnabl include imported goods in their analysis, based on the assumption that the R&D structure of the imported goods correspond to the structure of the importing country.

Figure 6.3: R&D linkages in Japan, 1990
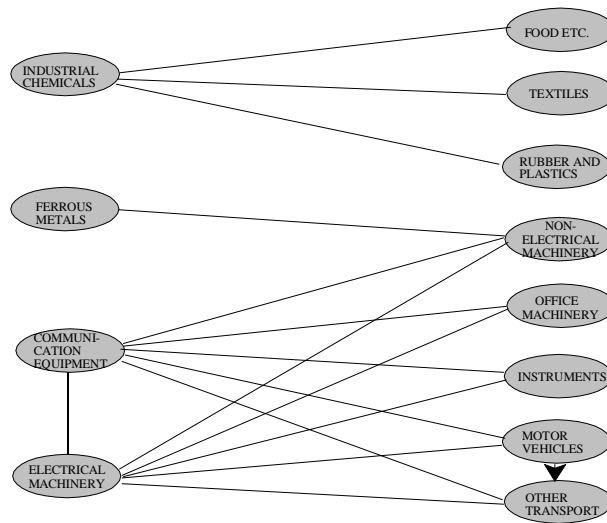
Already in the Meiji era (1868-1912) the military and the government in general played an important role for the industries which make up the backbone of the engineering industries. Two years after emperor Meiji came into power, a Ministry of Industry (*Kôbushô*, sometimes also translated as Ministry of Engineering or Ministry of Construction) was established in 1870. The Ministry was abolished in 1885, but in its fifteen years of existence it played a crucial role in the process of 'industrialisation from above', where industrialisation was forced through an ambitious programme of importing relatively advanced Western technology. The emphasis was put on the hired foreigners passing on their knowledge to their Japanese counterparts and then going home as soon as possible. This strategy was used in relation to railway construction, the creation of a nationwide telegraph network, mining, as well as iron works. The experts hired were mainly British. Historians generally agree that the Meiji policies, with their bias towards importing relatively sophisticated technologies, were commercial failures viewed from the point of view of state enterprises, but the policies were crucial to Japan's technological development. Technology was transferred from government to private firms from 1881 through selling government enterprises to a selected group of private buyers at very low prises. The entrepreneurs who bought the mines and factories gained not just cheap machinery and equipment, but also a ready trained source of technical expertise, as well as established technical links with Western firms. Mitsubishi is one example of a major company growing out of this process (Morris-Suzuki, 1994, pp. 73-79).

The focus on education during the Meiji era should also be mentioned. In 1871 a compulsory primary education with a considerable emphasis on scientific enquiry was introduced. Regarding high level education the Imperial College of Engineering was established in 1873, with a strong electrical engineering faculty which as far as is known appointed the first Professor of Electrical Engineering in the World. These colleges also to a large degree depended on foreign imported knowledge (Morris-Suzuki, 1994, pp. 80-82).

The military arsenals and navy dockyards also played a crucial role in the development of Japan as they used relatively sophisticated imported techniques and were sending their leading technicians abroad for training in major Western armament firms. The military expansion around the turn of the century had important spin-offs for civilian industry. E.g. government arsenals produced a wide range of industrial machinery which were sold to private enterprises, and workers trained in arsenals often moved on to employment in civilian industries, taking their knowledge of imported production techniques with them. And military demand provided a market for many of Japan's more technically advanced industries in their early stage of development. Toshiba is one example of a major company with its roots in industrial machinery which benefited from military demand (Morris-Suzuki, 1994, p. 79).

The Japanese economy took off around World War I with an increasing production especially in steel, machinery and other heavy industry (Odagiri and Goto, 1993). This was the time of the 'second industrial revolution' in the West, with a widespread diffusion of electrical power, the introduction of the automobile and aeroplane, and the techniques of mass production. To the Japanese government the technologies of the 'second industrial revolution' were not so much a source of growth, rather they were perceived as a challenge to Japanese security, and the fear for a 'total war' of the 20th century implied a blurring of the distinction between military and non-military industries. Thus the military played a central role in the development of both the automobile industry as well as the aircraft industry - in other words the technologies of war and peace were interrelated (Morris-Suzuki, 1994, p. 107 and pp. 124-125).

The Second World War caused Japanese production facilities to suffer severely, but still more than two thirds of the production capacity in the heavy industries was left intact after the war (Odagiri and Goto, 1993, pp. 83-85). Thus there was a considerable foundation for rebuilding the economy. And also somewhat paradoxically the unsuccessful attempt to win what was perceived as 'the war

of science and technology' left Japanese institutions, human skills and public attitudes well prepared for the new massive import of Western technology in the years to follow after the surrender to the Allies in 1945 (Morris-Suzuki, 1994, p. 157). In addition the combination of military procurement and protectionism through restrictions on imports and foreign investments until the early 1970's provided excellent conditions for the development of Japanese heavy industry, in particular for the motor vehicles industry (Odagiri and Goto, 1993).

Thus the government has played a significant role in the development of the electronics and transport related industries. But the success with chemicals related industries was much more moderate. Internationally Japan does not seem to have any particular advantages in chemicals related industries, maybe with textiles as one exception, Japanese firms being strong in synthetic textile fibres (Porter, 1990, p. 403). Japan does in fact have several large chemical firms, but Hikino et al. (1998, p. 103) point to the puzzle that the Japanese chemical industry, despite of an impressive growth and a large size, basically remains invisible on the international economic scene. One explanation might be that the strength of Japanese chemical companies has been quick learning and incremental process innovation capabilities, while they have not been very successful in developing great technological competencies in radical product or process innovation. Japanese chemical companies have been biassed toward capital and resource intensive areas, and away from the knowledge intensive parts of the chemical industry, including pharmaceuticals (Hikino et al., 1998, pp. 107-108). Education, or lack of education, is also proposed as part of the problem, since low effort has been put on high level education in chemical engineering. What the industry needed for absorbing and operating foreign technology was primarily a large supply of plant-level engineers, not trained researchers (Hikino et al., 1998, pp. 118-119). Finally the process of acquisition of foreign knowledge in chemicals differed from the one characterising the electrical machinery industry. A large degree of the technology flows from the West in electrical machinery during the turn of the century was facilitated through partnerships between Western and Japanese firms, as a way of Western firms to get access to the Japanese market, which in turn resulted in a combination of patent licenses, technical assistance and investment. The Western chemical companies relied on their own ability to dominate overseas markets, and were thus not interested in engaging in partnerships with Japanese firms. As a result of this the imports of know-how in chemicals tended to be limited to single patent-licencing arrangements (Morris-Suzuki, 1994, pp. 113-114).

The dominance of electronics and transport related industries is illustrated by a densely connected engineering cluster in figure 6.3. The figure supports Porter's findings of semiconductors (here included in communication equipment) and electronics as uniting a number of clusters/industries (Porter, 1990, p. 394). Industrial chemicals on the other hand are related to traditional low-tech manufacturing industries as receivers: food, textiles and rubber & plastics. Among these, food is the main industry from the perspective of production and employment. Industrial chemicals is an important industry in relation to R&D spending, but the industry is related to low-tech traditional manufacturing industries which might be important from a production and employment point of view, but none of these industries are important in an international context, and Porter describes chemicals as an area of continuing weakness in Japan (Porter, 1990, p. 420). Figure 6.3 clearly illustrates the segmentation of Japanese industry, and as opposed to figure 6.2 for Britain, where it was not possible from the figure alone to determine which area was the most prosperous, there is no doubt that the engineering area is dominating in the case of Japan.

In concluding on the determinants of Japanese success it is also important to remember the major cultural adaptions undertaken by Japan in the process of adapting to Western technology. A new technological system was necessary, which among other things implied that Japan had to make major changes in such fundamental areas as e.g. the time system: in 1873 the government issued a decree revising the calender and establishing a standardised 24-hour day to supersede the traditional complex time system with hours or varying lengths according to seasons, weather, the movement of tides etc. Japan was also the first Asian country to accept nationwide the use of the metric system (Morris-Suzuki, 1994, pp. 83-84). These major adaptations are what makes the Japanese system of innovation particularly interesting, and makes the history behind the well connected electronics-transport cluster so fascinating.

6.4.4   United States

Just like Britain and Japan, figure 6.4 shows that the R&D linkages of United States' system of innovation result in two separated main clusters, a chemicals cluster and an electronics related cluster. But also two other small separate clusters appear in the American system: between

pharmaceuticals and food, and between non-electrical machinery and motor vehicles.[6] In order to try to explain the background of this structure, it is necessary once again to go back in history.

Before the Civil War (1861-'65) the American economy was characterised by a regional specialisation in functions, but the war resulted in a political and ideological framework which permitted structural change and regional integration (von Tunzelmann, 1995, pp. 189-190).

Just like Japan, the United States' process of industrialization started off by borrowing and copying technologies from abroad. But the technologies were adapted to different supply and demand conditions. On the supply side a major difference from Britain (which was the major technology source for the United States) was the abundant supply of land, which influenced both the mechanization of agriculture (allowing a limited labour force to work more land) and the transport industry (providing mass transportation over large distances). On the demand side the demand structure, dominated by a large number of rural households with a strong preference for moderately priced consumer goods, allowed for standardisation and mass production. According

Figure 6.4: R&D linkages in the United States, 1990

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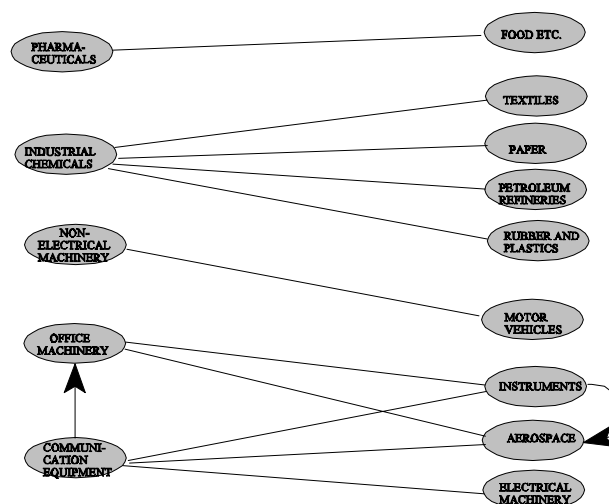
6   Just like for Japan, Düring and Schnabl (1998) ascribe a more central role to chemicals than what is found here, but the major relations from chemicals to petroleum and plastics and rubber respectively are confirmed. Electrical apparatus is a central technology source in Düring and Schnabl's analysis while this is not the case here. But I find communication equipment, which is included in electrical apparatus in Düring and Schnabl's analysis, to be a central source in the electronics cluster. Finally Düring and Schnabl find motor vehicles to be connected to electrical machinery/apparatus, which is not the case here.

to von Tunzelmann (1995, pp. 192-196) this demand structure was the key to American industrialisation.

Formal R&D was first developed for comparatively simple purposes (primarily in the major advancing industries like metallurgy, food processing and construction), and the emphasis in the 19th century was, especially in chemistry, on 'old' sciences. A greater use of experimental science was seen around the turn of the century, and the nature of the science base shifted from a concentration of chemistry based research toward the more physics based in areas such as electricity, transportation and instruments (von Tunzelmann, 1995, pp. 201-202).

Rosenberg (1976) ascribes a large strategic role in the industrialisation process to the machine tool industry which emerged in the last half of the 19th century. In the earliest stages machine producing establishments were part of or related to factories specialising in the production of a final product, most notably textiles, but eventually they developed into independent firms. The skills acquired in the production of one type of machine was transmitted to other types of machines, e.g. locomotive works grew out of the cotton textile industry. In general heavy, general purpose machinery grew out of the textile machine shops, while lighter, more specialised high-speed machine tools grew out of the production requirements of arms makers. The technological developments of the 19th century were largely dependent of the convergence of functional processes throughout the machinery and metal-using sectors, which contributed to the simultaneous growth of several, technologically related industries. Thus the machine tool industry can be perceived as the holder of a pool of skills and technical knowledge which could be used in the entire machine using sectors of the economy. E.g. the automobile industry was build on basic skills and knowledge already existing in the machine tool industry (Rosenberg, 1976, pp. 10-26).

As in the previous three systems, the educational strategy was crucial. A move towards public provision of universal primary education was initiated in the 1840's, which resulted in a relatively well-educated and trained labour force. A relatively widespread higher education with a special focus on practical education cannot be ignored either (von Tunzelmann, 1995, pp. 216-228).

Let us finally turn to the role of public funding of R&D, in particular related to defence, atomic energy and aeronautics. The Second World War had a crucial influence on the industrial success of the United States. The war spurred both electronics, chemicals and pharmaceuticals to new

heights (Porter, 1990, pp. 294-6). Huge expansions of Federal research funding during and after the Second World War moved universities and colleges into the lead in high-tech American industry, and the war also resulted in a large inflow of top scientific talent.

Chemicals had already been flourishing before the war. The early twentieth century was dominated by the chemicals industry and related industries, and the chemicals, glass, rubber and petroleum industries accounted for almost 40 percent of the number of laboratories founded during the period 1899-1946 (Mowery and Rosenberg, 1993, pp. 32-33). The strong position in chemicals was firstly based on natural resources, but also on technological capabilities (Arora and Rosenberg, 1998, p. 76). While the United States' raw material endowment was crucial to the growth of the chemical industry in the early phase, the size of the home market as well as research based technological advances in both products and processes took over in importance. The national oil and natural gas stocks thus played a role in giving the United States a first mover advantage in petrochemical technologies, where the United States takes a leading position (Arora and Rosenberg, 1998, p. 98), and there is a close linkage between chemicals and petroleum industries (also illustrated in figure 6.4). The American story of chemicals point to the importance of complementarities, as technology, market size, resource endowments, and supply of entrepreneurial capital all were important factors behind a successful American chemical industry (Arora and Rosenberg, 1998, p. 99).

The postwar expansion resulted in an American world dominance in innovation, but the primary focus was shifted from the industries that had represented the advanced technologies in the first half of the 20th century, i.e. chemicals, metal working, synthetics and plastics, towards a dominance in new sectors primarily related to electronics (von Tunzelmann, 1995, p. 228). The development of the electronics related industries was, like in Japan, largely related to the military, also after the war. A huge defence programme provided a market for advanced goods such as aircraft and electronics (Porter, 1990, p. 284). In the 1950's and 1960's the U.S. military market provided an important springboard for startup firms in microelectronics and computers, with new firms playing a large role in commercializing product technologies within the fields of semiconductors and computers as well as biotechnology. Profits and overhead from military procurement contracts supported company funded R&D. This support might have generated more civilian spillovers than R&D that was directly funded by the military. Also defence procurement lowered marketing barriers to entry, which allowed small firms to direct their development efforts to meeting the

performance and design requirements of a single large customer in the 1950's (Mowery and Rosenberg, 1993, pp. 48-54). But as the military needs have become more specialised, defence demand is no longer an undisputed strength, and it is claimed that the huge defence market in the recent years has distracted American firms from more important areas (Porter, 1990, p. 526). But still the American positions in e.g. aircraft and computers are related through the role of government spending (Porter, 1990, p. 511).

As in the British case, the separate development of chemicals and engineering related industries has resulted in two separate main clusterings.[7] This can be explained by von Tunzelmann's observation for the period 1930-1970, that

> *Rather than a single paradigm in manufacturing, this activity led to the rise of several technological paradigms. [....] There existed a range of sectors where the chemicals-related paradigm operated [....], another set of sectors where the electrical-electronic paradigm operated* (von Tunzelmann, 1995, p. 231).

What distinguished the two clusters was differences in their mode of problem solving, restricting each cluster to their own field of heuristics. But von Tunzelmann claims that this has been replaced by 'hyperchoise' problem solving in the recent years.

Turning to the relations depicted in figure 6.4, the low-tech technology receiver industries for chemicals are supplemented with the medium-tech petroleum refinery industry. Paper and printing, which is the largest employer among the manufacturing industries, and the second largest producer, is also a receiver industry in the chemicals cluster. Pharmaceuticals and food are not included in the chemicals cluster, but co-exist in an isolated mini-cluster. Agricultural products have been important from an export perspective for a long time, and its R&D dependence on the pharmaceuticals industry may indicate a relatively technologically sophisticated food industry.

Motor vehicles and non-electrical machinery is another mini-cluster, which in this case is isolated

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[7]

The defence connection is of course not the only factor which has influenced the prosperous engineering cluster in the U.S. The financial system with a well developed market for venture capital, and the 'entrepreneural spirit' cannot be ignored. But in terms of proposing explanations for the separate development of the engineering and chemicals clusters, the defence might have played an important role.

from the rest of the engineering cluster. The origins of the American motor vehicles industry around the turn of the century is interchangeably linked with mass production through Fordism. Henry Ford's mass production drove the motor vehicles industry for more than half a century, and was eventually adopted in almost every industrial activity in North America and Europe (Womack, et al., 1990, pp. 26-30). But now those same techniques are considered to be inflexible and out of touch with modern styles of organising production. The downfall of the American motor vehicles industry occurred with the increases in oil prices in the early 1970's, since American cars were neither space-efficient nor fuel-efficient. Thus the American motor vehicles industry had lost some of its importance by the early 1990's, where it appears to exists in isolation from the more dynamic part of the engineering related industries.

The engineering cluster consists of four of the five most R&D spending industries in the United States (see appendix D): office machinery, communication equipment, instruments, and aerospace. The fifth industry in the engineering cluster is electrical machinery. The four R&D heavy industries are also among the industries in which the United States is most strongly export specialised. These engineering related industries account for the strongest manufacturing positions of the American system of innovation.

Briefly concluding on the characteristics of the American system of innovation, similarities are found with Japan with respect to the role of technology import in the 19th century, but with much different needs for adaptation to technology. While Japan certainly also adapted imported technology to local conditions, they also had to make considerable cultural adjustments to technology. In the American case a very large home market allowed for adjusting technologies to mass production, which suited the emergent culture of mass consumption. The system is large enough to function quite effectively with separate clusters, which are not technologically related in any crucial way, but both have dominant positions in the world market, also from a technological point of view. The major strength has shifted from the chemicals to the electronics related 'paradigm' though.

6.4.5 Summing up

Despite of some common characteristics in the economic features of the four countries analysed here, both with regards to economic indicators and with regards to the main technology sources

being related to chemicals and/or electronic machinery etc., it has been illustrated that the four national systems of innovation are quite different. Different factors, institutional as well as 'exogenous'(e.g. engagement in wars) have shaped the systems and have been argued to be reflected in the structure of technological relations as they appear today.

The technology flow maps reveal two main patterns: in the case of Great Britain, Japan and the United States, at least two separate clusters appear. One cluster is centred around chemicals related industries, while another is centred around communication equipment, electronic and/or transport industries. At the pre-set filter values no embodied R&D flows connect the two clusters. Germany on the other hand reveals a more interrelated system with less clear tendencies of separate clustering, due to the crucial role played by the German chemical industry, as well as the relatively weak position in electronics and related industries. But even if Great Britain, Japan and the United States share a main structure, considerable differences between the three countries are also revealed in the patterns of relations.

It has been argued (Düring and Schnabl, 1995, p. 15) that the production patterns become more and more similar in a global economy, and that national innovation systems measured by relations weighted by R&D expenditures therefore should become much more similar over time. I, on the other hand, argue that differences in both formal and informal institutions, as well as the role played by history, are of such a fundamental importance that differences between systems will persist, and these differences will continue to stand out, also in graphical representations focussing on particular 'corners' of the systems, as in this case illustrated by embodied R&D linkages.

6.5   Conclusions

This chapter has dealt with the extent to which the differences in structure of interdependence can be explained by some underlying characteristics of each individual innovation system. The 'history matters' assumption has been the major guiding point.

The claim was that a relatively simple input-output based graph theoretical model would be able to capture some underlying differences in the basic features of each individual system. The focus has been on the industrial development of each country, and on the institutional factors influencing this development, relating this to the structure of interdependence of the system. And I argue that

I have indeed been able to illustrate that the structure of technological interdependence at the industry level is closely related to the historical process of industrialisation.

What I have not been able to illustrate (admittedly it was never the aim) is that there is a general recipe for how to build a successful innovation system. The four countries analysed have had very different starting points for embarking on technological development, and have followed different strategies, even though the systems have also been dependent on each other in different phases of the development process.

One common feature is that the educational system has had a large influence on what became national positions of strength. But whereas the military has played an important and positive role for technological development in Japan and the United States - first and foremost in relation to the electronics and transport cluster - the effect of military spending has been more doubtful in Great Britain.

A general conclusion which can be deduced from the analysis is that if two major industrial fields within a country develop at different pace, with different strategies, and with different starting points, these areas tend to remain largely separated in a technological sense. I claim that this is why separate chemicals and electronics clusters are found in three of the four countries. In the German case the chemical industry was the forerunner in the industrialisation process, which could help explain why industrial chemicals still today is a generic source of embodied technology, while the electronics cluster is relatively weak. Thus the distinctiveness of technology bases might not so much be determined by the inherent characteristics of technologies, but rather on whether different technological areas have developed in 'isolation' from each other, or whether they have developed in an integrated process.

Appendix D: Main economic indicators for 4 OECD countries, 1990

	Production*	Employment*	R&D*	SRCA (export spec.)*
Germany	1. Motor vehicles (12.8%)	1. Non-electrical machinery (11.7%)	1. Comm. equip. and semiconductors (19.1%)	1. Non-electrical machinery (0.15)
	2. Food, drink and tobacco (12.2%)	2. Fabricated metal products (10.7%)	2. Motor vehicles (17.7%)	2. Motor vehicles (0.13)
	3. Non-electrical machinery (11.7%)	3. Food, drink and tobacco (9.4%)	3. Industrial chemicals (15.7%)	3. Fabricated metal products (0.12)
	4. Industrial chemicals (8.9%)	4. Other transport (9.1%)	4. Non-electrical machinery (10.8%)	4. Electrical machinery (0.11)
	5. Fabricated metal products (6.6%)	5. Electrical machinery (7.6%)	5. Aerospace (8.7%)	5. Industrial chemicals (0.08)
Great Britain	1. Food, drink and tobacco (17.2%)	1. Non-electrical machinery (13.1%)	1. Pharmaceuticals (18.0%)	1. Aerospace (0.34)
	2. Industrial chemicals (8.6%)	2. Food, drink and tobacco (10.7%)	2. Aerospace (17.1%)	2. Other manufacturing industries (0.32)
	3. Non-electrical machinery (8.4 %)	3. Textiles & leather (9.9%)	3. Comm. equip. and semiconductors (13.5%)	3. Pharmaceuticals (0.29)
	4. Paper & printing (8.4%)	4. Paper & printing (9.6%)	4. Industrial chemicals (12.8)	4. Office machines and computers (0.22)
	5. Motor vehicles (7.0%)	5. Fabricated metal products (6.7%)	5. Motor vehicles (8.2%)	5. Instruments (0.09)
Japan	1. Motor vehicles (11.2%)	1. Food, drink and tobacco (11.2%)	1. Comm. equip. and semiconductors (16.3%)	1. Other transport (0.46)
	2. Food, drink and tobacco (10.1%)	2. Textiles & leather (10.9%)	2. Motor vehicles (14.4%)	2. Shipbuilding (0.43)
	3. Ferrous metals (8.5%)	3. Non-electrical machinery (9.9%)	3. Electrical machinery (11.2 %)	3. Comm. quip.and semiconductors (0.43)
	4. Non-electrical machinery (8.5%)	4. Comm.equip.and semiconductors (9.1%)	4. Industrial chemicals (10.1%)	4. Office machines and computers (0.28)
	5. Comm. equip. and conductors (8.4%)	5. Fabricated metal products (7.9%)	5. Office machines and computers (10.1%)	5. Instruments (0.26)
United States	1. Food, drink and tobacco (14.3%)	1. Paper & printing (11.9%)	1. Aerospace (23.2%)	1. Aerospace (0.48)
	2. Paper & printing (10.2%)	2. Textiles & leather (9.7%)	2. Comm. quip. and semiconductors (13.9%)	2. Office machines and computers (0.28)
	3. Industrial chemicals (8.3%)	3. Non-electrical machinery (9.2%)	3. Office machines and computers (13.2%)	3. Instruments (0.16)
	4. Motor vehicles (7.5%)	4. Food, drink and tobacco (8.7%)	4. Motor vehicles (11.5%)	4. Comm. quip.and semiconductors (0.14)
	5. Non-electrical machinery (6.7%)	5. Wood & furniture (6.9%)	5. Instruments (7.9%)	5. Industrial chemicals (0.05)

* Percentages are measured in relation to total production volume, employment and R&D expenditure in the manufacturing industries respectively. SRCA is the symmetric revealed comparative advantage (export specialisation), ranging from -1 (de-specialised) to 1 (specialised) (see chapter 7 for a definition and expanded explanation of the SRCA). A value of 0 is neutral (neither specialised or de-specialised). The export specialisation is calculated relative to the 20 OECD countries for which data are available: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Italy, Japan, the Netherlands, New Zealand, Norway, Portugal, Spain, Sweden, United Kingdom and the United States.

Appendix E: Industries included in the analysis of chapter 6

ISIC, rev. 2

3100	Food, drink and tobacco
3200	Textiles, footwear and leather
3300	Wood, cork and furniture
3400	Paper and printing
3510+3520 (-3522)	Industrial chemicals
3522	Pharmaceuticals
3530+3540	Petroleum refineries
3550+3560	Rubber and plastics
3600	Stone, clay and glass
3710	Ferrous metals
3720	Non-ferrous metals
3810	Fabricated metal products
3820 (-3825)	Non-electrical machinery
3825	Office machines and computers
3830 (-3832)	Electrical machinery
3832	Communication equipment and semiconductors
3841	Shipbuilding
3842+3844+3849	Other transport
3843	Motor vehicles
3845	Aerospace
3850	Instruments
3900	Other manufacturing industries

Chapter 7: Linkages as a determinant of International Export Specialisation[1]

> *Among all non-primary products, a country has a range of potential exports. This range of exportable products is determined by <u>internal demand. It is a necessary, but not a sufficient condition, that a product be consumed (or invested) in the home country for this product to be a potential export product</u>* (Linder, 1961, p. 87).

7.1   Introduction

The previous chapter compared national systems of innovation according to their differences in interindustrial linkage structures. It was illustrated there appeared to be some degree of coincidence between industries with several linkages to other industries, and industries in which a country was export specialised. Thus this chapter will analyse the statistical relation between linkages - both backward and forward - and export specialisation.

The explanation for international trade specialisation has been a central research topic in economics, at least since the publication of Ricardo's *Principles of Political Economy and Taxation* (1817/1951). Ricardo's explanation of trade specialisation rested on differences in labour productivity. Ricardo originally ascribed the differences in labour productivity to climate and other factors related to agricultural production, as well as to a relative immobility of capital.

Opposed to Ricardo's application of differences in labour productivity across nations, the standard explanation for international export specialisation has in contemporary economics relied on the factor endowments of countries (Heckscher, 1949; Ohlin, 1933). The factor proportions theory was first challenged by what became known as the 'Leontief-paradox' (1953), stating that the 1947 exports of the United States (a nation 'endowed' with an internationally high capital-labour ratio), were slightly less capital-intensive than its imports. The findings spurred a hot debate on the empirical validity of the theory. The explanation to the paradox offered by Leontief himself was that American labour was more productive than foreign labour, and the number of American

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1   This chapter draws on Laursen and Drejer (1999).

workers should thus be multiplied by a factor (Leontief suggested the factor 3) before comparing with other countries. When the labour force was multiplied by the chosen factor, the American capital/labour ratio decreased accordingly, thus 'eliminating' the paradox.

Leamer (1980) argued that Leontief's findings were based on a general misconception since the capital/labour rate in exports compared to imports does not in itself reveal anything about the national endowment of capital. Instead it is the capital/labour ratio in net exports compared to the capital/labour ratio in national *consumption* that reveals the true nature of the endowments. And Leontief's calculations could be used to show that American net exports were more capital intensive than American consumption, which according to Leamer implied that capital was abundant relative to labour in the United States (Leamer, 1980, pp. 495-496). But Trefler (1993) argued that Leontief's own explanation was in fact right, American labour was more productive than its major trading partners, and thus labour should be measured in productivity-equivalent units when determining the capital/labour ratio. Trefler further argued that the productivity gap has narrowed since 1947, which was the year studied by Leontief (1953). Thus the debate of the Leontief-paradox is far from dead.

Even though factor endowment analysis has been - and probably still is - the dominating string in international trade literature, a traditional factor endowment approach is not going to be applied in explaining international trade in the present chapter. Based on the findings of the previous chapters a more dynamic approach including interindustry linkages to advanced users and suppliers will be applied. Thus the analysis of the present chapter is more in line with the views of Dosi et al. (1990), who question the value of the factor endowment model in explaining international trade between advanced countries that are characterised by an excess supply of the traditional production factors:

> Does the [Hecksher-Ohlin] *model make any sense in explaining trade between countries that are often characterised by excess supply of labour or labour and capital? How can one account for the fact that differences in innovativeness are often much more important than primary endowments as determinants of trade flows?* (Dosi, et al., 1990, pp. 7-8).

The previous chapters, as well as this one, share the overall claim that technology and knowledge

are important economic factors. Another common element is that technology is developed, as well as diffused, through linkages to other economic entities. Thus these elements will also be emphasised in the present analysis of determinants of trade specialisation.

7.2 Determinants of international trade specialisation

The idea that temporary monopoly profits could be appropriated based on a technological lead was originally introduced by Schumpeter (1912/34), but it was applied by Posner (1961) in an international trade context under the label of 'technology gap theory'. Given the assumption that technology is not a free and universally available good, Posner argued that while technology might be important for trade in some sectors, and not in others, innovations made in one country (in technology intensive sectors) would benefit that country as long as the lead could be kept. That is, a country will benefit from first-mover advantages, until other countries have imitated the innovation. In the original formulation, once imitation has taken place, more traditional factors of adjustment and specialisation would take over and determine trade flows. However, as argued by Dosi and Soete (1988), there is not necessarily anything impermanent about the importance of technology in determining trade flows, since static and dynamic economies of scale flowing from the initial break-through acts to prolong the lead. Coupled with new product innovations, these economies of scale might well secure a continuous trade flow.

The idea that inter-sectoral linkages in the domestic economy have an impact on competitiveness has its most important roots in development economics. In this context Hirschman's (1958) distinction between backward and forward linkages, introduced in chapter 3, is relevant. Briefly recapturing, backward linkage effects are related to derived demand, i.e. the provision of input for a given activity. Forward linkage effects are related to output-utilisation, i.e. the outputs from a given activity will induce attempts to use this output as inputs in some new activities (Hirschman, 1958, p. 100). Thus the linkage concept can be generalised to the observation that activities can invite economic actors to take up new activities, creating a linkage between the ongoing and the new activity (Hirschman, 1958, p. 80). These 'new activities' emerging as a consequence of the supply and demand effects of ongoing activities could be perceived as induced innovations. Interpreted in relation to industrial competitiveness, the presence of a relatively strong domestic

producer might in turn improve the comparative advantage of (or the competitiveness of) domestic users. But as mentioned in chapter 3, the backward and forward linkages are not automatic, e.g. the technological 'strangeness' or 'alienness' of the new economic activities in relation to the ongoing ones play an important role for the effectiveness of linkages (Hirschman, 1977, pp. 77-78).[2]

The importance of domestic linkages in a trade theory context was suggested as the 'home-market effect' by the Swedish economist Staffan Burenstam Linder in his *Essay on Trade and Transformation* (Linder, 1961). The basic idea was that a country's domestic market could act as a 'kindergarten' for new products, before exports to foreign markets were initiated. It should be pointed out that Linder was primarily concerned with the quality of demand, rather than the mere size of demand. In other words, the original formulation made by Linder concerned the conditions for learning on the (national) home-market:

> *Whether it is a question of 'critical revision' of an invention or product development work in general, it must be carried out in close connection with the market. This gives us a [...] reason to believe there must be a home market for an export good, whether it is a consumer good or capital good. If, for some odd reason, an entrepreneur decided to cater for a demand which did not exist at home, he would probably be unsuccessful as he would not have easy access to crucial information which must be funnelled back and forth between producers and consumers. The trial-and-error period which a new product almost inevitably go through on the market will be the more embarrassing costwise, the less intimate knowledge the producer has of the conditions under which his product will have to be used. And, if there is no home demand, the producer will be completely unfamiliar with such conditions* (Linder, 1961, pp. 89-90).

That the 'home-market hypothesis' is not at general theory of export specialisation, and that

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2   As a passing remark it is interesting that Hirschman actually started his American career as an economist in the early 1940's by studying international trade. Hirschman's (1945) trade studies were also, just like his linkage work, centred around a few central indices. In the trade studies Hirschman's claim was that there was a relation between the structure of foreign trade and the power of a nation. Thus indices were developed to express the preference of a country for trading with small (weak) countries (a way to build a power situation), as well as for the concentration of a nations trade, expressing the degree to which a nation's trade was monopolized by other countries. This discussion of national power and trade structure was heavily influenced by the position of Germany, as the analysis was carried out during World War II, and Hirschman being a native German.

sectoral differences influence the importance of the home-market was, as pointed out by Fagerberg (1992a), acknowledged by Linder, as he did not expect the home-market to contribute much to the explanation of differences in trade performance in standardised products. In these cases Linder expected other factors to be of greater influence. In the model presented below of the relation between linkages and export specialisation this is taken into consideration by classifying the industries according to Pavitt's taxonomy, expecting the linkages to be of different importance in the four industry groups. As will be seen below, a range of other possible explanatory variables are also included. This is done in order to avoid the problem Fagerberg (1992a) identified in the analysis of the relation between trade specialisation and the home market effect carried out by Andersen et al. (1981), where the not very supporting results could be due to the method applied, calculating a simple correlation between the export specialisation of producers and their major home market group respectively,[3] ignoring all other possible influential variables.

7.3   The dynamics of user-producer interaction in a trade context

Lundvall (1988) introduces the organised market, which involves close, and sometimes face-to-face interaction between sellers and buyers as a fertile environment for innovation. The interaction may take the form of mutual exchange of information, but may also involve direct co-operation between users and producers of technology. Two properties of the user-producer relationship are important in a 'home market' context. Firstly, because it is time-consuming and costly to develop efficient channels of communication and codes of conduct (often tacit) between users and producers, the relationships are likely to be durable and selective. Secondly, when technology is sophisticated and changing rapidly, proximity in terms of space and culture is seen to be conducive to innovation and thereby to competitiveness (Lundvall, 1988, p.355). Thus, such localised and durable linkages give rise to dynamic increasing returns at the level of the country (or region). In the context of increasing returns, it should be pointed out that what is dealt with is interaction between firms, situated in different industries (as in Young, 1928), rather than activities internal to the firm.

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[3]

The export performance of the user industries is used as a measure of the home market sophistication (Andersen et al., 1981, pp. 17-23).

As pointed out by Fagerberg (1995, p. 245), given the tacit nature of the user-producer interaction, such enduring relationships are not only ways of increasing localised learning and innovation, but they also make it easier to appropriate the economic benefits from learning and innovation, at least in the shorter run. Thus, localised vertical linkages[4] might create/reinforce competitiveness or specialisation of both users and producers, making sectors co-evolve at the national level.

The linkages dealt with above, in particular in the case of Linder, are predominantly forward linkages from producer to user, as the home market approach emphasises the importance of (a competent) home demand. But here backward linkages are perceived to be equally important, as these linkages express the influence advanced suppliers have on the receivers' competence development, as well as the inflow of 'embodied' technology flows discussed in previous chapters.

As mentioned in chapter 4, linkages might somewhat mistakenly be interpreted as localised 'spillovers'. The aim of a major part of the mainly empirical spillover literature is to estimate the effect of technological spillovers on productivity, while the aim of the linkage hypothesis in this chapter is to give an explanation for international trade specialisation. It should also be pointed out that spillovers can be both national or international in scope, whereas home market linkages are localised (national) per definition.

7.3.1 Pavitt's taxonomy in a trade context

As pointed out above, the home-market effect is assumed to play the most significant role for the trade performance in industries largely dependent on non-standardised (innovative) products, while other factors are assumed to be of greater importance in industries based on standardised products. This is translated into a distinction between the role of technology in different industries.

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4   von Tunzelmann (1995, pp. 12) introduces a distinction between upstream/downstream process links and backward/forward product links. von Tunzelmann relates upstream/downstream linkages to capital good connections, while backward/forward linkages are related to the progressive processing of a product, and finds it disturbing that both types of linkages are described as vertical linkages. As our vertical linkage measure expresses the exposure to advanced/sophisticated users and producers, it captures both perceptions of linkages though.

Pavitt's (1984) taxonomy distinguishes between firms according to their principal activity. The taxonomy emerged out of a statistical analysis of more than 2000 postwar innovations in Britain (see chapter 5) and was explained by the sources of technology; the nature of users needs; and means of appropriation. Four types of firms were identified: supplier dominated firms; scale-intensive firms; specialised suppliers and science-based firms. *Supplier dominated* firms are typically small and found in manufacturing and non-manufacturing sectors. Most technology comes from suppliers of equipment and material (see figure 7.1 for an illustration of the main external technological sources of different types of firms). *Scale intensive* firms are found in bulk materials and assembly. Their internal sources of technology are production engineering and R&D departments. External sources of technology include mainly interactive learning with specialised suppliers, but also inputs from science-based firms are of some importance. *Specialised suppliers* are small firms, which are producers of production equipment and control instrumentation. Their main internal sources are primarily design and development. External sources are users (science-based and scale-intensive firms). *Science-based firms* are found in the chemical and electronic sectors. Their main internal sources of technology are internal R&D and production engineering. Important external sources of technology include universities, but also specialised suppliers.

Even though the taxonomy was devised at the level of the firm, it has implications at the level of the industry, as it is expected that the broad sectoral regularities of firms is to be reflected in the aggregate behaviour of the industry. Thus, given the above description of the taxonomy, one would expect internal technological activities to be most important for specialisation in science-

Figure 7.1: Main technological linkages amongst different categories of firms
Source: Pavitt (1984, p. 364)
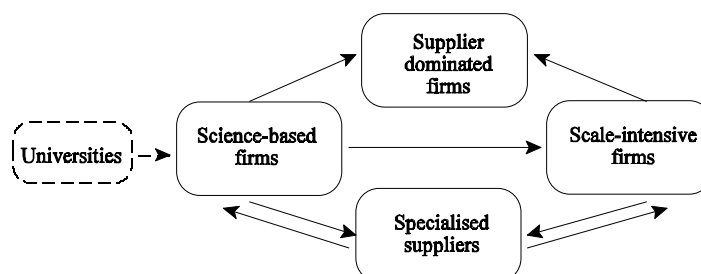
based industries, while backward and forward linkages should be expected to be more important in the case of specialised suppliers. For scale intensive sectors, both backward and forward interindustry linkages as well as investment - but also to some extent internal technological activities - should be of importance, while supplier dominated industries should to some extent be expected to be influenced by backward linkages. But as the industries dealt with in this case are in traditional manufacturing, more traditional factors (resource endowments) might be particularly important for these industries.

A criticism of the taxonomy is that the industrial setup undergoes evolutions, and new dominating types of industries emerges. As a consequence of this, Pavitt and colleagues (Tidd et al., 1997) introduce a fifth sector, information intensive firms, and Kristensen (1999) proposes a sixth type, specialised service suppliers. Both of theses new types of sectors are proposed as a consequence of the increasing importance of service industries. But since the analysis in this chapter is confined to manufacturing industries, only the original four types of Pavitt sectors are dealt with. Also the taxonomy inevitably simplifies, as also pointed out by Tidd et al. (1997, p. 110).

7.4 An empirical analysis of the relation between national linkages and export specialisation

Empirically, the home market hypothesis has gained some support by the previously mentioned analyses by Andersen et al. (1981) and Fagerberg (1992a; 1995). Andersen et al. analysed the relation between a sophisticated home demand for engineering products and export specialisation by calculating the correlation between the export specialisation figure for the engineering products and the export specialisation figure for these industries' home market products in 11 OECD countries for selected years in the period 1954-1972. Thus the sophistication of the home demand is identical with the export specialisation figure of the user industry. The producers and their users are coupled 'manually' before calculating their correlation. At the industry level Andersen et al. find positive correlation coefficients for all industries, but only few are significant. At the country level a positive and significant relation is found for 6 of the 11 countries. Thus the results are not very supporting of the hypothesis that internationally competitive users buy their technology from internationally competitive producers. As mentioned in section 7.2, Fagerberg (1992a) suggests

that this might be due to Andersen et al.'s lack of inclusion of other explanatory variables.

Applying the same basic method for identifying producers and their advanced users as Andersen et al., Fagerberg (1992a) tries to compensate for the problem with ignoring other explanatory factors by testing a model at the sector/product group level for 16 OECD countries and selected years 1965-1987, where export specialisation is dependent on the home market effect, a natural resource effect, as well as a measure of domestic opportunities for exploiting economies of scale. For 14 of 23 industries included in the analysis, the model suggests that the 'home market hypothesis' should be accepted (Fagerberg, 1992a, p. 235). In Fagerberg (1995) the test is carried out at the country level, applying the same data. As was the case with Andersen et al. (1981), Fagerberg did not find support for the 'home market hypothesis' for all countries included in the analysis: the hypothesis was strongly supported for five countries[5], while seven countries showed a slightly less support.[6] The remaining four countries[7] showed only weak or no support to the home market hypothesis.

The tests conducted by Andersen et al. and Fagerberg only applied a variable reflecting a 'forward linkage' from the producer to the (sophisticated) user, and does not apply data on economic transactions in identifying the linkages between users and producers. Also the sophistication of the users is based on export specialisation only.

This chapter will, in accordance with the previous chapters, apply data on actual economic transactions (input-output data) used as weights on the technological output from backward or forward industries with respect to the industry to be explained. Further a technology measure of the sophistication of the users will be applied. Thus size (Hirschman) and quality (Linder) of demand are combined. In this chapter patent grants are used as the technology indicator. The previous chapters have relied more on the R&D indicator than on the patent indicator, but in this case the patent indicator is found to be a more appropriate measure, as data are pooled for several years, and thus the value of applying a technology measure which is not subject to inflationary

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5   Denmark, Finland, Japan, Norway and Switzerland.

6   Canada, Germany, Italy, the Netherlands, Spain, Sweden, and the United States.

7   Belgium, Austria, France and the United Kingdom.

fluctuations must be considered.[8]

Patent data are taken from the United States' patent office. Like in the previous chapters applying patent data, the patent data used concerns patent grants, dated by the year of grant. Whenever a patent is attributed to more than one, say m sectors, the patent is counted as $1/m$ in each of these. US patents are used, rather than patent statistics from each of the national patent offices, because US patents are subject to a common institutional system (novelty requirements, etc.), and moreover, the US, for most of the period under consideration, constituted the largest 'technology market' in the world.

All other data applied are taken from the OECD STAN database. The main limiting factor is the use of the STAN input-output tables, which are only available for nine OECD countries (Australia, Canada, Denmark, France, Germany, Great Britain, Japan, the Netherlands, and the United States). Also the input-output data are only available for five points in time (early 1970s, mid 1970s, early 1980s, mid 1980s and 1990). It should be noted that the input-output tables are not exactly from the same year. For instance, the 'mid 1970s' observation is 1974 for Australia, while this observation for Canada was obtained in 1976. Even though the inclusion of input-output data severely reduces the amount of observations, the inclusion allows for the calculation of backward and forward technological linkages, based on 'real' economic transactions. Often, in this kind of study, the intensity of economic transactions between industries are calculated on the basis of one country. Accordingly, the *intensity* of transactions between industries of that country is then assumed to be the same in other countries in the analysis, while e.g. the structure of production differ. So this advantage has to be judged against the smaller number of observations, and a number of missing values. Concerning the selection of years, the other variables were picked so that they match the input-output data as well as possible (i.e. 1973, 1977, 1981, 1985 and 1990).

The dependent variable is the Revealed Comparative Advantage (Balassa, 1965):

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8   Of course the input-output tables are based on pecuniary values, but only coefficients are used, this is
     not found to be a major problem.

$$RCA_{ij} = \frac{X_{ij}/ \sum\limits_{i} X_{ij}}{\sum\limits_{j} X_{ij}/ \sum\limits_{i}\sum\limits_{j} X_{ij}}.$$

The numerator represents the percentage share of a given industry in national exports - X_{ij} are exports of industry i from country j. The denominator represents the percentage share of a given industry in OECD exports. The RCA index, thus, contains a comparison of national export structure (the numerator) with the OECD export structure (the denominator). When RCA equals 1 for a given industry in a given country, the percentage share of that industry is identical with the OECD average. If the RCA is above 1 the country is said to be specialised in that industry and vice versa if the RCA is below 1. However, since the RCA turns out to produce data that does not conform to a normal distribution, the index is made symmetric, obtained as *(RCA-1)/(RCA+1)*; this measure ranges from -1 to +1. The measure is labelled 'Revealed Symmetric Comparative Advantage' (*RSCA*), which e.g is applied by Dalum et al. (1996).

The forward linkage-variable can be defined as:

$$FL = (\mathbf{x}_{ik} \times \mathbf{Y}_i^{-1}) \times \mathbf{P}_k, \qquad for \ \ i \neq k$$

where $\mathbf{x}_{ik}$ is a matrix of intermediate deliveries from the industry i to industry k, $\mathbf{Y}_i$ is a vector of total output from industry i. $\mathbf{P}_k$ is a vector of US patents taken out by the industries receiving inputs from industry i (normalised for country-size), as a proxy of the technological competence of these industres. In other words the variable measures industry k's importance as a user of industry i's output. Only *direct* linkages are applied in this chapter, as opposed to the Rasmussen and Cuello specifications of the Hirschman linkage measures (see chapter 3), as well as the flow charts in the previous chapters. The direct linkage is found to be closer to the idea of a home market effect than total (direct + indirect) linkages.

Likewise for the backward linkage variable:

$$BL = (\mathbf{x}_{ki} \times \mathbf{Y}_i^{-1}) \times \mathbf{P}_k, \qquad for \ \ i \neq k$$

where $\mathbf{x}_{ki}$ is a matrix of intermediate deliveries from the industry k to industry i, $\mathbf{Y}_i$ is, like above

for *FL,* the vector of total output from industry *i*, and $\boldsymbol{P}_k$ is the vector of US patents taken out by the industries supplying inputs to industry *i*. Thus, the variable measures industry *k*'s importance as a supplier to industry *i*.

7.4.1 Applying the Pavitt-taxonomy in a international trade context

Each of the 19 industries included in the analysis have been assigned to the four Pavitt sectors. The classification is shown in appendix F. However, since any such assignment is somewhat arbitrary on the boundaries, the chosen classification deserves some comments. First of all the classification according to the Pavitt taxonomy used in this chapter, to a large extent follows OECD (1992a), and differs only from this in the case of 'industrial chemicals'; 'instruments'; and 'fabricated metal products'. In the two first cases, the industries are on the boundaries of the 'Pavitt sectors'. Firms in the 'industrial chemicals' industry posses both science based characteristics, but also some scale intensive characteristics, and firms in the instruments industry both carry specialised supplier characteristics, but also some science based characteristics. In both the original Pavitt classification was opted fore, as science based and specialised suppliers respectively. If one look at the ISIC nomenclature, under 'fabricated metal products', it can be seen that this sector produces mainly standard products (nails, screws, steelwire etc.). In contrast to the OECD, the argument put forward here is that this type of production is not mainly carried out by specialised supplier firms.

The *a priori* reasons for including 'food, drink and tobacco' and 'petroleum refineries' as supplier dominated industries, even though the firms in these industries are probably to some extent scale-intensive, is that the analysis deals with national specialisation. Thus the specialisation in these industries is to some extent determined by what goes on in the (related) primary industries, which in turn are supplier dominated, in addition to being influenced by natural resource availability. As other industries on the boundary should be mentioned non-ferrous metals (classified as supplier dominated, but could be classified as scale intensive) and electrical machinery (classified as supplier dominated, but have some science based properties).[9]

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      Because of the somewhat arbitrary assignments of some of the industries, tests of sensibility to the aggregation chosen have been carried out. The results of these experiments will be briefly presented in
(continued...)

For now, the empirical model can be set up as follows:

$$RSCA_{ij} = \alpha_{ij} + \beta_1\, INV_{ij} + \beta_2\, ULC_{ij} + \beta_3\, RSTA_{ij} + \beta_4\, BL_{ij} + \beta_5\, FL_{ij} + \epsilon_{ij},$$

where *RSCA* is the 'revealed symmetric comparative advantage', i.e. the export specialisation measure. *BL* is the proxy for backward linkages touppliers described above, while *FL* is the proxy of forward linkages with users also described above. Since I am fully aware of the fact that linkages are not the only factors influencing the export specialisation, and thus avoiding the problem of a poor fitting model due to the exclusion of other important explanatory variables, a number of other economic and technological variables have been included: *RSTA* is 'revealed symmetric technological advantage', expressing the technology level in the industry in question, measured in a way equivalent to the export specialisation, but by applying patents. The inclusion of own industry technology level follows the arguments of Posner and Dosi & Soete mentioned in section 7.2: in some industries in particular, technology and innovation plays an important role for international competitiveness. The remaining two variables are more traditional economic variables expressing capital and labour respectively: *INV* is a measure of investment calculated in a way equivalent to the specification of the export specialisation variable. The representation of the variable is chosen in order to reflect the size of the capital stock in each industry, as this chapter is dealing with levels. A variable like the ratio of investment to production would for instance reflect the growth of the capital stock, rather than the level. In addition, it is attempted to treat investment and technology in an analogous way. *ULC* is unit labour cost, measured as labour compensation per employee in the industry in question (relative to the average).

The expectations on behalf of the specific 'Pavitt-sectors' were described above. However, some more general expectations are also present, which will be described subsequently. Both of the 'linkage' variables are expected to have a positive impact, just as the technology variable. The investment variable is also expected to turn out with a positive sign, as physical capital is expected to be a necessary condition for being specialised in a given sector. There are no a priori expectations about the wage variable as it might reflect low labour costs (negative sign), as well

9 (...continued)
    footnote 12 of this chapter.

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as a high skill requirement (positive sign).

All countries, all sectors, and all years are pooled, and a model is estimated for the whole sample, using ordinary least squares. The slopes of the different variables are allowed to vary according to which Pavitt-sector each individual sector belongs. The results are reported in table 7.1. The estimations are heteroscedasticity consistent. As country specific mechanisms are likely to be present, country-specific dummies were included in addition to the Pavitt-sector constants present in the model. The estimations of the country and (Pavitt) sector specific constants are shown in appendix G.

Given the presence of multicollinarity[10] between the backward and forward linkage measures, three separate models have been estimated. In other words, if industries have many forward linkages, they have many backward linkages as well, and, further, as pointed out in chapter 3, the forward linkages of one industry is the backward linkages of another. Hence, first two separate models (models I and II) were estimated, each including the backward and forward linkage measures, respectively. In addition to that, principal component regression has been applied, which is one way of tackling multicollinarity. Principal component analysis is a type of factor analysis, and the analysis computes linear combinations of the original variables. Given a data set with p numerical variables, p principal components can be computed. The first principal component has the largest variance of any linear combination of the observed variables, and the last principal component has the smallest variance of any linear combination of the observed variables. In other words, each principal component maximises 'the explained residual variance' in p rounds. As the synthetic variables (i.e. the principal components) are jointly uncorrelated by definition, the methodology can sometimes be useful in addressing multicollinarity. Thus, in table 7.1 synthetic variables have been computed for backward and forward linkage measures (model III). Only the first principal component is used in the regressions, as the explained variance exceeds 0.86. In other words, only 14 per cent of the variance of the two variables is left out. The parameters of the so-called factor

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The variance inflation factor (VIF) display high values for the backward and forward linkage measures, which indicates that these variables might be involved in multicollinarity. For the ith independent variable, the variance inflation factor is determined as $1/(1-R^2_i)$, where R^2_i is the coefficient of determination for the regression of the ith independent variable on all other independent variables. The VIF statistic show how multicollinarity has increased the instability of the coefficient estimates.

loadings (i.e. the parameters relating the original variables to the principal components) display identical signs (positive); i.e. the contribution of each of the two original variables to the first of the principal components goes in the same direction.

The results of the estimations for the *supplier dominated industries* are found in the top of table 7.1. The first principal component (i.e. the synthetic combination of the backward and forward linkage measures) is not significant[11], indicating that national linkages do not appear to be of importance for specialisation in supplier dominated industries. However, backward linkages were expected to be of importance for specialisation in this type of industry. One possible explanation for this might be that strongholds of countries in these industries are to some extent determined by the ability to absorb technology developed elsewhere. If that is the case, backward linkages need not be national. *Unit labour costs* and *investments* come up with the expected signs, although unit labour costs are insignificant. Technological specialisation appears to be positively related to export specialisation.

While this finding is not untenable, it should be pointed out that these sectors might be particularly influenced by natural resource availability, such as arable land, forest, oil and so on. Since such factors are not included in the present chapter, the regressions presented in table 7.1 might be exposed to mis-specification in relation to the supplier dominated types of industries.

With regard to the *science-based industries*, the insignificant linkages confirms the findings of Laursen (1996), concluding that interindustrial linkages do no not seem to be of critical importance for science-based industries more generally, and for pharmaceuticals in particular. Instead, as expected, the coefficients for technological specialisation are found to be the highly significant. The coefficient is relatively high, both when compared to the other variables in the regression, but even more so, when compared to the other types of sectors.

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More generally, the results based on the application of principal components did not differ in any dramatic way from the results of the estimation based on separate estimations of backward and forward linkages.

Table 7.1: Regression results for explaining international trade specialisation (n=662)

Sector type	Variable	Model I R²=0.40		Model II R²=0.40		Model III R²=0.40	
		Estimate	p-value	Estimate	p-value	Estimate	p-value
Supplier dominated	INV	0.616	0.0000	0.612	0.0000	0.617	0.0000
	ULC	-0.107	0.1831	-.0107	0.1826	-0.108	0.1757
	RSTA	0.306	0.0023	0.336	0.0007	0.321	0.0014
	FL	0.480	0.3582				
	BL			-0.194	0.7395		
	P1					0.008	0.7444
Science based	INV	0.395	0.0000	0.429	0.0000	0.411	0.0000
	ULC	0.059	0.1017	0.067	0.0591	0.064	0.0758
	RSTA	0.480	0.0000	0.465	0.0000	0.472	0.0000
	FL	0.339	0.2473				
	BL			-0.131	0.7109		
	P1					0.006	0.7017
Scale intensive	INV	0.460	0.0000	0.453	0.0000	0.458	0.0000
	ULC	0.075	0.0000	0.071	0.0000	0.073	0.0000
	RSTA	0.077	0.4659	0.056	0.5943	0.069	0.5112
	FL	0.734	0.0085				
	BL			0.672	0.0352		
	P1					0.036	0.0092
Specialised suppliers	INV	0.388	0.0000	0.446	0.0000	0.416	0.0000
	ULC	-0.036	0.0001	-0.042	0.0000	-0.039	0.0000
	RSTA	0.047	0.8143	0.227	0.2300	0.137	0.4774
	FL	1.242	0.0000				
	BL			1.244	0.0000		
	P1					0.058	0.0000

Country and (Pavitt) sector specific constants are documented in appendix G.

INV = Investment specialisation
ULC = Level of unit labour costs, relative to the average
RSTA = Revealed symmetric technological advantage
FL = Forward linkages (technology (patenting) level in forward linked industries weighted by output-coeff.)
BL = Backward linkages (technology (patenting) level in backward linked industries weighted by IO-coeff.)
P1 = Principal component, based on FL and BL.

For what concerns *scale intensive industries* a number of points should be made. First of all, the linkage variables are significant in this case, as would be expected for one of the two 'production intensive' type of industries. Secondly, the (direct) technology variable does not seem to be of importance for these industries, which was not expected. Thirdly, investment is (also) highly significant in this case. Finally, it is worth noting that the wage variable is significant, but that it has a positive sign, thus probably implying the importance of high-skill requirements for human capital in these industries.

With regard to the *specialised supplier* type of industries, both of the linkage variables are significant, and have a high parameter. This finding corresponds neatly to the idea that specialised suppliers have the most technological linkages to the surrounding system (cf. figure 7.1). A negative correlation is found between trade specialisation and relative unit labour costs of the industries. In other words, those countries which are specialised in these industries, also appear to have the relatively lowest unit labour costs, although the parameter is rather small.[12]

7.6   Conclusions

This chapter has followed the indication from chapter 6, that there appears to be a relation between national interindustry linkages and the export specialisation pattern of a country. Thus this final empirically based chapter has opened the discussion of the *effect* of linkages as opposed to the *mapping* of linkages, which has been the major focus of the preceding empirical chapters.

The theoretical background for expecting a relation between linkages and export specialisation is

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As mentioned in footnote 9, the sensibility of the aggregation has been tested. Thus 'food, drink and tobacco'; 'petroleum refineries'; and 'non-ferrous metals' have been reclassified to scale intensive sectors from supplier dominated sectors, and 'electrical machinery' is reclassified to science based from specialised supplier sectors, in order to test for the sensitivity to the chosen 'sectoral affiliation'. The results of this experiment display (not explicitly documented for reasons of space), that for supplier dominated sectors only investment is significant. In this context it should be pointed out that only 'textiles, footwear and leather' is left in this Pavitt sector. For science based sectors, investment and US patent specialisation are robust to the change made. For scale intensive sectors investment, unit labour costs and the linkages variables are all robust to the changes made, while the parameter for the technology variable becomes positive and significant, given the changes made. For specialised suppliers, investment and the linkage variables retain their sign and significance.

primarily found in the work of the Linder (1961). In accordance with e.g. Dosi et al. (1990) Linder relates export specialisation to innovation and product development, and the foundation of the 'home market hypothesis' is that,

> it is a country's <u>own</u> needs which are the mother not only of innovation but also invention [....] The resulting products will suit the needs of the home marked and will only gradually be tried on the export markets (Linder, 1961, p. 89).

The 'home market hypothesis' is extended to the general hypothesis that linkages to both advanced users and advanced producers influence the competitive strengths of an industry, since these forward and backward relations express a qualified demand as well as a qualified input which operates as both inputs and inducement factors to a knowledge enhancing process within the industry at question. But based on the patterns of interdependence between industries identified in the previous chapters, the effect of these linkages were expected to differ according to industry affiliation.

Based on these assumptions an econometric model of the relation between export specialisation and interindustry linkages, as well as other possible explanatory factors, was estimated. The difference in importance of industry affiliation was taken into account by allowing for different slopes, according to which Pavitt-sector each individual industry belongs. The results displayed that the linkage variables appears to be important for the export specialisation of scale intensive sectors, but even more so for specialised supplier sectors.

Regarding the other variables included in the analysis, investment in physical capital appear to be important for all types of sectors. Unit labour costs had a negative impact in the case of specialised supplier types of sectors, whereas the positive relationship for scale intensive sectors might well imply the importance of high skilled labour in these sectors. Revealed technological advantage had the expected positive impact for science-based sectors, but surprisingly also a positive impact for supplier dominated sectors.

Hence, it seems fair to conclude that both interindustrial linkages and technological activities in the nationally located industry are important in the determination of national export specialisation

patterns. However the importance differs according the mode of innovation in the industries, distinguished according to Pavitt sector characteristics.

Even though a first step of identifying patterns of interindustry linkages has been taken in this work, along with a discussion of different methods of identifying these linkages, a lot of work remains to be done, in particular in relation to assessing the economic effect of linkages in areas such as e.g. productivity and profitability studies. With this work I hope to have contributed to creating a renewed interest in the field of interindustry studies, which is a necessary condition for promoting attempts to solve the many unsolved problems.

Appendix F: Industries used in the analysis, classified according to Pavitt sector and compared to other studies applying the Pavitt taxonomy

	Pavitt (1984)	Amable/Verspagen (1995)	OECD 1992	This chapter
1 Food, drink and tobacco	SCAI	SDOM	SDOM	SDOM
2 Textiles, footwear and leather	SDOM	SDOM	SDOM	SDOM
3 Wood, cork and furniture	-	-	SDOM	-
4 Paper and printing	-	-	SCAI	-
5 Industrial chemicals	SCIB	SCIB	SCAI	SCIB
6 Pharmaceuticals	SCIB	SCIB	SCIB	SCIB
7 Petroleum refineries	-	-	SDOM	SDOM
8 Rubber and plastics	-	PROD	SCAI	SCAI
9 Stone, glass and clay	SCAI	PROD	SCAI	SCAI
10 Ferrous metals	SCAI	PROD	SCAI	SCAI
11 Non-ferrous metals	SCAI	PROD	SDOM	SDOM
12 Fabricated metal products	SCAI?	PROD	SDOM	SCAI
13 Non-electrical machinery	SPEC	PROD	SPEC	SPEC
14 Office machines & computers	SCIB	SCIB	SCIB	SCIB
15 Electrical machinery	SPEC	SCIB	SPEC	SPEC
16 Comm.equip. & semiconduct.	SCIB	SCIB	SCIB	SCIB
17 Shipbuilding	SCAI	PROD	SCAI	SCAI
18 Other transport	-	PROD	SCAI	SCAI
19 Motor vehicles	SCAI	PROD	SCAI	SCAI
20 Aerospace	-	SCIB	-	SCAI
21 Instruments	SPEC	PROD	SCIB	SPEC

SDOM = Supplier dominated
SCAI = Scale intensive
SPEC = Specialised suppliers
SCIB = Science based
PROD = Production intensive (specialised suppliers + scale intensive)
–   = Not included in the analysis

Appendix G: Country specific effects for the regression (n=662)

		Model I		Model II		Model III	
Sector type effect		Estimate	p-value	Estimate	p-value	Estimate	p-value
Supplier dominated	Australia	-0.080	0.5440	0.000	0.9981	-0.021	0.8393
	Canada	-0.017	0.8915	0.062	0.6091	0.042	0.6543
	Denmark	0.156	0.1928	0.237	0.0336	0.220	0.0103
	France	0.100	0.4351	0.192	0.1163	0.162	0.0810
	Germany	0.099	0.4131	0.190	0.0938	0.166	0.0564
	Great Britain	0.131	0.2770	0.223	0.0524	0.196	0.0221
	Japan	-0.008	0.9519	0.091	0.4549	0.061	0.5172
	The Netherlands	0.084	0.4907	0.149	0.2039	0.138	0.1214
	United States	-0.009	0.9457	0.089	0.4760	0.056	0.5687
Science based	Australia	-0.296	0.0000	-0.251	0.0003	-0.262	0.0001
	Canada	-0.234	0.0000	-0.190	0.0012	-0.199	0.0002
	Denmark	-0.060	0.2265	-0.014	0.7931	-0.022	0.6617
	France	-0.117	0.0223	-0.059	0.3056	-0.080	0.1075
	Germany	-0.118	0.0175	-0.062	0.2695	-0.075	0.1097
	Great Britain	-0.086	0.0613	-0.029	0.5819	-0.046	0.3182
	Japan	-0.224	0.0000	-0.161	0.0038	-0.181	0.0009
	The Netherlands	-0.133	0.0120	-0.102	0.0770	-0.103	0.0528
	United States	-0.225	0.0001	-0.162	0.0074	-0.185	0.0002
Scale intensive	Australia	-0.406	0.0000	-0.402	0.0000	-0.316	0.0000
	Canada	-0-343	0.0000	-0.341	0.0000	-0.253	0.0000
	Denmark	-0.170	0.0000	-0.165	0.0001	-0.075	0.0324
	France	-0.226	0.0000	-0.210	0.0000	-0.133	0.0000
	Germany	-0.227	0.0000	-0.213	0.0000	-0.129	0.0001
	Great Britain	-0.195	0.0000	-0.180	0.0002	-0.099	0.0028
	Japan	-0.333	0.0000	-0.312	0.0000	-0.234	0.0000
	The Netherlands	-0.242	0.0000	-0.253	0.0000	-0.157	0.0000
	United States	-0.335	0.0000	-0.313	0.0000	-0.239	0.0000
Specialised suppliers	Australia	-0.310	0.0000	-0.310	0.0000	-0.155	0.0063
	Canada	-0.247	0.0000	-0.248	0.0000	-0.092	0.0116
	Denmark	-0.074	0.1178	-0.072	0.0990	0.085	0.0115
	France	-0.130	0.0056	-0.117	0.0069	0.027	0.3889
	Germany	-0.131	0.0040	-0.120	0.0037	0.031	0.2795
	Great Britain	-0.099	0.0145	-0.087	0.0166	0.061	0.0252
	Japan	-0.238	0.0000	-0.219	0.0000	-0.074	0.0350
	The Netherlands	-0.146	0.0013	-0.160	0.0003	0.004	0.9230
	United States	-0.239	0.0000	-0.220	0.0000	-0.079	0.0092

Part IV: Conclusions and Policy Perspectives

This final part of the thesis presents the main results of the analysis presented in the previous three parts. Following the setup of the thesis, the conclusions presented in chapter 8 will touch upon both theoretical, methodological and empirical issues. Chapter 8 will also briefly discuss issues for further research in interindustry studies.

Chapter 9 presents some policy perspectives of the analysis, taking the Danish cluster policies of the 1990's (resource areas) as the point of departure. The chapter presents a critical discussion of these policies based on the findings of the preceding chapters.

Part IV also contains a summary of the thesis in English and Danish respectively.

Chapter 8: Concluding Remarks - What Has Been Accomplished and Where to Go From Here

Among the many factors that have promoted economic change, I believe that technology or, rather, change in technology is the most prominent. I realize that it is dangerous to look for 'ultimate causes' in a world where everything seems to depend on everything else. But I believe that for the most part the economy, and ultimately the society, must adapt to the conditions that technology creates. If it cannot adjust to the challenges of changing technology, it fails (Leontief in Carter, 1996b, p. 315).

8.1   Main conclusions

Chapter 1 presented three groups of research questions, representing a theoretical, methodological and empirical level each. At the theoretical level the main question was:

> *What are the theoretical and conceptual requirements for building a bridge between the input-output (Leontief) and technological change (Schumpeter) research traditions?*

This question was primarily dealt with in chapters 2 and 3. Theoretically it is necessary to accept that a theory of technological change cannot be a general theory in the same sense as e.g. the general equilibrium theory. A theory of technological change with the same wide applicability as the general equilibrium theory seems improbable, because of the way the general equilibrium theory treats factors like tastes, technology, and resources. These factors, which are of special interest in economics of technological change, are - due to the need to be restrictive in the number of factors a generally applicable theory can include - treated as constant, non-economic factors in the general equilibrium theory. Thus a theory of technological change will probably always be appreciative in nature, in the sense that it will be less formal, and more a means of organising analysis in the undertaking of applied work (Nelson and Winter, 1982, p. 46). The input-output framework can be used for identifying the basic economic structures which set up the limits for technological linkages. The assumption that linkages are sources of technological change through

both diffusion and exchange of knowledge plays a crucial role in this setting.

Conceptually the extension of the interpretation of the input-output coefficients are an important bridge builder between the two research traditions. If input-output coefficients are not just expressing exchange and production bot also - through a weighting by a knowledge variable - direct exposure to external knowledge, then the applicability of input-output tables becomes much wider.

But as illustrated in chapter 3, linkage measures based on the traditional Rasmussen specifications of Hirschmanian linkages, leading to the identification of key industries, are insufficient when the objective is to create a synthesis between traditional input-output economics and economics of technological change. Thus chapter 3 primarily served the purpose of identifying the theoretical and empirical starting point for a study aiming at identifying interindustrial linkages, stating the need for alternative methods and measures in the process of identifying potential dynamic interindustry relations.

This conclusion leads on to the methodological of research question:

> *What are the methodological requirements for creating a synthesis between the input-output and technological change traditions in empirical measures of industrial interdependence?*

Answers to this question are primarily to be found in part II. Chapter 4 introduces a selection of knowledge indicators to be applied in the process of identifying interindustry knowledge flows: R&D expenses, patent grants (US patent data), and fraction of employees with a degree in technical or natural sciences. Also chapter 4 introduces two related input-output based methods for identifying knowledge flows. Both these methods rely heavily on the assumption that knowledge can be embodied in goods and services.

Chapter 5 introduces yet another knowledge indicator: innovations. In this chapter knowledge flows are primarily identified through flows of product innovations, but the bilateral character of

knowledge relations is also revealed by including the input to the innovative process from firms in user industries in the analysis. In other words in chapter 5 innovation flows run from producers to users, while information flows from users to producers. Both types of flows can be perceived as knowledge flows.

A primary methodological requirement for establishing a synthesis between the two research traditions is related to the issue of indicators. The combination of input-output tables with different knowledge indicators each expressing different features of 'knowledge levels' in the individual industries introduces the possibility of assessing the sophistication of user and producer industries respectively, and thus it opens up new avenues to explore in relation to embodied knowledge flows and the related concept of 'indirect (acquired) knowledge', clustering of knowledge relations, the effects of knowledge linkages (explored in part III of the thesis), etc.

But also the combination of different methods for identifying knowledge linkages proved to be important. The two methods applied in chapter 4 are very similar, as they both are based on the combination of input-output coefficients weighted by knowledge indicators, but whereas one method focusses on identifying the quantitative extent of knowledge flows with no emphasis on which industries are related through the flows, the other method focusses on the qualitative aspects of identifying and mapping the linkages between sources and receivers, with no emphasis on the size of the flows. As a supplement to the analysis of chapter 4, chapter 5 contributes to the methodological discussion of embodied knowledge flows inseparably connected to economic transactions of a certain volume, versus innovation flows which do not necessarily appear between industries that are related through economic transactions of any considerable volume. An important methodological contribution also lies in the introduction of information flows as mentioned above.

Thus methodologically the synthesis between the traditions initiated by Leontief and Schumpeter respectively requires a less rigid perception of input-output coefficients (as pointed out in relation to the theoretical research question), as well a broad approach concerning both models and data applied. This conclusion is build on the observation that the introduction of the Schumperian perspective in the input-output framework requires combinations of different sources and

approaches in order to capture as many elements as possible of the complex phenomenon 'technology'.

The methodological considerations are only an intermediate step in the analysis, as the final goal is to increase the understanding of economic systems. This leads to the final research question, which relates to both part II and part III of the thesis:

> *How does the empirical mapping and measurement of linkages contribute to characterising an economic system?*

Part II combines the exploration of methods for identifying linkages with the identification of different characteristics of the Danish economic system.

Directing the attention towards the results of chapter 4, a main characteristic of the Danish economy is the role of the food industry. The food industry has a dominating position in the Danish economy, in terms of volume of production as well as in terms of export specialisation. The food industry is a low knowledge industry, but it is to a large extent an important user of production inputs from knowledge intensive industries, i.e. it has an absorptive capacity for using inputs containing embodied knowledge.

Another characteristic is the role of the service industries which - with the exception of business services - are low knowledge industries (at least judging from the presently available knowledge indicators). But services are, just as the food industry, intensive receivers of embodied knowledge, illustrated by a flow of embodied knowledge from a few manufacturing industries and business services to a broad range of service industries.

Regarding the knowledge sources, two very different industries are found to be the most important sources of embodied knowledge diffusion in the Danish economy: on the one hand the role of business services confirms that knowledge intensive services plays a central role as a knowledge source, not just for manufacturing but also for other services. On the other hand a traditional manufacturing industry, machinery, still plays an important role as a knowledge source. Also the

analysis of chapter 4 shows, by the example of machinery as compared to e.g. instruments and the medical industry, that it is not necessarily the most knowledge intensive industries that are the most important sources of embodied knowledge flows.

Another issue dealt with in part II is the clustering of technological relations. In chapter 5 some support can be found for the assumption that technological relations tend to cluster in areas with extensive economic relations. But on the other hand innovative relations also often appear between industries which are not closely economically linked. Thus two types of space seem to be of importance to the existence of technological linkages: proximity in *economic space* can explain some technological relations, while others are assumed to be based on *technological proximity* or overlapping knowledge bases.

Empirical support to the proposition that innovative activity is an interactive process is also found in chapter 5. Active participation in the innovative process from the user side is most outspoken in the case of industries which are 'specialised' in supplying product innovations to firms in one single or few industries, but also in the case of more 'generic' technology sources some user involvement is reported.

The degree of interaction in the innovative process can be used for identifying two main types of innovative clusters, which differ with regards to their extent of and relations to users. One type of cluster is characterised as a user-producer cluster; while the other type is a single-industry innovative cluster.

The cluster discussion is continued in chapter 6, although from a different point of view. A cluster is in this setting a group of industries related through embodied knowledge flows. The focus of chapter 6 is on industrial development and institutional factors influencing this development, claiming that the structure of technological interdependence at the industry level is closely related to the historical process of industrialisation.

Two main patterns of clustering are identified: in the case of Great Britain, Japan and the United States, at least two separate clusters appear. One cluster is centred around chemicals related

industries, while another is centred around communication equipment, electronics and/or transport industries. Germany on the other hand reveals a more interrelated system with less clear tendencies of separate clustering, due to the crucial role played by the German chemical industry, as well as the relatively weak position in electronics and related industries. The general conclusion from chapter 6 is that if two major industrial fields within a country develop at different pace, with different strategies, and with different starting points, these areas tend to remain largely separated in a technological sense.

Put boldly, chapter 6 discusses whether there are differences between linkage structures in different countries, and chapter 7 moves on to the discussion of the effects of this difference. From chapter 6 it appeared that there is a relation between national interindustry linkages and the export specialisation pattern of a country. Following this indication, chapter 7 opens the discussion of the *effect* of linkages as opposed to the *mapping* of linkages. And chapter 7 indeed finds that a relation can be detected between linkages to sophisticated users and suppliers, and international export specialisation. This is in particular the case for scale intensive industries (following the Pavitt (1984) taxonomy), and specialised supplier industries, while no significant results for the effect of linkage variables could not be found for supplier dominated industries and science based industries. Thus linkages to sophisticated users and producers appear to have the largest effect on export specialisation in industries which are either characterised by large scale production, or by close relations to their users. On the other side, the most technologically advanced industries, as well as the least technologically advanced industries, appear to be influenced by other factors when it comes to explaining export specialisation.

Summing up, the empirical mapping and measurement of linkages can contribute to the characterising economic systems in many ways: the identification of knowledge sources and receivers respectively; the identification of different types of clusters; the discussion of the importance of the historical process of industrialisation on current structure; and the explanation of economic positions of strength (export specialisation).

Many more possible avenues are open when it comes to characterising economic systems through the use of linkage analysis. The final section of this chapter will touch upon some of these avenues.

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8.2   Where to go from here

The title of the present work is *Technological Change and Interindustrial Linkages*, underlining that the emphasis has been on directing new attention towards linkage studies, taking the traditional linkage studies as the point of departure. But as the subtitle - *Introducing Knowledge Flows in Input-Output Studies* - indicates, a new perspective is called for if linkage studies are to be of relevance in an economic system where the role of knowledge is perceived as being of increasing importance.

The major contribution of the present work lies in the application of new methods of measuring and mapping linkages, including the use of different indicators of knowledge and technology. This mapping has illustrated both the importance of business services as a knowledge source, along with more traditional manufacturing industries like machinery, as well as pointed to the comparatively large role played by acquired knowledge in traditional 'low-knowledge' industries, thus challenging the traditional distinction between high and low knowledge production processes in different industries. The method of mapping linkages has also shown its applicability in comparative studies, here in relation to comparing national systems of innovation, illustrating the extent to which 'history matters'. But a lot of work remains to be done in relation to measuring the economic effect of knowledge based interindustry linkages. Chapter 7 presents a first attempt to measure the effect of linkages, here expressed by export specialisation. But theory suggests many other effects of linkages. In the most general expression linkages are assumed to affect the competitiveness of an industry. Export specialisation is one expression of competitiveness, but other important measures related to competitiveness are productivity and growth. Before exploring these measures' relation to linkages, it is necessary to establish which factors are the central 'input' and 'output' factors in relation to measuring productivity, and which parameters of growth are most appropriate: employment, turnover or output, to mention some of the most common factors. Even though the effect of linkages on productivity has been quite extensively analysed from a spillover perspective, a lot of work still remains to be done on this area.

Another important issue, which has not been dealt with here, is how to handle the emergence of new industries, as well as shifts in industry boundaries. In relation to the analysis of developing

countries moving into already existing industries, the problem is manageable, but the ability to capture the emergence of completely new industries is a theoretical as well as empirical challenge.

In relation to policy formulation the capability to measure the effects of linkages is important, but at least in Danish policy formulation more diffuse effects such as an increased communication and the establishment of potentially dynamic relations have been among the aimed outcomes of recent cluster policy initiatives. As a final perspectivation, the final chapter will discuss policies based on a linkage approach, taking the Danish cluster policies of the 1990's as the point of departure. The by now well known cluster approach, which ascribes its world fame to the work of Porter in the early 1990's, is the first method discussed in chapter 9. Technology is not an explicit factor in cluster studies of the Porter type, rather the criteria for being a dynamical cluster is international competitiveness. Porter-type cluster studies are included in the wrapping up of the present work since they have played an important role from a policy perspective, and as such have contributed to turning an increased attention towards the systemic - interdependent - nature of economies. Thus I find it an appropriate final exercise to discuss the implementation of linkage inspired policies in light of the findings of this thesis.

Chapter 9: The Application of Linkages and Industrial Clusters in Public Policy Formulation[1]

The traditional way of looking at the economy was based on a division into sectors, *which distinguished between primary producers, manufacturers and service industries. In practice, though, relations of interdependence go across the sectors boundaries. [...] A resource area [...] often includes several industries comprising a network of primary producers, manufacturers, subcontractors and service systems.*
(Ministry of Business and Industry, 1997, p. 6)

9.1   Introduction

This final chapter of the thesis will relate the linkage concept to policy formulation. Based on the findings of the previous chapters regarding how to measure and interpret linkages, this chapter will assess the use of linkage and cluster studies in industrial and technology policy in Denmark in the last two decades. Thus the chapter provides a policy perspective on the findings in the previous chapters.

Cluster studies have in the later years been a corner stone in Danish business and industry policy making, but attempts to identify production clusters can be dated back to the early 1980's.

In the first studies in the early 1980's a cluster - an industrial complex - was defined according to supply-and-demand linkages in the production structure. Production linkages and equal policy framework conditions were used in defining the clusters which are used in Danish business and industry policy making today (resource areas).

Porter (1990) has been the main reason for directing the international attention towards cluster policies 1990's. In Porter (1990) cluster studies from 10 countries were the basis of an analysis of the forces behind the competitive advantages of nations. But several very different cluster
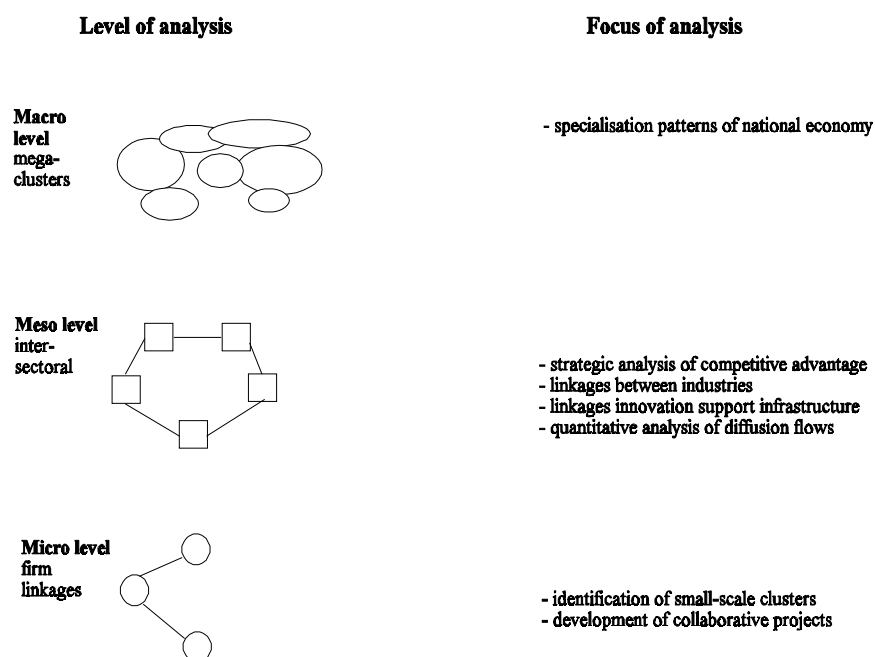
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[1]   This chapter draws to a large extent on Drejer, Kristensen & Laursen (1999).

initiatives have been introduced with a subsequent confusion regarding what a cluster - and accordingly a cluster policy - really is. Figure 9.1 presents an overview of different levels of analysis for cluster studies and their corresponding analytical focus.

Boekholt (1997) presents a categorisation of policies for clustering with the primary aim of developing a tool for policy makers aiming to initiate such policies.[2] Boekholt defines a cluster as a group of firms, knowledge centres and innovation support organisations with a functional affinity, which cooperate - in a formal or informal manner - to achieve new market strategies, product or process innovations. The clusters dealt with by Boekholt are primarily micro level clusters. A distinction between cluster policies aimed at sustaining existing clusters (often geographically based clusters with a long historical tradition) and policies aimed at creating new linkages and networks is introduced. A 1993-review of European policies for establishing

Figure 9.1: Cluster approaches at different levels of aggregation
Source: Roelandt and den Hertog (1997)

Level of analysis		Focus of analysis
Macro level mega-clusters		- specialisation patterns of national economy
Meso level inter-sectoral		- strategic analysis of competitive advantage - linkages between industries - linkages innovation support infrastructure - quantitative analysis of diffusion flows
Micro level firm linkages		- identification of small-scale clusters - development of collaborative projects

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networks and clusters for innovative SME[3]s identified 23 policy initiatives, most oriented towards SMEs only, others with a mix of small and large firms (Boekholt and Fahrenkrog, 1993). It is characteristic of most cluster initiatives that they are aimed at creating networks and linkages between firms operating in the same geographical region and/or in the same line of business.[4] Sometimes a large contractor or 'mentor' firm is also involved in the cluster.

A slightly different definition of a cluster is presented by Roelandt et al. (1997): a cluster is an economic network of strongly interdependent firms, knowledge producing agents and (demanding) customers, linked to one another in a value-adding production chain. Following this definition Roelandt et al. present cluster studies carried out in the Netherlands at the meso level. A pre-publication manuscript of Porter (1990) was the background for a study of the economic strength of the Netherlands, which started a row of research projects in which traditional sectoral studies were gradually replaced by cluster studies focussing on competitive strengths (Roelandt et al., 1997, p. 13). Gradually the analyses moved from being analytical devises for gaining a better insight into the competitive strengths of individual clusters, towards being starting points for strategic advices on making clusters more competitive and identifying important knowledge issues.

Finland is another country is which the cluster concept has been widely applied in analyses of industrial strongholds at the meso level. Rouvinen and Ylä-Anttila (1997) point to the identification of network relations as the starting point of a cluster analysis. These include relations with competing producers, R&D cooperation, and user-producer connections.

Historically speaking comparative advantages in factor conditions are often the impetus behind the development of a cluster, but in the fastest growing industries today the sources of

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[3]   Small and Medium sized Enterprises.

[4]   Much in line with Marshall who stated that:

When an industry has thus chosen a locality for itself, it is likely to stay there long: so great are the advantages which people following the same skilled trade get from near neighbourhood to one another (...) And (..) subsidiary trades grow up in the neighbourhood, supplying it with implements and materials, organizing its traffic, and in many ways conducing to the economy of its material. (Marshall, 1890/1920, p. 271)

competitive strength is the created and advanced factors (Rouvinen and Ylä-Antilla, 1997, p. 15). Thus clusters of this type cannot be forced to emerge, some sort of competitive strength based on a special advantage must be present. Accordingly the policy initiatives in relation to the emergence and strengthening of clusters are closely related to education and competence building, i.e. they are very general policies.

Other countries have performed more isolated cluster studies of selected areas of their national economy (see e.g. OECD, 1999), but apart from the analyses leading to Porter (1990) - see section 9.3 - the above examples represent the most wide applications of the cluster approach in national analyses.

The Danish cluster policy has the same starting point as the above mentioned initiatives: Porter (1990). But the Danish cluster policy initiative distinguishes itself from most other cluster initiatives in being a cornerstone in the industrial policy, aiming at including the total business environment in the initiative. Before going into detail with the Danish cluster policies of the 1990's some of the earlier analyses which paved the way for the clusters of the 1990's will be briefly presented.

9.2 The first cluster studies - industrial complexes

In the early 1980's a sequence of studies of so-called industrial complexes were carried out in Denmark. The studies were part of a project financed by the Danish Technology Council focussed on the development and diffusion of new technology in the Danish economy, more specifically on how the use of micro electronics influenced central economic variables such as the balance of payments and employment.

The four industrial complexes studied were:

- the agro-industrial complex;
- the textile complex;
- the environmental complex; and
- the office machinery complex.

The main idea behind the concept of industrial complexes is that the linkages between, on the one side, firms developing new technology expressed in components, machines and production systems, and, on the other side, firms using this technology, are at the core of the economic system. These linkages are crucial for the development, diffusion and use of new technology. The concept of industrial complexes, defined as a group of industries connected through important flows of goods and services, can be dated back to Lodh and Lewis (1975) and Czamanski and Czamanski (1977), but the theoretical foundation is to be found in Dahmén's (1988) development blocks mentioned in chapter 2. Transformation is a central factor in defining a development block. The introduction of micro electronics is related to several types of transformation processes, especially processes concerning production methods, including the organisation of production, and the development of new products and services. This implies that even though an industrial complex cannot in a narrow sense be perceived as an innovative cluster, there is an obvious linkage to innovation and new technology trough the focus on technological development in general and the microelectronic development in particular.

9.2.1   The four complexes

The four chosen complexes, which by no means are representative of the total economic system in a statistical sense, each represent different types of relations between producers and users of new technology.

Different methods, primarily related to vertical linkages between users and producers, were applied in identifying the complexes.
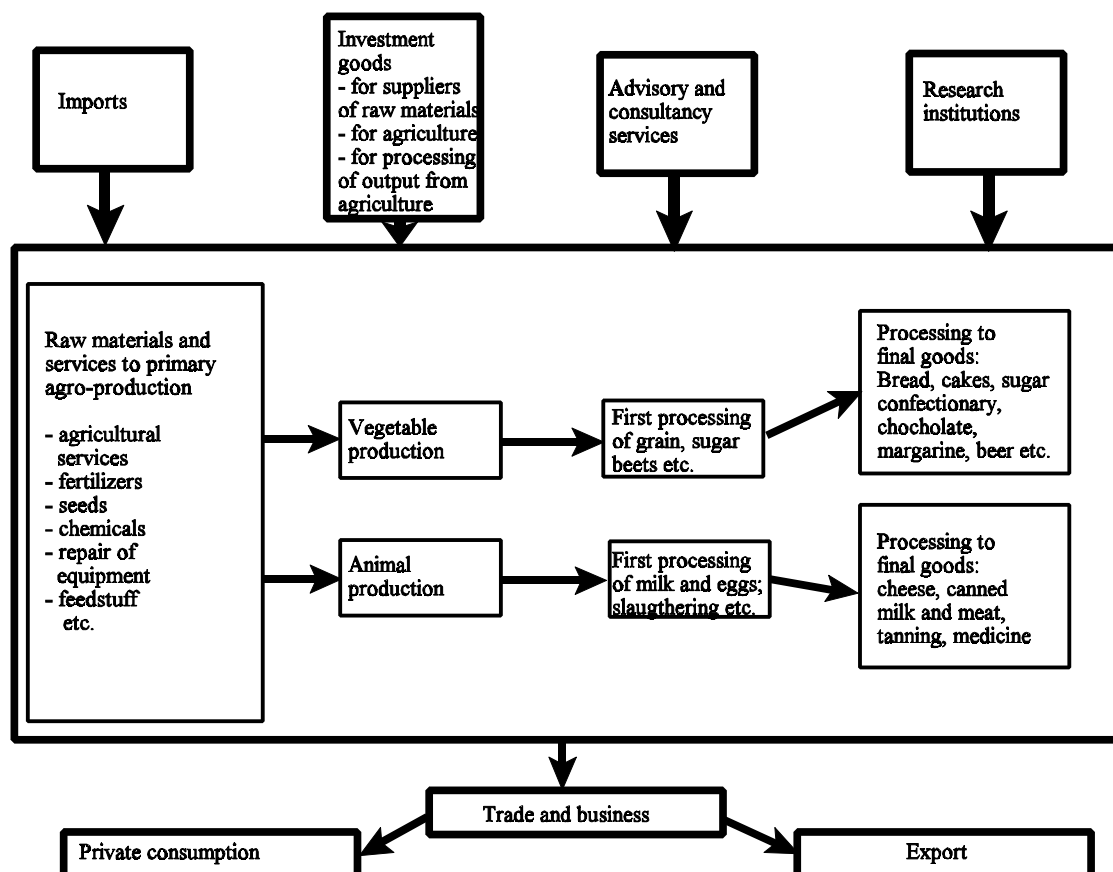
The *agro-industrial complex*, which was subject to the most detailed study, was mainly identified by the use of input-output tables, and the method was thus related to the ones used in the previous chapters for identifying linkages. Sectors either receiving a relatively large fraction of their input (i.e. being forward linked) or delivering a relatively large share of their output (i.e. being backward linked) to the core sector of the complex (primary agricultural production) are considered as part of the complex. Sectors which are only indirectly connected to the core areas of the complexes are also included (identified by the use of the Leontief inverse input-output

matrices). In order to capture the flows of capital goods, other means than input-output tables were included though. The structure of interdependence in the agro-industrial complex is described in figure 9.2.

The agro-industrial complex was by all means the largest integrated complex in the Danish economy, with a production value of almost the same size as all other manufacturing sectors added together in the observed period. Therefore, production related to agriculture played - and still plays - a major role in the Danish economy, both in terms of consumer and investment products (Lundvall et al., 1984).[5]

Figure 9.2: Flows of goods and services within the agro-industrial complex
Source: adapted from Lundvall et al. (1984, p. 19).

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[5]   Cf. the central role of the food industry as a knowledge receiver identified in part II.

The agro-industrial complex also illustrates the importance of the home market for international trade specialisation, which was explored in chapter 7. A particular part of the complex is 'the dairy vertical' consisting of the producers of dairy machinery and systems on the one side, and dairies on the other. An important part of the vertical consists of the linkage between users of dairy equipment (large Danish dairies) and manufacturers of machinery for the use in this sector. In the ISIC nomenclature, dairy export belongs to the food, drink and tobacco sector, whereas dairy equipment is included in non-electrical machinery; two sectors in which Denmark is heavily specialised. Thus, an important part of the knowledge base of these sectors is created in the interaction between the two, thereby resulting in a co-evolution between the sectors, which tends to produce international competitiveness in both fields.

The second complex studied is the *textile complex,* which is defined as the textile producing industry and its main suppliers and users. Even though this also builds on an input-output approach, lack of detail in the aggregation of the input-output tables made it impossible to use the tables in the actual definition of this complex. As opposed to the agro-industrial complex, machinery is almost negligible in the textile complex, which makes the textile complex close to identical with the textile and clothing industry (Thøgersen, 1986).

Lack of statistical data was a major obstacle in the analysis of the *environmental complex*, which was to a large extent based on interviews, in particular with people connected to the area of waste water treatment. The environmental complex was defined as constituted by users and producers of environmental technology as well as intermediates, i.e. actors external to the actual users and producers, who are instrumental in supplying information and advice about new technological opportunities (Gregersen, 1984).

The analysis of *office machinery* is only marginally related to the complex approach. The basis of the analysis was a questionnaire survey regarding electronic data processing and office automatisation in Danish municipalities. The basic difference between the analysis of the three above-mentioned complexes and the analysis of office machinery is that in the latter case the focus is on a specific type of users as opposed to a focus on the interdependence between producers and users. The producers are indirectly present in the analysis though, since the office technology used

by the municipalities to a large extent consists of systems developed by the public company 'Kommunedata' ('Danish Municipal Software House'). The fact that both the users and the producers are part of the public sector offers a new perspective on the interdependence between the two types of actors (Brændgaard et al., 1984).

The analysis of the four complexes, through their variety in focus and method, showed some general characteristics of the technological changes experienced in the different complexes, and some characteristics of the influence of these changes on the Danish employment and competitiveness.

9.2.2   *Main results of the industrial complex studies*

In the *agro-industrial complex* a major aim was to analyse whether is was possible to identify either the presence or possibility of technological dynamics that were crucial for liberating the complex from its vulnerable specialisation in standardised products within a stagnating market. The study concluded that qualified and demanding users had played an important role for the development of new technology, but signs of an increasing inequality in competences between producers and users of new technology, which could have negative effects on production, export and employment, could be identified. Concerning possible new technological dynamics the bio-technological field was identified as having by far the largest potential with regards to renewal in the agro-industrial complex, not just with regards to the supply of innovation from outside the complex, but also in terms of using biotechnology for practical purposes inside the complex in both primary agriculture and processing industries. But new technology by itself is no solution without proper organisational changes, which lead to a recommendation of a strengthened 'sector' or 'complex policy' aimed at improving the vertical relations between sectors as opposed to specific 'microelectronic policies' or 'technology policies' (Lundvall et al., 1984, pp. 126-148).[6]

In the analysis of the *textile complex*, Pasinetti's (1981) production based model of technological

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[6]   A recent analysis of the food area concludes that food related industries are facing major problems being a low-wage, low-skilled and low-productivity area, indicating that the focus on the food area as a major position of strength in the Danish economy has not secured a continuous development of the competencies within the area (Arbejderbevægelsens Erhvervsråd, 1998).

dynamics, linking economic growth to structural change (see chapter 2), together with the product life cycle theory, are the main theoretical starting points. The main conclusion is that although the complex as a whole seems quite mature with tendencies of 'dissolvement' of the linkages in the complex as a result, certain new or emerging product fields could be identified (e.g. carpets), indicating that the interactions could still result in dynamic (Hirschmanian) effects. The technological development had also mainly had the characteristics of a mature set of industries with a clear tendency towards standardisation. New products and processes, created through the interaction between the agents at different levels in the complex, were perceived as needed in order to fight decline in domestic production and employment in the textile complex.[7]

The *environmental complex* differs from the two above mentioned complexes by having the public sector as a main user as well as an important regulator. In this regard the complex study gives new insights to the role of the public sector in the building up and maintenance of national competencies, through its actions as a competent user. But as a complex or cluster study it is atypical.[8]

As mentioned above, the analysis of *office machinery* is only marginally related to the complex approach. Again the public sector is in focus, the theme of the study being the Danish municipalities as users of electronic data processing and office automatisation, and the consequences of this for employment. The main conclusion is that the introduction of office machinery in the municipalities had not been driven by an aim to reduce employment, whereas the possibilities for keeping the introduction of new technology employment-neutral in the future are more uncertain.

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[7]   As history has shown, the domestic production, and thus the employment, was not maintained, and if an analysis of the textile complex was to be carried out today, it would not be possible without including the production placed abroad in low-wage countries. The consequences of the moving out of production for the vertical linkages in the complex are not discussed in the present chapter.

[8]   But it has some value as a study of *causal* Hirschman linkages from the public sector to enviromental industries.

9.3.3   Methodological problems

The main methodological problems with the industrial complex studies are the above mentioned differences in approach and focus. Even though user-producer linkages are the main determinants of an industrial complex, no general way of identifying complexes, e.g. through forward and backward linkage measures or other types of linkage measures as introduced in previous chapters, was developed. The study of the agro-industrial complex is the most consistent in relation to a cluster approach, and it is also in this study that the method is most clearly defined and developed. Some general problems of using input-output data are apparent though - problems that to some degree also are relevant for the analyses carried out in the previous chapters. First of all the level of aggregation is to a large extent given in advance, a level which might not be appropriate for identifying the most important user-producer linkages. This is why the input-output method proved to be inadequate in the study of the textile complex. The lack of dynamics in the analysis, as discussed in chapter 1, is also apparent. Finally the studies of industrial complexes are not representative of the Danish economy, but each represents an area which *in isolation* is an interesting object for analysis. The four complexes analysed cannot be perceived as *the* important clusters in the Danish economy though, and as such their main value lies in the detail of each individual study, as well as in the demonstration of the importance of linkages at different levels.

The following sections will illustrate how the linkage thought has been applied in more recent policy oriented industrial cluster studies. The industrial complexes can be perceived as the 'forerunners' of the resource areas introduced by the Danish Ministry of Business and Industry in 1993. The fact that the agro-industrial complex was the most consistent is underlined by the survival or rather revival of the complex as a 'Food Products Resource Area'. The other complexes studied are all part of larger resource areas.[9]

9.3   The Porter Studies

The industrial complexes and micro-founded studies of Danish clusters dealt with in section 9.2

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[9]   Textiles are mainly part of the 'Consumer Goods/Leisure Resource Area'; environment is mainly relevant to the 'Transport/Utilities Resource Area'; while office machinery is placed in the 'Communications Resource Area'.

have all been either a direct input to, or a reference point when developing the resource areas. However, the most direct influence is the Danish Porter studies. Denmark participated as one of ten countries[10] in Porter's analysis of clusters of competitive advantages. The studies were later used as the empirical foundation for the theory presented in *The Competitive Advantages of Nations* (Porter, 1990).

Porter's prime interest is the underpinnings of economic prosperity for either firms or nations, specified into the questions of why a nation becomes a home base for successful international competitors in a given industry, or rephrasing it, why some firms based in a particular nation are able to sustain competitive advantage against the world's best competitors in a particular field? And why is one nation often the home for so many of an industry's world leaders (Porter, 1990, p. 1)?

In order to provide new explanations as to why some nations are competitive and others are not, Porter initiated studies of several industries within each of the above mentioned ten countries. All the industries selected for study were ones in which the nation had a significant international market position - be it gaining strength, maintaining the position, or being in decline - in the year 1985. In other words the sample of industries was chosen to be representative of the most important groups of competitive industries in the economy. In the Danish case this implied that food, agricultural machinery and furniture were among the chosen industries (Porter, 1990, p. 26). Although Porter's overall aim of explaining the localization of successful companies in specific countries is very close to Marshall's notions of localised industries and internal vs. external economies (Marshall, 1890/1920), Porter only refers sporadically to Marshall, and such the hereditary element of the economic principles underlying Porter's analysis is largely ignored. References to traditional linkage studies are also absent, even though linkages play an important role in defining or delimiting a cluster.

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[10]   The other countries were Germany, Italy, Japan, Korea, Singapore, Sweden, Switzerland, the United Kingdom and the United States.

9.3.1   The importance of linkages in cluster studies

Porter views demand conditions, as well as vertical relationships among industries, as stimulators of competitive advantage. Following this line of thought Porter groups industries based on end-use application. Sectors containing industries whose primary products are inputs to products in many other industries are termed *upstream sectors* - in a Hischmanian setting these sectors would be forward linked.[11] This group consists of materials/metals, forest products, petroleum/chemicals, as well as the relatively new sector semiconductors and computers, which contains a modern category of products that are basic inputs to virtually all industries. A second group of industries are broad end-use sectors involving *industrial or supporting functions*. Most of these industries are related to particular end-uses such as transportation or defence, and the group includes multiple business (containing industries such as measuring instruments and power tools, whose products are ancillary or supporting products used in many end-use sectors), transportation, general power & distribution, office, telecommunications and defence. The final group of industries are end-use sectors primarily associated with *final consumption goods*: Food/beverage, textiles/apparel, housing/household, health care, personal and entertainment/leisure. Within each broad sector, industries which are internationally successful are grouped into primary goods, machinery and other equipment used in making the goods, specialised inputs into the goods, and services associated with the goods or their production. This grouping allows for an examination of the vertical relationships among successful industries and the depth of national clusters. Often related industries are found within the same broad sector, but in all nations there are linkages among groups of industries that extend beyond the broad sectors (Porter, 1990, pp. 287-288).

Porter's qualitative analysis focussed on the upstream and downstream value chain relations of the firms, the institutional setting, the firm's surroundings and the firm itself. The theoretical approach was to employ both the broad sector grouping described above, as well as what has become known as 'Porter's Diamond' (see figure 9.3 below), developed by Porter in earlier works. Furthermore, the analysis also had an historical angle since 'path dependency' often is important in explaining why a region or country hosts a particular set of firms working in the same

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[11]   It is worth noticing that these industries differ from the forward linked industries identified in chapter 3, which were mainly service industries as well as primary sectors.

sector.

*9.3.2   The Porter Diamond*

Since Porter's Diamond of factors and relations influencing competitiveness is central not only to the Danish Porter studies, but also to the later resource area analysis, the central ideas in the diamond will shortly be presented here.

The answer to why a nation achieves international success in a particular industry lies in the attributes that shape the environment in which firms compete. The basic unit of analysis is the industry, but nations do not succeed in isolated industries, they succeed in clusters of industries connected through vertical and horizontal relationships (Porter, 1990, pp. 71-73), as e.g. illustrated by the example of the food (dairy products) and electrical machinery (dairy equipment) mentioned in section 9.2.

The home base, where the firms are allocating the bulk of their resources to R&D, is seen as central to the firms' competitiveness. This in turn implies that it is not enough to analyse the firm alone, in order to explain the firm's competitiveness. Further, it is argued that it is crucial for economic growth that a nation is an attractive home base. The question then is why and how regions have developed to be centres of excellence for a particular industry.

Figure 9.3: Porter's diamond
Source: Porter (1990) and Dalum (1992).

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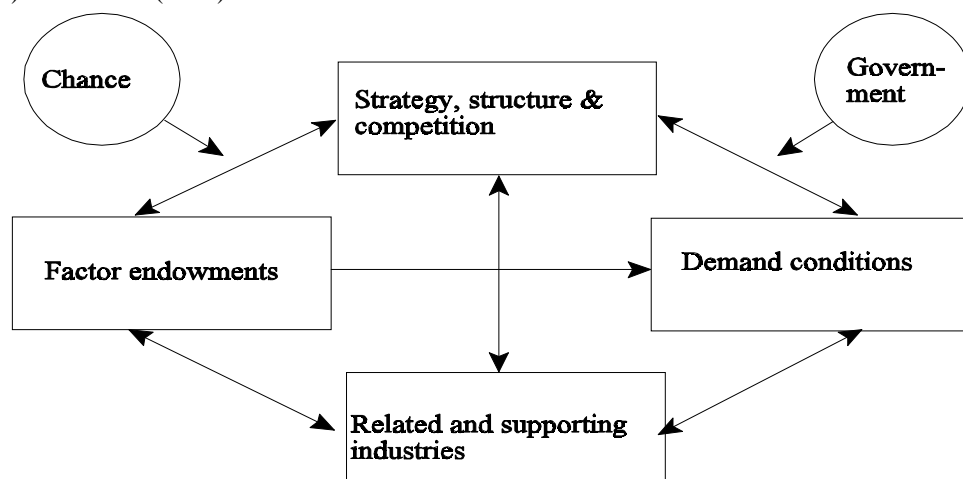
The diamond, which is basically a model of relations and interactions, is used as the analytical tool in the analyses of the interactions between the firm and its surroundings. The diamond consists of the following central parts:

1. *The firm, its strategy, structure and rivalry*: the strategy and the management of the firm, as well as the organisation and routines of the firm, are important factors, since in the end it is the firm that must gather and use the knowledge as well as the factors of production in an effective way.

2. *The related and supporting industries*: the presence or absence of supplier industries as well as related industries that are internationally competitive, and either supplying or adopting technology in a way that stimulate a cumulative and interactive process, is influential. This is where the horizontal and vertical linkages are at play.

3. *Demand conditions*: the relative size of the home market and the quality of the demand plays a crucial role (cf. the discussion of Linder in chapter 7). In sectors with increasing returns to scale a historical large home market can be an advantage. In relation to the fact that not only quantity but also the quality of demand is important in relation to the home market, the public sector can in particular play a central role.

4. *The factor conditions*: the factors are both traditional factor endowments but also the infrastructure, the human resources and the technological ability of the country. Usually natural resources have been the sole factors considered, and the differences in factor endowments between countries have been used to analyse and explain trade patterns. These have proven to not be sufficient and cannot explain features such as the 'Japanese miracle'.

5. *The state*: regulations related to sectors or business in general. The state's investments in e.g. infrastructure, as well as the state's role as an advanced user is central. In general the state is setting the boundaries for the factor advantages or factor conditions. Laws related to standards, patents, anti-trust and so on are crucial. Further the state's allocation of resources to science and education are highly important.

These very broad elements are at the focus of analysis, and the interplay between all elements of the diamond determines the competitive advantages or disadvantages. As mentioned earlier, history matters and many of the clusters we see today have been initiated and developed through

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long periods (in line with the discussion in chapter 6). This implies that cumulative processes have a strong influence, but also that advantages take a long time to build.

9.4   The Danish Studies and the Resource Areas

The work on clusters in Denmark, employing the Porter analysis and theory, was carried out from 1987 to 1991. In the Danish Porter project the following industry case studies were carried out (Porter, 1990, p. 26):

- agricultural machinery;
- building maintenance services;
- consultancy engineering;
- dairy products;
- food additives;
- furniture;
- industrial enzymes;
- pharmaceuticals;
- specialty electronics;
- telecommunications equipment;
- waste treatment equipment.

On the basis of these sector studies Porter points out the following clusters:

- the agricultural cluster;
- household products and furnishings;
- health (pharmaceuticals, vitamins, medical equipment etc.),

where the health cluster is linked to the agricultural cluster by technology and raw material equipment (Porter, 1990, p. 149).

Porter criticised the Danish economy for being less dynamic than many other countries, lacking motivation and competition as well as being too dominated by the state (Porter, 1990, p. 567-568). Thus the studies and the results gave rise to an intense discussion on the competitiveness and dynamics of Danish firms, and also on the public policies to support development.

The Danish Business Development Council (Erhvervsudviklingsrådet), which has as its

assignment to advise the Danish government on business policies, took up the idea of clusters as a new perspective on business policies, and initiated the analysis of the resource areas in Denmark. Since the Porter studies there had been ongoing analyses of clusters, areas or blocks in several Danish ministries and agencies. Especially the Danish Agency for Development of Trade and Industry (Erhvervsfremme Styrelsen) has carried out several studies. Also the Danish Ministry of Finance carried out studies of the Danish industry employing a cluster terminology. In 1992 the Ministry of Finance presented an analysis of four 'blocks': a*gro/food*, *construction and housing*, *shipbuilding and sea transport,* and *health and medicine* (Ministry of Finance, 1992). These blocks were all characterised by having an export/import rate larger than 1, i.e. the firms in these blocks were able to compete on international markets. The blocks, which consisted of both producers of final goods and services as well as suppliers of raw materials, production equipment and business services, accounted for 60 percent of the Danish export and 43 percent of the total private production, and were thus in general highly important in the Danish economy (Ministry of Finance, 1992, p. 248). In the later resource areas these four blocks are carried on in four of the total eight areas. Thus the initiation of the resource areas can been seen as the outcome of a cumulative process, where the results from the Danish Porter studies, and the Porter way of thinking about industry policy, played a central role.

The Porter diamond was the cornerstone in the analysis of the relations and interplay in the resource areas, and the methodology to analyse the connections and flows was qualitative with a historical perspective. It is explicitly stated that the deviation from earlier industry divisions lies in the focus on the end-product. The firms (or industries) in the resource areas are all the firms (or industries) that deliver either knowledge, capital equipment, components or services to the core activities of the area, thus we are dealing with an expanded linkage wiev.

The method applied in the resource area analysis differs slightly from the Porter studies and cluster studies in general. The primary difference is due to the decision that all Danish industry - initially the public sector was not incorporated - should be included in a resource area or in the general supplier group, which was a final residual group including industries which could not be placed with reason in any single area. In the Porter studies around 40% of all Danish firms were represented in the clusters, thus the resource areas have a wider scope than the Porter clusters and clusters in general.

Qualitative studies were carried out in eight areas: services; agro/food; construction; environment/energy; transport/communication; medico/health; consumer goods; and tourism/leisure. These eight areas were defined through a process of dialogues in the Business Development Council, with reference to the Porter studies and other related studies made by or for the agencies or ministries, based on a primary criterion of the mutual dependency of common resources and competences within each area.

In the day-to-day work with the resource areas there is an ongoing development of the methodology and of the understanding of the areas. Several analyses have been carried out of the resource areas, but foremost there is an ongoing and intense dialogue with representatives of firms, organizations and public institutions and ministries. This work has, besides resulting in several policy suggestions, also been used to develop and redefine the resource areas. In the process of redefining the resource areas a clearer definition was developed:

- A resource area covers a range of industries that have a joint identity and potential for improved prosperity and employment;
- A resource area most often includes industries comprising a network of primary producers, manufacturers, subcontractors and service systems. The industries in a resource area are mutually dependent because they together supply a specific group of products and cover large, stable areas of goods and services;
- The firms in a resource area are dependent on the same critical framework conditions (Ministry of Business and Industry, 1997).

This is the official definition of a resource area, and employing this definition, there are now six areas as well as a group of general supporting industries:

- *Food products*. This resource area covers agriculture (primary production); fish, meat, milk etc. (manufacturing); and consultancy, wholesale and retail trade related to food products (service industries etc.) The area as it is defined today is very similar to the agro-industrial complex described in section 9.2.1. It contains several of the industries found to be internationally competitive in the Porter studies.
- *Consumer goods and leisure*. This resource area covers e.g. apparel, electrical equipment,

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household articles, furniture and non-food consumables (manufacturing); catering, culture, hotels, personal services, wholesale and retail trade related to consumer goods and leisure (service industries). Here we find the furniture cluster, which also was found in the Porter studies and in the micro-based studies of particularly strong Danish industries.

- *Construction/Housing*, covering raw materials (primary production); building materials and supporting industries for construction (manufacturing); and contractors, skilled trades, building administration, cleaning, consultancy related to construction as well as supply of building products (service industries etc.).

- *Communications*, including printing industry, communication and media equipment, and supporting industries to communications (manufacturing); as well as media, post and telecommunications, services and wholesale and retail trade related to communications (service industries).

- *Transport/Utilities*, covering petroleum industry etc. (primary production); shipyards, manufacture of other transport equipment, suppliers of environmental equipment and suppliers of energy-supply equipment (manufacturing); vehicle maintenance and repair, road, sea, air and rail transport etc., water, electricity, gas and heating supply, sale of fuel and trade in waste matter as well as sale of transport equipment (service industries). Here we find the environmental complex found in the industrial complex study.

- *Medical/health*, covering medicinal products and medicinal technology and equipment (manufacturing); as well as pharmacies, health services and care of elderly and handicapped (services industries etc.). Here we find the pharmaceutical industry and the medico-health cluster identified in the Porter analysis.

- *General supporting industries*, which is an aggregation of sectors producing and supplying goods that either are so general in nature, that they cannot be asserted to one area, or they produce highly special equipment to several sectors in different resource areas. These general suppliers include metal industry, other production industry (manufacturing); and organisations, operational services, financial services, education and research, consultancy in general, various wholesale trades and well as public administration and other services (Ministry of Business and Industry, 1997, pp. 12-13).

One reason for the redefinition was the wish to incorporate the public sector, since in some of the areas the publicly produced goods are vital parts of the area. Services are no longer a separate

area due to the service sector being very heterogeneous, and in most cases actually providing services that are closely related to all other areas.

Another visible change is that communication is now an area of its own, where it before was a part of telecom/transport. This is due to the finding that a combination of communication and transportation did not function coherently. Secondly, it was also evident that communication was growing fast in volume as well as in importance, thus it could 'carry' an area of its own.

The resource areas, and the applied working method and analysis, are first of all aimed at formulating policies and identifying problems, future threats and strengths for the firms, which in turn leads to new policy initiatives.

9.4.1 A discussion of methodology

In a discussion of the strengths and weaknesses of the methodology used in the analysis of resource areas it is important to notice that many different methodologies are employed. The most central method used in the initial analysis was the qualitative and historical studies of the development and interaction in the respective resource areas. Another methodology that is often used in relation to the resource areas, is to measure positions of strength. Positions of strength are based on trade specialisation, and the general idea behind the method is to use the RCA index applied in chapter 7 to determine in which sectors a trade specialisation can be found.

As previously mentioned the resource areas, in their present form, covers the entire Danish economy. In the definition of an area the coherency, the interdependence, and the need for common policy conditions are stressed as factors delimiting a resource area. When we look at other studies of clusters in Denmark and in other countries, the scope of a resource area is considerably wider. During the process, both related to the initial division, but also in connection to the redefinition, the resource areas have been criticised for including more clusters within a single resource area, which has led to a situation where the coherency in some areas can be questioned. Second, because of the broad scope, it is questionable whether the interdependencies between firms and sectors in a resource area are all equally outspoken and important.

In relation to the findings in the previous chapters, the Porter method, as it has been applied in relation to the Danish research areas, lacks a focus on knowledge based relations. The user-producers type relations as identified in chapter 5 are in accordance with the research area boundaries, e.g. food and paper are both included in the food products area (paper as a supporting industry, much in accordance with the finding of paper as an innovation source for the food industry). Also telecom equipment firms and electronics firms, which also were found to be related in an innovative cluster in chapter 5, are included in the same resource area, the communications area. But the relations between generic knowledge sources, as business services and machinery identified in chapter 4, and their knowledge users, are not captured in a resource area clustering. The general finding is that the linkage concept is too wide in the resource area approach, which can make the important knowledge linkages 'drown' in the analytical picture.

Turning to the qualitative and historical studies of the relations in a resource area, the strengths are that most of the relations are intangible in the sense that they are hard to measure statistically. Many important relations will not show in input-output tables. Especially when a cluster, as in the Porter and resource area tradition, is understood as a highly complex interaction of several factors, causal relations cannot be measured; only the ex post outcome of the relations can be measured. Therefore qualitative interviews are perhaps - as also pointed out by Hirschman - the only way to bring about information on possible causal relations. In that context especially comparative studies are very useful since the importance of factors are more easily determined in the comparisons. The weakness is of course that in a complex world other factors than the ones stressed could be important, and often qualitative analysis is criticised for subjectivity due to the fact that the issues at hand cannot be measured.

9.5   Conclusions

It is obvious that theoretically based studies and practical policy actions do not always combine easily. While theoretically based studies aim at providing clarity and coherence in the analysis, policy making is concerned with 'muddling through' the complex reality. An example of this trade-off can be found in the history of the Danish resource areas, discussed in this chapter. On the one hand, it can be said that the areas are to some extent based on theoretically based cluster studies. On the other hand each resource area also has the function of acting as a framework for

dialogues between firms and public authorities. Hence, it would not be wise in a policy context to exclude some firms in certain sectors, because such sectors were not identified as a cluster or as a part of a cluster. Thus, this trade-off should be acknowledged, so that a balance between allowing for pragmatic policy making (with more than a single aim) on the one side, while not losing the theoretical foundation on the other, can be maintained.

The recommendation from the complex studies, that specific technology policies need to be replaced by a strengthened sector or complex policy aimed at improving vertical relations between sectors, has at least partly been followed in the resource area policies. Porter's methodology for identifying clusters is based firstly on competitive strengths, and secondly on linkages. This implies that the clusters in focus are clusters which are dominated by a flagship showing some degree of international competitiveness, and the linkages thus descends from this flagship industry. Following this approach the linkages are identified in a secondary manner, defining the 'nodal industry' first, and identifying linkages second. If linkages (expressed as vertical relations) are to be in focus, it seems more appropriate to identify linkages first, and then decide which industries are 'nodal' based on these linkages. As illustrated in chapter 7, there is a relation between linkages and international competitiveness (expressed as export specialisation), but it does make a difference weather the identification of linkages is first or second priority.

Of course the approach depends on the aim of the study, but if the aim is to increase the understanding of the role of linkages as bridges for knowledge exchange and development, then the focus has to be more narrow, as well as does the cluster concept, in order to avoid being too general in the discussion of key industries and the importance of vertical linkages.

Also there is a call for alternative measures of linkages in advanced economic systems. It is the claim of the present thesis that the need is primarily for a move towards a more dynamic expression of linkages and clusters. I propose to follow in the footsteps of Dahmén and his like-minded, who focus on clusters based on a systemic view. Clusters are in this context complexes of industrial interrelations that can be perceived as factors stimulating economic development through different push and pull effects as well as more indirectly by creating a stimulating environment (in geographical as well as economic space) in the lines of Marshallian external economies.

Disregarding the critical points, the Danish resource area policies have played an important role in directing an increased focus towards the role of interdependence in economics, and as such the policy initiatives are an important step towards a more system based policy approach.

Summary

The thesis takes off by claiming that the theoretical foundation for the study of technological interdependence and the role of interdependence in technological development is rather weak. This is characteristic of an emerging scientific field.

The thesis does not bring theory much further, rather the theoretical contribution lies in the discussion of the link between interdependence studies as they were expressed in traditional input-output theory, and contemporary (Schumpeterian) studies of the role of interdependence in technological development. This link has been largely ignored, based on the inherently static nature of input-output analysis. Just as Leontief's 'dynamic' input-output analysis was only a more complex method for comparative statics than traditional static input-output analysis, so is the present analysis also basically static. But the static analysis contributes to identifying the most likely dynamic areas in economic space by pointing to areas characterised by both intense economic transactions and a high knowledge level. Part I introduces some slight alterations of traditional input-output and linkage expressions, which make it possible to include technology and knowledge into the analysis. Thus the theoretical and methodological considerations of part I serve as a foundation for the empirical work of parts II and III, and is thus the general reference point of the following chapters. Additionally part I also provides an overview of history of economic thought in relation to interdependence studies.

Part I ends up with the conclusion in chapter 3, that a simple expansion of linkage specifications of the Hirschman-Rasmussen type, by including different knowledge indicators in the linkage specifications, is not a sufficient way to increase our knowledge of key knowledge industries in advanced economic systems, thus other methods are called for in order to understand potential dynamic interindustry relations. Accordingly part II attempts to identify these methods and measures.

In chapter 4 the focus is on linkages as sources of knowledge inputs at the industry level. Two supplementary methods are used, based on the same basic calculations but leading to a quantitative and graphical representation of linkages respectively. The main contribution of

chapter 4 is first that it presents the combination of different methods for measuring linkages, and second, that it develops the methods by introducing a broadened range of indicators to be applied in an analysis of this kind. The chapter applies the notions of direct versus indirect knowledge, the direct knowledge being generated internally while the indirect knowledge is acquired through the purchase of knowledge intensive intermediate goods and services. It is illustrated that the indirect, acquired, knowledge contributes considerably to the knowledge intensity of the products of traditional low-technology industries like textiles, food as well as non-business services. The chapter applies three different knowledge indicators: R&D expenses, patenting activity as well as formal training of employees, in order to provide a nuanced image of knowledge intensive and 'extensive' industries respectively, with the primary benefit of leading to the identification of business services as a very knowledge intensive industry. Apart from calculating the quantitative importance of indirect knowledge, chapter 4 also maps the central knowledge flows between knowledge sources and knowledge receivers. The primary knowledge receivers are non-business services and the food industry, while the primary knowledge sources are industries like machinery, business services, iron and metal and construction. The most knowledge intensive industry of all is the medical/pharmaceutical industry, but this industry does not play a major role as a knowledge source. Thus the most important knowledge sources are not necessarily the most knowledge intensive industries.

The methodological contributions of chapter 4 concerns the value from combining different indicators and methods in the knowledge linkage analysis. But chapter 4 rests heavily on the embodied knowledge assumption, and the methods applied are not capable of capturing knowledge linkages which are not based on economic transactions. Thus chapter 5 is an important supplement to chapter 4, as it analyses interindustry knowledge linkages based on survey data on product innovation flows. The first aim of chapter 5 is to analyse the extent to which the input-output based linkages identified in chapter 4 can be supported by interindustry flows of product innovations. In general, most of the linkages from chapter 4 can be found in one form or another in chapter 5. But a great number of new linkages/flows are also identified, which is interpreted as an expression of economic relations in general leading to innovative relations, while innovative relations do not necessary lead to economic relations to any notable extent. It is proposed that knowledge bases can be one explanation of this phenomenon, claiming that industries that are not

closely economically related can have some common features in knowledge bases.

Two main types of innovation (knowledge) sources are identified: i) source industries that supply firms in many different industries with product innovations, but do not in general get a lot of inputs to the innovative process from firms in their user industries ('generic knowledge sources'); ii) source industries that have their receivers of product innovations concentrated in one or a few industries, with firms in the user industries often providing inputs to the innovative process in the supplier industries; this is labelled a 'true interdependence' (of the Lundvall kind) between innovative producers and their users.

In part III the international perspective is introduced by applying OECD data. In chapter 6 the linkage discussion is explicitly placed in a national system of innovation framework. The chapter illustrates that the way technologies have developed seems to have influenced the clustering of relations today. The linkages, superficial as they in many respects are, can actually illustrate some fundamental differences in institutional set-up in different systems of innovation. Furthermore chapter 6 indicates that there is a relation between the industries which are heavily integrated into the system through knowledge linkages, and the industries in which a country is export specialised. Thus chapter 7 analyses the statistical relation between both backward and forward linkages and export specialisation in a number of OECD countries. The analysis of chapter 7 shows that linkages are significantly related to export specialisation for scale intensive and specialised supplier industries, while no significant relation can be found for supplier dominated and science based industries. The relation between chapter 6 and 7 can be summed up by stating that chapter 6 analyses whether there is a difference in the structure of interindustry linkages between nations, and chapter 7 analyses the implications of this difference.

As a final perspective on the linkage discussion, chapter 9, following the conclusions in chapter 8, discusses linkages in a policy perspective taking the by now well known cluster approach as the point of departure. The cluster approach ascribes its world fame to the work of Porter in the early 1990's. Technology is not an explicit factor in cluster studies of the Porter type, rather the criteria for being a dynamical cluster is international competitiveness. Porter-type cluster studies are included in the present work since they have played an important role from a policy

perspective, and as such have contributed to turning an increased attention towards the systemic -

interdependent - nature of economies.

Resumé

Det teoretiske fundament for studier af teknologisk interdependens og betydningen af teknologi for teknologisk udvikling er relativt uudviklet. Dette er karakteristisk for et videnskabeligt område, der endnu er i sin vorden. Nærværende afhandling sigter ikke direkte mod at udvikle dette teoretiske fundament, det teoretiske bidrag ligger snarere i diskussionen af forbindelsen mellem interdependens-studier, med udgangspunkt i traditionel input-output-teori, og nyere (schumpeterianske) studier af betydningen af interdependens i f.m. teknologisk udvikling. Denne forbindelse er hidtil stort set blevet negligeret p.g.a. input-output-analysens grundlæggende statiske natur. Leontiefs 'dynamiske' input-output-analyse var udelukkende en mere kompleks metode til komparative statiske analyser i f.t. traditionel statisk input-output-analyse, og den nærværende analyse er da også grundlæggende statisk. Men den statiske analyse bidrager til at identificere de mest sandsynlige dynamiske områder i det økonomiske rum ved at fremhæve områder, der er karakteriseret af både intensive økonomiske transaktioner og et højt vidensniveau. Del I af afhandlingen introducerer nogle mindre justeringer af traditionelle input-output- og linkage-udtryk, som muliggør inddragelsen af teknologi og viden i analysen. Del I udgør således det teoretiske og metodiske udgangspunkt for de empiriske analyser i del II og III. Del I byder endvidere på et teorihistorisk overblik over feltet.

Del I rundes af med, at der i kapitel 3 konkluders, at en simpel udvidelse af Hirschman-Rasmussen linkage-specifikationerne, via inkluderingen af forskellige vidensindikatorer, ikke bidrager tilstrækkeligt til at øge vores viden om vidensbaserede nøglebrancher i avancerede økonomiske systemer. Det er således nødvendigt at anvende andre metoder i bestræbelserne på at forstå potentielle dynamiske interbranche-relationer. Del II sigter således mod at identificere sådanne metoder.

I kapitel 4 fokuseres der på linkages som kilde til vidensinput på brancheniveau. To komplementære metoder, baseret på de samme grundlæggende beregningsmetoder, men resulterende i hhv. en kvantitativ og en grafisk repræsentation af linkages, anvendes. Hovedbidraget fra kapitel 4 er først og fremmest denne kombination af forskellige metoder til måling af linkages, og dernæst kombinationen af forskellige vidensindikatorer i denne type

analyse. Kapitlet introducerer en skelnen mellem direkte og indirekte viden, hvor direkte viden genereres internt i branchen, mens den indirekte viden erhverves gennem købet af vidensintensive 'halvfabrikata' (varer og tjenesteydelser). Det illustreres, at den indirekte, erhvervede, viden bidrager betydeligt til den totale vidensintensitet i produktionen i traditionelle lavteknologiske brancher, såsom tekstil, fødevarer og serviceydelser (excl. forretningsservice). Kapitlet anvender tre forskellige vidensindikatorer: FoU-udgifter, patenteringsaktivitet samt det formelle uddannelsesniveau for beskæftigede i den pågældende branche. Denne kombination af indikatorer skal bidrage til et mere nuanceret billede af hhv. vidensintensive og '-ekstensive' brancher, med den primære fordel at forretningsservice identificeres som en meget vidensintensiv branche. Ud over at beregne den kvantitative betydning af indirekte viden, kortlægger kapitel 4 også de centrale vidensstrømme mellem videnskilder og vidensmodtagere. De primære vidensmodtagere er serviceydelser (excl. forretningsservice) og fødevarebranchen, mens de primære videnskilder er brancher som maskinfremstilling, forretningsservice, jern & metal samt bygge & anlæg. Den mest vidensintensive branche i Danmark er medicinalindustrien, men denne branche spiller ikke nogen markant rolle som videnskilde. Dette illustrerer, at de vigtigste videnskilder ikke nødvendigvis er de mest vidensintensive brancher.

De metodiske bidrag fra kapitel 4 vedrører værdien af at kombinere forskellige indikatorer og metoder i en videns-linkage-analyse. Men kapitel 4 bygger i høj grad på antagelsen om, at viden indarbejdes i varer og serviceydelser, og de anvendte metoder er ikke i stand til at fange vidensrelationer, der ikke er baseret på økonomiske transaktioner. Derfor er kapitel 5 et vigtigt supplement til kapitel 4, da det analyserer videnslinkages mellem brancher baseret på survey-data om produktinnovations-strømme. Et af målene med kapitel 5 er at analysere i hvilken grad de input-output-baserede linkages, der blev identificeret i kapitel 4, kan underbygges af faktiske strømme af produktinnovationer mellem brancher. Generelt kan størstedelen af linkages fra kapitel 4 genfindes i en eller anden form i kapitel 5. Men der identificeres også et betydeligt antal nye linkages/strømme. Dette tolkes som et udtryk for, at økonomiske relationer generelt fører til innovative relationer, mens innovative relationer ikke nødvendigvis fører til nogen særlig grad af økonomiske relationer. Det antages, at vidensbaser kan bidrage til forklaringen af dette fænomen, ud fra den opfattelse, at brancher, der ikke er nært relaterede i økonomisk forstand, kan have overlappende eller korresponderende vidensbaser.

Der identificeres to hovedtyper af innovations- (videns-) kilder i kapitel 5: i) videnskilder, der leverer produktinnovationer til mange forskellige brancher, men som ikke modtager inputs til innovationsprocessen fra brugere i nogen særlig høj grad ('generiske videnskilder'); ii) videnskilder, der har modtagerne af produktinnovationer placeret i en enkelt eller få brancher, og virksomheder i disse modtagerbrancher leverer ofte inputs til den innovative proces i den innoverende branche/virksomhed. Dette sidste fænomen betegnes som 'sand interdependens' (i 'lundvallsk' forstand) mellem innovative producenter og deres brugere.

I del III introduceres det internationale perspektiv via anvendelsen af OECD-data. I kapitel 6 placeres linkage-diskussionen eksplicit i en national innovationssystem-ramme. Kapitlet illustrerer, at den måde, hvorpå teknologier er udviklet i historisk perspektiv, angiveligt påvirker den måde, hvorpå brancher er forbundet i clusters den dag idag. Linkages kan, på trods af at de på mange områder er overfladiske, illustrere nogle fundamentale forskelle i institutionelt set-up i forskellige innovationssystemer. Endvidere indikerer kapitel 6, at der er en relation mellem brancher, der er stærkt integrerede i systemet via videnslinkages, og brancher, der har et positivt eksportspecialiseringsindeks. Derfor analyseres den statistiske sammenhæng mellem linkages (både forward og backward) og eksportspecialisering i en række OECD-lande i kapitel 7. Analysen i kapitel 7 viser, at der er en signifikant relation mellem linkages og eksportspecialisering i skalaintensive og specialiserede leverandør-brancher. Der kan derimod ikke påvises en signifikant relation mellem linkages og ekportspecialisering for leverandørdominerede og vidensbaserede brancher. Kort fortalt er relationen mellem kapitel 6 og 7, at kapitel 6 analyserer, hvorvidt der kan påvises i forskelle linkage-strukturen mellem nationer, og kapitel 7 analyserer betydningen af disse forskelle.

Kapitel 9 byder på en afsluttende perspektivering ved, som en opfølger på konklusionen i kapitel 8, at diskutere linkages i et policy-perspektiv, med udgangspunkt i den efterhånden velkendte cluster-tilgang. Den berømmelse, clustertilgangen høstede i begyndelsen af 1990'erne, kan primært tilskrives Porter. Teknologi er ikke en eksplicit faktor i Porter-inspirerede cluster-studier, kriteriet for et dynamisk cluster er derimod international konkurrenceevne. Porter-clusters er inkluderet i denne afhandling, eftersom de har spillet en stor rolle i policy-sammenhæng, og derved har de bidraget til at skabe en øget opmærksomhed om den systemiske - interdependente - dimension af

en national økonomi.

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