THE RELATIONSHIP BETWEEN SCIENCE AND TECHNOLOGY IN EUROPEAN ADVANCED INDUSTRIAL ECONOMIES, 1980-2000

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THE RELATIONSHIP BETWEEN SCIENCE AND TECHNOLOGY IN EUROPEAN ADVANCED INDUSTRIAL ECONOMIES: 1980-2000

Adrian Stoian Petrescu PhD

University of Pittsburgh, 2003

Economists, policy analysts, and policy makers alike are puzzled by an intriguing fact regarding technological innovation in some advanced industrial economies. Europe as a whole, in spite of its relatively strong scientific performance, paradoxically does not fare so well in technological innovation. European wide policy initiatives in the early 1980s have sought to improve the worldwide competitiveness of Europe in high tech. They have focused much on improving Europe's capacity to apply its good science base in practice, resulting in increased technological advancement and implicitly in improved market presence and enhanced economic growth. Two decades after the initiation of the policies, some European countries do not conform to the expected relationship between science and technology, whereby strong performance in science shall lead to strong technological performance. This is even more puzzling as the UK, a historical stronghold of inventions and innovations, finds itself among countries with weak technology, or as Germany, a historical stronghold of scientific discovery, finds itself among countries with weaker than average scientific performance.

The relationship between science and technology is very much interdependent or symbiotic. The strength and primary direction of the relationship at a given moment in time varies largely by field of science or technological innovation, as well as across long periods of time. In this exploratory study, I identify plausible explanations for the puzzling relationship between science and technology in certain economically advanced countries. I find that:

(1) The science-technology link in a country may depend on the overall scientific and technological level of development in that country. The strength and interdependent nature of this link has a historical evolution that varies across fields of science and technology. The strength of the link between science and technology in a country is affected by scientific and technological specialization. Different technological fields have different scientific intensities, or degrees of building upon the science base. Specialization of countries across scientific and technological fields varies, making it natural for the strength of the science-technology link to differ from one country to another. The high technological specialization of a country may impact its technological performance more than its immediately current scientific performance does.

(2) High levels of foreign funded R&D in a country may mislead the measurement of the technological performance of that country.

(3) Dependence of a national economy on R&D intensive sectors may impact the image of that country in terms of its technological performance.

As there are plausible explanations for the puzzling behavior of the science-technology link in developed countries, I convert these explanations into a few suggested policy recommendations.

Dedication

First, I dedicate this very modest work to the many all-European pioneering scientists, inventors and innovators who are unfairly not sufficiently well remembered by the World's scientific and technical history due in part to their Romanian origin or work:

Conrad Haas (1509-1579)	Father of rocket principle
Nicolae Vasilescu-Karpen (1870-1964)	Father of the combustion pile
Traian Vuia (1872-1950)	Aviation pioneer
George (Gogu) Constantinescu (1881-1965)	Father of sonicity theory
Aurel Vlaicu (1882-1913)	Aviation pioneer
Henri Coanda (1886-1972)	Father of air-reactive flight
Aurel Persu (1890-1977)	Father of automotive aerodynamics
Herman Oberth (1894-1989)	Rocket science pioneer

and many many others...

Second, I dedicate this work to my parents, Viorica and Stoian A.T., themselves pioneering scientists and innovators, who have sparked, fueled and guided my interest in science and innovation. Their constant love and affection have helped me grow worry free.

Third, I dedicate this dissertation to my grandparents, Aurel and Maria, and Stoian and Elisabeta, whose own innovative work in their respective fields has sparked my interest in political science and diplomacy, and management and engineering respectively, and has provided me strong models to follow. I miss their lifetime of love and proverbial grandparents' spoiling. I wish they could all witness this moment.

Last but certainly not least, I dedicate this project to my daughter Darian Isabel (Mica) who, without even knowing it, has contributed most to it, for she has taught me what life is really about. I wish her the strength to further her family tradition and to enjoy being a knowledge seeker "out in the wilderness" herself.

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This project and many others I have started during my doctoral years with GSPIA would not have existed without the support, help, guidance or candid scholarly criticism of University of Pittsburgh Professors Michael Brenner, Phyllis Coontz, David Bobrow, Laura Hastings, Bob Donnorummo, Louise Comfort, William Mattlack, Sky Foerster, Simon Reich, and Angela Foster-Williams.

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Senol Duman, my dear friend, colleague and co-author of past, current and hopefully many future works has enriched beyond belief with his mind, wisdom and soul my years at GSPIA and GSPH and beyond. I never could have put *"punct"* (full stop)

without him. His true friendship and partnership in finding answers to new puzzles will always be appreciated.

I could never thank enough our dear friends Ed and Bernice Born who have been like a second family to my wife, our daughter and me through the hard adaptation to a new life and culture, and through the difficult balancing of parenthood and doctoral studies. Their support, advice, wisdom and the models of kindness and friendship they represent to us will always guide me. They will always remain our beloved "Pittsburgh grandparents" of Isabel.

I am thankful to all my friends and colleagues worldwide for standing behind me and for their constant friendship even from so much afar throughout these years.

I thank profoundly my friend Professor Doug Chaffey of Chatham College and my colleagues at Indiana University of Pennsylvania and Eastern Michigan University for the support, advice and encouragement they have given me in my teaching and research throughout the last few years of my doctoral years.

Finally, I wish to express my appreciation to my wife Claudia.

Canton, MI, April 5, 2003

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Motto:

"There is no national science
just as there is no national multiplication table."

Anton Chekov (1860–1904)

1. Introduction

In Simon Kuznets's[1] words, a distinctive feature of modern industrial societies is their ability to apply to the economic sphere systematized knowledge derived from scientific research (Rosenberg, 1982, 141)[2]. In other words, in advanced industrial economies a strong scientific base should lead to strong technological and economic performance.

There seems to be a puzzling and yet so far not fully explained behavior of the relationship between science and technology in many advanced industrial economies. The European Commission finds that Europe's relatively strong scientific performance is not mirrored in Europe's weaker technological performance. In some EU member states strong national scientific performance does not translate into the expected high technological performance. Conversely, certain EU countries have strong technological performance even though they do not have an equally strong national scientific performance[3].

1.1. Brief History and Importance

The European Communities adopted in 1981 policies meant to close the gap in R&D expenditures and innovation between Europe and the US and Japan. These policies consisted of three main parts: (1) the abandonment of "national champions" states' policies of support for national high tech related firms; (2) the establishment of Community sponsored pre-competitive R&D programs opened for any interested party from the industry and/or the academia; (3) the establishment of the premises for a trans-European cross domain of activity network between academics, beneficiaries and suppliers of high tech research or basic research with direct technological applicability meant to facilitate a more effective exchange of information pertinent to European R&D in high tech (Carli 1983, Molina 1990, Sandholtz 1992, Petrescu 1998, 1999).

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[1] See Kuznets 1966, chapter 1, cited in Rosenberg, 1982, 141.

[2] Rosenberg however goes to a great length in demonstrating that the relationship between science and technology is much more complex, primarily one of interdependence, with the strength of the influence from science to technology or from technology to science varying in time, as I discuss in chapter 2.

[3] The puzzling behavior of the science-technology link in Europe has been referred to as "the European innovation paradox" (ERSTI 1994; ERSTI 1997, XIII and 175). However, the notion of the European Innovation Paradox is broader in its content, as analyses of the paradox recognize the fact that innovation is also affected by other factors than solely by the strength of the science base. In chapter 2 I present some of the factors affecting the paradox, inside and outside the relationship between scientific and technological performance.

Implementation of these policies started in 1983. A re-assessment process and a set of recommendations for continuation/enhancements of these policies or programs were conducted after the first two years and every four-five years later on. Part of the policies are today best known as the Framework Programmes (FP), numbered from 1 to 6. Notably, the policies content often changes from one FP to the next, in direct accordance with the changes in priorities perceived by European policy-makers. Thus, a program meant initially only to facilitate an increase in Europe's capacity in innovation has inherited later in its development many of the other components of European policies, from regional integration to social welfare. Both the content of the policy interventions and the evaluation criteria for assessing their success have been therefore adapted to mirror the new objectives included in consecutive versions of the FPs.

The functioning of two links, the first from scientific performance to technological innovation, and the second from there to improved competitiveness as one measure or driving force of economic growth[4], were some of the fundamental assumptions behind these policies. Moreover, they remain the basis for the much-enhanced programs and policies that Europe has implemented since and are the core assumptions behind the plans to further these policies and programs even more with the recently-initiated European Research Area (ERA).

As any European Union official, politician, or even some EU skeptics will agree, these measures and policies are not primarily targeting an abstract notion of technological competition or economic growth for their own sake. Rather, the implication of improved quality of life, including through maintaining or establishing European economies capable of sustaining the welfare state, is at the core of the need for these policies.

A comprehensive body of literature explains why member states have preferred the new programs against their traditional nation based "national champion" approach (Sandholz 1992), or what has made the policies change in time (Peterson and Sharp 1998), or even the vast (if not primarily determinant) impact of such industry initiated action on the very establishment of the European Single European Act (SEA) of 1987 and later of the 1992 European Project itself (Green Cowles 1994).

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[4] For an analysis of the interplay between the elements of this relationship, inside what has been called the "chain-link" model of innovation, see Kline and Rosenberg (1986). I describe the model in more detail in Chapter 2 herein.

On the policies impact front, Commission reports find repeatedly[5] that while the implemented programs have proved successful, Europeans still lag behind their competitors in many high tech sectors, while bridging the gap or even leading the world in some sectors. These reports justify most often the continuation of existing policies combined with new enhancements, or with an increase in funds and redefinition of core objectives for the respective programs. The latest such major new policy initiative is Europe's recent drive to establish the European Research Area (ERA), one of the most recent items on the EU's policy agenda, past the last major achievement which has been establishing the Eurozone.

In designing the appropriate policy directions for the ERA, as well as in determining what the proper policies applied to future new member states shall be, experts continue to try to address and explain the reasons for Europe lagging behind in innovation. These questions go beyond simply recognizing Europe's lower R&D expenditures, but seek an understanding of the reasons for consistently lower rates of return in innovation for those expenditures. Parts of the reasons sought are related to the puzzling behavior of the science-technology link in Europe. In particular, some European Union member states do not conform well to the expected application in technology of their good science base, while others have a strong technological performance even in the absence of a current strong scientific performance.

A good understanding of this puzzle would therefore drive closer to optimal policy recommendations for the ERA. The issue has become even more pressing today, not solely for the same reasons it was important more than two decades ago, but as the European Union undertakes the responsibility of supporting the economic growth of its new acceding members, invited to join the Union by 2007. The ERA is perceived to encompass new future member states too. Countries in Central and Eastern Europe have already been strongly co-opted in the EU's scientific and technological efforts since the early 1990s. Thus, the success or lack thereof of policies tested in the EU in the past two decades may affect the future success of boosting economic growth in Central and Eastern Europe as those same policies or new policies are adapted and re-enacted.

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[5] See for example ERSTI 1994 and ERSTI 1997.

1.2. Problem Statement

In a 1997 comprehensive report, the European Commission writes:

> "[t]here is a growing perception that Europe's science and technology (S&T) system is in a paradoxical situation. Although Europe's educational and scientific research base is acknowledged to be of high quality, it seems to be failing to convert this advantage into strong technological and economic performance." (ERSTI 1997, 175)

Moreover, a similar puzzling behavior of the relationship between scientific performance and technological performance also occurs among different EU member states. In the same report, (ERSTI 1997, XIII, 175), the European Commission finds that:

> "the paradox[6] is most clearly confirmed for Belgium, Greece, Spain, Sweden and UK, countries with high scientific output, but below average technological returns on investment. [...] Austria and Germany appear to be technologically successful without any strong science-push [...]" (ERSTI 1997, XIII)

Only the remaining EU member states conform to the theoretical expectations. At one end, "France, Italy and Portugal perform below average in both science and technology output" (ERSTI 1997, XIII), albeit their below-average performance is not easily explained either. Meanwhile, Denmark, Finland and the Netherlands, "the best performers, [which] boast high levels of both patents and publication output" (ERSTI 1997, XIII) are the only EU member states conforming to the theoretical expectations in a positive way.

The problem for consideration in this study is therefore the weak relationship between scientific and technological performance in European Union member states.

For clarification, scientific performance is measured as the efficiency of a country's efforts in basic science, while technological performance is measured as the efficiency of a county's efforts in applied research. The efficiency of a country's efforts in basic scientific research is usually measured with scientific propensities[7]. A good measure of the efficiency of a country's efforts in technological applied research is usually technological propensity[8]. The reasoning behind using these measures is that

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[6] See footnote 3 above.

[7] Scientific propensities are calculated as scientific publications per full time employed (FTE) non-business research scientists and engineers (RSE). There are multiple methods to calculate it, such as the direct year method, the time lag method and a method considering the depreciation in time of work performed. For a detailed presentation of these methods, see appendix 3.

[8] Technological propensities are calculated as patent activity per business expenditures in R&D. The same different methods exist, the direct year method, the time lag method and the depreciation method. See

non-business scientists contribute to basic science whereas business R&D expenditures contribute to technological innovation.

1.3. Research Question

In this work I take the stance that the puzzling behavior of the science-technology link in European advanced industrial economies has plausible explanations. The research question then becomes:

> What are some of the plausible explanations for a weak science-technology link in European advanced industrial economies?

The generally accepted view among scholars in science and technology policy and the economics of innovation is that the relationship between scientific performance and applied technological achievement is more complex than a simple "linear" one-way relationship. Rather, a model characterized by multiple influences and feedbacks inside the broader relationship between scientific and technological knowledge, markets and society seems to be the case. This "chain-link" model (Kline and Rosenberg 1986) describes a complex relationship of interdependence that evolves in time and is also specific to the "age" of the scientific and technological field in question.

1.4. Plausible explanations for a weak science-technology link in Europe

When looking at the distribution of scientific publications across sectors in Europe and the US, I found (ERSTI 1997) for one example that Europe has reached the US's 1980 percentage of publications in engineering from total (14.4%) in 1992. Publications in engineering fields are more likely to be more strongly correlated with patent activity than the rest of scientific publications. Furthermore, different technological fields have varying degrees of relying on science. In many more traditional technological fields, the underlying science base has been taken into account some time ago, or less new science is necessary to further develop new technologies. Thus, the distribution of scientific efforts by field of science becomes a good plausible explanation for the weak science-technology link in Europe's case.

A strong national science base may be indeed needed as a predetermining condition for strong national technological innovation. However, the history of inventions and science abounds in major examples whereby technological advancement

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footnote 7 above.

has lead to scientific discoveries that in turn have lead to further technological developments, that have further created the need for and have facilitated new scientific discoveries. At the same time, cross-countries scientific transfers have most often been the norm.

In the past innovation has often lead to scientific discovery, which in turn has facilitated further technological innovation. Today more than ever tremendous technological advancement is necessary to support research efforts in basic science (Rosenberg 1982, 141-2). Modern fields of innovation such as biotechnology, genetic engineering, pharmaceuticals or nanotechnology are more and more dependent on intense scientific advancement. Studies on the science-technology link suggest that there is a complex interdependent relationship between science and technology (Rosenberg 1982, Kline and Rosenberg 1986, Todd 1993). As technology is a form of knowledge in itself, in many "classic" fields of innovation, technological performance often develops upon itself, without the need for as much new scientific discovery.

Different countries focus their efforts, or specialize, in different scienctific and technological fields. As different fields of innovation are more or less dependent on new science, it follows that the strength of the link between science and technology in a country is influenced by the scientific and technological specialization of that country.

Technological advancement has been stronger in countries with a well developed technological tradition and capacity, likely to be able to apply more efficiently into inventions and innovations knowledge originating in the general scientific pool developed in other countries.

Flows of intangible capital[9] may affect both the strength and the image of the science technology link. Levels of foreign funded R&D in Europe become significant in the past two decades. These flows may put certain EU member states at a disadvantage in image as technological performance becomes underrepresented by national patent outputs, as some patents become controlled from outside their country of origin.

While science and technology transfers may be universal in nature, both scientists and innovators do tend to flow towards "attracting poles", usually centers of intense scientific discovery or centers of innovation in top tier developed countries. R&D funds also follow a pattern of being attracted towards centers of intense scientific or technological activity. These are now represented mostly by the US and several EU member states in just the same way as Britain, France, Austria or Germany have attracted top scientists and engineers all throughout the 18th and 19th centuries. Such flows of highly skilled human capital also affect the strength and the changing nature of the link between science and technology. The link may weaken in countries with high outflows and it may strengthen in countries with high inflows of highly skilled scientists, engineers and technologists.

National economies may rely more or less on R&D intensive sectors. As an economy relies more on R&D stock than on capital and labor, this translates in higher relative expenditures in R&D when compared to economies that rely less on R&D intensive sectors. These differences may make economies relying more on R&D intensive sectors look surprisingly poorer in terms of their technological performance, as technological performance is usually measured as patent activity per business expenditures in R&D.

1.5. Implications

I conclude that there are plausible explanations for the puzzling behavior of the science-technology link in Europe's case and within Europe. The symbiotic and field variant chain-link nature of the relationship between science and technology, scientific and technological specialization, and historical scientific, technological and economic development of countries, yield a different strength or primary direction of influence of the link in different European advanced economies.

The most puzzling cases, the UK and Germany, are most likely explained through the UK's latest specialization in advanced technological fields requiring more scientific advancement, such as biotechnology, compared to Germany's traditional specialization in fields such as engineering and chemistry which require less new science but more previous technological innovation for succesful new technological improvements.

For many of the smaller EU member states, the relationship between scientific performance and technological performace functions as expected. Improvements in the scientific performance of Portugal, Greece and Ireland, driven in much part by increased knowledge spill over facilitated by the EU and national policies supporting cross-country

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[9] Intangible capital encompasses factors of production other than labor and capital. They are R&D

cooperative agreements and tighter relations between centers of science and industry centers of technology, have lead to the expected increase in the technological performance of these countries.

Across the study period, 1980-2000, most countries conform to a convergent trend of moving in time towards a stronger science-technology link.

There is however much variance as to the speed of this trend from one country to another, with Belgium managing to build the fastest increase in its technological performance based on a relatively stable in time scientific performance, or with Sweden regressing somewhat in time in its scientific performance but maintaining an average level of technological performance in spite of this "regress" in science. France alone is apparently lowering in time its technological performace at relatively constant levels of its scientific performace. This may be the result of France undertaking innovation in new fields with higher levels of dependence on science, or scientific intensities.

The EU average stays rather unchanged over the study period, with a modest trend towards increased scientific or technological performance. This is perfectly natural as both convergence and divergence occurs among EU member states. Countries move towards a stronger science-technology link from different previous behaviors of the link, making the science-technology link for the EU as a whole change only little. European wide programs supporting innovation and amplifying cross country cooperation and exchanges in both science and technology may have the effect of reducing variance in historically different technological potential of EU member states.

However, as technology advancement is also in much part driven by access to markets, access of European firms to much larger markets has been facilitated much by the Single European Act of 1987. It is probably too early to measure the effect of these major changes of market conditions on the strengthening of Europe's overall ability to better transform its strong science base in improved technological capacity. Nonetheless, the opening up of new markets in Central and Eastern Europe, as well as access to previously undersused highly skilled scientists and engineers there may contribute to the further improvement of Europe's technological capabilities.

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expenditures, or stock, human capital, knowledge stock. See chapter 2.

2. Literature Review and Conceptual Framework

Looking at the relationship between science and technology in Europe requires determining how the link relates to economic development. I first start with a description of the puzzling behavior of the science-technology link in Europe. To introduce the complexity of the link between science-technology and economic growth, I look at how science and technology affected two most major events in the recent history of mankind, the first industrial revolution, and the post-industrial revolution.

I further survey some of the pertinent literature on the relationship between science and technology, as well as between technological performance and economic growth. I find, along with Bernal (1944, 1971), Rosenberg (1982), Kline and Rosenberg (1986), Todd (1993) and others, a complex nature of the link between scientific and technological advancements. I outline some characteristics of the relationship between science and technology in time, and across fields and different degrees of economic development. I examine the influence of science and technology on markets and economic growth, as well as on military strength of nations and their political or economic power, as well as the reversed influence, by these factors back on science and technology. I end this section with a set of explanations available so far for the puzzling lower technological performance in Europe and for the puzzling behavior of the science-technology link in European advanced industrial economies.

2.1. Inconsistency of science-technology link in advanced industrial economies

The puzzling behavior of the science-technology link in Europe means that the European Union's strong scientific performance does not seem to translate in an equally strong technological performance. Meanwhile, Japan's higher technological performance occurs even with a lower scientific performance in Japan (ERSTI 1997, 164).

The US case seems to be the only one supporting the notion of a strong link leading from scientific to technological performance. The EU and Japan both seem paradoxical cases, only in different ways. Identifying factors that may affect the different functioning of the science-technology link inside the EU may lead to (1) a better policy analytical ability to address the complex nature of the science-technology link in modern economies and to (2) the translation of such knowledge into more informed policy recommendations.

The European Commission has identified a puzzling behavior of the science-technology link in Europe[10] (ERSTI 1997, XIII, and Chapter 4.). In Figure 1 I present the four categories of EU member states by their scientific and technological strengths.

		Technology	
		Weak	Strong
Science	Weak	Portugal, Italy, France ↓S, ↓T **Strong link** science-technology	Germany, Austria ↓S, ↑T **Weak link** science-technology
	Strong	UK, Spain, Sweden, Greece, Belgium ↑S, ↓T **Weak link** science-technology	Denmark, Finland, the Netherlands ↑S, ↑T **Strong link** science-technology

Figure 1: Inconsistency of science-technology link among EU member states

In the cases of the UK, Spain, Sweden, Greece and Belgium, above average scientific performances (marked with ↑S) do not yield equally high technological performances (marked with ↓T).

Conversely, Germany and Austria have better than average technological performances (↑T) without having strong scientific performances (↓S). The paradox then becomes defined in terms of an unexpected weak or non-existent link between scientific and technological performances.

The other EU member states conform to the expected link between scientific and technological performance. In the positive case, Denmark, Finland and the Netherlands manage to take advantage of their high scientific performance translating it into high technological performance. At the other end, in Portugal, Italy and France, lack of scientific performance translates into below average technological performance.

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[10] This puzzling behavior of the science-technology link is usually referred to as the European Innovation Paradox. (ERSTI 1997, XIII, 175). See footnote 3 above.

2.2. The relationship between science and technology in the "early days"

The invention of the steam engine[11], the driving force of the first industrial revolution, made the development of the science of thermodynamics possible. In Feynman's words:

> "Thermodynamics Science began with the analysis made by the great French engineer Sadi Carnot (1796-1832) in his genial paper *Ideas about motric of fire and machines capable of developing this power* (1824), of the problem: how should we build the best and the most efficient machines? This constitutes one of the few famous cases in which engineering had a contribution to physical theory." (Feynman, 1966).

The German engineer Clausius wrote his first and second laws of thermodynamics in 1850 based on Carnot's theoremes (Bejan 1988). Those principles were applied in Germany by Otto in 1876 and Diesel in 1892 to the Otto and Diesel internal combustion engines[12] (Heywood 1988, xvii). Here science has preceded technology and made invention possible.

Nonetheless, the science base necessary for the invention of the Otto engine in France and Germany and of the Diesel engine in Germany was initiated and developed based on the thorough study by Carnot in France of an invention precedeing it, the steam engine, originating in Britain.

Similarly, Rankine wrote the theories behind the steam engine thermodynamical cycle only in 1864, almost a century after the invention in need for a scientific explanation was perfected by Watt in 1770, following Newcomen's[13] 1712 improvement of Savery's original crude steam engine of 1695 (Bernal 1944, 25).

Inventions and innovations, originating not as much in well developed science unavailable at their time, but rather in the ingenuity of pioneers faced with a practical problem, has in this case changed dramatically the nature of economic and social

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[11] The steam engine was invented by Savery in Britain in 1695 (Bernal 1944, 25).

[12] Scientifically, but also in part technologically, the Otto thermodynamical cycle was actually invented by the French engineer Beau de Rochas (who also owns the patent) in the 1860s, as he tried to build a similar engine. Unlike Otto later on, Beau de Rochas did not succeed. Bernal (1944) uses this example as a case of scientific transfer from France to Germany. Germany's more intense industrialization made the successful application in practice of the Beau de Rochas/Otto internal combustion engine possible. The internal combustion engine has driven economic success (and in much part the second industrial revolution and its many social implications) much past the borders of either Germany, France or Britain, through the US's Henri Ford's early 1900s vision of mass producing automobiles.

[13] Newcomen's design added the use of pistons and cylinders, the latter built using canon-making technology.

systems, just the same as they have created new puzzles for scientists to solve. In other words,

> "[i]t was in Leads, Manchester, Birmingham, Glasgow and Philadelphia, rather than Oxford, Cambridge and London, that the science of the industrial revolution took root." (Bernal 1944, 25)

2.3. Relationship between science, discovery and innovation and economic growth, military power and future technological innovation and scientific discovery

The steam engine allowed for the British Royal Navy to take control of the seas, and in colonies also control of the land through the establishment of railroads. Yet, the largest steam locomotive ever, the Pacifica, was built in the US and has too contributed to facilitating US historic economic growth through a better access to the US's vast territories.

More to the present, as the information and communications technologies also become a factor considered of equal importance with the steam engine for shaping the post-industrial revolution, it may help to consider briefly the history of making computers and the Internet possible. The Difference Engine of 1821 created by the British mathematician Charles Babbage (1791-1871), perfecting the reliability of the much too crude calculator of Blaise Pascal of 1642, established the principles of digital computing.

It was again military need that made Babbage's original invention become the ENIAC (created in 1945), through financing for the US Ballistic Research Laboratory and with work performed with the Moore School (created in 1945), indeed only after the actual first computer created by Atanasoff and Berry in 1939 at Iowa State University[14].

After the "Personal Computer revolution" of the 1980s, and facilitated in large part by it, a modified ARPANET (the US Department of Defense precursor to the Internet), became in time the medium for new business practices that is the Internet today[15]. This change used contributions of knowledge and innovation by Paul Baran (1926-) for digital packet switching, Vannevar Bush (1890-1974) for the principles and

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[14] Much conflict developed later over the patent, finally attributed to Atanasoff and Berry in court, as the invention patent never got applied for initially by Iowa State University. The dispute was with John von Neumann, John Mauchly, and Presper Eckert, the joint creators of ENIAC.

[15] It is very interesting to note that a strong hike in the US patenting activity occurs in the 1990s, considered to be explained in much part through the initiation of a new trend, patenting of Internet based business practices. Compared to patents in fields of technological innovation requiring much scientific research,

precursor of today's ubiquitous HTML, or hypertext markup language, and Tim Berners-Lee of the UK working at CERN in Switzerland for the URL, or universal resource locator[16], inventions and innovations that combined make the World Wide Web.

The "market" applications of these technological inventions, and their political and social implications are widely cited, as (1) the steam engine is deemed the father of the first industrial revolution, but also a strong facilitator of the British empire domination, further (2) the computer is deemed the facilitator of the post-industrial revolution, but also at the core of today's US military superiority worldwide, and finally (3) the World Wide Web (indirectly an unintended consequence of the ARPANET) is deemed the facilitator of the so called "New e-Economy", but also a facilitating medium for a new type of war, cyber-warfare.

These examples leave one with the unanswered question: is technological advancement driving economic growth for its own sake, or does economic growth often times become a collateral effect of otherwise military-driven technological advancement?

Scientific discovery leads to further technological innovation and improvement. Markets and profits as well as nations' need for military and economic power drive the search for and application of technological innovation. However, often market assessment and the need for continued profits from older technologies, or the high risks involved in imposing the new technologies in the market may block temporarily the application of available new technologies. Social and political pressures may also affect timing of introduction of new technologies.

Based in much part on Bernal's comprehensive analysis, and on half a century of economists trying to understand the endogenous factors of economic growth, Kline and Rosenberg (1986) propose their "chain-link" model of the relationship science-technology (both as intertwined forms of knowledge)-markets-economic growth.

In contrast with the strong technology-science link of the early years of the industrial revolution, today Rosenberg (1982) finds that much more science is required to sustain technological innovation. The speed of the influence from technology to science

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such as biotechnology, these patents in business practices cost much less. When aggregating all patents, the US overall effectiveness in patenting tends to look much better in the 1990s due in part to this trend.

[16] Berners-Lee, guided by an open source philosophy, never took steps to gain intellectual property or other commercial rights for the Web. The patent for the first Web browser using technology developed in part by Berners-Lee belongs to Mark Andressen and Eric Bina. (MIT 1999)

and back to technology may have changed. Does the application into practice of science and technology as well as the underlying nature of the relationship change too?

Technological knowledge builds not only upon new science but very often upon previous technological knowledge and traditions.

In time traditional fields of technological advancement become less dependent on new science, and more dependent on the self-perpetuating nature of innovation through creative accumulation (Schumpeter Mark II innovation regimes[17])

In contrast, newer fields of technological advancement are both more dependent on new science and more intertwined with the development of new science. In these new fields scientific advancement is driven by the very need for technological advancement.

In other words the speed of functioning of the chain-link is accelerated in new high tech fields, while the scientific intensity of these new technological fields is also higher.

Market sizes drive sizes of profits, and the economic capacity to promote further both technological and scientific advancements.

2.4. Economists view of the relationship science-technology-economic growth

A survey of the framework of theories addressing economic growth finds for the past century a strong disciplinary evolution in economics, from classic economic growth theories, through neo-classical economic growth theory, neo-Schumpeterianism (Soete and Ter Weel 1999), and endogenous growth theories (Romer 1994).

This evolution has constituted what Abromovitz describes very well as the search for minimizing our ignorance, stemming from the neglect in classic economic growth theory of "the whole intangible side of total capital accumulation", all still lumped together in the "big Residual" that used to be total factor productivity (Abramovitz 1993, 218).

An essential feature valid across all of the four latter categories is the recognition that the role of intangible capital may be much larger than the role of traditional factors of production, labor and capital. In effect, the past fifty years or more of economic theorizing have shown beyond any doubt that the sum of human capital, R&D driven

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[17] In his classic work Schumpeter defines two different innovation regimes, one by "creative destruction", called a Mark I regime, and one by "creative accumulation", called a Mark II regime. See section 2.4.2. below.

knowledge creation, and technological transfers through foreign direct investment and trade have[18] the strongest influence on economic growth, while classic (tangible) factors of production do not drive growth by themselves but only facilitate it in the presence of the right amount of the intangible factors of production.

2.4.1. Science, technology and markets

According to Kuznets, a characteristic of advanced economies is their ability to transform scientific knowledge into economic growth through technology (Kuznets 1966, cited in Rosenberg 1982, 141)

However, Rosenberg (1982), considering that technology itself is applied knowledge, finds that once initiated, technology can develop based in much part upon improving applied knowledge itself, with a more limited need for further input from the science base. The relationship between science and technology changes in time with the evolution of both applied and scientific knowledge in a given field. New technological fields rely more on the science base, just the same as advancements in such new fields require a stronger input from scientific discoveries.

According to Kline and Rosenberg (1986), the relationship between science, technology and the economy, society and markets is a more symbiotic or interdependent one than a simple linear relationship stipulating that strong science leads to strong technology. Their chain-link model suggests a relationship of multiple feed-backs and cross influences between the elements, whereby:

1. Technological inventions facilitate advancements in science—understanding how and why inventions work[19]
2. Science facilitates new technological innovation/inventions--optimizing, improving and applying[20]
3. Markets drive technological advancement and their application. Decisions on pursuing technological advancement are profit driven. These decisions may at times accelerate or impede the pursuit of the application of certain technologies into marketable products.

Interesting enough, in a US study, "Project Hindsight" (AAAS 2000), the functioning of the science-technology component of the chain-link on US defense related

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[18] Debates continue as to the relative influence of these factors compared to one another, as well as on their additive or non-additive nature, notwithstanding cross-correlations between them that still need to be honed out in meticulous econometric models.

[19] See Carnot example above

innovations was rather disproved, with only 0.3% of 700 major technological events having a direct connection to or dependence on basic science. At the same time, another US study has found that in contemporary times there is a minimum of nine years between a scientific discovery and its application in practice through technological innovation. When compared to the much longer times needed for mutually supported advancements in science and technology centuries ago, this finding confirms in part Rosenberg's (1982, 141-152) view that the science-technology link is changing its nature in time. It also confirms Bernal's presumption that the mutual interdependence "spiral" between science and technology speeds up in time (Bernal 1944, 1971).

2.4.2. Innovation regimes

Joseph Schumpeter's classic Mark I and Mark II modes of innovation are recently fueling a new breadth of studies of the link between innovation and market success, and further with sustained economic growth (Soete and Ter Weel 1999).

Schumpeter's Mark I mode, through "creative destruction" by small independent innovators finding niches in markets, is however often neglected. The focus is more often on technological progress facilitated by large multinationals innovating in Schumpeter's Mark II mode, through "creative accumulation", or sustained innovation facilitated by a cascade effect and the re-investing in R&D of relatively large profits obtained from previous innovations marketed in already well established market presence.

2.4.3. R&D and Economic Growth

R&D outputs, whether in applied science or technological innovation, are recognized as one of the most important parts of intangible capital contributing to economic growth. Economists have focused on measuring the impact of R&D on growth, as well as on determining the factors that affect the efficiency of R&D expenditures.

The literature on R&D and productivity agrees that (1) R&D expenditures can be treated as an R&D stock factor, in production functions usually used to model economic growth, and that (2) this approach is for now the best modeling of the R&D's impact on economic growth available in spite of the many known problems embedded in it. (Griliches 1998, 2000).

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[20] See Otto and Diesel engines examples above

2.4.4. Knowledge spill-overs

A relatively recent trend in the economic study of R&D is, next to the traditional building of cross-countries comparative models, the systematic study of knowledge spill overs within countries inside and across sectors, and particularly from other countries and other sectors, whereby country studies have proven the relatively large contribution such spill overs may have on technologically driven economic growth (Soete and Ter Weel 1999, Verspagen 1997).

As this is a recent trend, across countries and sectors analyses using technology flow matrixes to determine the differing levels in which these spill overs affect different sectors and countries are still rare (Verspagen 1999). Knowledge spill over may occur primarily in technology, more so than in basic science. Economists explain this difference through a process of "learning by doing" (Arrow 1962) or of "learning by using". A high scientific base is not by necessity required for all technological advancement. Alternatively, technology spill over may lead to new advances in science as well.

2.4.5. Science and technology moves towards attracting poles

In 1993, in the middle of the new endogenous growth revolution in economics, Romer concludes in the end of his "Origins of Endogenous Growth" article that:

> "In evaluating different models of growth, [Romer has] found that Lucas (1988) observation, that people with human capital migrate from places where it is scarce to places where it is abundant, is as powerful a piece of evidence as all the cross-country growth regressions combined." (Romer 1993, 19)

This seems to apply equally to scientists and technologically innovative individuals. Indeed, through field work with small innovative European firms I have found that in the late 1990s many highly innovative technology small businesses in Europe often had a strategic objective to grow past a certain limit that will open up doors for their opening branches in the US. From these US branches they could further benefit from the growth potential in the US, including possibly through Initial Public Offerings (IPOs), and even from the selling of the firms. This latter strategy outlines essentially the .com model, much praised, used and somewhat abused in the late 1990s in the US[21].

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[21] The .com model is considered in much part a contributing reason for the overvaluation of technology

As Romer continues,

> "this kind of fact, like the fact about intra-industry trade or the fact that people make discoveries, does not come with an attached t-statistic. As a result, these kinds of facts tend to be neglected in discussions that focus too narrowly on testing and rejecting models." (Romer 1993, 19-20).

2.4.6. Development of science may follow influxes of technology

Studying Australia's late nineteen-century scientific and technological development, Jan Todd (1993) concludes that:

> "contrary to common assumptions, an empirical focus on science-technology links suggests that scientific and technological dependencies were not running in parallel, but out of phase, with science as the laggard" (Todd, 1993, 33).

Todd's explanation of the development of the Australian scientific base following "colonial" driven technology advancements as in:

> "it appears that science in the late-nineteen-century Australia may have developed more from its interaction with technological systems than from its own internal dynamics" (Todd 1993, 33)

suggests the possibility of a more complex nature of the relationship between science and technology than simply assuming that good performance in science should lead to good performance in technological advancement (Todd 1993, 33).

Similar developments have lead to Japan's own technological strength after World War II, through the influx of technology from the US (Nakayama 1991, Bartholomew 1989, Anderson 1984). Germany too has received a new influx of US technology after World War II. In both cases, the basis for taking advantage efficently of the new influx was already present. In the German case a strong scientific base was also in existence. In both of these cases, such influxes of technology have lead to sustained economic growth, which in turn has further facilitated technological innovation. The interest as well as the US's measures in supporting Japan's scientific development has followed, mirroring in Germany's and Japan's cases Todd's findings from earlier on in history with respect to the British involvment in Australian technology and science.

2.5. Characteristics of the complex relationship between science and technology

Based on all of the above, and consistent with Rosenberg (1982) one cannot find easily an absolute rule about the temporal precedence between science and invention. A conclusion even more interesting as it is based in part on a few inventions of such

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driven markets in the late 1990s and early into this decade.

magnitude that they have revolutionized the whole development of mankind for centuries to follow.

The above practical examples of inventions following or preceding (and facilitating) scientific discovery confirm the notion of an interdependent relationship between science and technology.

Science seems to relate to technology in complex ways. The relationship is much more likely a symbiotic one rather than a one way link only from scientific performance to technological advancement.

The following few synthetic points may be drawn as characteristics of the relationship between science and technology:

(1) The link between science and technology is most often an interdependent one (Rosenberg 1982, 141-159), as a rich (applied) scientific field may lead to innovation and inventions, but as inventions without a strong scientific base may lead equally to major advancements in science; at the same time advances in basic science require more and more very advanced supportive technologies;

(2) Long times are often needed for major advancements in technology through combinations of multiple discoveries by multiple individuals in many locations;

(3) The science-technology link changes its nature in time. Both the direction and the strength of the link may be affected by this change, as newer technology may rely more on science than older technology, but can also drive or facilitate further scientific discovery much more and faster than in the past;

(4) Technology may develop further independently based on the applied knowledge base. Established technologies are likely to develop this way, whereas new technologies may need to rely much more on new advancements in the science base.

(5) There may be different levels of scientific content in innovative technological application, with significant variance from one field of innovation to another. In other words, different technological fields have different scientific intensities.

(6) Flows of science and technology are often universal in nature, but both do tend to flow towards attracting poles (Romer 1994, Lucas 1988), usually centers of intense scientific discovery or centers of innovation in top tier developed countries. These are now represented mostly by the US and several EU member states just the same as Britain, France, Austria or Germany attracted top scientists and engineers all throughout the 19th and early 20th centuries;

(7) Military interest in a technology could facilitate its being pursued and perfected;

(8) Military developed technologies, once declassified or made publicly available, are often made widely available in commercial applications that in turn have enormous

effects on society and human behaviors, the economy, and even power arrangements inside the international system;

(9) The interest in developing top tier new technologies in partnership and cooperation between multiple contributing players (academia, research centers, technology parks) worldwide may be over shadowed by the interest in maintaining secrecy and primacy over a technology, for military or commercial benefits;

(10) Patenting cultures, or the interest in seeking or protecting intellectual property rights for innovations, may vary widely between different geographic locations in the world, between different individuals affected by different upbringings, or between social, cultural or economic ties and practices.

2.5. Explanations of the lower technological performance in Europe

A number of hypothesis have been proposed directly related to the gap in technological and market competitiveness between the US and Japan on the one hand, and Europe on the other.

The European Commission, in several comprehensive analyses (ERSTI 1994, ERSTI 1997) addresses the equally convergent and divergent trends between EU member states in their technological competitiveness, while pointing out to large sectorial variance as well, whereby Europe technological performance is high in several sectors (chemicals, lately aerospace, and most importantly latest in communications equipment, particularly mobile telephony technology).

Sandholz (1992) uses the failure of traditional industrial policies in the member states to explain why member states have embraced wholeheartedly EU policies and programs in the early 1980s. National industrial policies were translating in a duplication of efforts that needed addressing in the face of increased worldwide competition in high tech fields. Peterson and Sharp (1998) address the reasons for and mixed results of embedding other EU policies (namely, regional policies and social and employment policies) in technological competitiveness policies.

Muldur (2001), among others, addresses the misallocation of R&D resources in Europe, differences in attention given to military driven R&D expenditures between the US and the EU, as well as a continuation of cross-European duplication of efforts (Carli 1983, Muldur 2001) even past the establishment in the early 1980s of multiple European wide cooperative programs aimed at reducing Europe backwardness in high tech.

Different rates of participation of private and public R&D capital between Europe and the EU is brought as a possible explanation by the European Commission. In the EU, lower private expenditures in R&D than in the US may lead to lower efficiencies in innovation (ERSTI 1997, ERSTI 2003 preview).

A historical technology gap, possibly facilitated by resource abundance in the US as opposed to other Triadic members (David and Wright 1992) is often used as an explanation of differences in economic growth (Fagerberg 1987, 1994). This too is an interdependent relationship, as slower economic growth self-sustains the continuation of a technology gap making efforts to curb it less likely to be successful.

Some studies note the essential role large businesses have played in the establishment of the new Europe past the 1987 Single European Act (SEA) and the 1992 Project (Green Cowles 1994), but also the troublesome teething problems of agenda setting efforts among European stakeholders and institutions in core advanced fields such as biotechnology (Patterson 1998).

2.6. Scientific and technological specialization and different scientific intensities of technological fields

The European Commission report identifying and addressing the problem suggests two possible explanations. The first is the linkage between technological developments and their science base. The second is the role of technological and sectorial specialization on the EU's performance (ERSTI 1997, 181).

The report finds that Europe is less able than its competitors to transform its scientific base into technological innovation[22]. Commission cautions however against too strong of an interpretation of these findings. It hints at different scientific intensities of technological fields, combined with the technological and scientific specialization of EU member states.

Variance of the strength of the science-technology link from one country to another could come from countries specializing in technological fields with different scientific intensities. Scientific intensity of a technological field is a measure of the amount of science needed for or included in technological innovation in that respective field. (ERSTI 1997, 181)

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[22] See footnote 3 above.

In the Commission's own words,

> "[a] possible explanation for the [low] performances observed [with respect to Europe's technological innovation] may be found in the linkage between basic science and technology development. (ERSTI 1997, 181)

The linkage between basic science and technology development

> "can be measured using information routinely recorded in patent documents, namely references to the relevant scientific literature underlying the technology described in the patent. An index can be calculated to reflect the science intensity of patents for a particular country or technology area. The more references to basic science, the higher the science intensity index, and the stronger the inferred science-technology linkage." (ERSTI 1997, 181)

A number of studies (Narin and Noma 1985; Grupp and Schmoch 1992; Grupp 1996; ERSTI 1993; ERSTI 1997, 183) detail the argument and the methodology for measuring the scientific content of technological innovation, or the scientific intensity index of a technological field. The indexing is based on the "frequency of non-patent literature references in patent documents [that are] taken as an indicator of the dependence of the patented technology on the science base" (ERSTI 1997, 183).

Different scientific intensities of specific technological fields combined with Kline and Rosenberg's chain-link framework lead to understanding that the chain-link "transmission speed" and "transmission rate" vary from one field to another, as the chain-link's functioning is field dependent.

2.7. Analytical limitations

Both short range, and mid- and long range, economic models require continuity across the study period. WWII for example is always recognized as a major point of discontinuity that needs careful addressing and usually the considering of interruptions in models. In the presence of the findings immediately above, one can easily infer that for the period under study, 1980-2000, at least three major factors contribute to continuity requirements not being easily met at all. The Single European Act of 1987, the European Project of 1992 and most importantly the End of the Cold War are all events that may have on the problem under consideration herein an impact of a magnitude similar with that of WWII on the economic growth of developed nations in general. In other words, addressing the US or Europe 15 technological competitiveness in the late 1990s can not be conceived without a serious consideration of some of these three events as interrupting or affecting the trends inside the two decades under study. In addition, the limited time that has past since these events may be too short to allow an entirely conclusive analysis for the purposes of mid- and long range economic modeling.

This study has however a policy analytical focus. Therefore, the scope is not to build cross-country econometric models informing economic theories, but rather to determine the evidentiary basis for better informed policy recommendations. .

2.8. Plausible explanations to the weak science-technology link in European advanced economies

In this section I introduced the conceptual framework surrounding the science-technology link in developed countries. Consistent with the breadth of the literature surveyed herein, I argue that the relationship between science and technology may vary significantly from one country to another and from one region to another, even among industrial countries.

There are many factors that may affect the relationship, factors that can all translate into a combination of plausible explanations to the puzzling behavior of the relationship between scientific and technological performance in European advanced industrial economies.

In the next section I introduce in more detail the research question and the plausible explanations that I selected for testing, stemming from inferences derived from the literature. I also describe the research design, namely hypotheses, the variables and indicators necessary for testing hypotheses, as well as the operationalization of variables and analytical methods.

3. Research Design

In this section I introduce the research questions and the methodology used for answering them. I discuss the plausible explanations selected as potentially influencing the puzzling behavior of the science-technology link in Europe. The purpose of this section is to describe the variables and indicators needed and their operationalization, as well as the analytical methods necessary for answering the research questions.

3.1. Research Question

The overall research question of this study can be expressed as:

> Are there factors that can explain the puzzle of a weak relationship between science and technology in some EU member states, compared to a stronger relationship in other EU member states?

This study becomes therefore an exploratory study that identifies factors affecting the link between scientific and technological performance among developed countries.

Finding one or more explanations for the puzzling behavior of the science-technology link in Europe can be done through identifying a set of characteristics that are consistently different between countries inside a group and countries inside another group.

Europe is made in fact of multiple types of economies performing differently in distinct sectors. An analysis of Europe's innovation by country and sector could identify distinguishing factors from country to country and from sector to sector affecting the relationship between scientific, technological and market performances in each country. Such an analysis would in turn inform a set of policy recommendations that could serve better Europe's objective of improving its overall technological competitiveness. However, an exhaustive analysis of this magnitude is beyond the scope of this project. Rather, I select only a set of factors potentially affecting the science-technology link and I verify their impact on selected European countries that do not fully conform with a strong relationship between their scientific performance and their technological performance.

3.2. Research Hypotheses

As outlined in the previous section, there are many factors inside and outside the science-technology link recognized as having an effect on the strength or direction of the relationship between scientific and technological performance. In answer to the research question, in this work I focus on three of these factors, considered as potential explanations for the weakness of the relationship between scientific and technological performance in European advanced economies, namely:

(1) the scientific and technological specialization of countries combined with the difference in scientific intensities across technological fields;

(2) patterns of intangible capital flows, particularly of foreign funded R&D, and

(3) an economy's dependence on R&D intensive economic sectors.

These three factors may potentially influence more the technological performance of a country than its science base does.

The three research hypotheses I consider in this study are respectively that each of the above factors influences the relationship between scientific and technological performance in selected European advanced industrial economies.

3.3. Hypotheses, variables in the study, operationalization and analysis

In this section I first introduce the indicators used for measuring scientific and technological performances. Then I discuss individually each of the above selected factors, as well as the methodological considerations necessary for addressing the three research hypotheses.

3.3.1. Measuring scientific and technological performances

To be able to make further empirical inferences, I calculate measures for scientific and technological performance respectively.

For measuring scientific performance I use a widely accepted measure, namely the scientific propensity, measured as number of scientific publications divided by the number of non-business full time equivalent (FTE) research scientists and engineers (RSE).

For measuring technological performance I use a widely accepted measure, namely the technological propensity, measured as patent activity divided by business expenditures in R&D (BERD).

The reasoning for calculating technological propensity based on BERD is that business R&D expenditures are usually meant in their majority to produce technological advancement, i.e. innovations (as measured through patent activity).

At the same time, it is non-business research scientists and engineers (primarily working in government and higher education research institutions) that facilitate scientific advancements (as measured through number of publications), thus the use of non-business FTE RSEs when measuring scientific propensities.

As there are competing interpretations of the timing of the impact of R&D upon either scientific or technological productivity, just the same as there are multiple possible measures of patent activity, I use a selection of multiple methods for calculating both scientific and technological propensities.

Methods for measuring scientific and technological propensities

As there is by necessity a time lag between when the R&D expenditures are used and when the output becomes visible, and thus measurable, this time lag should be considered when defining scientific and technological output propensities. Accordingly, aside from the direct year method, there are two more available methods: the first is considering a five year lag for technological output and a three year lag for scientific output. The second is using depreciation of R&D stock or of the work of FTE RSEs, across five years for technological output, and across three years for scientific output respectively[23].

Scientific propensities can then be calculated dividing the number of publications by the number of non-business full time (FTE) research scientists and engineers (RSEs) in the same year, three years before, or with their past three years stock of work depreciated (usually by 5% a year)

Similarly, technological propensities are also calculated using the same three methods, respectively same year, with a time lag (usually five years) and with depreciation of R&D capital stock in (usually five) previous years. For patent activity, there are a few options, selecting from patents granted and patent applications, by

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[23] In appendix 3 I have included a detailed operationalization of all the measures used, according to the three calculation methods briefly mentioned herein.

publication or by priority year, and from USPTO patents or the European Patent Office (EPO) patents[24].

In this study I have used only the same year method. The reason is related to the need to aggregate data from multiple sources in order to be able to calculate scientific propensities. The number of publications by country was not collected by the OECD, and thus the length of the time series available from European Commission data (ERSTI 1997) was much shorter. Lagging it would shorten the series even more. When comparing trends in scientific output propensities with trends in technological output propensities the longer the two time series are the better the inferences can be. Thus, I chose to use the same year method only.

However, a US study, namely "Project Hindsight", conducted by the American Association for the Advancement of Science, suggests that a nine year period is necessary for major advancement in science to translate into technological advancement (AAAS 2001). Accordingly, I choose to compare scientific propensities lagged a number of years with technological propensities in a given year. I used a three year, a six year and a seven year lag between the two, with scientific propensity being advanced by the given number of years, for example comparing the scientific propensity in 1980 with the technological propensity in 1983, 1986 or 1987. Unfortunately, given the short time series for scientific propensities, I could not use a nine year lag, as the two series would not intersect anymore for many countries in the study group[25].

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[24] I used patent applications to the EPO by priority year, as the OECD S&T database only reported this data for the EPO. The data is in time series form, for 1980-2000. See section 3.4. for details on data collection, indicators and calculations used for the analyses. Unfortunately, a good measure of comparative technological innovation between EU member states and the US or Japan as comparison cases can only be achieved using two measures simultaneously, namely patents to the EPO and at the USPTO. The reasoning comes from the "home patenting" bias. The US is primarily patenting with the USPTO and EU countries in turn are primarily patenting with the EPO. Thus, using only one of the two measures would skew the results. The technological performance of any EU member state could be underreported with USPTO patents and the US technological performance could be underreported with EPO patents. Comparing EU countries among themselves using EPO patent applications assumes that the "home patenting" bias affects equally all EU member states. This may or may not be the case, as some European countries may prefer US patenting. This assumption can be verified by comparing results obtained with EPO patents with results obtained using USPTO patents. The European Commission's analysis confirms in part the validity of the assumption, even though there are countries, notably Denmark, Germany and Austria, which patent relatively more with the EPO than with the USPTO (ERSTI 1997, 181).

[25] Ideally, with longer data series for all the indicators needed for calculating both scientific and technological propensities, the method using depreciated knowledge stock should be used for measuring scientific and technological performances of a country.

3.3.2. Scientific and technological specialization and scientific intensities of technological fields

As suggested by the literature review, a country's tradition in technological innovation, combined or not with its *specialization in technological fields with lower scientific intensity*, i.e. requiring a lesser use of the science base or of new science, may affect the relationship between scientific and technological performance in a country.

Different scientific intensities of technological fields, combined with the technological and scientific specialization of EU member states may therefore be one cause of the puzzling behavior of the science-technology link in Europe.

Variance of the strength of the science-technology link from one country to another could come from countries specializing in technological fields with different scientific intensities.

As a technological field develops more it uses less the science base, and thus further development in the respective technological field relies more on technological knowledge than on new input of scientific knowledge. By contrast, a new field of innovation such as biotechnology relies more on the science base, and it also may return more technological capabilities and requirements for further exploration back to scientific laboratories. In time however, this new field of innovation may too become less dependent on the science base and more on applied knowledge.

I consider therefore that one plausible explanation for the weak relationship between scientific and technological performance in a country is the scientific and technological specialization in that country. Also, the science-technology link in a country may depend on the overall scientific and technological level of development in that country. Different technological fields have different degrees of historical development, and different degrees of building upon the science base, or scientific intensities. Scientific and technological specialization of countries varies, making it natural for the strength of the science-technology link to differ from one country to another. The high technological specialization of a country may improve its technological performance more than its immediately current scientific performance does, especially if the technological specialization occurs in fields with low scientific intensity.

The methodology for determining scientific intensities (i.e. the amount of science a patent is directly relying upon) of patents in different technological fields was developed by a number of scholars. According to the Commission (ERSTI 997. citing Narin and Noma (1985), Grupp and Schmoch (1992), Grupp (1996) and the Commission (1993),

> "Science linkage in patents can be measured using science intensity indices. The data from which they are calculated arise at the examination stage of patent application, when the prior state of science and technology must be researched. Patent office examiners may document the prior state of the art in related S&T fields by referencing relevant scientific literature. The frequency of non-patent literature references in patent documents can be taken as an indicator of the dependence of the patented technology on the science base. Such citations are made by independent officials with reference to an established set of rules and are not affected by personal idiosyncrasies. Consequently they are free from the uncertainty and doubts associated with questionable self-citations in scientific literature. The science intensity indices [...] are calculated from data relating to patents registered at the European Patent Office. The higher the index, the stronger the inferred linkage between the patent technologies and the underlying science base." (ERSTI 1997, 183)

Accordingly, for scientific intensity I used data as well as the methodology used by the Commission (ERSTI 1997, 183) following the traditional approach with respect to this indicator[26]. The distribution of technological fields by their scientific intensity is shown in Figure 6. The reliance on the science base of a technological field is larger the higher the value of its scientific intensity. We can infer from the figure that biotechnology, pharmaceuticals or organic chemistry have the strongest scientific intensity, while space technology, mechanical elements, consumer goods or civil engineering have the lowest scientific intensity.

For scientific specialization of a country I use a proxy. If a country has high quality of scientific publications in a field it means that it does specialize in that field. In Table 7 I replicated and adapted through normalization the Commission's collected data on quality index of scientific publications by country. The table suggests that the US specializes in virtually all fields of science evenly, as the US's quality index of scientific publications is highest in the world for all fields but biological sciences, agricultural and

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[26] See Narin and Norma (1985), Grupp and Schmoch (1992), Grupp (1996), and ERSTI (1993) cited in ERSTI (1997, 183).

food sciences, and engineering. The UK in turn specializes primarily in biological sciences, Ireland in agriculture and food science and Denmark in engineering[27].

3.3.3. Differences between EU member states in foreign funded R&D

Another differentiating factor between the groups of countries responding or not to the expected science-technology link can be the percentage of R&D expenditures financed from foreign sources. The Commission suggests the possibility of the use by foreign multinationals of good scientific and technological grounds, as well as very well prepared scientists and engineers, in certain EU member states for an addition to those multinationals' technological innovation performance. In such cases however, the patenting occurs in the name of the multinational, and thus does not get reported under the EU member state where the work was performed, but rather under the home country of the multinational having financed and facilitated the work in its EU subsidiary.

I propose the following possible explanation:

> The financing from abroad of a relatively large percentage of the gross R&D expenditures in a country may yield a misleading image when measuring the country's technological performance using national based technological propensities.

There are two implications here. The first one is a measurement implication. National technological propensities may significantly under-represent the technological performance of countries with high levels of foreign financed R&D. The second implication is fueling yet another explanation to the puzzle. Namely, higher levels of foreign involvement in R&D in some European countries may yield higher levels of technological spill over from advancements in other parts of the world. Thus, the expected link between national based scientific propensity and technological propensity becomes even less justified. In some countries the technological knowledge is taken more from the worldwide pool of scientific knowledge and applied it to technology. The innovation system of firms inside these countries facilitate it with comparatively larger efficiencies than those of innovation systems in other countries.

Patterns of increased foreign funded R&D in advanced industrial economies bring about a potentially important measuring problem, significant as the levels of foreign

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[27] This interpretation only deals with the primary scientific field(s) in which countries are very successful. A detailed interpretation needs a country by country and field by field analysis of the data in Table 7, as

funded R&D become substantial in many EU member states. For example, the foreign funded business R&D expenditures (BERD) for the entire EU have grown from 5% in 1980 to 9% of total BERD in 1996. The level of foreign funded R&D in the UK has grown from around 10% in 1980 to over 22% in 1996. Italy's latest levels are slightly under 10% while France's are at around 12%. In contrast Germany's levels stay low at around 2%.

As discussed above, technological propensities[28] are measured as patent activity per business expenditures in R&D. Foreign funded R&D most likely translates in patents submitted in the host country of the multinational funding the research, rather than in the country where the research is performed.

When measuring the technological performance of a country, the measurement becomes negatively affected by this problem twice. First, British technological innovations for example are not counted for Britain or the EU. Second, the same share of British technological innovation is counted for another country, possibly either inside the EU or the US or Japan. Triad members in the comparison, namely the US or Japan[29], as the home country of the multinational having financed the R&D[30].

This becomes even more problematic when considering that the multinationals invest in R&D in another country primarily given a strategic decision based on their perception of a strong advantage for them in accessing the technological innovation potential of that country. But the indicator used to measure the technological performance of the country tells a different story than the perceived reality behind the multinationals' decision.

To measure the impact of foreign funded R&D I used country specific business R&D expenditures funded from abroad, relative to the EU average.

I used graphic based cross-tabs between foreign funded R&D by the perceived strength of the relationship between scientific and technological performance, as determined per the methods described in section 3.3.2. above. I sought inferences from

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performed in the analysis part.

[28] As discussed in section 3.3.1. above, technological propensities are one most common used measure for assessing a country's technological performance.

[29] Indeed, corrected with the equivalent impact of the same measurement error considering EU investments in R&D abroad. Nonetheless, these levels are lower than those of foreign R&D funds coming into the EU.

[30] To address this issue I propose a correcting formula for measuring actual national technological propensities. Please see Appendix 1, proposed corrected formula for accurately measuring national scientific and technological performances through technological propensities.

pattern matching using visual analysis of variance, based on the scatterplot of technological propensity by scientific propensity in time on the one hand, and levels of foreign funded R&D in time on the other.

In addition, as discussed in more detail in Appendix 1, I proposed a correcting formula for calculating technological propensities, that includes a correction for the patenting abroad of innovations potentially originating in a given country. I calculated the corrected technological propensities using this formula and (1) used scatterplots to graph the relationship between scientific and technological performance, the latter as adjusted. I also used linear regression analysis comparatively, using technological propensities without and with the correction, to determine whether or not the correction may improve the perceived strength of the science-technology link.

3.3.4. Economies of EU member states rely more or less on R&D intensive sectors

The economies of different countries may have depended more or less on available R&D stock during 1980-2000. If there are patterns of these different dependencies that may superimpose over the categories identified by the Commission in the science-technology grid of European countries, the structure of EU member states economies becomes an explanatory factor for the puzzling behavior of the science-technology link in Europe.

As an economy relies more on R&D stock than on capital and labor, this translates in higher relative expenditures in R&D when compared to economies that rely less on R&D intensive sectors. These differences may make economies relying more on R&D intensive sectors look surprisingly poorer in terms of their technological performance, as technological performance is usually measured as patent activity per business expenditures in R&D.

Furthermore, a high dependence on R&D intensive sectors would tend to self-perpetuate through further increases in available funds due to implications from the functioning of Schumpeter's "creative accumulation" (Mark II) innovation regime, such findings would support the idea of a continuing divergent nature of the economies of some EU member states, unless medium and long term measures, policies and structural changes are in place to ensure a more convergent trend among European economies.

The unit of analysis is an European Union member state. I considered all the 15 EU member states in the analysis. For comparison purposes I included the US as well.

The independent variables are labor compensation, capital stock, and business R&D stock in total manufacturing, by year, considered for all EU member states and the US.

The dependent variable is value added in total manufacturing, by year, for all EU member states, and for the US.

I use a linear regression model using the Cobb-Douglas production function. I compare country specific coefficients for R&D capital stock, and use pattern recognition by comparing with cross-tabs of scientific and technological propensities relative to the EU average.

Cobb-Douglas production functions have been used extensively to determine an economy's comparative reliance on different factors of production. When looking at the impact of R&D expenditures, treated as R&D stock (Griliches 1998; 2000), a Cobb-Douglas production function looks like[31]:

$$Y_{j,t}=A_jK_{j,t}^{\alpha}L_{j,t}^{\beta}RD_{j,t}^{\rho} \tag{1}$$

Where subscript j usually refers to sector j and t is the time indicator. K is the capital stock, L is the amount of labor used in the production process and RD is the R&D stock. Y is the value added in the respective sector j in the year t. The parameters α, β and ρ are the elasticities of the respective variables.

In this study I used the Cobb-Douglas production function to assess the dependence on different factors of production in total manufacturing, thus subscript j becomes superfluous.

Consistent with standard practice, I determined the capital and R&D stock using a standard perpetual inventory method, as in:

$$K_t=(1-\varphi)K_{t-1} + I_{K,t}$$

and

$$RD_t=(1-\chi)RD_{t-1} + I_{RD,t}$$

where φ and χ are the depreciation rates of the capital stock and R&D stock respectively and $I_{K,t}$ and $I_{RD,t}$ are the annual investments in either stock, capital and R&D respectively.

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[31] For a full treatment of this econometric tool, please see Greene 2003, particularly Chapter 15. For a similar model with the one used here in the case of Netherlands alone, but taking into account knowledge spill-overs as well, please see Soete and Ter Weel 1999.

Following standard practice (Griliches 1980 and Soete and Ter Weel 1999) I calculated initial stocks using:

$$K_0=(I_{K,1})/(\varphi+0.05)$$

and

$$RD_0=(I_{RD,1})/(\chi+0.05)$$

When writing equation (1) above in log form, after dividing every variable by L and taking logarithms, the Cobb-Douglas production function becomes[32]:

$$y-l=a+\alpha(k-l)+\lambda l+\rho(rd-l)$$

which becomes the linear regression equation I use to estimate dependency of a country's economy on R&D stock.

3.4. Data Collection

To be able to calculate the indicators needed for the analysis herein, I collected data from multiple datasets, originating with the OECD and with the European Commission.

For calculating scientific and technological propensities, data had to be aggregated from the OECD Main Science and Technology Indicators database and from data on publications by country collected by the European Commission, as this data was not reported by the OECD. OECD data was available in time series form, for 1980-2001, by country and by year. European Commission collected data (ERSTI 1997) on publications by country was however only available for 1980, 1985, and 1990-1995. In a separate European Commission report (ERTIS 1994) data on publications by country was available in time series form for 1980-1992. However, the two datasets were not fully compatible. Therefore I could not use an aggregation between the two. To build the ability to further analyze issues related to the science-technology-markets relationship in advanced European countries, I have collected data on more countries and many more indicators than only the ones used herein.

Upon aggregating several indicators, such as Gross Expenditures in R&D (GERD), business expenditures in R&D (BERD), total full time equivalent (FTE) research scientists and engineers (RSEs), business FTE RSEs, and patent applications to the EPO by priority year, all by country and by year, taken from the OECD S&T

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[32] Please note that $\lambda=\alpha+\beta+\rho-1$.

database, with publications by country and year taken from European Commission data (ERSTI 1997), I calculated the scientific and technological propensities for each country, by year, which I used in the analyses herein.

For scientific intensities, and scientific or technological specialization of countries, and quality of scientific publications (citations), I used data already collected and available from the European Commission (ERSTI 1997).

I collected data on foreign funded R&D from the National Science Foundation. Data was in time series format, for 1980-2000. However, not all European Union member states were covered. To verify inferences and further them I also used a complementary dataset from the European Commission (ERSTI 1997), also in time series format, but in a shorter time series, for 1980-1995, verifying that comparative analyses conducted with data from the two datasets lead to the same inferences.

For the Cobb-Douglas production function based part of the analysis, I have constructed a separate database using data aggregated from two OECD databases, namely STAN (Structural Analysis), and ANBERD (Analysis of Business Expenditures in R&D). I used data on value added, labor compensation and capital stock by country, by manufacturing sector and year from STAN, and data on business R&D expenditures by country, by manufacturing sector and by year from ANBERD. Data came in time series form, but the series length was much shorter in the ANBERD database than in the STAN database, allowing for the analyses solely in the years of intersection between the two datasets. Even though in this present study I have used only data for total manufacturing, I have collected data for all sectors and all European Union Member States, the US and Japan, to provide the ability to address variance by sector in cross-country analyses in further work. The total number of separate indicators collected, and aggregated across the two databases was around 6500. This data collection effort will facilitate the conduct of further analyses on other potential plausible explanations affecting the behavior of the science-technology link among industrial countries.

4. Analysis and answer to research question

In this section I detail the analysis performed in search for answers to the research question pertaining to the puzzling behavior of the science-technology link among European advanced industrial economies.

The section is divided in four parts. First, I correct the European Commission's grouping of countries into the science-technology grid[33]. Then I address in turn the three research hypotheses introduced in the previous section as potential explanations for the puzzling behavior of the science-technology link. These hypotheses are respectively dealing with (1) the impact of scientific and technological specialization of countries, through different technological traditions and different scientific intensities of different fields of technological innovation, (2) the impact of levels of foreign funded R&D, and (3) the impact of different dependencies of EU economies on R&D intensive sectors.

The core argument of this section is that the three factors above may contribute to explaining in part the puzzling behavior of the science-technology link in European advanced industrial economies.

4.1. Specifying the puzzling behavior of the science-technology link in the European Union

The corrected depiction of the puzzle, based on the corrected grouping of European member states by their strength in scientific activity and technological activity, is shown in Table 1 and Table 2 below respectively.

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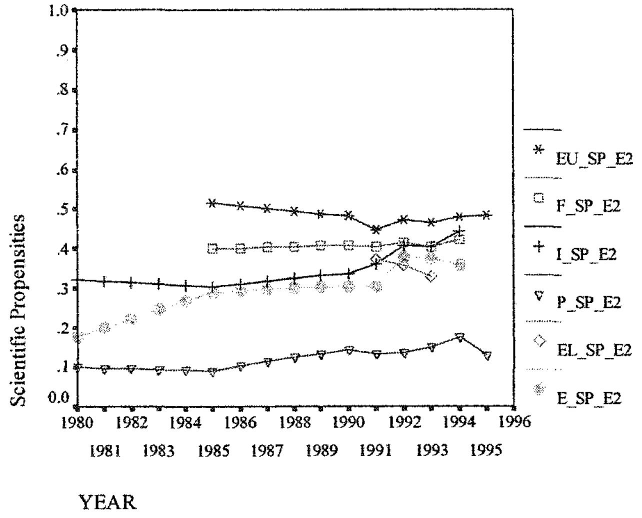
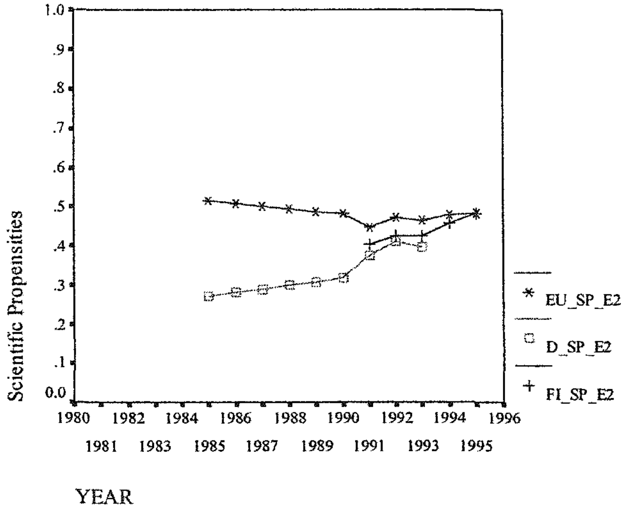
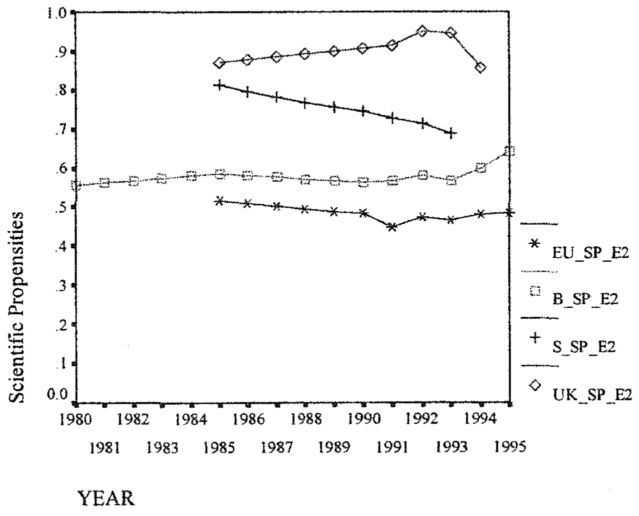
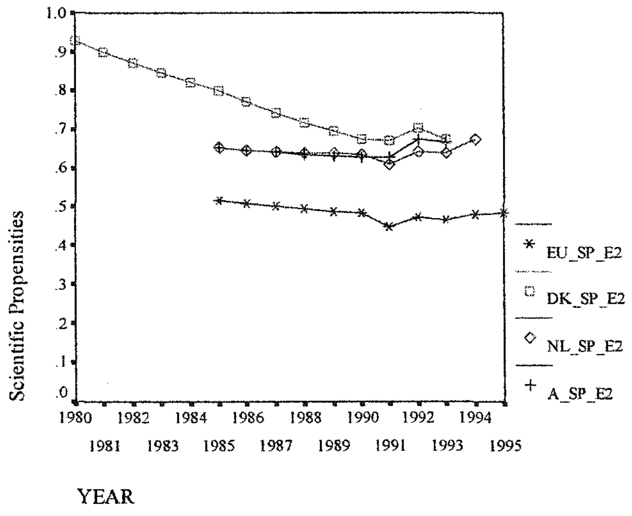
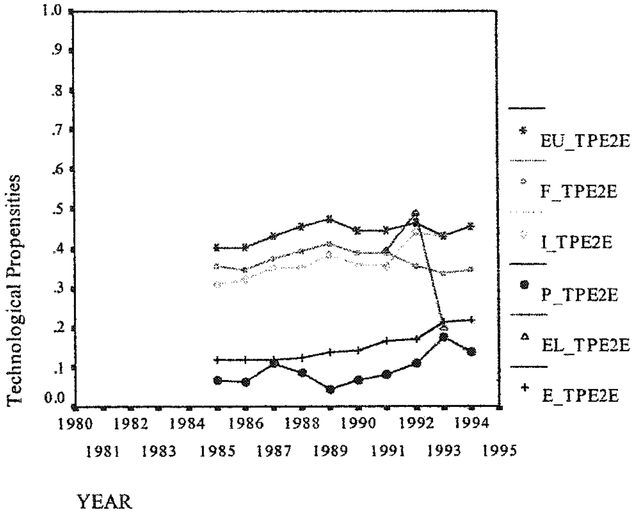
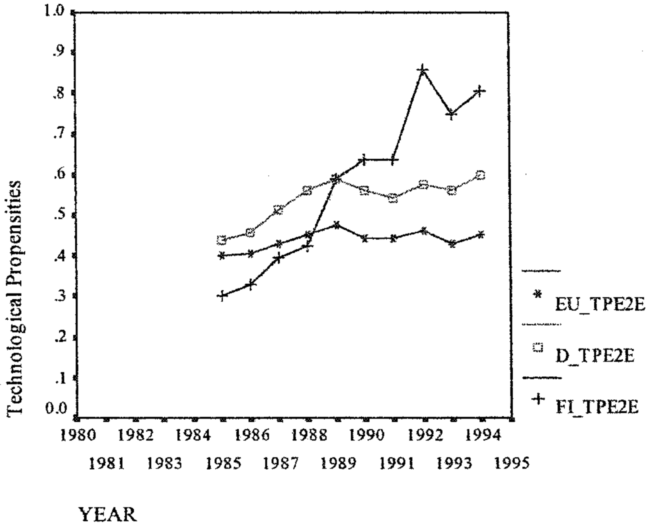
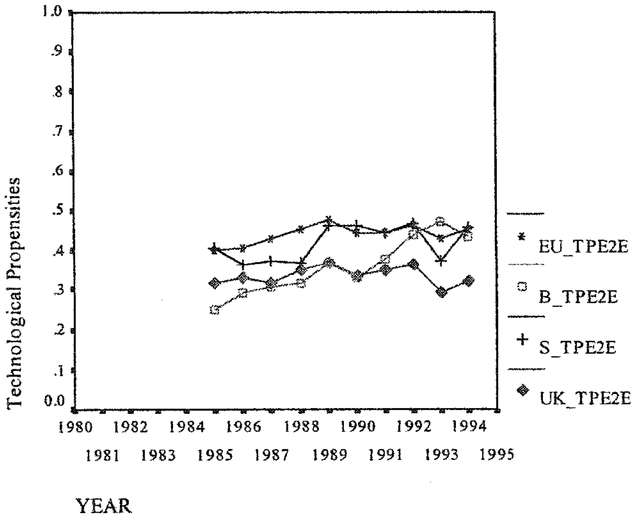
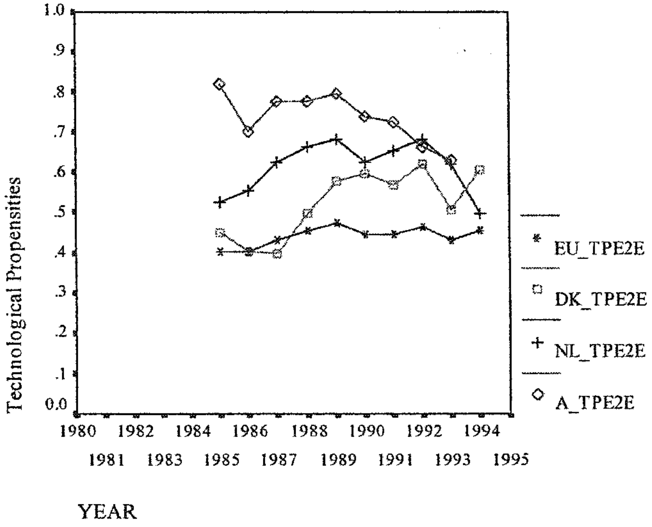
[33] The difference in grouping stems from the fact that I use scientific propensities calculated per number of non-business research scientists and engineers, whereas the Commission used scientific propensities calculated as publications per non-business expenditures in R&D.

		Technology	
		Weak	Strong
Science	Weak		
	Strong		

Source: own calculations based on data from European Commission (ERSTI 1994; ERSTI 1997).

Table 1: Corrected placement of EU member states in science-technology grid, by scientific propensity (1980-2000)

		Technology	
		Weak	Strong
Science	Weak		
	Strong		

Source: own calculations based on data from European Commission (ERSTI 1994; 1997)

Table 2: Corrected placement of EU member states in science-technology grid, by technological propensity (1980-2000)

As it is apparent from the tables above, the placement of EU member states in the science-technology grid needs some adjustment, showing a "redefinition" of the European Innovation Paradox within the EU as compared to the European Commission's findings.

The proposed corrected placement is shown in Figure 2.

		Technology	
		Weak	Strong
Science	Weak	Portugal, Italy, France, Greece, Spain ↓S, ↓T **strong link** science-technology	Germany, Finland[34] ↓S, ↑T **weak link** science-technology
	Strong	UK, Sweden, Belgium ↑S, ↓T **weak link** science-technology	Denmark, the Netherlands, Austria ↑S, ↑T **strong link** science-technology

Figure 2: Corrected placement of EU member states in science-technology grid

The puzzling behavior of the science-technology link occurs in the cases of the UK, Sweden, and Belgium, where strong science does not yield equally strong technological performance, and conversely in the cases of Germany and Finland, where strong technological performance exists even absent an equally strong scientific base.

4.2. Scientific and technological specialization of countries and different scientific intensities of technological fields

A synthetic image of the puzzling behavior of the science technology link in Europe is offered by Figure 3[35]. The figure shows how Portugal (P), Spain (E), Italy (I), Greece

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[34] As depicted in Table 2, Finland starts with low technological performance in the early 1980s, moving in 1988 above the European Union average, with its placement in the grid reflecting its current position.

[35] The latest available data was used. It is important to note that calculating scientific and technological propensities requires data from multiple data sources. The result is that the indicators can only be calculated for years for which all data sources report all the required data.

(EL) and France (F) in the lower left quadrant, and Netherlands (NL), Austria (A) and Denmark (DK) in the upper right quadrant conform to the expected behavior of the science-technology link. In the case of these countries, low scientific performance leads indeed to low technological performance for the former, while high scientific performance leads indeed to high technological performances for the latter.

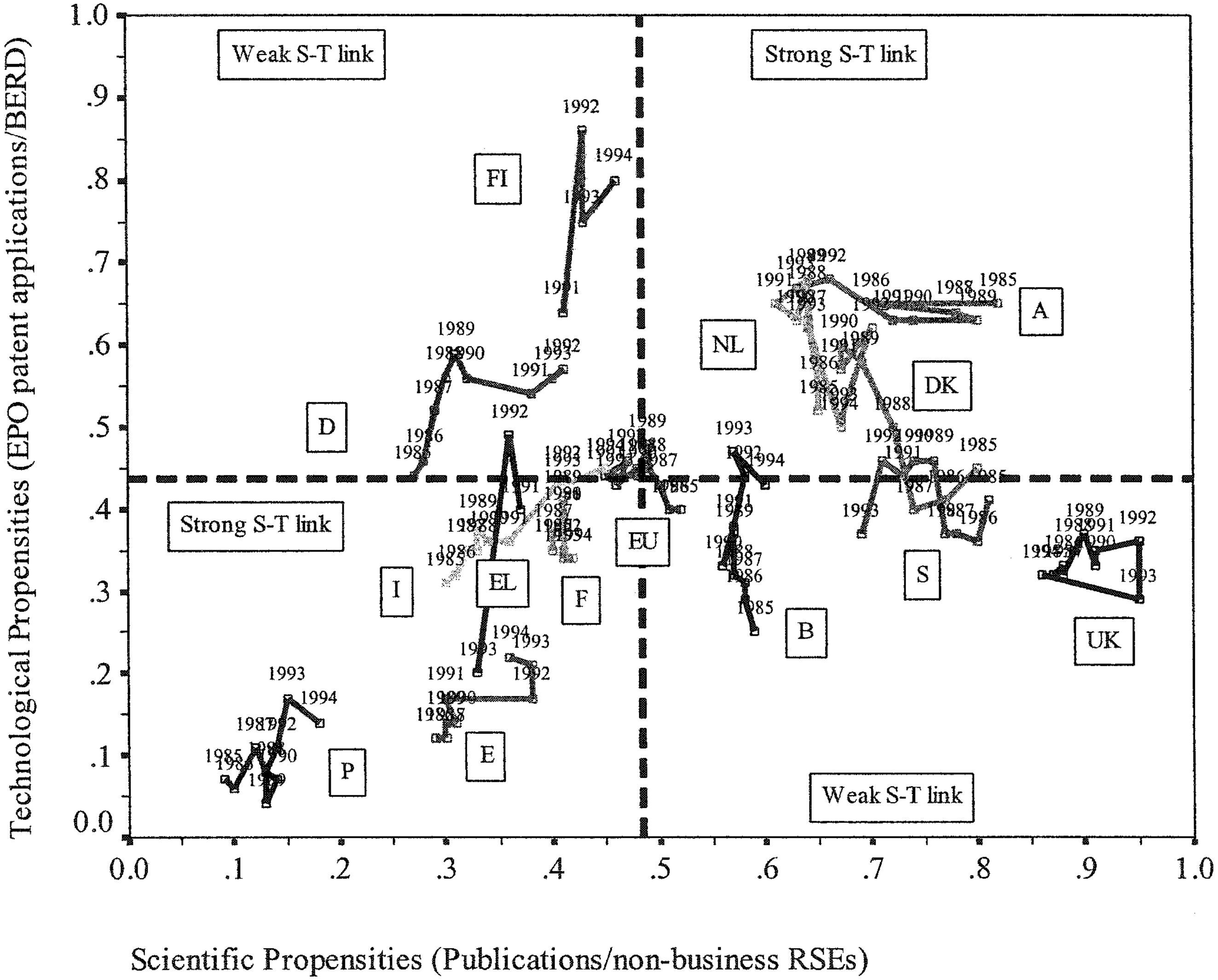

Figure 3: Technological Performance by Scientific Performance in European Union countries (1980-1995)

Source: own calculations based on OECD (Main S&T indicators database) and European Commission (ERSTI 1997) data

In contrast, in the cases of Germany (D) and Finland (FI) in the upper left quadrant, or Belgium (B), Sweden (S) and the UK in the lower right quadrant, the puzzle is apparent.

For the UK, the highest in Europe scientific performance is not yielding an equally strong technological performance[36].

Belgium has a lower than the EU average technological performance at a higher than average scientific performance. Nonetheless, Belgium has increased its technological performance in time, with the latest data available showing Belgium having over-passed the EU average in technological performance. In time therefore Belgium has started to conform more to the expected behavior of the science-technology link.

Sweden in its turn crosses from the lower-right puzzling quadrant to the upper right quadrant and back into the lower right quadrant. Its strong scientific performance seems to translate relatively well into technological performance at the EU average. Indeed, data available and used for Sweden in Figure 3 is in fact pre its accession to the EU in 1995. The initiatives and involvement of Swedish firms (particularly Ericsson) in supporting European Communities wide R&D programs even prior to Sweden's accession to the EU are however well known.

It seems then that both Sweden and Belgium conform relatively well to a strong science-technology link. Only the UK remains a true anomaly.

In the case of Germany and Finland, weaker scientific performance yields nonetheless strong technological performance, contradicting the expected science-technology link in reverse than Belgium, Sweden and the UK.

As underlined in chapter 2, Germany has historically a strong technological performance, having used often the general pool of science available worldwide to apply it in innovation. In Bernal's classic words, writing about late 19th century:

> "In Germany [...] industrialization was far more intense [than in the British empire]; science was being used on quite another scale. The Technische Hochschulen were turning out thousands of trained chemists and physicists, who were being absorbed into the laboratories of industry, and in a few years the chemistry of dye-stuffs and explosives, for which the foundations had been laid largely in France and Britain, had been

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[36] It is probably not a coincidence that the EU country with the highest rate of publications per non-business research scientists and engineers is the UK, one of only two English speaking EU member states, the UK and Ireland. As the US drives in much part the practice in scientific publications, the language barrier may constitute a limiting factor to non-English speaking scientists' ability to publish in English language journals. Verification of such argument would need analyzing data on (1) the distribution of EU member states' publications in scientific journals by language of the journal, (2) comparative acceptance per submissions rates between EU member states.

> captured as part of a new German industry which held the virtual monopoly of the world market" (Bernal, 1944, 29)

Germany's broad science base, its long tradition in technology, as well as Germany's very early initiation of the model of the technological universities (Bernal 1944, 29), involving close cooperation between academic centers and centers of applied technological research, make possible a strong technological performance while Germany's current scientific propensities look below average. Germany's technological base is broad, across fields, and this is only possible given Germany's historical mainstream role in science across fields.

Finland's case is rather different. A close look at the domains of patent activity and strong economic growth in Finland[37] shows that both growth and innovation in Finland are primarily in the telecommunications equipment sector.

The use of the science base needed for technological advancement varies with the field of technology. Established technological fields such as mechanical engineering, engines, chemical engineering, or even space technology to name only a few need less new science for sustained new improvements. Meanwhile, newer and top of the line technological fields rely much more on a strong science base, and on new scientific advancements necessary for their development. Nanotechnology, biotechnology, pharmaceuticals, semiconductors and others fall into this latter category. Countries have both scientific and technological specialization. Some have historical traditions and strengths in particular fields of science and in particular fields of technology. The traditions of Germany in mechanical engineering, engines, or chemical engineering have a history of over a century long[38]. These traditions and accumulated experience contribute to Germany's strength in continued technological advancement in such fields, not requiring a too high reliance on many new scientific developments[39].

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[37] See appendix 6 for an analysis of the structure of R&D expenditures in Finland.

[38] See Bernal (1971).

[39] German firms do of course also engage in technological advancements in many other much more modern fields, from semiconductors to pharmaceuticals. However, its particular strength in the fields requiring less new scientific advancement probably make it possible for sustained patenting to occur in Germany in these fields requiring less new scientific advancement. This interpretation is consistent with Schumpeter's view that strong technological innovation in the "creative accumulation"—Mark II—innovation regime builds capacity for amplified further technological innovation. Scientific performance may affect less a significant part of the German innovation system, than German prior technological strengths in selected fields affect it. This happens simply because less new science is required in some of the technological fields Germany is strong in.

A measure of the content of science needed for advancement in a particular technological field is the scientific intensity of the technological field. The ranking of scientific intensities by technological field are represented in Figure 6.

The UK's puzzling low technological performance can be explained by looking in more detail at the structure of British science and priorities it gives to different technological fields. During 1993-1995 Britain held 17.0% of world shares in patents to the EPO in the genetic modification of plants, second after the US with 42.5%. This figure for genetic modification of plants is the largest share of world patents held by Britain in any patenting field.

The scientific intensity of biotechnology ranks highest of all patenting fields. This means that the amount of scientific discovery necessary for patenting successfully in this field is highest across all technological fields. Britain has the world's highest index of quality of publications in the biological sciences. Therefore Britain's overall efficiency of translating scientific discovery into patents is naturally lower, as more science is necessary in the innovation fields in which Britain specializes.

In contrast, Germany's index of quality of its scientific publications does not stand out in any field of science, with normalized values of the index ranging between 0.43 in chemistry and 0.77 in earth and environmental science. In other words not only Germany has a somewhat lower scientific performance, but the quality of its scientific publications is not standing out in any field either[40]. However, Germany's historical tradition in technology and the lower scientific intensities of most of the technological fields in which Germany specializes explain in part why Germany can have Europe's highest technological performance without too strong scientific performance. Germany is best worldwide in patents in transport and environmental processes. Transport has the 26th out of 30 rank in scientific intensity. Environmental processes has the 17th out of 30 rank in scientific intensity. Germany also patents well in industrial processes (out of the rank of the first 30 technological fields considered), materials (ranking 18), instruments-optics (ranking 7), and electric and electronic components (ranking indeed 4—see semiconductors). Therefore, on average the scientific intensities of the technological

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[40] The only country holding the highest index of quality of scientific publications in a multitude of scientific fields remains the US. The only fields in which the US does not hold the highest place are very interestingly engineering (with the US second to Denmark), biological science (with the US fourth to the UK, Netherlands and Ireland), and agriculture and food science (with the US sixth after Ireland, Sweden, Netherlands, the UK and Denmark). See Table 6 and Table 7. for details on the comparative quality of scientific publications in advanced industrial economies, by field of science.

fields in which Germany is good at are lower. This allows Germany to have high levels of innovation even absent many new developments in science, as the underlying science behind most of its patents is already well established, and as Germany has held the lead in these technologies for a long time.

4.3. Differences in levels of R&D funded from abroad

The levels of business R&D expenditures funded from abroad in selected EU member states are shown in Figure 4 and Figure 5 respectively, using two different data sets, with NSF data and European Commission data.

First, by comparing the respective graphs in Figure 4 and Figure 5 we can infer that the two datasets, while different, are somewhat compatible. Both the trends and the levels of the percentage of R&D financed from abroad are about the same between the graphs constructed with the two datasets, where data was available from NSF. Accordingly, we can safely extend our interpretation for the ERSTI data originating graphs.

The most interesting finding is offered by interpreting Table 1 and Table 2 in connection with either one of Figure 4 or Figure 5. In Figure 4 we can notice that the crossing of the line for Europe's technological propensity as a whole by a country's technological propensity occurs in ways possibly connected with the crossing of the line for Europe's total percentage of R&D financed from abroad by the respective country specific line for its percentage of R&D financed by foreign funds.

The crossings or general shapes of the technological propensities curves offer good general suggestions. So do the general placement of percentages of R&D financed from abroad for a country, compared with the placement for the same country's technological propensity.

By looking at the value for foreign funded R&D in the UK, compared to the values for Germany for example, and comparing these values with the respective technological propensities for the two countries, one can infer that the levels of foreign funded R&D seem to run counter to the country's technological propensity. It was through this analysis that I have determined the possibility of a measurement error when calculating a national based technological propensity[41].

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[41] Based on this inference I have proposed the modified formula for a country's technological propensity, described in appendix 1

It seems apparent that the levels of foreign funded R&D have an impact at least on the measurement of a country's technological propensity. In any event, it would be inconceivable for a foreign multinational to invest heavily in R&D in a European host country if that host country would not have an actually strong technological performance. Thus, I infer that the placement of the UK[42] in the science-technology grid can be slightly inaccurate, due to the measurement error underscored herein. Further analysis may be needed with respect to the impact high levels of foreign R&D have on a country's technological performance in the medium and long run.

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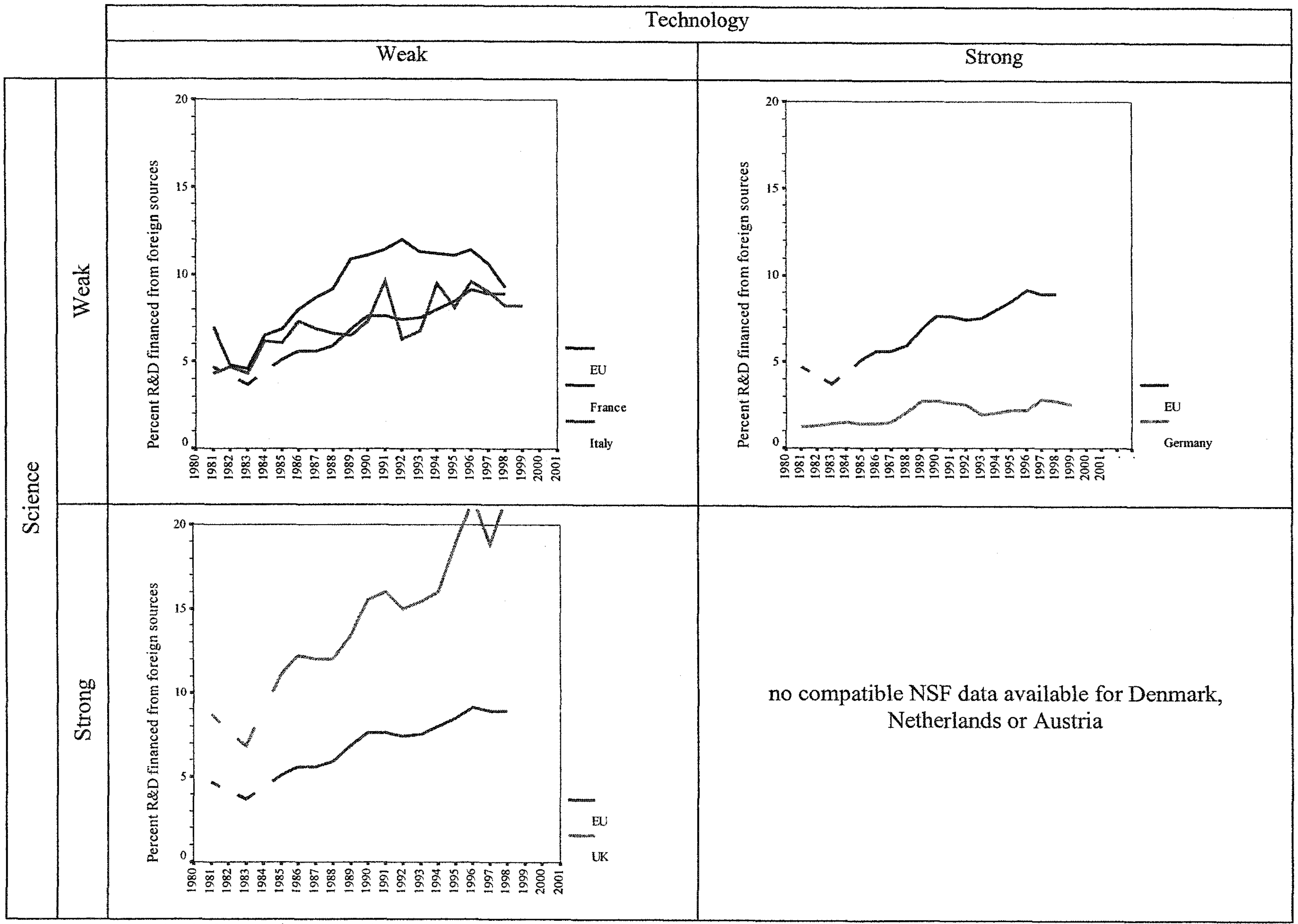
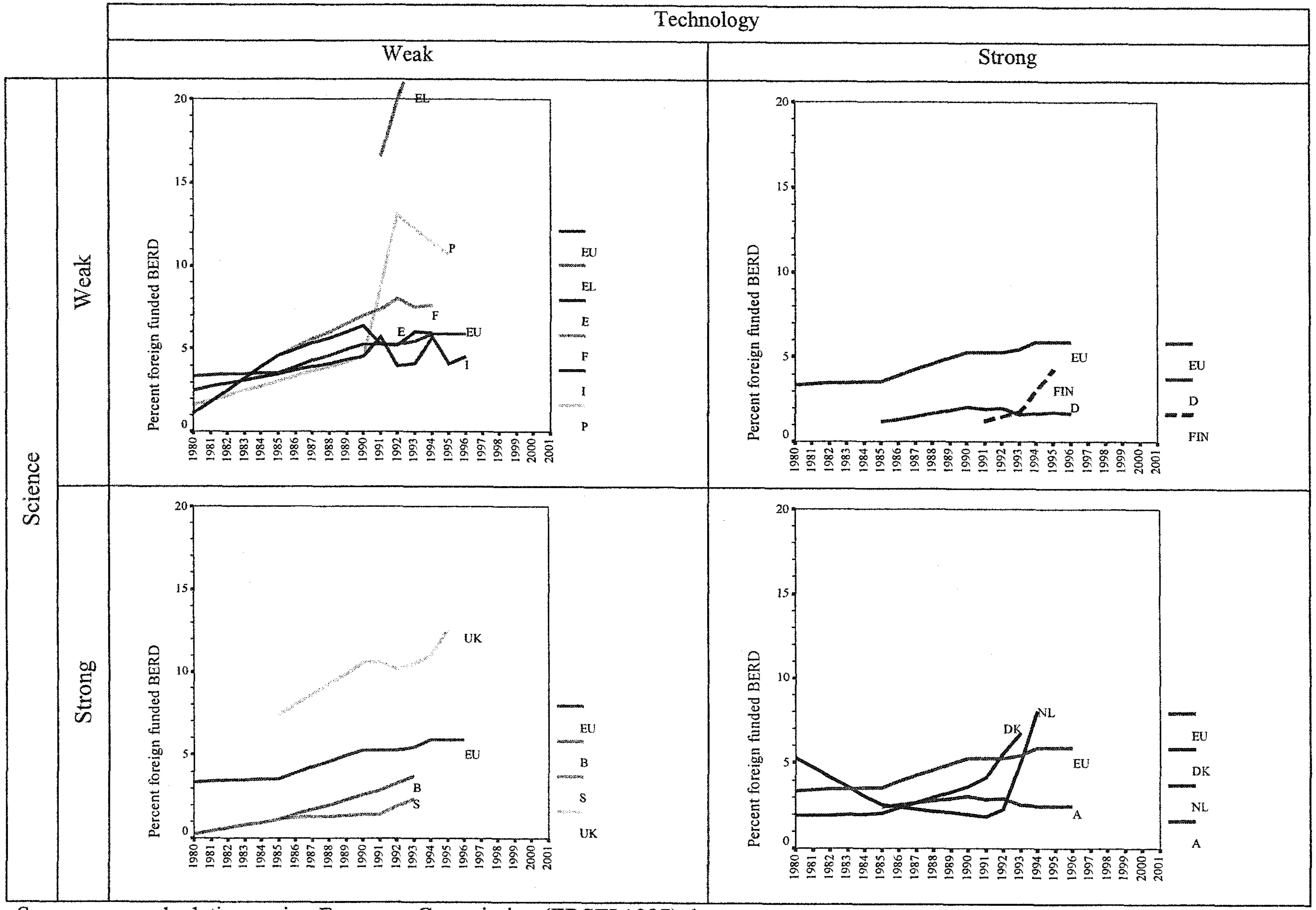
[42] The UK is the most extreme case, with the highest levels of foreign funded R&D in Europe, at around 22% in 1996.



no compatible NSF data available for Denmark, Netherlands or Austria

Source: own calculations using NSF data

Figure 4: Foreign funded R&D in selected EU countries, corrected placement of countries in S-T grid, 1980-2000, NSF data



Source: own calculations using European Commission (ERSTI 1997) data

Figure 5: Foreign funded R&D for EU member states, corrected placement of countries in S-T grid, 1980-2000

4.4. Economies of advanced EU member states rely differently on sectors with high R&D intensity

I used the general Cobb-Douglas production function to determine the relative impact of capital stock, labor compensation and R&D stock[43] in selected European countries.

Given the relatively short data series, especially for R&D expenditures, the intent of using these models is not to build econometric models defining the EU member states economies. Rather, the limited scope is to find a way to determine these economies' overall reliance on R&D intensive sectors in manufacturing during the period 1985-2000.

The results of the models are given in Table 3.

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[43] As specified in chapter 3, Griliches (2000), among others, points out to all the problems of using the theory of R&D stock as a factor of production. However, as indicated in Chapter 3, this is the most advanced currently available theory.

Table 3: Results for Cobb Douglas Production Functions Based Models, selected EU member states, total manufacturing (1980-2000)

	constant p (t)	k-l p (t)	rd-l p (t)	l p (t)	N cases	adj. R-square model's p	D-W
Austria	.562 .552 (.610)	-.205 .618 (-.510)	.449 .016 (2.733)	.049 .711 (.377)	18	.770 .000	.887
Belgium	-4.685 .247 (-1.228)	-.952 .069 (-2.040)	.905 .016 (2.908)	.671 .160 (1.519)	14	.502 .018	1.235
Denmark	-	-	-	-	6	-	-
Finland	2.214 .426 (.831)	-.360 .213 (-1.329)	.433 .087 (1.898)	-.101 .689 (-.411)	14	.478 .023	1.385
France	-	-	-	-	13	.219 .168	.979
Germany	37.408 .309 (1.353)	-5.375 .265 (-1.533)	2.295 .236 (1.675)	-2.367 .325 (-1.294)	6	.928 .043	2.337
Italy	-	-	-	-	10	.334 .156	1.847
Netherlands	2.373 .172 (1.472)	1.003 .023 (2.692)	-.184 .395 (-.890)	-.304 .168 (-1.487)	14	.652 .003	.984
Spain	2.771 .054 (2.219)	.793 .001 (5.175)	-.711 .056 (-2.193)	-.347 .004 (-3.768)	13	.691 .003	1.328
Sweden	3.498 .150 (1.590)	-.665 .153 (-1.577)	.968 .022 (2.838)	-.0024 .989 (-.014)	12	.515 .032	1.181
UK	2.610 .575 (.584)	.505 .332 (1.033)	-1.281 .079 (-2.014)	-.260 .558 (-.611)	12	.357 .093	1.089
US	-2.750 .007 (-3.112)	.0313 .760 (.310)	-.0699 .581 (-.564)	.233 .004 (3.382)	20	.917 .000	1.061

The conclusion for this part of the analysis is that the economies of different EU member states rely in different proportions on R&D intensive sectors in their manufacturing sectors.

From Table 3 above we can infer that during 1985-2000 Austria, Belgium, Finland, Denmark and Sweden have had their manufacturing sector benefiting somewhat strongly from R&D. Unfortunately data for Germany is very limited and the model's statistical strength for Germany is thus extremely low.

In contrast, during 1985-2000, the economies of Netherlands, Spain and the UK have not relied so much on R&D, but rather on the other two factors of production. Surprisingly, the US's own reliance on R&D for this period has been low.

These findings are extremely interesting as Belgium, Sweden and Finland are countries for which the science-technology link has a puzzling behavior. Their high reliance on R&D intensive sectors may have Belgium's and Sweden's technological performance look poor when measured per million $ spent in business R&D expenditures. At the other end, Finland's economy is highly specialized on mobile telephony. Its entire technological advancement is based on this sector. A strong applied science base may have been present in this particular field, this current stage being an easily explainable amplified innovation phase predicted by the implications of the "creative accumulation" of a Schumpeterian Mark II innovation regime.

The UK's placement in the strong science but weak technology quadrant is most likely affected by a measurement error. The UK has in 1996 as much as 22% of its business R&D funded from abroad, which translates into a potential under measurement for its technological propensity than the UK's true technological performance, as UK originating patents may count in either the US or Japan. I have addressed this in more detail in section 5.3.

5. Conclusions, Limitations and Policy Recommendations

In this chapter I recapitulate the findings of the study, drawing theoretical, methodological and especially policy recommendations from them. I further address the limitations of the study as well as the suggestions for further research to which the conduct and results of the study have lead.

5.1. Results and Conclusions

5.1.1. Findings

The science-technology link in a country may depend on the overall scientific and technological level of development in that country. The strength and interdependent nature of this link has a historical evolution that varies across fields of science and technology. The strength of the link between science and technology in a country is affected by scientific and technological specialization. Different technological fields have different scientific intensities, or degrees of building upon the science base. Specialization of countries across scientific and technological fields varies, making it natural for the strength of the science-technology link to differ from one country to another. The high technological specialization of a country may impact its technological performance more than its immediately current scientific performance does.

High levels of foreign funded R&D in a country may mislead the measurement of the technological performance of that country.

Dependence of a national economy on R&D intensive sectors may impact the image of that country in terms of its technological performance.

There are potential significant measurement errors when using technological propensities as a proxy for technological performance, especially in light of high and growing foreign funded R&D inside the Triad. Part of Europe's low technological performance compared with the US's may be the result of measurement error.

There are some flaws in measurement and analysis—measurement artifact of high levels of foreign funded R&D, and of high tech human capital flows inside the Triad.

In this work I have identified a group of advanced industrial countries that have their economies highly dependent on R&D stock, that are the same with those countries that comprise the bulk of the countries where a weak science-technology link is present.

High levels of foreign funded R&D in a country have a dual impact. First, they fuel a measurement error for the country's technological performance. Second, they maintain the respective country in the mainstream of technological innovation. It would be inconceivable to think that foreign Multinational Corporations (originating outside Europe) investing in R&D in the UK at rates of 22% of the UK's total business R&D expenditures would do so if Britain indeed had a low technological performance. By the levels of expenditures being high in comparison with many other EU countries, combined with much of Britain-originating patents being reported elsewhere, the technological propensity indicator for Britain in this example plays against Britain's image twice.

Different dependence of advanced economies on R&D intensive high tech fields may also affect the perceived functioning of the science-technology link. Contribution of R&D as a factor of production in a country's output varies largely from country to country, when compared for total manufacturing. This is consistent with differing structures of the respective economies across sectors, and thus with differing proportions of R&D intensive sectors in the overall economy of different European countries. Technological propensities too follow countries' specializations. Instead of anything puzzling, countries' specialization makes differing technological propensities natural.

The science-technology link functions in general as expected in European advanced economies. The exceptions, the UK, Belgium, Sweden, Germany and Finland all have explanations for not conforming to a stronger such link. In addition, if assessing the functioning of the link in time, a better conformity is obtained for all European countries. In other words, when considering a three, six and seven years respectively time lag for scientific performance to get translated into technological performance, the explanatory power of a model whereby science drives technology increases from an R-square of 81% to an R-square of about 86%, with a reduced spread of the countries around a technology by science regression line.

5.1.2. Conclusion

Based on the findings underscored above, I conclude that there are plausible explanations for the apparently puzzling behavior of the science-technology link in European developed countries[44].

5.2. Policy implications for the European Union

5.2.1. Accelerate catch up effort

Europe should attempt to accelerate it's catch up effort by way of implementing policies meant at (1) further accelerating the reach of the US structure of funding academic research (higher percentage spent in engineering compared to basic science than in the EU), at (2) using the EU's current strong position in several fields to further advancement—namely accelerate the facilitation of cooperation, both intra-European and extra-European (a good model is GSM/UMTS—one case in which the European Commission's facilitation of cooperation has had the effect of diminishing duplication of technological efforts)

5.2.2. Learning from mistakes while promoting best practices

Europe should learn from its prior mistakes (ISDN example—telling of a central authority's inability to always predict market forces or technological advancement). Maintain the coupling of non-technology advancement policies to technological advancement policies, but ensure the maintaining of a proper equilibrium between the two categories. Accurate detailed analysis should offer insights into this equilibrium. An example would be measuring the impact larger inward FDI and/or R&D levels has on the quality of life of the population in the countries involved (combining the impact of EU structural funds with the impact of increased business involvement).

5.2.3. Informing the policy design of the European Research Area

- Better measurement methodologies provided herein. Their application could yield better grounded analytical results that could inform better policy recommendations.
- Europe should follow more closely the NSF example.

- In issues related to applied research, upon a more careful consideration of a potential role of the passage from a Schumpeter Mark I innovation regime to a Mark II innovation regime in accelerating technological performance, more attention should be given to policies facilitating a successful such Mark I-Mark II migration. Improve current policies targeting SMEs.

5.2.4. Other policy recommendations

Seeking full convergence of the innovations systems of European Union member states could most likely be a mistake.

Shifting significantly the distribution of R&D expenditures for basic science in Germany could have the unintended effect of lowering its technological performance in the fields Germany is good at.

Adapt efforts to historical scientific and technological strengths. This would be consistent with David Ricardo's principle [...]

Divergence of innovation systems is beneficial to a large extent. It adds to Europe's diversification capabilities.

Strengthening however scientific and technological fields cross-fertilization between EU member states with strengths in different domains could be beneficial.

5.2.5. European Research Area and Central and East European Countries

Using ready-made solutions that do not take into account particularities of countries involved could also be a mistake.

Adapting solutions to the strengths of each country would rather be much more beneficial.

A good example is Ireland and lately Greece.

- software development
- it would be only a further miss-allocation of resources to invest R&D funds in Greece on biotechnology, instead of concentrating those funds in Belgium, the UK etc, while concentrating funds in Greece on telecommunications.

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[44] For other plausible rival hypotheses beyond the ones addressed herein, please see appendix 10, Further Work.

- it would be equally detrimental to use R&D funds in Romania on nanotechnology or biotechnology, instead of recognizing Romania's potential in medical sciences, instrumentation, electronics, software, machinery, or chemicals.

Similarly, Finland–trying to transform it into a science stronghold in basic science across all fields instead of taking advantage of its high specialization in telecommunications would represent miss-allocation of resources as well.

Accelerate knowledge transfer from highly specialized (and efficient in these domains) countries to other countries specializing in fields that could benefit from these advancements.

5.3. Limitations: Beyond the Research Hypotheses

In conducting this study, I ran across several potentially interesting questions that I have left unanswered. Beyond the direct empirical findings herein, it may be worth considering further a few points, which I did not address herein, and which are detailed in Appendix 10, Further Work.

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Appendix 1: Proposed Corrected formula for accurately measuring national scientific and technological performances through scientific and technological propensities.

Measuring national scientific and technological performances through scientific and technological propensities may be subject to a measurement error potentially introduced in by the role of flows of intangible capital such as human capital and foreign funded R&D. To avoid such measurement errors, I am proposing a corrected formula that shall need further testing. For technological propensities, the formula is[45]:

$$TP^{*}=TP(1+\Sigma j_i a_i w_i)$$

Where:

TP^{*}=corrected technological propensity

TP=standard technological propensity, calculated as patent activity divided by business expenditures in R&D (BERD)

$i=1\ldots4$, detailed further below

$j_i=\pm1$, depending on the direction of the flow in intangible capital, inward or outward

w_i=percentage of the flow (for example British outward patent activity flow is around 22% in 1996, as mentioned above, which will make the value for the respective $w=0.22$)

a_i=correcting factor for the given flow. For patent activity (outward/inward flows driven by inward foreign funded R&D and outward R&D funded abroad), $a=1$; the value for this coefficient for human capital flows will be determined in future work[46]

The values of the sign factor "j" are as follows:

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[45] A similar formula can be conceived for corrected scientific propensities. In further work I will address some of the issues herein using the corrected scientific and technological propensities as measures of technological performance. See Appendix 10 for a description of this intended work. I applied a limited version herein, the results of which are included in Appendix 5.

[46] It is conceivable that the value for the "a" coefficient for high skilled human capital flows shall take values between 0.5 and 2. The reason is related to a concern expressed often in the brain drain literature , namely that many of the departing scientists and engineers are the *crème de la crème*, i.e. star scientists or innovators who are the brightest and whose talents can have many spill over benefits for their host countries (Mahroum 2002). Thus their contribution in the new host country may be much larger than

For i=1 (inward foreign funded R&D), j_1=+1,

For i=2 (outward R&D funded abroad), j_2=-1,

For i=3 (inward brain drain in technology fields), j_3=-1,

For i=4 (outward brain drain in technology fields), j_4=+1.

Depending on the scope of the particular analyses performed with the respective technological propensities, some components could be omitted from the corrected technological propensities. For example, when analyzing the true work of the science-technology link for a country, inward brain drain in technology should be omitted. When analyzing a country's true own technological performance or its technology-economic growth link all factors should be considered.

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expressed by a sole unitary count for each. A further distinction between "brain drain" and "brain waste" may need to be drawn as well. For brain waste cases, the "a" coefficient becomes sub-unitary.

Appendix 2: Operationalization of scientific and technological performance: calculating scientific and technological propensities

a) direct year method

Scientific propensities are calculated by dividing the number of scientific publications by non-business FTE RSEs in the same year.

Technological propensities are calculated by dividing a measure of technological innovation (patent activity) by business R&D expenditures. As explained above, I use both patent applications to the EPO and patents granted by the USPTO for patent activity. The data is by priority year of the patent, in time series format, for 1980-2000. Please see below the detailed relations between variables and measurable constructs.

b) time lag method

Scientific propensities are calculated by dividing the number of scientific publications by non-business originating R&D expenditures three years before.

Technological propensities are calculated by dividing the selected measure of patent activity by business R&D expenditures five years before.

The reasoning for selecting a three-year time lag for scientific propensities and a five-year time lag for technological propensities is, consistent with practice I encountered in the literature (ERSTI 1997, 179), is that scientific R&D efforts are considered to take less time to come to fruition than technological oriented R&D efforts.

c) RSEs work depreciation method

Scientific propensities are calculated by dividing the number of scientific publications by a sum of depreciated (by 5% per year is the standard practice) numbers of non-business research scientists and engineers (RSEs) having performed work in all the three previous years.

Technological propensities are calculated by dividing the selected measure of patent activity by the R&D stock in the same year. The R&D stock is calculated as a sum of depreciated values (by 15% per year is the usual practice) for business R&D in all the five previous years.

Using this method is consistent with its use in other studies that have addressed the same issue (ERSTI 1997, 179; Henderson and Cockburn, 1996, Griliches 2000, Soete and Ter Weel 1999).

When calculating scientific propensities I use a three year period for calculating the impact of the depreciated (by 5% per year is the usual practice) work of non-business FTE RSEs. When calculating technological propensities I use again a five year period for the depreciated business R&D expenditures.

Specification of variables used for measuring scientific and technological performances

Combining all of the above, I use the following variable definitions for calculating scientific and technological propensities respectively[47]:

- scientific propensities
a) same year
eu_spa=eu_pub/(eu9_tota-eu25_bus)
us_spa=us_pub/(us9_tota-us25_bus)

b) 3-year time lag
eu_spb=eu_pub/LAG((eu9_tota-eu25_bus),3)
us_spb=us_pub/LAG((us9_tota-us25_bus),3)

c) with depreciation over 3 years of the work performed by non-business research scientist and engineers (engaged in basic science research)[48]

eu_spc=eu_pub/(.95*.95*.95*LAG((eu9_tota-eu25_bus),3)+.95*.95*LAG((eu9_tota-eu25_bus),2)+.95*LAG((eu9_tota-eu25_bus),1)+(eu9_tota-eu25_bus))

us_spc=us_pub/(.95*.95*.95*LAG(us9_tota-us25_bus,3)+.95*.95*LAG(us9_tota-us25_bus,2)+.95*LAG(us9_tota-us25_bus,1)+(us9_tota-us25_bus))

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[47] Eu_pub, us_pub represent scientific publications. Eu1_gros and similar for the US and JP represent gross R&D expenditures. Eu9_tota and similar for US and Japan represent total number of full time employed (FTE) research scientists and engineers (RSEs). Eu25_bus and similar for US and Japan represent number of non-business full time employed (FTE) research scientists and engineers (RSEs). Eu21_bus and similar represent BERD. Eu63a_nu and similar for the US and JP represent number of patent applications to the EPO, by priority year. Eu63b_nu and similar represent number of patents granted by the USPTO, by priority year. Please also see appendix 1, variables in this study, where all the measured constructs used in the multiple databases built for this study are listed comprehensively. Data comes from OECD ST database (R&D expenditures and RSEs) and ERSTI 1997 (publications) respectively.

[48] I include herein this method of calculating propensities for reference only but I will not use it in the analysis. I shall include in future work the analysis of the relationship between scientific and technological propensities calculated with the three and five year respectively depreciation method.

```
jp_spc=jp_pub/(.95*.95*.95*LAG(jp9_tota-jp25_bus,3)+.95*.95*LAG(jp9_tota-
jp25_bus,2)+.95*LAG(jp9_tota-jp25_bus,1)+(jp9_tota-jp25_bus))
```

- technological propensities

1) using EPO patent applications (by priority year):

a) same year

```
eu_tpea1=eu63a_nu/eu21_bus
us_tpea1=us63a_nu/us21_bus
jp_tpea1=jp63a_nu/jp21_bus
```

b) 5-year time lag

```
eu_tpeb1=eu63a_nu/LAG(eu21_bus,5)
us_tpeb1=us63a_nu/LAG(us21_bus,5)
jp_tpeb1=jp63a_nu/LAG(jp21_bus,5)
```

c) with depreciation of R&D expenditures[49]

```
eu_tpec1=eu63a_nu/(.85^5*LAG(eu21_bus,5)+.85^4*LAG(eu21_bus,4)+.85^4*LAG(eu
21_bus,3)+.85^2*LAG(eu21_bus,2)+.85*LAG(eu21_bus,1)+eu21_bus)

us_tpec1=us63a_nu/(.85^5*LAG(us21_bus,5)+.85^4*LAG(us21_bus,4)+.85^4*LAG(us
21_bus,3)+.85^2*LAG(us21_bus,2)+.85*LAG(us21_bus,1)+us21_bus)

jp_tpec1=jp63a_nu/(.85^5*LAG(jp21_bus,5)+.85^4*LAG(jp21_bus,4)+.85^4*LAG(jp2
1_bus,3)+.85^2*LAG(jp21_bus,2)+.85*LAG(jp21_bus,1)+jp21_bus)
```

2) using USPTO patents granted (priority year)

a) same year

```
eu_tpua1=eu63b_nu/eu21_bus
us_tpua1=us63b_nu/us21_bus
jp_tpua1=jp63b_nu/jp21_bus
```

b) 5-year time lag

```
eu_tpub1=eu63b_nu/LAG(eu21_bus,5)
us_tpub1=us63b_nu/LAG(us21_bus,5)
jp_tpub1=jp63b_nu/LAG(jp21_bus,5)
```

c) with depreciation of R&D expenditures[50]

```
eu_tpuc1=eu63b_nu/(.85^5*LAG(eu21_bus,5)+.85^4*LAG(eu21_bus,4)+.85^3*LAG(e
u21_bus,3)+.85^2*LAG(eu21_bus,2)+.85*LAG(eu21_bus,1)+eu21_bus)

us_tpuc1=us63b_nu/(.85^5*LAG(us21_bus,5)+.85^4*LAG(us21_bus,4)+.85^3*LAG(us
21_bus,3)+.85^2*LAG(us21_bus,2)+.85*LAG(us21_bus,1)+us21_bus)
```

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[49] See footnote 48 above.

[50] See footnote 48 above.

jp_tpuc1=jp63b_nu/(.85^5*LAG(jp21_bus,5)+.85^4*LAG(jp21_bus,4)+.85^3*LAG(jp21_bus,3)+.85^2*LAG(jp21_bus,2)+.85*LAG(jp21_bus,1)+jp21_bus)

3) using total EPO and USPTO patent applications (priority year)

a) same year
eu_tpta1=eu63c_nu/eu21_bus
us_tpta1=us63c_nu/us21_bus
jp_tpta1=jp63c_nu/jp21_bus

b) 5-year time lag
eu_tptb1=eu63c_nu/LAG(eu21_bus,5)
us_tptb1=us63c_nu/LAG(us21_bus,5)
jp_tptb1=jp63c_nu/LAG(jp21_bus,5)

c) with depreciation of R&D expenditures[51]

eu_tptc1=eu63c_nu/(85^5.*LAG(eu21_bus,5)+.85^4*LAG(eu21_bus,4)+.85^3*LAG(eu21_bus,3)+.85^2*LAG(eu21_bus,2)+.85*LAG(eu21_bus,1)+eu21_bus)

us_tptc1=us63c_nu/(85^5.*LAG(us21_bus,5)+.85^4*LAG(us21_bus,4)+.85^3*LAG(us21_bus,3)+.85^2*LAG(us21_bus,2)+.85*LAG(us21_bus,1)+us21_bus)

jp_tptc1=jp63c_nu/(85^5.*LAG(jp21_bus,5)+.85^4*LAG(jp21_bus,4)+.85^3*LAG(jp21_bus,3)+.85^2*LAG(jp21_bus,2)+.85*LAG(jp21_bus,1)+jp21_bus)

Depreciation of Business Research Stock

jp_brdsd=((((((LAG(jp23_ber,5)/.2)*.85+LAG(jp23_ber,4))*.85)+LAG(jp23_ber,3))*.85)+LAG(jp23_ber,2)*.85+LAG(jp23_ber,1))*.85+jp23_ber

Scientific Propensities (same year)

jp_sp_3a=(jp_pub_1)/(jp7_tota-jp25_bus)

jp_sp_3c=(jp_pub_1)/(((LAG(jp_nbrse,3)/.1)*.95+LAG(jp_nbrse,2)*.95)+LAG(jp_nbrse,1))*.95+jp_nbrse

where:

eu_nbrse= eu7_tota-eu25_bus

Using method c. implies a rather strong theoretical assumption, namely the actual use of FTE research scientists and engineers as a stock of scientific knowledge production. The theoretical assumption is certainly consistent with the treatment of R&D stock as a factor

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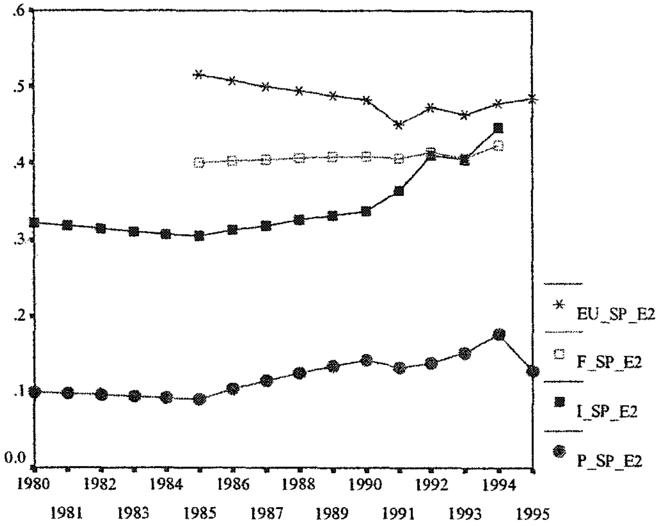
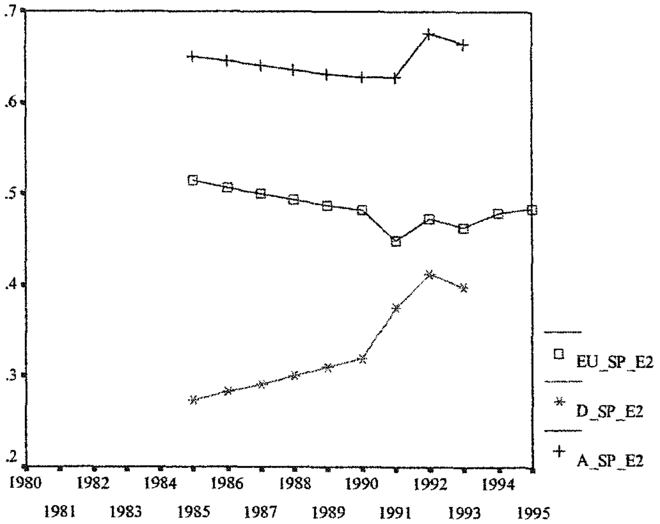
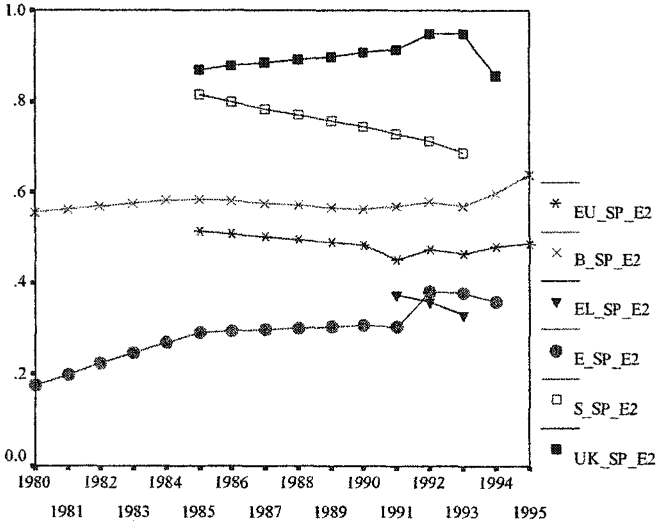
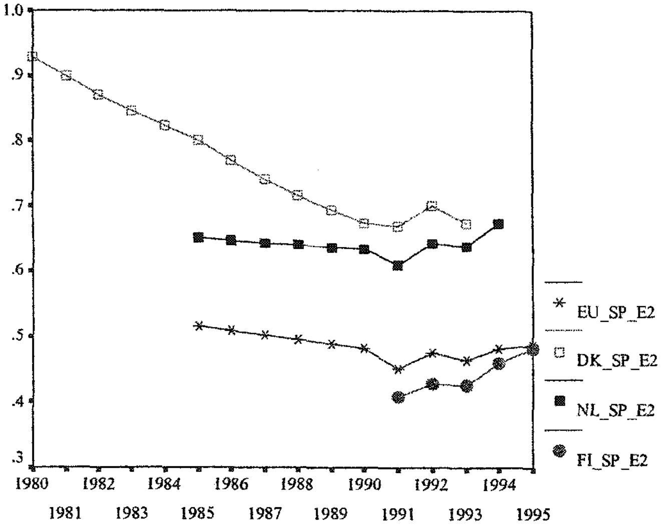
[51] See footnote 48 above.

of production (Grilliches 2000), as well as with the relative different nature scientific work has compared to general labor. Indeed, productivity of labor is mirrored almost entirely in current products whereas scientific productivity is also replicated in amplified productivity as applied to future scientific works. It is for these reasons that I do find method c. as a more valid approach, as compared to methods a. or b..

Appendix 3: Scientific and technological propensities of selected European Union member states

1. Assessing scientific propensities of selected EU member states

Using data provided by the European Commission (ERSTI 1997), I have graphed the scientific propensities of selected EU member states, and placed them in their respective quadrants in a two by two table depicting the Commission's definition puzzling placement of European Union member states in the science-technology grid (ERSTI 1997, Chapter 4), as showed in Table 4 below.

		Technology	
		Weak	Strong
Science	Weak		
	Strong		

Source: own calculations based on data from ERSTI 1997; Note: data points for 1981-1984 and 1986-1989 are estimates.

Table 4: EU member states placement in science-technology grid, by scientific propensity (1980-2000)

The graphs in Table 4 suggest that the grouping proposed by the Commission may not be ideal. The EU member states included in the upper left corner make the only group that is well identified with countries placed in it according to their scientific propensity compared with the EU's overall scientific propensity.

In the upper right quadrant it would seem that only Germany's performance in science justifies it's placing in the quadrant. Austria's better than the EU's aggregate scientific performance, assuming its technological performance is weak, makes it be placed better in the lower right quadrant. Similarly, Finland should probably be moved from the lower right to the upper right quadrant, alongside Germany.

In the lower left quadrant, Spain (E) and Greece (EL) also seem misplaced, their scientific propensity being lower than the EU's as a whole. Thus, provided their technological performance is indeed strong, Spain and Greece belong rather in the upper left quadrant, alongside with France, Italy and Portugal.

2. Assessing technological propensities of selected EU member states

Before rearranging the groups according to the above interpretation of scientific performance (comparing countries scientific propensities with the EU's), I test the Commission's placement in the two by two taxonomy with respect to the countries' technological performance, using again technological propensities for the assessment[52].

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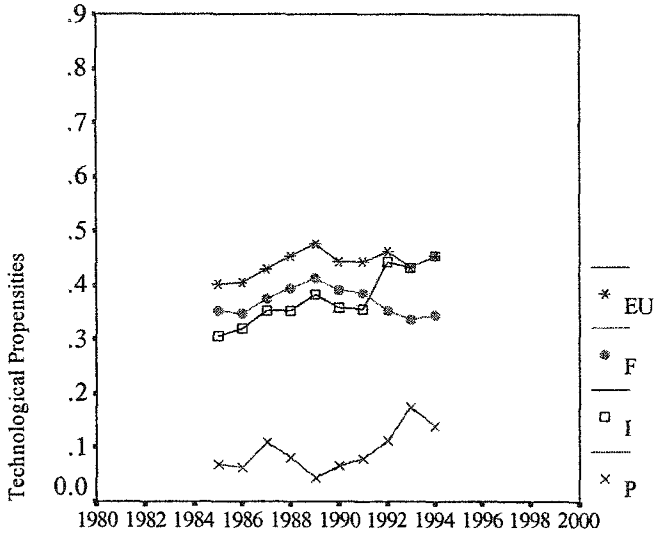
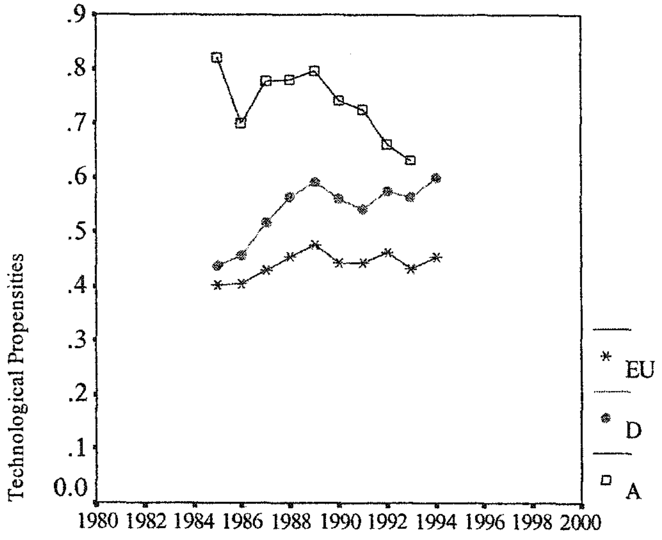
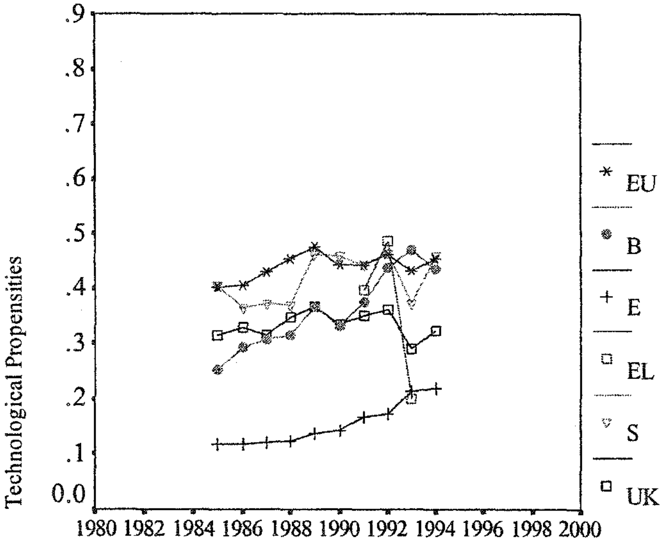
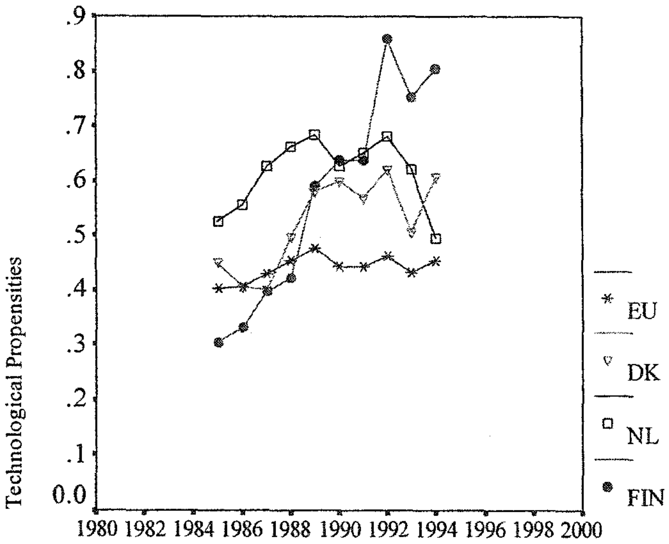
[52] For better data consistency only patent applications to the EPO, by priority year are used when comparing technological propensities between European countries. Given the relatively short data series available for European countries, I only compute the technological propensities using the a. method (please see above, in chapter 5 methods), namely the same year method. Calculating the other two versions using lagged values of BERD would shorten an already short series too much. As demonstrated above in chapter 6.2 there are only very little differences in the propensities' tendencies between the three methods considered, same year, lagged or considering depreciation of R&D. Because these are EPO patent activity based technological propensities, comparisons among them are valid and reliable for the time frame considered. The same is not true however when comparing any of these technological propensities with those of the US or Japan, due to "home patenting" preferences for the US, or increased possible importance given by Japan to USPTO patenting over EPO patenting, as discussed above at 6.2.5.

Table 5 accomplishes this task.

		Technology	
		Weak	Strong
Science	Weak		
	Strong		

<u>Source</u>: own calculations based on data from ERSTI 1997; <u>Note</u>: some data points are based on estimated interpolations.

Table 5: EU member states placement in science-technology grid, by technological propensity (1980-2000)

Compared to the grouping by scientific propensity above (Table 4), in the case of technological propensity (Table 5) the grouping is consistent with the Commission's categories. Indeed, the technological propensities depicted above by groups of countries in comparison with the EU's overall technological propensity are all as expected to be in accordance to the Commission's findings.

In the upper left quadrant, France, Italy and Portugal all have their technological performance lower than the EU's aggregate, as expected. Similarly, in the lower left quadrant, Belgium, Spain (E), Greece (EL)[53], Sweden and the UK also have their technological performance lower than Europe's as a whole.

The upper right quadrant contains only countries, Germany and Austria, which have their technological propensities higher than the EU's aggregate values. Similarly, the same holds true for the group in the lower right quadrant, made of Denmark, the Netherlands and Finland, with all three having better technological propensities than Europe in aggregate.

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[53] As the data for Greece was very limited, caution is needed when using the case of Greece in the analysis.

Appendix 4. Scientific intensities of technological fields and scientific and technological specialization of countries

	MAX	MIN	B	DK	D	EL	E	F	IRL	I	NL	A	P	FIN	S	UK	US	JP
Basic Life Science	**1.46**	**0.41**	0.99	0.79	0.95	0.41	0.42	0.79	0.95	0.55	1.02	0.81	0.47	0.92	0.78	1.19	1.46	0.57
Biomedical Science & Pharmacology	**1.30**	**0.38**	0.82	0.66	0.81	0.45	0.38	0.74	1.11	0.65	0.81	0.83	0.51	0.78	0.82	1.10	1.30	0.43
Clinical Medicine & Health Science	**1.40**	**0.50**	1.22	1.11	0.82	0.53	0.58	0.88	1.32	0.81	1.18	0.82	0.98	1.23	1.16	1.14	1.40	0.50
Biological Science	**1.34**	**0.36**	0.74	0.98	0.89	0.36	0.42	0.76	1.14	0.40	1.24	0.80	0.49	0.64	1.10	1.34	1.13	0.50
Agriculture & Food Science	**1.25**	**0.28**	0.93	1.15	0.70	0.43	0.48	0.88	1.25	0.60	1.20	0.60	0.74	0.98	1.21	1.15	1.02	0.28
Earth & Environmental Science	**1.30**	**0.32**	0.84	1.00	1.05	0.46	0.32	0.84	0.95	0.45	1.18	0.44	0.49	0.69	0.86	1.12	1.30	0.50
Chemistry	**1.94**	**0.60**	1.09	1.63	1.09	0.75	0.67	0.90	0.93	0.83	1.72	0.93	0.6	0.95	1.44	1.31	1.94	0.73
Engineering	**1.50**	**0.40**	1.16	1.50	0.94	0.40	0.53	0.83	0.81	0.64	1.24	0.71	0.54	0.78	0.96	0.82	1.38	0.60
Computer Science	**1.41**	**0.43**	1.35	1.22	0.97	0.52	0.44	0.81	:	0.69	0.89	1.18	0.43	1.07	0.58	0.84	1.41	0.45
Mathematics & Statistics	**1.43**	**0.46**	0.83	1.40	0.96	0.46	0.51	1.16	0.71	0.83	0.94	0.79	0.85	0.69	0.78	1.18	1.43	0.75
Physics & Astronomy	**1.79**	**0.42**	0.91	1.50	1.25	0.59	0.78	1.04	0.88	0.85	1.38	1.04	0.42	0.87	1.09	1.16	1.79	0.80
Average	**1.41**	**0.49**	**0.99**	**1.18**	**0.95**	**0.49**	**0.50**	**0.88**	**1.01**	**0.66**	**1.16**	**0.81**	**0.59**	**0.87**	**0.98**	**1.12**	**1.41**	**0.56**

Table 6: Quality index of scientific publications, by country and field of science

Source: European Commission (Key Figures 2002, 46): DG-Research Key Figures 2002; Data: ISI, CWTS (treatments)

Notes: The index is calculated as the ratio of the number of actual papers divided by the expected papers in the top 5% of most cited papers.

Publication years 1996, 1997, 1998; citation years 1996-1999, 1997-2000, 1998-2001. Green signals the highest, purple the lowest scores.

Calculation not possible for L and IRL (Computer Sciences) due to too low publication numbers.

	B	DK	D	EL	E	F	IRL	I	NL	A	P	FIN	S	UK	US	JP
Basic Life Science	0.60	0.43	0.56	0.10	0.11	0.43	0.56	0.22	0.62	0.44	0.15	0.54	0.42	0.77	1.00	0.24
Biomedical Science & Pharmacology	0.53	0.37	0.52	0.17	0.10	0.45	0.81	0.36	0.52	0.54	0.23	0.49	0.53	0.80	1.00	0.15
Clinical Medicine & Health Science	0.82	0.71	0.42	0.13	0.18	0.48	0.92	0.41	0.78	0.42	0.58	0.83	0.76	0.74	1.00	0.10
Biological Science	0.45	0.67	0.59	0.10	0.16	0.47	0.82	0.14	0.91	0.50	0.22	0.36	0.78	1.00	0.81	0.23
Agriculture & Food Science	0.70	0.91	0.49	0.24	0.29	0.66	1.00	0.40	0.95	0.40	0.53	0.75	0.96	0.91	0.79	0.10
Earth & Environmental Science	0.58	0.72	0.77	0.23	0.10	0.58	0.68	0.22	0.89	0.21	0.26	0.44	0.60	0.83	1.00	0.27
Chemistry	0.43	0.79	0.43	0.20	0.15	0.30	0.32	0.25	0.85	0.32	0.10	0.34	0.66	0.58	1.00	0.19
Engineering	0.72	1.00	0.54	0.10	0.21	0.45	0.44	0.30	0.79	0.35	0.21	0.41	0.56	0.44	0.90	0.26
Computer Science	0.94	0.83	0.60	0.18	0.11	0.45		0.34	0.52	0.79	0.10	0.69	0.24	0.48	1.00	0.12
Mathematics & Statistics	0.44	0.97	0.56	0.10	0.15	0.75	0.33	0.44	0.55	0.41	0.46	0.31	0.40	0.77	1.00	0.37
Physics & Astronomy	0.42	0.81	0.65	0.21	0.34	0.51	0.40	0.38	0.73	0.51	0.10	0.40	0.54	0.59	1.00	0.35
Average	**0.60**	**0.75**	**0.56**	**0.16**	**0.17**	**0.50**		**0.31**	**0.74**	**0.44**	**0.27**	**0.50**	**0.59**	**0.72**	**0.95**	**0.22**
Total	**6.64**	**8.21**	**6.13**	**1.76**	**1.87**	**5.52**		**3.46**	**8.11**	**4.89**	**2.94**	**5.55**	**6.44**	**7.91**	**10.50**	**2.37**

Table 7: Normalized quality index of scientific publications, by country and field of science

Source: adapted based on European Commission (Key Figures 2002, 46): DG-Research Key Figures 2002; Data: ISI, CWTS (treatments)

Notes: The index is calculated as the normalized (values between 0.1 and 1.0) ratio of the number of actual papers divided by the expected papers in the top 5% of most cited papers. Normalization is necessary for easier comparison across fields and countries. For example, Belgium has a similar quality of scientific publications in basic life sciences (0.60) with the UK's quality in physics and astronomy (0.59).

Publication years 1996, 1997, 1998; citation years 1996-1999, 1997-2000, 1998-2001. Green signals the highest, purple the lowest scores.

Calculation not possible for L and IRL (Computer Sciences) due to too low publication numbers.

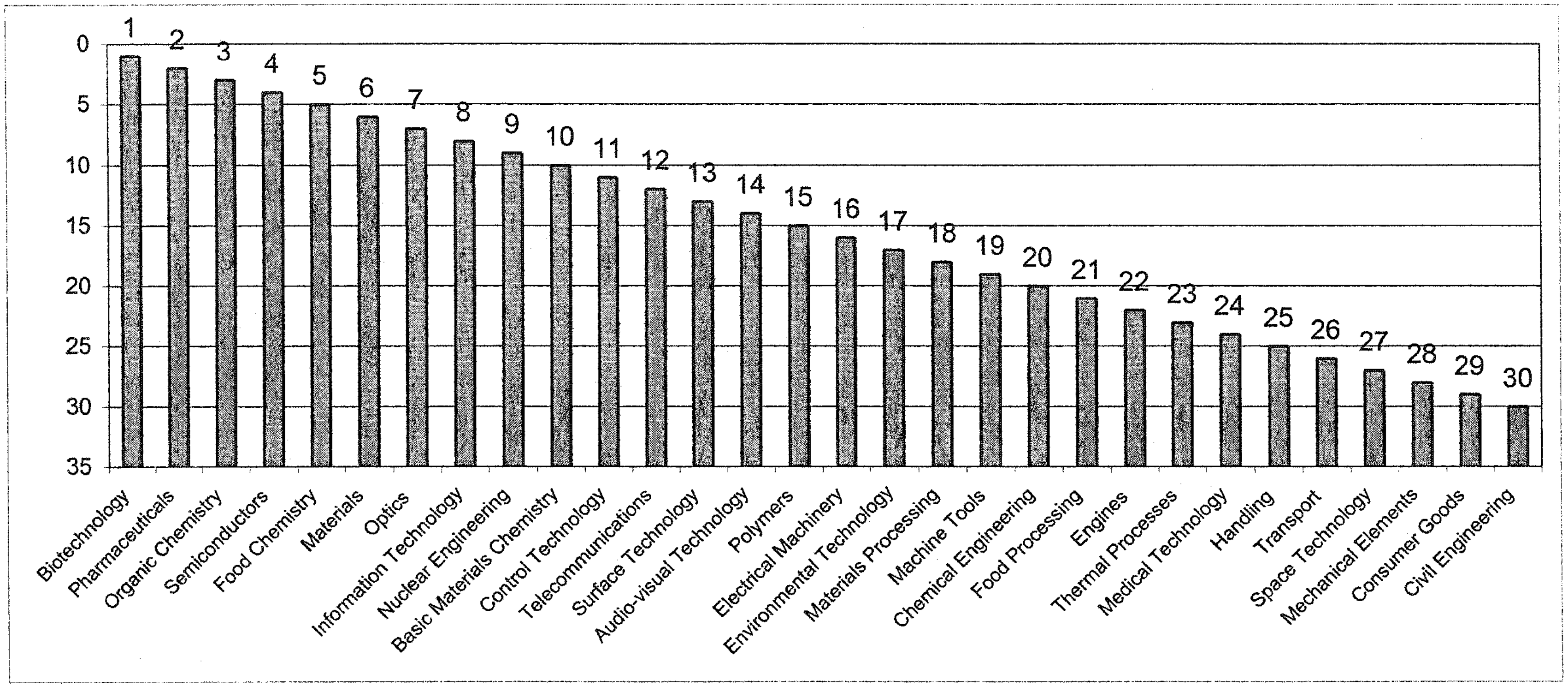


Figure 6: Ranked order of technological fields by their scientific intensity

Source: adapted from European Commission (ERSTI 1997, 183): DGXII (Research)-AS4/FhG-ISI; Data: European Patent Office

		B	DK	D	EL	E	F	IRL	I	NL	A	P	FIN	S	UK
Life sciences	Basic life sciences	1					1	1			1			1	
	Biological sciences	1	1			1		1			1		1		
	Biomedical sciences	1	1								1		1	1	
	Clinical medicine	1	1					1	1		1		1	1	1
	Dentistry		1		1			1		1			1	1	1
	Food science & agriculture	1	1			1		1		1			1	1	
	Health sciences		1							1			1	1	1
	Pharmacology	1				1			1				1	1	
Earth & Environ. sci.	Earth sciences		1				1								1
	Environmental sciences		1			1							1	1	1
Computer sci.	Computer science				1				1	1	1	1	1		
Mathematics & Statistics	Mathematics			1	1	1	1	1	1		1	1			
	Statistical an. & probability	1		1	1	1				1					
Chemistry	Chemistry			1		1	1					1			
Physics & Astronomy	Astronomy & Astrophysics			1		1	1		1	1					
	Physics			1			1		1		1				
Engineering	Aerospace engineering			1			1	1	1						
	Chemical engineering			1	1	1				1		1			
	Civil engineering		1		1					1		1	1	1	1
	Electrical engineering	1			1			1	1						1
	Fuels & energy			1			1					1			
	Geological engineering				1				1						1
	Instruments & instrumentation	1		1					1		1	1			
	Materials science			1			1				1	1		1	
	Mechanical engineering				1		1	1				1			1
	Other engineering sciences	1			1			1		1	1	1			1

Table 8: Relative specialization profile by country and field of science, 1996-1999

Source: European Commission (Key Figures 2002, 44): DG Research
Data: ISI, CWTS (treatments), DG Research (calculations)
Notes: (1) Publication period: 1996-1999
(2) Shaded fields with a "1" indicate relative specialization of the country in the respective field.

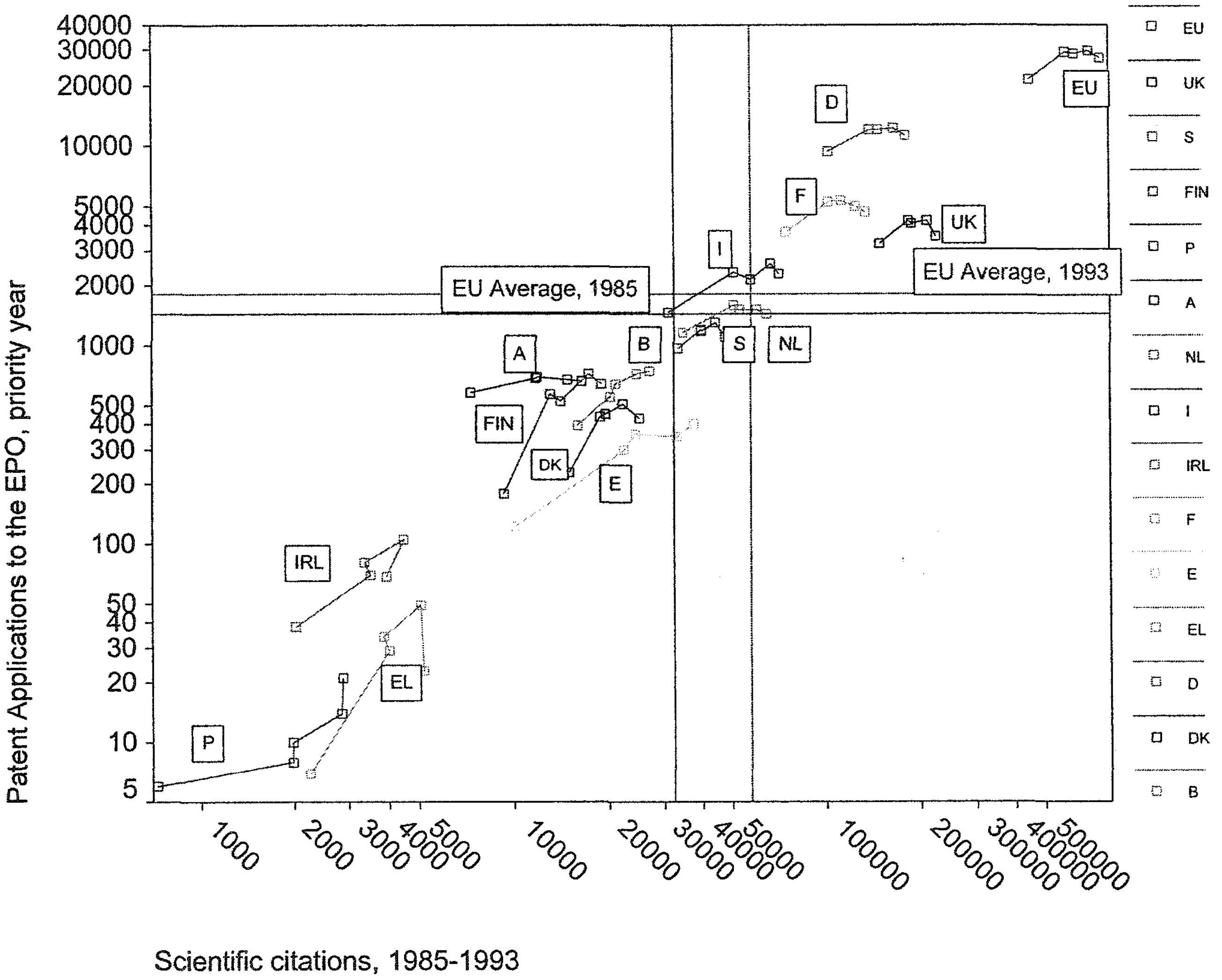
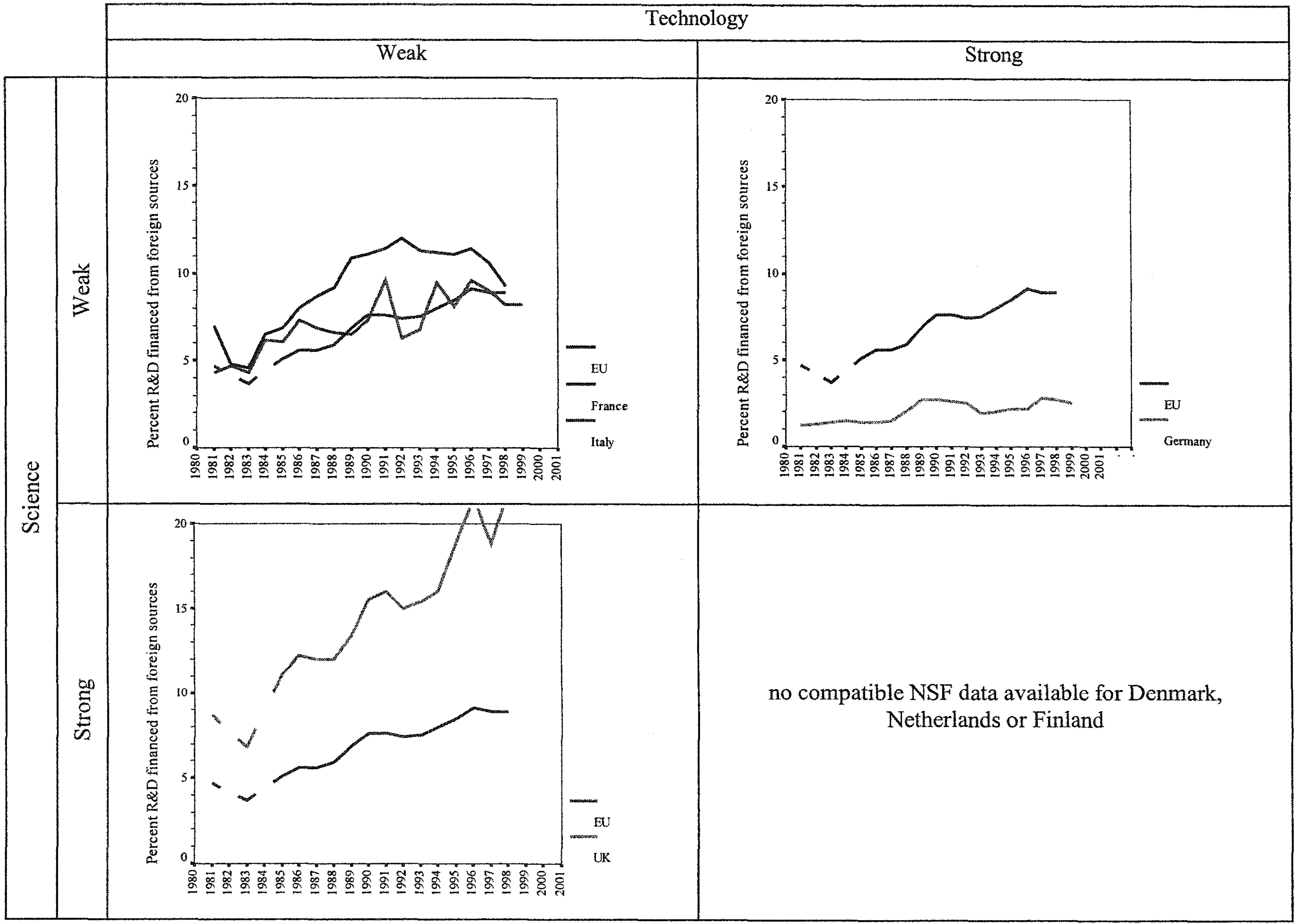


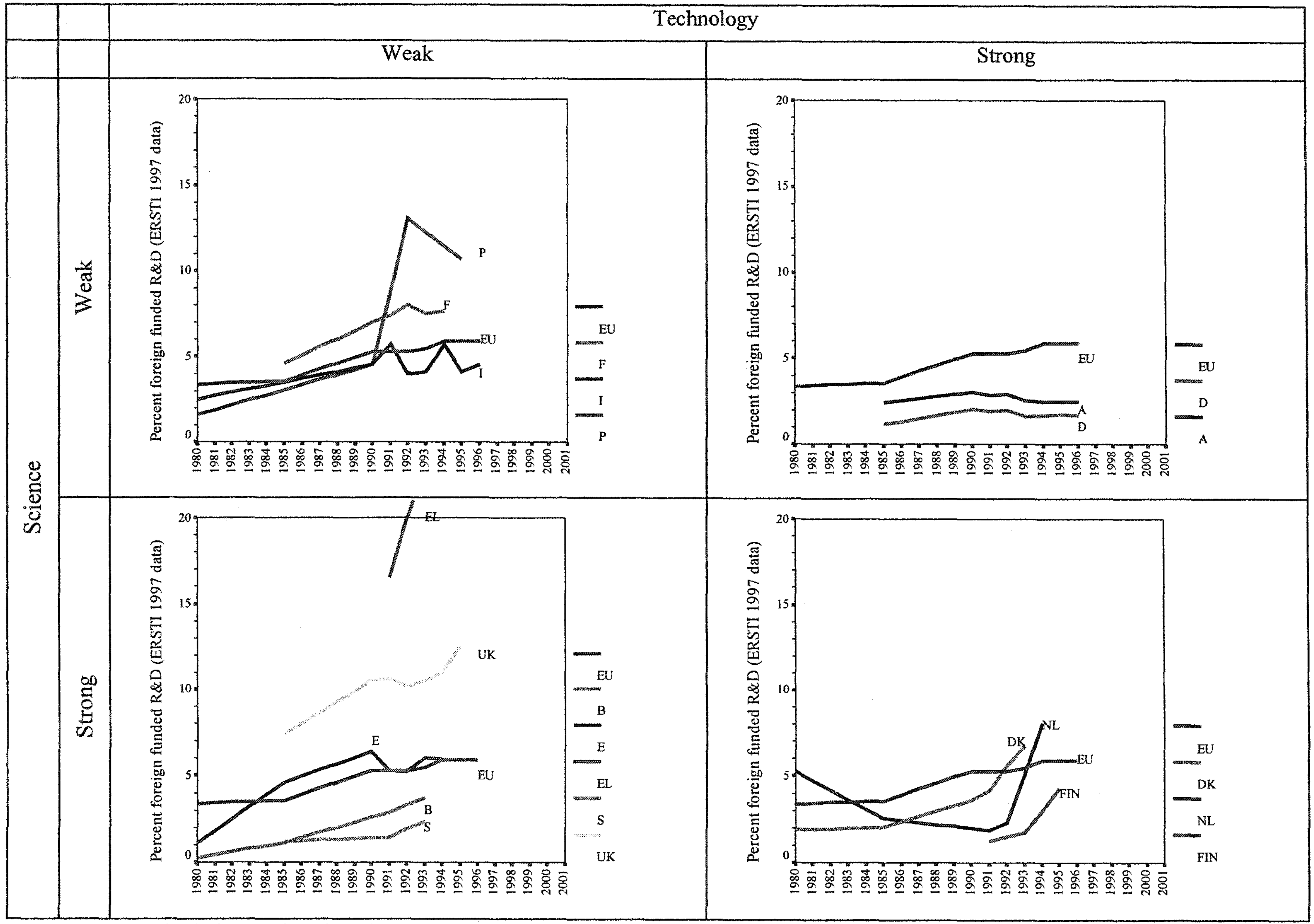
Figure 7: Technological output (patent applications) by scientific output quality (scientific citations) in EU member states (1985-1993)

Appendix 5: Foreign funded R&D expenditures in selected developed countries



Source: own calculations using NSF data

Figure 8: Foreign funded R&D expenditures in selected EU member states, 1980-2000, NSF data



Source: own calculations using data from ERSTI 1997 Note: some data points used are interpolated estimates

Figure 9: Foreign funded R&D for EU member states, 1980-2000, European Commission data

Both Figure 8 and Figure 9 were built around the Commission's own grouping of EU member states with respect to the paradox "within" the EU. According to the findings in section 6.2.3. above, the grouping of the countries had to be corrected according to their placement in the science-technology performance grid in Figure 2. If considering this correction, the figures representing levels of foreign funded R&D for EU member states need to be rebuilt with the new grouping of countries.

I have done this in Figure 4 for the NSF data and in Figure 5 for the ERSTI 1997 data. Unfortunately however, with the NSF data limited to only a few European countries, Figure 4 does not inform us more than Figure 8 did.

Appendix 5: Successive stages of analysis of science-technology link in European advanced industrial economies

The figures herein show in their respective succession that the strength of the link between science and technology becomes more apparent if measuring technological performance lagging scientific performance in time. The lowest explanatory power is the one of a direct year model science-technology at 82.84% (Figure 10). The highest explanatory power is for the seven year lagged model, whereby scientific performance of today is considered to impact technological performance seven years later, at 85.89% (Figure 13). If adding the correction for the measurement influence of foreign funded R&D on technological propensities of a country, the explanatory power increases further to 86.55% (Figure 14).

However, the statistical power of the successive models decreases with the lagging, as the number of paired cases decreases with the lagging.

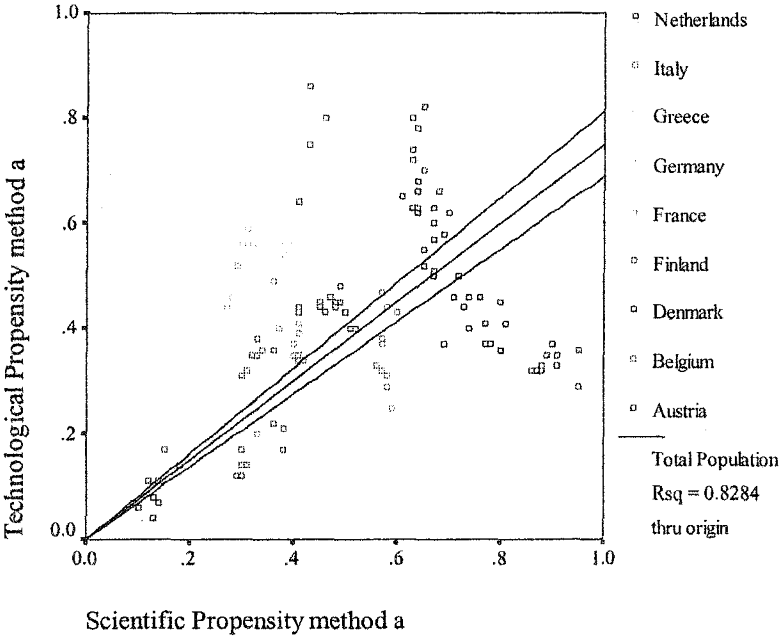


Figure 10: Technological Propensities by Scientific Propensities in EU member countries, 1985-1995, direct year

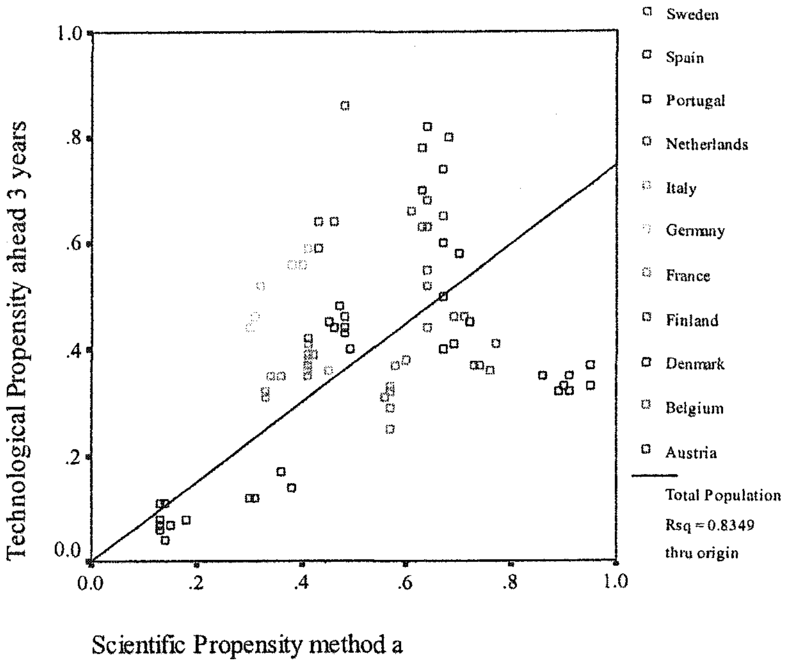


Figure 11: Technological Propensities by Scientific Propensities three years earlier in EU member countries (1985-1995)

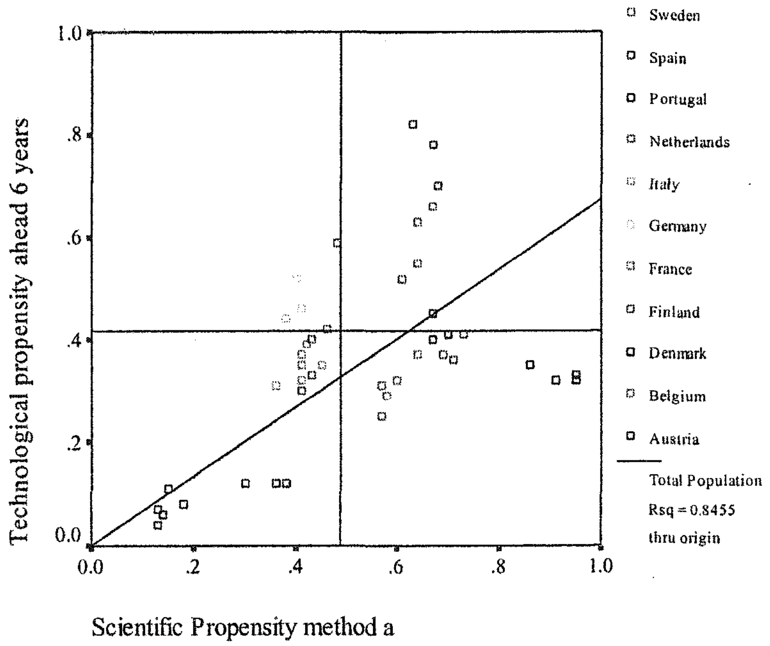


Figure 12: Technological Propensities by Scientific Propensities 6 years earlier in EU member countries, (1985-1995)

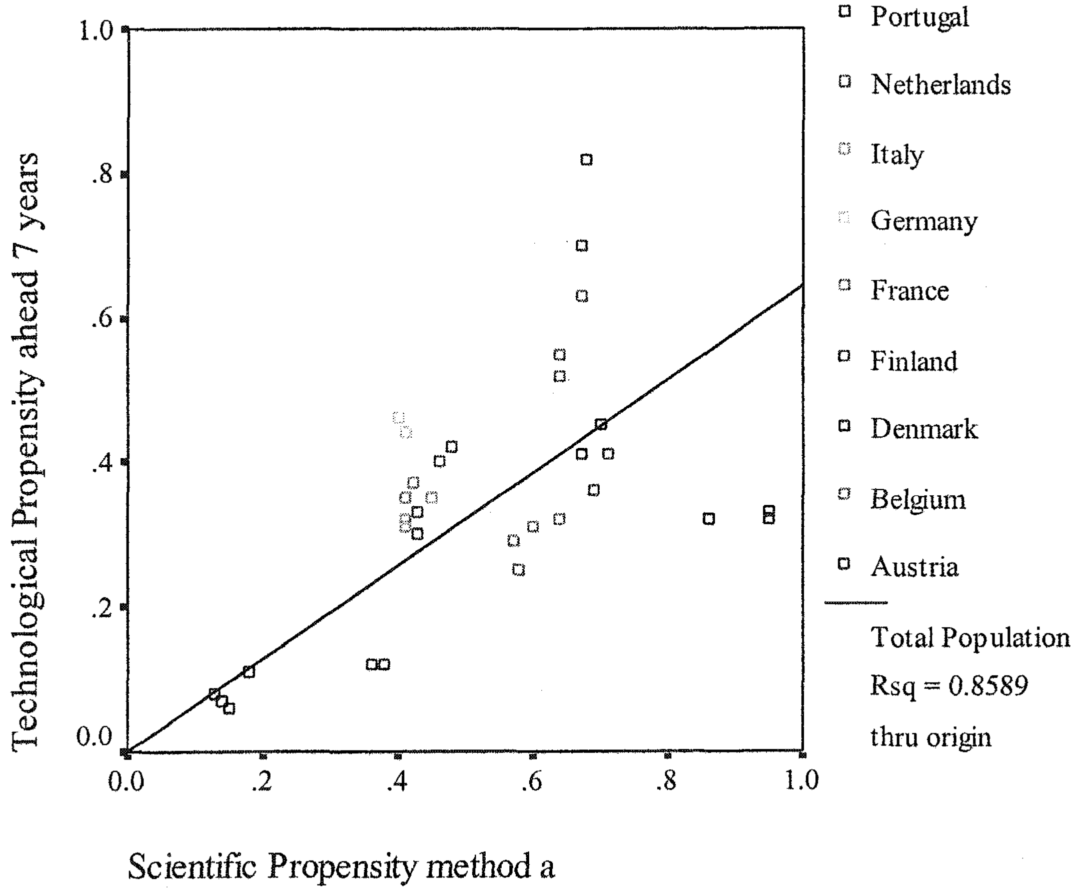


Figure 13: Technological Propensities by Scientific Propensities 7 years earlier, EU member countries (1985-1995)

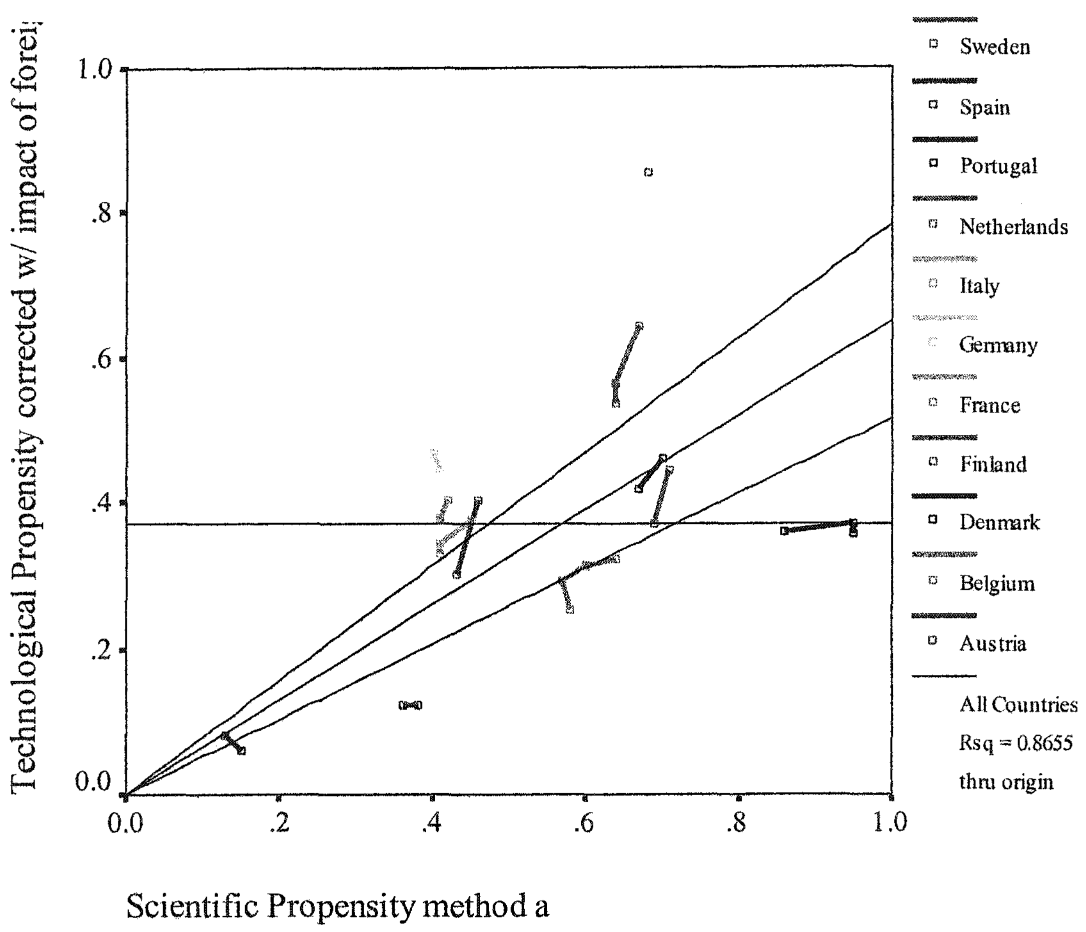


Figure 14: Technological Propensities (TP) by Scientific Propensities 7 years earlier, with TP correction applied for taking into account impact of foreign funded R&D on measuring patenting activity in a country, EU member states (1985-1995)

Appendix 6: Structure of R&D expenditures in Finland

This figure shows how Finland's allocation of R&D funds in manufacturing is focusing on one sector, namely radio, television and communications. In other words, in Finland R&D has focused on the sector that Finland has become very well known for, namely mobile telephony. Finland high technological innovation is thus not equal across a variety of fields, but rather solely in mobile telephony infrastructure, where efforts have been concentrated.

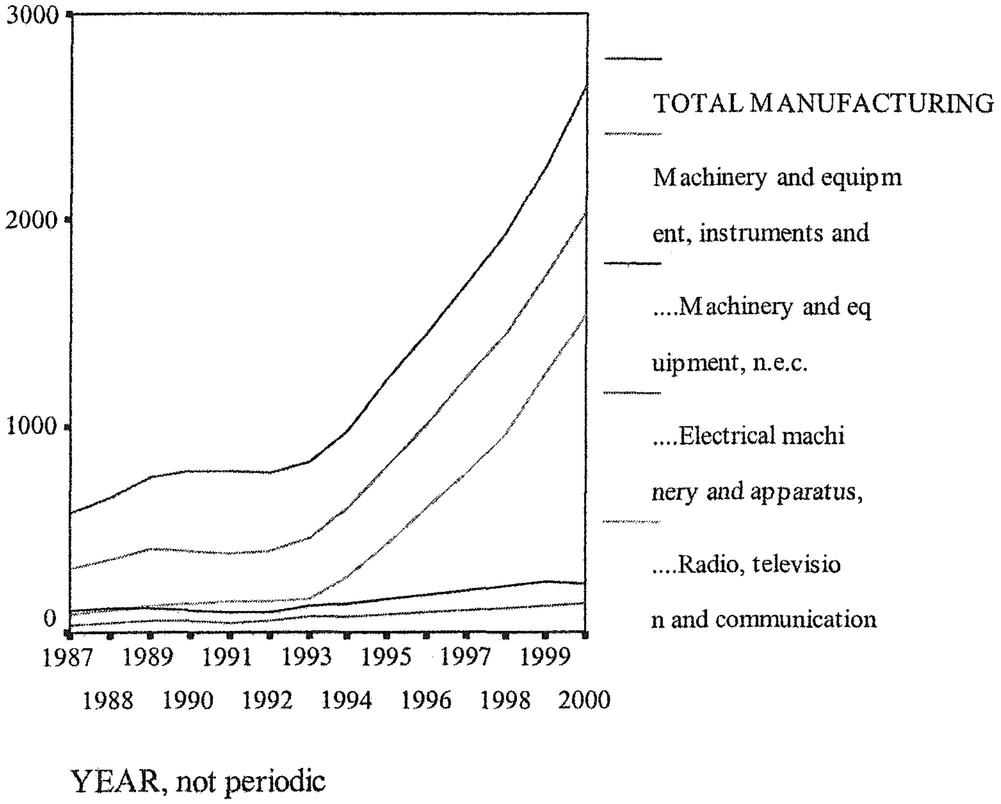


Figure 15: Structure of R&D expenditures in Finland, 1987-2000

Appendix 7: Cobb-Douglas production function based models for selected West European countries

1. Value added in total manufacturing

Comparative value added graphs for total manufacturing in European Union member states are depicted in Figure 16, Figure 17, and Figure 18 below.

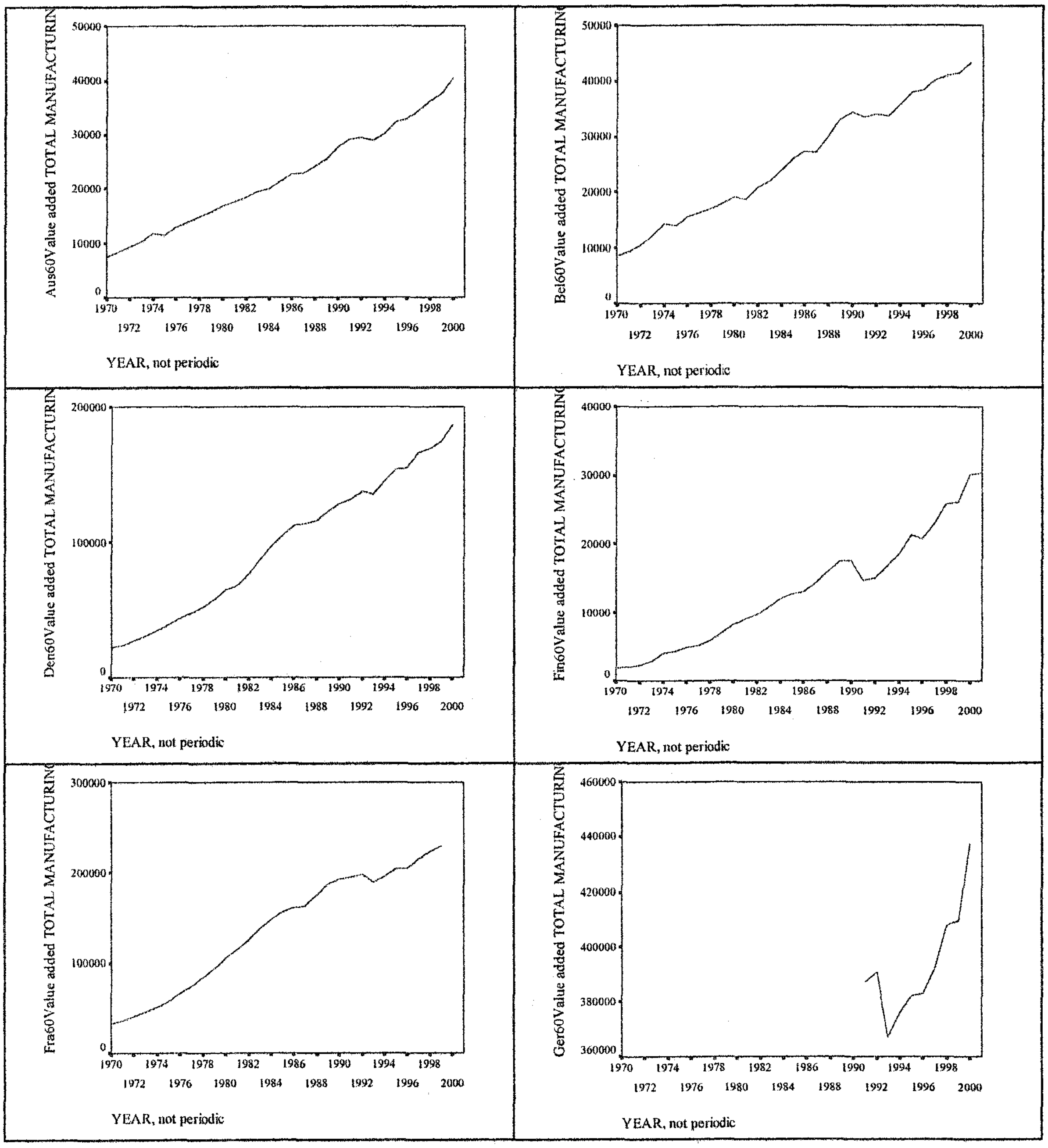


Figure 16: Value Added of selected EU member states, total manufacturing (1) (1970-2000)

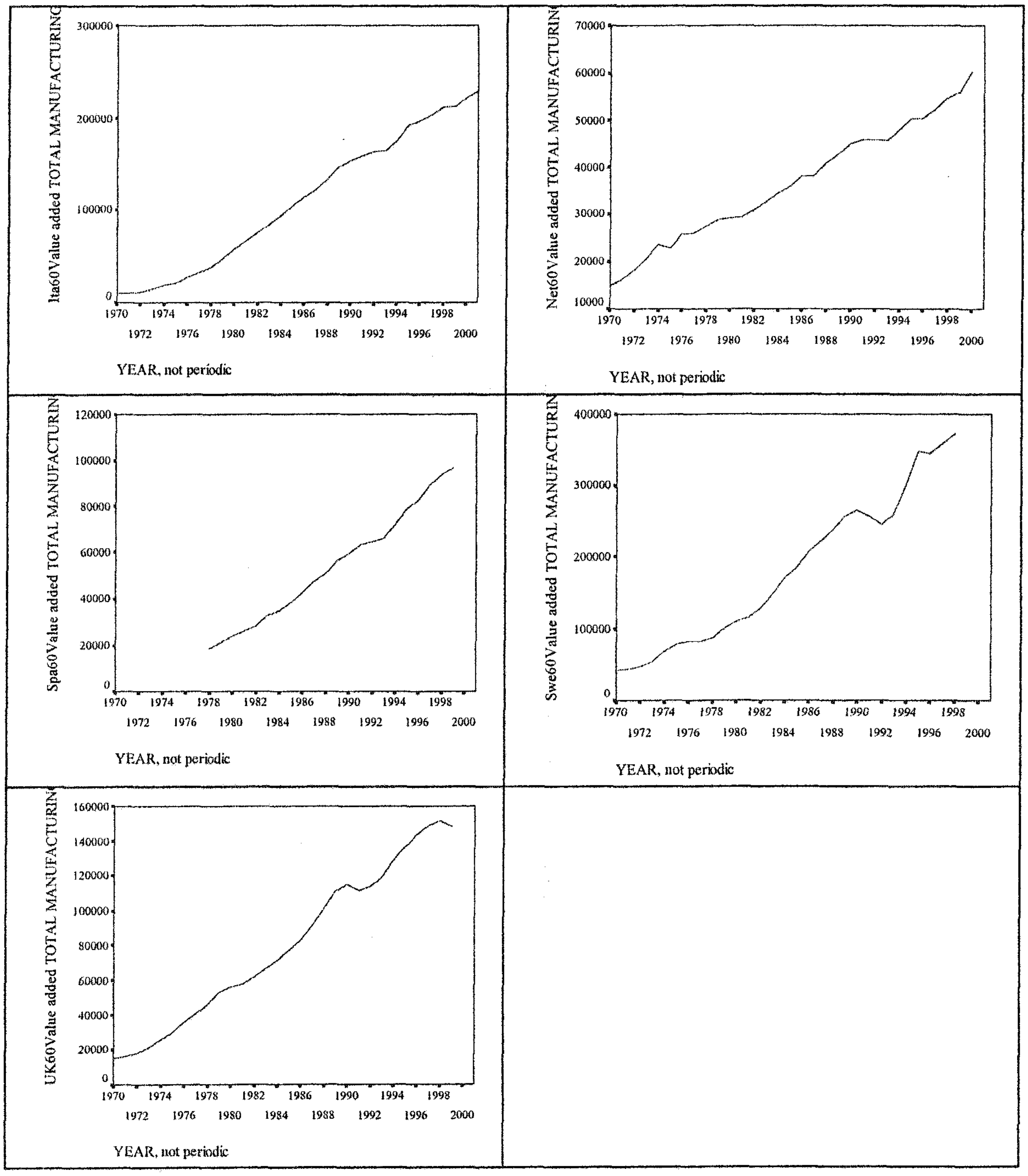
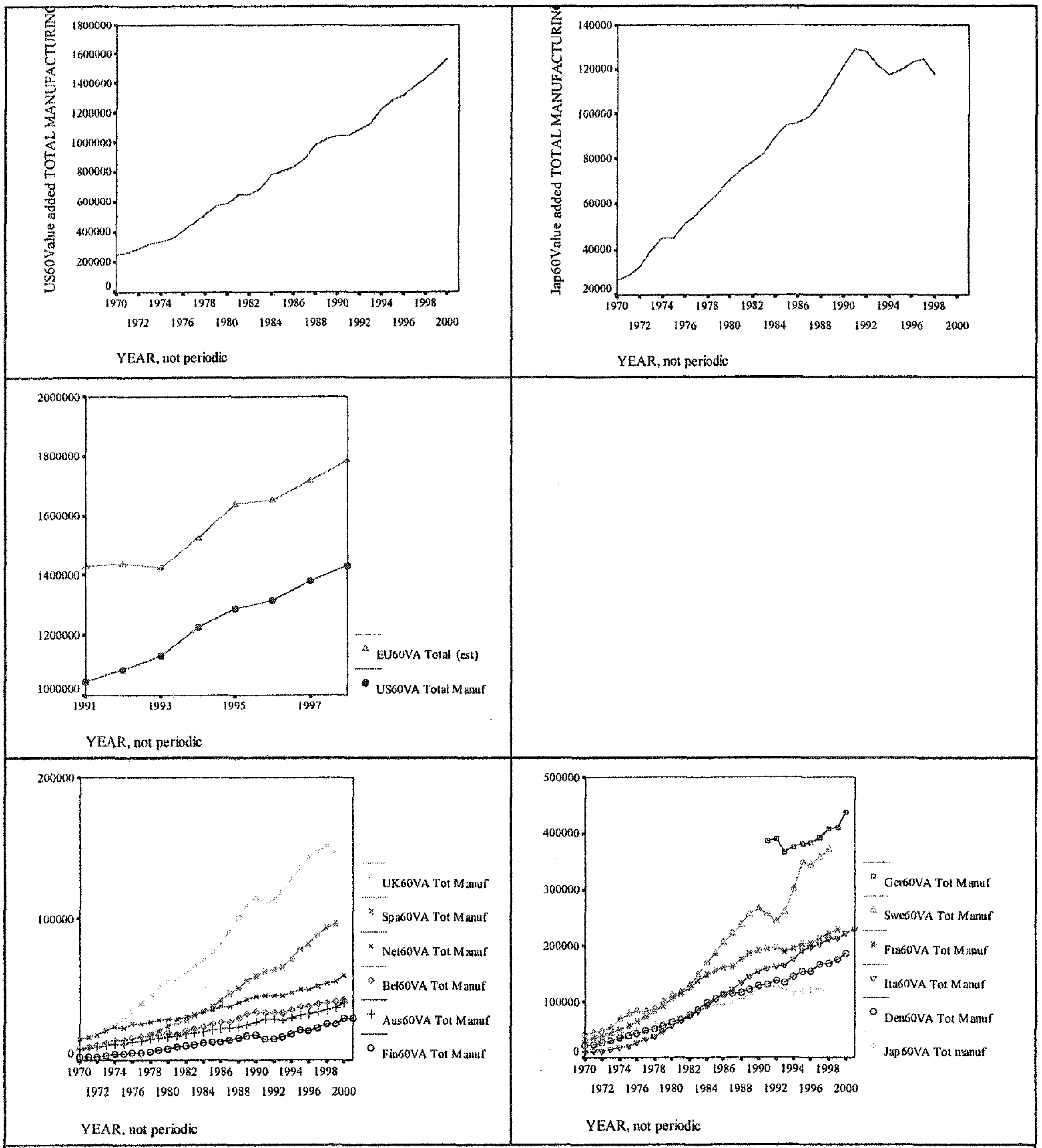


Figure 17: Value Added of selected EU member states, total manufacturing (2) (1970-2000)

We notice that while all EU member countries have had increases in value added over the three decades considered, the rate of growth varies widely from one country to the other. Austria and Belgium have very similar trends, in spite of Belgium being an original member of the Common Market, and Austria becoming an EU member only in 1995. Both countries have started at around 10,000 mil. constant PPP $ in 1970, to grow their value added about fourfold by 2000, at a rate of about 1 billion $ a year.

Denmark and France have followed relatively similar growth paths as well, both countries having grown their value added over the past three decades from under 30,000 mil. constant PPP $ in 1970 to around 200,000 mil. constant PPP $ in 2000, representing an over six fold growth at a rate of about 6 billion $ a year. Given the differences in sizes and populations between the two countries, Denmark's record becomes quite impressive.

Data for Germany is absent unfortunately prior to 1990, given the discontinuity set up by the German reunification. Nonetheless, Germany's record is the most impressive in the EU, as even with having to offset its efforts to incorporate and rebuild its new *länder*, Germany has managed past 1993 to grow at a steady rate from 360,000 mil. constant PPP $ in 1993 to 440,000 mil. constant PPP $ in 2000, or at a rate of over 10 billion $ a year, the largest rate in Europe.



Source: own calculations based on data from OECD STAN database.
Note: EU (est.) excludes Portugal, Ireland, Greece and Luxembourg; data for Germany was not available prior to 1990, thus 1970-1990 period is not included in EU (est.)

Figure 18: Comparative Value Added in the US, EU and Japan, and selected EU member states, total manufacturing (1970-2000)

Notably, Europe's total value added in manufacturing is higher than the US's. Also, there are huge differences in levels of value added between the top European economies (Germany, Sweden, France, Italy, Denmark or the UK) and the rest. Also, Europe's top economies all outperform Japan in value added in total manufacturing.

2. Productivities in total manufacturing

Obviously the value added in itself does not inform us entirely. Much more important is a country's productivity. Comparative productivities for total manufacturing in selected European countries are given in Figure 19 and Figure 20 below.

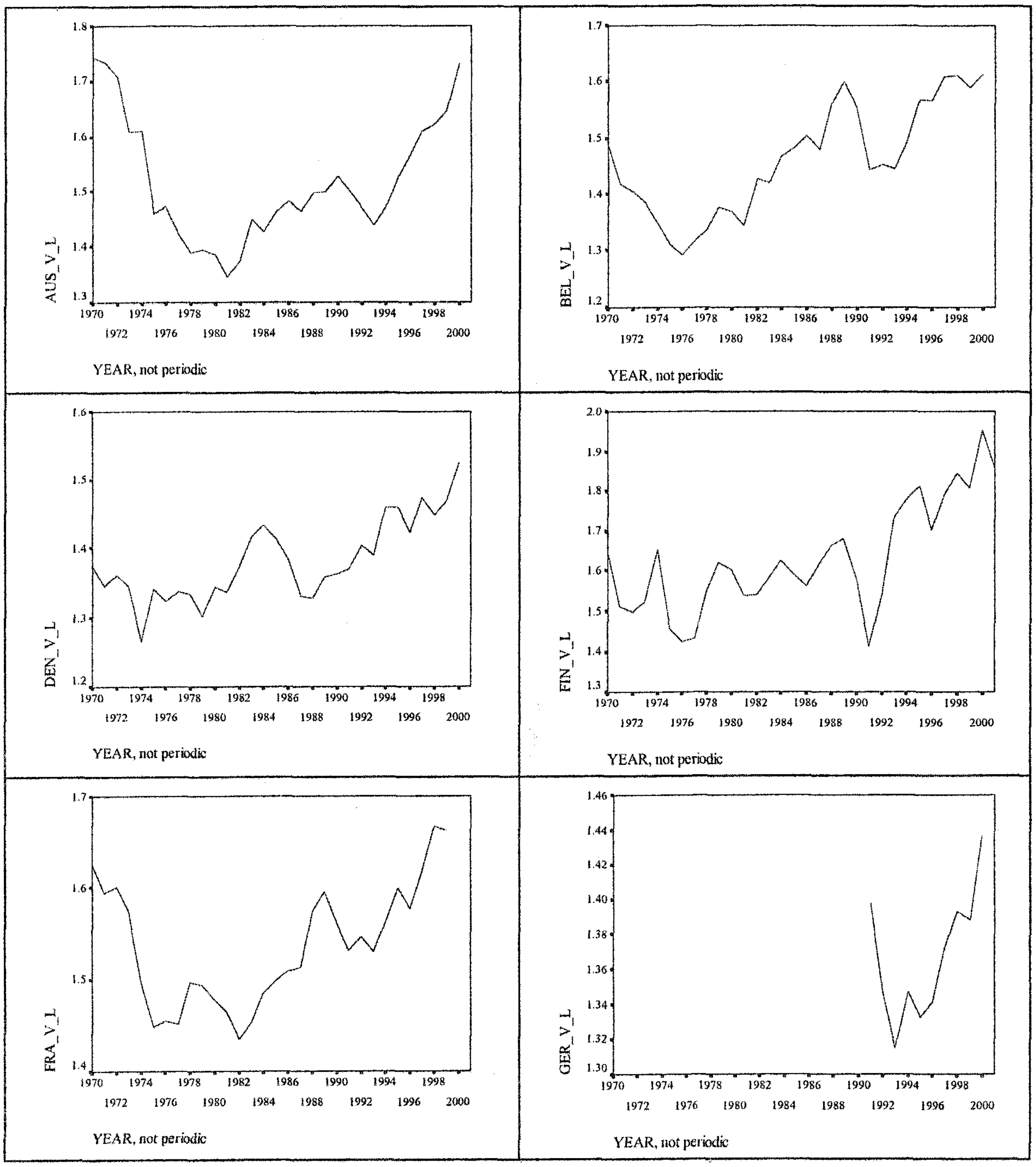


Figure 19: Productivities in selected EU member states, total manufacturing (1) (1970-2000)

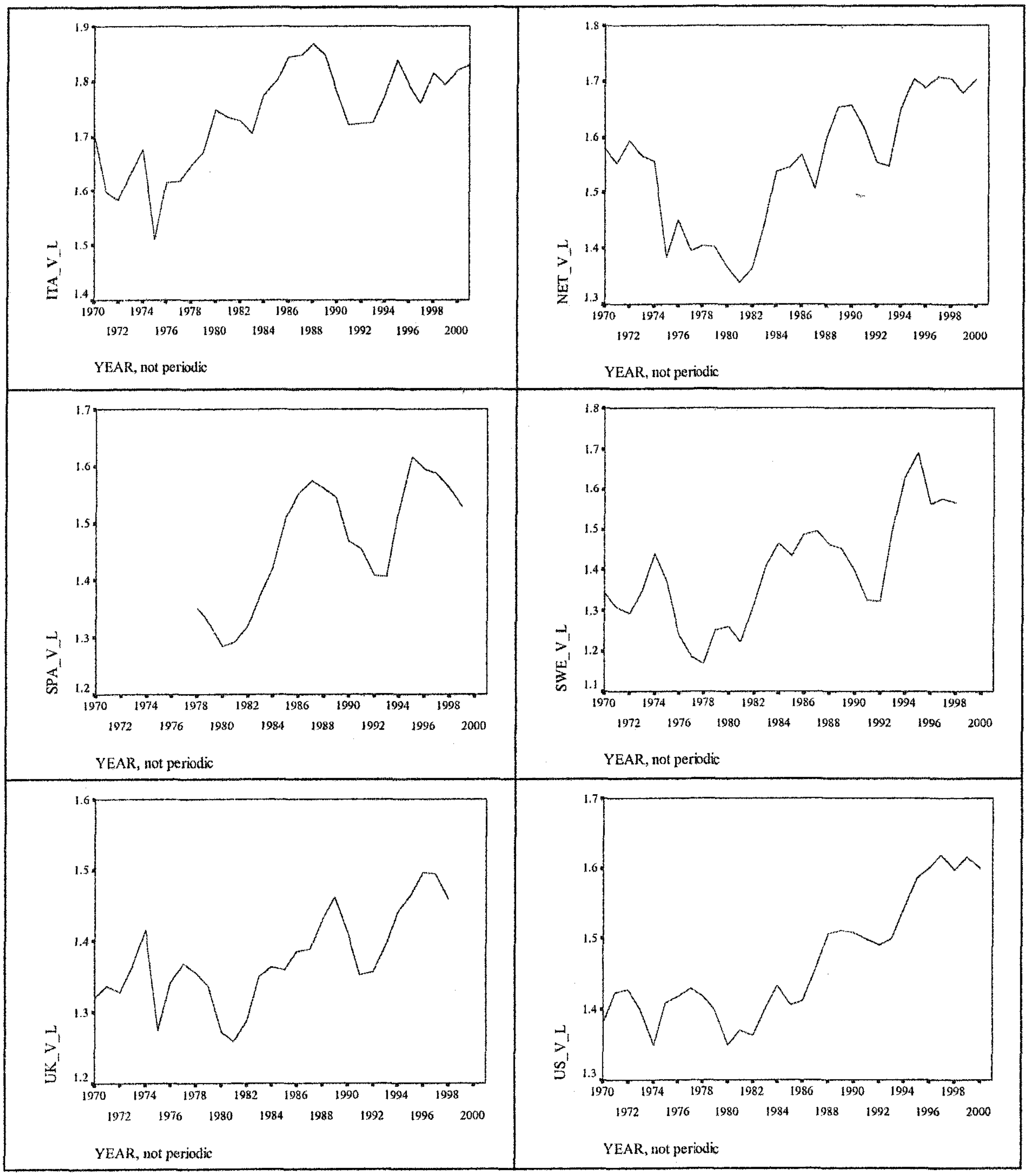
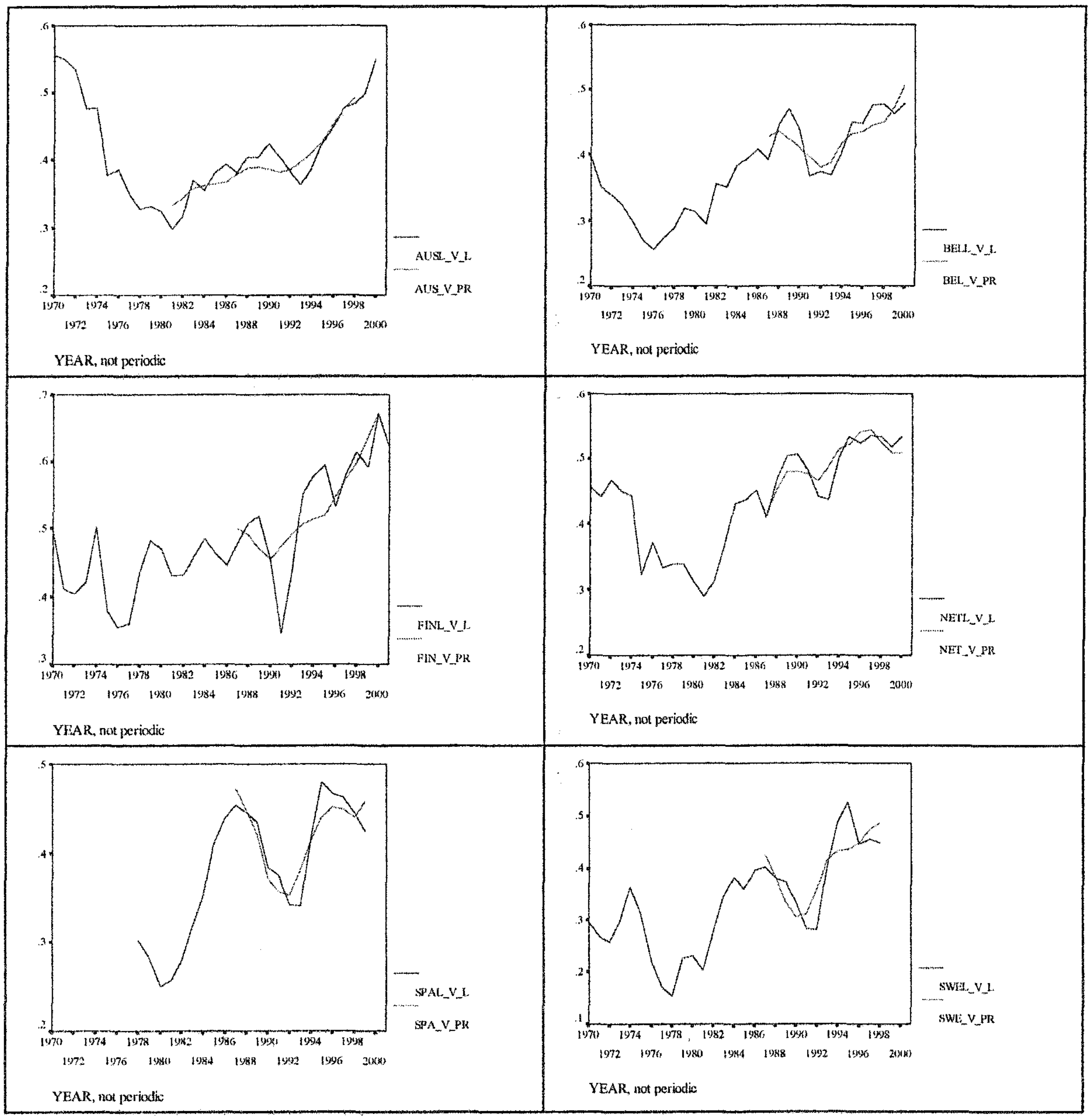
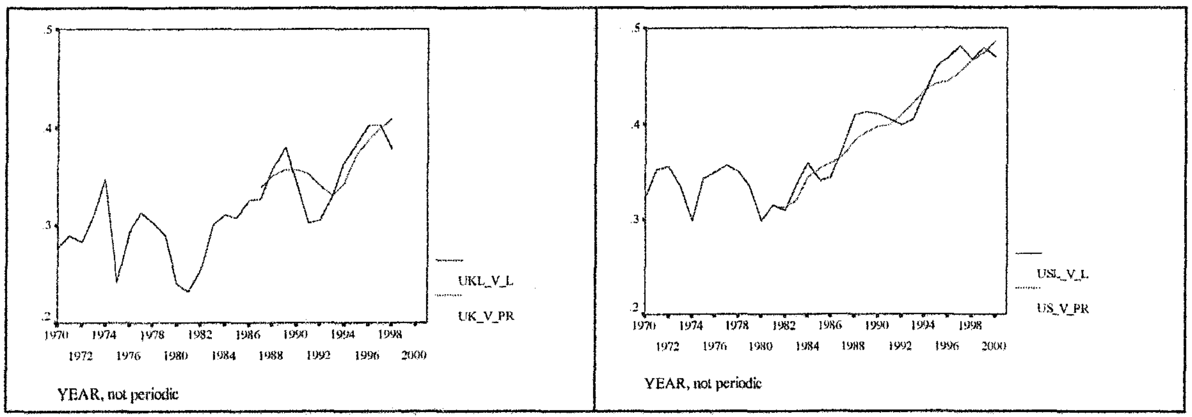


Figure 20: Productivities in selected EU member states and the US, total manufacturing (2) (1970-2000)

Appendix 9: Models fit curves for Cobb-Douglas production function based models

The fit curves for the Cobb-Douglas production function based models are depicted for across Europe comparison purposes in Figure 21.





Source: own calculations based on data from OECD STAN and ANBERD databases.
Figure 21: Model fits for Cobb-Douglas production function models, selected EU member states, total manufacturing (1980-2000)

Appendix 10: Further work

Upon conducting this study, I developed the interest in further conducting work answering these following new interesting questions: In this section I thus briefly describe a few further research paths that seem to need further addressing.

1. Context validation of analytical framework on factors affecting national technological performances

I intend to determine a more systematic set of rival hypotheses affecting technological innovation as well as an "approximate completeness" test for the analytical framework used by the comprehensive Commission reports (ERSTI 1994, 1997, 2003) and other analyses available on European innovation.

In parallel work started alongside of this study I have adapted an already well developed and tested methodology for context validation (Dunn 1997, 2002) to the particular specifics of the problem of European innovation. In much part this work will further already existing Commission efforts in the evaluation of innovation and on expert and stakeholder views on factors favoring innovation (ERSTI 1997, Appendix), that offers invaluable qualitative insights into the views the community of knowledgeables hold on the issue, opinion which constitute the starting point for the context validity testing proposed herein.

Consequently, I intend to seek Commission funding to (1) integrate all rival hypotheses included in the analytical framework used by the Commission itself in the latest ERSTI (2003) report and in related literature, (2) use context validity tests to determine "approximate completeness" of the identified analytical framework[54], (3) further conduct a Delphi exercise based on this pre-existent framework, if the context validity test fails to show completeness, and finally (4) use the results of the Delphi exercise to test further hypotheses that have not been included in previous analyses.

---

[54] As illustrated in Dunn (1997, 2002), one recurring question with quasi-experimental research designs used to address complex problems deals with knowing when to stop the search for further rival hypotheses. This problem is referred to as the problem of infinite regress, meaning that further new hypotheses can always be developed irrespective on how many have already been identified and tested. Dunn (1997, 2002) proposes a criterion for sufficiency in determining what he calls an "approximately complete" set of rival hypotheses, thus designing a method for addressing the infinite regress problem.

2. More detailed analysis of human capital flows

I intend to complete the current analysis using the appropriate tests on more detailed data on human capital flows and the potential impact of the discontinuity in the trends of these flows for Europe with the End of the Cold War.

Unfortunately, in designing and executing this study I was not able to retrieve time series data on flows of high skilled scientists and engineers into and out of Europe, or the US or Japan. These data, even in repeated measures format only, are known to be unreliable, with inconsistent collection and reporting practices, and most often being underreported. I intend to develop proxies for measuring with some accuracy these uneven human capital flows using existing reliable data, and further this work with the use of such developed measures.

3. Detailed analysis of flows of foreign funded R&D and human capital on knowledge spill over

I plan on using the technology flow matrix technique (Verspagen 1997b) to further specify and verify cross country knowledge spill-over specificities as they may be impacted by (1) foreign funded R&D, (2) human capital flows, and (3) cooperative agreements, both between industry partners, and between academic and applied research centers and their business partners.

In this respect, the human capital flows data are available with some more accuracy and reliability within the EU than they are into and out of the EU, and compared with into and out of the US and Japan. In the latest only recently published Commission report on science and technology indicators (ERSTI 2003 preview), a special attention seems to be given to this factor inside the EU. The report may contain data and analyses that could provide grounds for the analysis proposed herein.

4. Transitional Schumpeterian innovation regimes and the role of small and medium enterprises in initiating and facilitating innovation driven economic growth

I plan to further specify and verify a Schumpeter Mark 1, Mark 2, and Mark 1/2 (inbetween) transition innovation regime[55], that may be necessary based on the puzzling analysis of some major innovative firms (Microsoft and many successful software based service industry firms) done in the context of neo-Schumpeterianism.

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[55] Please see section 2.3 above and Soete and Ter Weel 1999 for a comprehensive description of these innovation regimes.

In work related to the conduct of this study I am already building an analytical framework furthering extensive European Commission work on assessing comparatively views on factors of innovation by large scale businesses versus small and medium enterprises. A better understanding is necessary for the conditions of a Schumpeter Mark 1 innovation regime initiation in an SME, as well as for the conditions for potentially transforming such a regime in time into a Schumpeter Mark 2 regime. Successful such transitions may have a positive effect on effective use, possibly sector specific, of the general Science pool, but with "science performance" measured differently for the initiation of Mark I regimes. A more fit measure would be not through scientific propensities as herein, but rather through the general knowledge of the population, namely levels of higher education per country, possibly in selected fields, connected with technology innovation.

This further research path is connected with possibly using firm level data. Also, the use of international citations in patents may measure well the use of the general science pool.

5. Dormant patents and the impact of business strategic decisions to withhold implementation of innovations on the link between innovation and market strength.

I plan to further address the issue of dormant patents, due to businesses lack of interest to apply new technology before the benefits of the old die out. (Griliches 1984, 1998, 2000; Rosenberg 1982, 1992). Upon designing measures for and collecting data on percentages of dormant patents, a further correcting formula for technological performance needs to be used before addressing with increase analytical reliability the link between technological performance and market strength of either firms or countries.

6. Relationship between productivity growth and technological performance

I plan to further address the issue of the relationship between productivity growth and technological performance. Consistent with the quasiexperimental tradition (Cook and Campbell 1979, Dunn 1997, Dunn 2002), other potential explanations for the puzzling behavior of the science-technology link in Europe could be offered by the rival hypothesis that high technological propensities of some countries could lead to differences in productivity growth in those countries, which in turn further facilitate technological progress. This approach would be consistent with neo-Schumpeterian explanations of economic growth. It brings up however a challenge for the researcher, as the relationship between the two could be perceived as a double arrow one, as each influences the other.

In future work I will thus try to identify patterns between trends in labor productivities (expressed by value added divided by labor compensation) in EU member states and the trends of the technological propensities in the same countries. Such analysis can be conducted cross-countries intra sectors or cross-sectors intra countries.

7. Systematic cross-country analysis of impact of levels of defense related R&D expenditures

Another available rival hypothesis that may inform the puzzling behavior of the science-technology link in developed countries is that high defense related R&D expenditures yield by necessity strong overall technological performance in a country.

A systematic cross-country analysis of a potential relationship between levels of defense related R&D and national technological performances may be interesting to perform. The reasoning is given by the inconsistency across developed countries of the argument that high levels of defense related R&D may induce higher technological performances.

There are cases when this happens (the US) just the same as there are cases when it does not (UK, France have high defense expenditures and yet below the EU average technological performance), or where high technological performance is present even absent high defense R&D expenditures. (Japan, Germany have very low defense R&D expenditures have high technological performance).

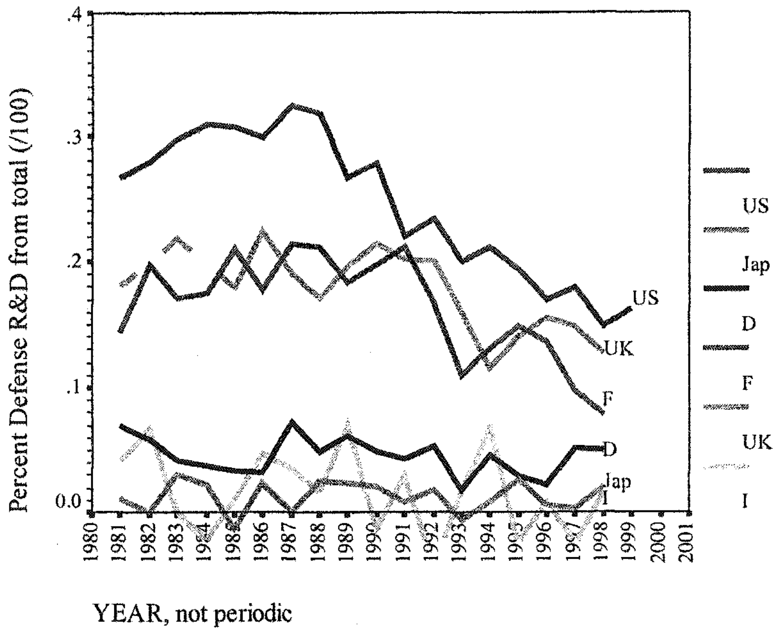

Figure 22: Percent of defense related R&D from total gross domestic expenditures in R&D, selected European countries, US and Japan, NSF data (1980-2000)

A closer look at the percentages of defense related R&D expenditures in selected European countries, the US and Japan, depicted in Figure 22, can give us a preliminary assessment of the intricacies involved in the claim that high related defense R&D expenditures may lead to higher technological performances. This figure needs to be analyzed in connection with the respective European countries' technological propensities depicted in Table 2, and with the technological propensities for the EU, the US and Japan depicted in **Error! Reference source not found.**, **Error! Reference source not found.**, or by a different measure but for the EU and US only in **Error! Reference source not found.** and **Error! Reference source not found.**.

In the US case, high percentages of defense related R&D expenditures from total are present while high technological performance is also present. In the cases of Japan, Germany and Italy however (for this inference I use Figure 22, combined with Table 2 for Germany, and with **Error! Reference source not found.** for Japan), low defense R&D expenditures are present, but the two countries have high technological performances nonetheless. In the case of Italy, low defense related R&D expenditures are present while Italy's technological performance is also low. In contrast, the UK and France have high defense R&D expenditures but below EU average technological performance (before the measurement corrections suggested in appendix 1)

There does not seem therefore to be any consistency in an argument about a positive impact that high levels of defense related R&D expenditures may have on a country's national technological performance, except in the case of the US. More work could thus be used in this respect

8. Analytical application of correcting formula for national technological propensities

I intend to develop further and test the proposed correcting formula for technological propensities introduced herein (section 4.1.3.). Upon testing the formula's validity, new more systematic models can be developed and tested using the formula for many of the other proposals for further work above.

9. Other rival hypotheses

- Vernon's product cycle theory has initially made the Japanese phenomenon possible. Later on the Chinese phenomenon. The application of a new version of Vernon's theory seems to be extended today to what he was referring to as top tier products as well. In fact, it is not as much to products, but to the applied R&D that yields the innovation leading to the development of new top tier products. It may be useful to study such a new version of a Vernon "innovation cycle theory" in more detail.
- Knowledge transfer in innovation intensive fields has been traditionally achieved through the import of the knowledgeables themselves. This trend continues undisturbed, and innovative companies and research centers have newly available resources to tap into, from China to Eastern Europe.
- A new pattern emerges in force, namely the "outsourcing" of innovation itself. As the needed intensity of innovation processes necessary for maintaining in a sustainable manner a market edge has grown tremendously, a new pattern of de-nationalizing innovation has emerged. While this may seem a brand new trend, there are already available theoretical approaches to address it, stemming from previous work on science and technology "at the periphery" (Todd 1993), combined with using an adaptation of Vernon's (1966) product cycle theory to technological innovation as well.
- An analysis of Schumpeter Mark I to Mark II innovation regimes transition, and the potential impact of its functioning on economic growth.

- Testing more accurately the science-technology link "paradox" with a newly proposed measure of technological propensity, taking into account accurate measures of inflows and outflows of intangible capital, particularly highly skilled human capital and scientific and technologic outputs into and from a country or region.
- Does foreign (intra-European or extra-European) financing of R&D in a country, whether through an increased penetration by multinational companies, or through Brussels facilitated (or not) intra-European cross-national funding programs have a measurable effect on a country's relative influence of R&D stock on its productivity? These findings could be applied directly to EU's ERA initiative and its inclusion in the policies towards Central and Eastern European applicants.
- Does an increase in foreign funded R&D in a country yield in the long run (1) a higher proportion of high tech in a country's outputs, and (2) higher rates of scientific and technological spill-over for that country?

Appendix 11: Variables in the Study: Database for Cobb-Douglas production based models determining the dependence of the economy of a country on R&D intensive sectors.

The database constructed for performing the cross-country analysis using Cobb-Douglas production functions included all the values for value added, capital, labor and R&D expenditures for all manufacturing sectors, in all the countries considered, in Europe, the US and Japan, resulting in a database with over 6500 separate variables. The database allows cross sector and cross country further analyses. In this study I have used for the analysis only the values for total manufacturing. Only those variables in the database are listed in Table 9 herein.

Table 9: Variables codes and definitions for Cobb-Douglas production function based models

CODE	Meaning	Type/Source
Aus321gr	Aus321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
Bel321gr	Bel321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
den321gr	Den321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
fin321gr	Fin321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
fra321gr	Fra321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
ger321gr	Ger321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
ita321gr	Ita321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
jap321gr	Jap321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
net321gr	Net321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
spa321gr	Spa321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
swe321gr	Swe321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
uk321gro	UK321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
us321gro	US321Gross fixed capital formation TOTAL MANUFACTURING	actual value, OECD STAN database
aus118la	Aus118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
bel118la	Bel118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database

Table 9: Variables codes and definitions for Cobb-Douglas production function based models

CODE	Meaning	Type/Source
den118la	Den118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
fin118la	Fin118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
fra118la	Fra118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
ger118la	Ger118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
ita118la	Ita118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
jap118la	Jap118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
net118la	Net118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
spa118la	Spa118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
swe118la	Swe118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
uk118lab	UK118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
us118lab	US118Labour compensation of employees TOTAL MANUFACTURING	actual value, OECD STAN database
aus60val	Aus60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
bel60val	Bel60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
den60val	Den60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
fin60val	Fin60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
fra60val	Fra60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
ger60val	Ger60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
ita60val	Ita60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
jap60val	Jap60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
net60val	Net60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
spa60val	Spa60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
swe60val	Swe60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
uk60valu	UK60Value added TOTAL MANUFACTURING	actual value, OECD STAN database
us60valu	US60Value added TOTAL MANUFACTURING	actual value, OECD STAN database

Table 9: Variables codes and definitions for Cobb-Douglas production function based models

CODE	Meaning	Type/Source
aus321ks	Aus321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
bel321ks	Bel321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
den321ks	Den321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
fin321ks	Fin321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
fra321ks	Fra321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
ger321ks	Ger321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
ita321ks	Ita321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
jap321ks	Jap321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
net321ks	Net321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
spa321ks	Spa321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
swe321ks	Swe321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
uk321ks	UK321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
us321ks	US321Gross fixed capital stock (calc. w .05 depreciation) TOTAL MANUFACTURING	calculated
aus_r_tm	AusBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
bel_r_tm	BelBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
den_r_tm	DenBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
fin_r_tm	FinBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
fra_r_tm	FraBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
ger_r_tm	GerBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
ita_r_tm	ItaBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
jap_r_tm	JapBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
irl_r_tm	IrlBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
net_r_tm	NetBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
spa_r_tm	SpaBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database

Table 9: Variables codes and definitions for Cobb-Douglas production function based models

CODE	Meaning	Type/Source
swe_r_tm	SweBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
uk_r_tm	UKBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
us_r_tm	USBusiness R&D Expenditures (BERD) TOTAL MANUFACTURING	actual value, OECD ANBERD database
aus_r_s	AusRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
bel_r_s	BelRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
den_r_s	DenRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
fin_r_s	FinRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
fra_r_s	FraRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
ger_r_s	GerRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
ita_r_s	ItaRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
jap_r_s	JapRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
irl_r_s	IrlRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
net_r_s	NetRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
spa_r_s	SpaRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
swe_r_s	SweRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
uk_r_s	UKRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated
us_r_s	USRD stock (calc. w .15 depreciation) TOTAL MANUFACTURING	calculated

Data Source: OECD STAN and ANBERD databases