Do Important Home-Made Innovations Affect Productivity Growth? Some Industry-Level Explorations*

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ABSTRACT

International differences in productivity performance are often attributed to differences in innovative performance. Much empirical work supports this contention, but problems in quantifying innovative output prevent researchers from drawing a clear picture. In this paper, we try to assess the importance of innovations by linking labor productivity growth at the level of industries to various counts of patents. Since it is well-known that patented innovations are very heterogeneous regarding their importance, we construct importance indicators by means of patent citation data taken from the US Patent Office. We present descriptive statistics to reveal the technological specialization patterns of 26 countries, in terms of their focus on important innovations at the industry level. Our preliminary regressions do not find a strong relationship between the production of (important) innovations and labor productivity growth. We give a few potential explanations for this result and indicate which future plans we have to deal with these issues.

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1. Introduction

Empirical investigations into the relationships between innovation and productivity growth have gained popularity among academics, especially after the advent of the so-called "endogenous growth theory" in the late 1980s and early 1990s. It attributed a paramount role to innovative activities and its outcomes in growth processes. Since the output of innovation activities is hard to measure, several indicators have been used in such empirical studies. Patent indicators feature prominently among these.

In a seminal paper, Griliches (1990) argued that the use of patent counts as output indicators is riddled with problems. One of the most prominent problems is that the actual impact of patents is extremely heterogeneous, both within and across industries or technology fields. For instance, many patents do not relate to a substantial innovation over current practice, but are mainly applied for by the eventual patentee with strategic considerations in mind. In a recent series of papers and books, citation counts have been used to take "importance" of patents into account. Jaffe and Trajtenberg (2002), for instance, contains some classic articles in which several indicators of "importance" were constructed and used to analyze the innovative performance of firms, universities and other research institutes. Jaffe and Trajtenberg also initiated the construction of the NBER Patent-Citations Datafile that includes the data to operationalize their importance indicators for empirical research. The most basic indicator is the unweighted forward citation count: the more citations a patent receives in subsequently granted patents, the more important it is considered to be.

In this paper, we aim at using the NBER data and Jaffe and Trajtenberg's (2002) forward citation count indicator to answer an important question that does not relate to firms but to industries in EU countries: does generation of "important" innovations by an industry in a specific country affect its productivity performance? To this end, we will first construct a database which includes indicators of the number of "important" patents that have been granted to industries in countries studied in the EUKLEMS project.

Official documents of patents granted by the US Patent Office contain one or more SIC codes that correspond to the industries that are most likely to produce the patented product or to use the patented process. This information is used to assign patents to EUKLEMS industry classes, using a concordance. The documents also include indications of the country in which the first inventor was located. These indications are used to assign patents to countries. Using quantile measures for the worldwide distributions of importance indicators, the number of "important patents" assigned to industries in countries are computed, on an annual basis.

The innovation indicators constructed along the lines described above are linked to labor productivity growth rates derived from a predecessor of the EUKLEMS database (the "60-industry database) already available from the GGDC website. Descriptive statistics and simple regression techniques are used to come up with first explorations to provide provisional answers to the research question formulated above.

The organization of the paper is as follows. In Section 2, we discuss data issues. The indicator of patent importance is introduced, the data used to actually construct it are discussed and we devote some attention to the construction of our labor productivity indicators. Section 3 presents descriptive statistics at the industry level. It provides information on the total number of patents produced relative to the size of the industry and offers insights into specialization into either "important" or less important innovations. Estimates of the impact of differences in (important) patenting on labor productivity growth are presented in Section 4. Section 5 is devoted to discussions of a couple of issues that could explain the absence of a clear link in the regression analyses. We focus on possible solutions, both concerning econometric specifications and operationalizations of potentially useful concepts. Section 6 concludes.

2. Data Issues

2.a Construction of importance indicators

This paper contributes to the relatively recent literature that attempts to capture the importance of innovations by means of patent citation data. In one of the pathbreaking articles in this tradition, the basic source of information is succinctly described as follows:

"If a patent is granted, a public document is created containing extensive information about the inventor, her employer, and the technological antecedents of the invention, all of which can be accessed in computerized form. Among this information are "references" or "citations". It is the patent examiner who decides what citations a patents must include. The citations serve the legal function of delimiting the scope of the property right conveyed by the patent. The granting of the patent is a legal statement that the idea embodied in the patent represents a novel and useful contribution over and above the previous state of knowledge, as represented by the citations. Thus, in principle, a citation of Patent X by Patent Y means that X represents a piece of previously existing knowledge upon which Y builds." (Jaffe et al., 1993, p. 580)

As was first confirmed by Trajtenberg (1990), patents that are often cited by later patents are more important than patents that are virtually never cited. Of course, this importance depends on the question whether inventors were really aware of the knowledge claimed in earlier patents. An affirmative answer to this question is not warranted, since the applicant does not include citations, but an expert employee of the patent office. In a recent paper, Jaffe *et al.* (2000) use results of surveys among inventors to conclude that citations do give indications (although noisy ones) of spillovers from the cited invention to the citing invention.

In this paper, we will use data contained in the NBER Patent-Citations Data File to distinguish between important and less important innovations. In previous work by us (Akkermans *et al.*, 2005), three measures of importance were studied, i.e. the "number of citations received", a "measure of generality" and a "measure of originality". The first measure was introduced by Trajtenberg (1990), the latter two by Trajtenberg *et al.* (1997). For reasons of space, we will focus on the first indicator in this paper. We will denote the indicator "number of citations received" by NCITING, in line with the notation adopted by Trajtenberg *et al.* (1997). This indicator simply supposes that a patent that is cited more often than another one has had more impact on subsequent technological developments and can therefore be seen as more important.[1]

We will define important innovations using rankings of patents based on the NCITING indicator discussed above. A few things should be taken into account before the indicator values for two arbitrary patents are directly compared. First, as is well known, the propensity to patent innovations differs considerably across industries. Since, we want to study relationships between labor productivity growth and patent output at the industry level, a substantial part of this problem does not apply to this study. Since the level of aggregation is relatively high, however, this problem is not entirely irrelevant. Second, not all citations are received at once. Verspagen & De Loo (1999) report that the (skewed) distribution of citations to patents issued by the European Patent Office applied for between 1979 and 1997 had a mean of 4.67 years. Based on citations to USPTO patents issued during a much longer period, Hall *et al.* (2002) even find mean lags of up to 16 years. The consequence of the often long lags is that relatively new patents will often have received fewer citations (and/or citations in fewer technological fields) than older patents. Another issue that precludes reasonable comparisons of citation-based indicators across years relates to observed increasing propensities to cite. As Hall *et al.* (2002) argue, increased computerization of the patent system led to less time-consuming queries by patent examiners, as a consequence of which the citations to patent ratios rose considerably in the 1980s.

To deal with these differences, we based our rankings on industry-specific cohorts of patents granted in a given year. That is, we first constructed quantiles for patents associated with industry i granted in year t.[2] Now, we could define the patents in the 10th decile as important innovations.[3]

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[1] Like in input-output studies of the impacts on employment growth of final demand, one could also take second-order higher-order effects into account. That is, we could consider whether citing patents are heavily cited or not. Trajtenberg *et al.* (1997) do this, by constructing their IMPORTF indicator. For reasons of brevity, we do not study this indicator here.

[2] In future versions of this paper, we will use the year of application, rather than the year of granting of a patent, since the timing of the actual innovation is nearer to the latter date of application than to the date of granting.

We represent the number of these patents granted to inventors in country *k* by n_{it}^{*k}. Next, useful aggregations can be obtained by summing over appropriate indexes. The number of important innovations produced by country *k* in year *t*, for example, can be defined as $n_t^{*k} \equiv \sum_{i=1}^{m} n_{it}^{*k}$ (with *m* standing for the number of industries), and the number of important innovations produced by industry *i* in country *k* over the entire period can be written as $n_i^{*k} \equiv \sum_{t=1}^{T} n_{it}^{*k}$ (with *T* representing the number of years). For some analytical techniques described below, frequencies of incremental innovations are also required. The notation will be equivalent, but asterisks will be reserved for radical innovations. The number of patents related to incremental innovations granted to inventors in country *k* will thus be indicated by by n_{it}^{k}.

The assignment of patents to countries was done by means of the records for the variable "country of first inventor" in the NBER Patent-Citations Datafile. Unfortunately, the database does not include information about licences sold by inventors to firms. Licensing to foreign firms could, of course, affect the productivity performance of the foreign industry as much as its domestic counterpart. This study focuses on the question, however, whether innovations should be "home-bred" or not. As such, our country assignment serves our purposes well.

As mentioned above, our main source of data is the NBER Patent-Citations Data File, which contains data on patent citations to utility patents granted by the U.S. Patent Office in the period 1963-1999. For the present analysis, we used the large subset of these patents granted in 1970 and later. This dataset contains over 2.4 millions of patents, of which nearly 1.0 millions were granted to inventors outside the U.S. These patents include patents granted to individuals and governments, but more than 75% were awarded to non-governmental organizations (corporations and universities).[4]

The NCITING importance indicator was taken in unchanged form from the same source. These indicator values are based on citations included in patents granted from 1975 and 1999. Hall *et al.* (2002) report that more than 16.5 millions of citations were involved in the underlying computations. Self-citations (i.e., citations to previous patents granted to the same organization) are included.

The assignment of patents to industries consisted of two steps. First, we used OTAF classification codes contained in U.S. patents. These codes are not contained in the NBER Patent-Citations Datafile, but the industry codes in USPTO's PATSIC-CONAME database could easily be matched to the citation data. The OTAF classification assigns patents to one or more industries that are most likely to use the patented process or to manufacture the patented invention. To this end, a concordance was set up that maps 124,000 USPC classes onto 41 fields,

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3 Of course, it is rather arbitrary to define the bottom 90 percent of innovations as unimportant and the top 10 percent as important. Below, we will also report some analyses based on 95/5 percent, 75/25 percent and 50/50 percent divisions.

4 See Hall *et al.* (2002, p. 413) for details.

plus one "other industries" category. Thus, at the most detailed level, 42 OTAF- industries are discerned.[5]

An issue we had to deal with is that 30% of the patents examined by USPTO were assigned to multiple OTAF codes. Actually, some patents got as many as seven codes. In studies like these, two approaches can be adopted. If the "whole counts" approach is chosen, the patent count for all industry codes concerned is increased by one. This resembles the nonrival nature of knowledge, in the sense that the usefulness of a patent for a given industry is not necessarily reduced if other industries could also benefit from it. A drawback is that if one would like to aggregate patent counts over industries, one ends up with more patents than have been granted to inventors in that country. This disadvantage is avoided by the second approach, "fractional counting". This approach amounts to adding $1/z$ to patent counts of SICs assigned to the patent. This implies that the patent is "shared". We opted for the fractional counting method, because we would encounter problems in assigning patents to radicality deciles if a patent would fall in the xth decile for one industry and in the yth decile for another relevant one. Results for aggregate economies would be flawed, because either the recorded number of patents would be higher than the actual number, or the deciles would not be reprsented equally in the population of all patents granted by USPTO.[6]

A second stage in the assignment of patents to industries was required to arrive at data that are compatible to labor productivity data at hand (which will be described in the next subsection). A concordance was set up between OTAF industries and EUKLEMS industries. This involved aggregations that are reported in the Appendix. After these procedures were carried out, we ended up with data on the quantity and importance of patents in 20 industries.

2.b Other data issues

In our regression analyses, labor productivity growt rates are the variables to be explained. The data required to compute levels (these were used as additional explanatory variables in some regeression equations not spoecified here) and growth rates are all originating from the 60-industry database of the Groningen Growth and Development Center (GGDC). Value added and labor inputs (expressed in hours worked) were used. Since data on investment in physical capital goods is not yet available, we could not extend our analyses to studies of multifactor productivity growth. We ended up with 26 countries, although the dataset is not complete for all countries. We included EU countries in the analysis, but also made comparisons to important trade partners like the U.S. and Japan. Moreover, we also included some of the emerging East-Asian Tigers (Taiwan and South Korea). For the full set of countries, the reader is referred to the

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5 See Hirabayashi (2003) for an overview of issues related to the principles underlying the PATSIC database. Griliches (1990, p. 1667) was quite critical about early versions of the OTAF classification, but improvements have been sizeable.

6 The latter problem would occur if we would decide to assign the patent to the highest decile found across the industries to which it is assigned by the PATSIC data.

appendix. The remainder of this section is devoted to discussion of some procedures we had to follow in order to get the productivity data in line with the patent data discussed above.

To compute labor productivity levels we needed to convert data expressed in national currencies into a common currency. For this purpose exchange rates could be used. However this could easily lead to misleading results, because exchange rates do not necessarily represent the actual price relationship between two countries for each product or industry. At the GGDC, industry-specific PPPs were constructed to solve this problem. Recently, Ypma and Timmer (2005, unpublished) constructed new PPPs for the manufacturing industries of 26 countries. These can be used to convert national currencies to US dollars and thus make labor productivity level comparisons possible.

The above-mentioned differences between the EUKLEMS (for which PPPs were constructed) and OTAF industry classifications caused a few additional problems. To solve one of these, the PPP of industry 31 (ISIC rev. 3) was applied to industry 11 and 12. In a similar vein, the PPP of industry 32 (ISIC rev. 3) was applied to industries 13 and 14, and the PPP of industry 31 (ISIC rev. 3) was used for industries 16-18. For industries 2 and 20, Ypma and Timmer's PPPs of industries 17-19 and 20-22, and 36-37 (ISIC Rev. 3), respectively, were aggregated.

Another problem, which concerns both the PPPs and the labor productivity data from the 60-Industry database, is the fact that industry 4 "Petroleum and natural gas extraction and refining" consists of two 2-digit ISIC Rev. 3 industries, namely industry 11 "Extraction of crude petroleum and natural gas and services" and industry 23 "Coke, refined petroleum products and nuclear fuel". The problem is that industry 11 is not distinguished as an industry in the 60-Industry database or the PPP-database. It is contain in "Mining and Quarrying" (ISIC Rev. 3 10-14). However, for most countries industry 11 "Extraction of crude petroleum and natural gas and services" is the biggest part of Mining and Quarrying. Therefore the PPP of industries 10-14 and 23 have been aggregated to one PPP and for the labor productivity figures the data of industries 10-14 and 23 have been aggregated as well.

To adequately measure productivity growth, price declines and quality improvements should be taken into account when deflating value added. For certain industries this is more important than others. Notably ICT-producing industries, like "Office machinery" and "Electronic components" are the most prominent examples of such industries. Price declines and quality improvements can be measured by using hedonic price indices. Most countries do not yet use these hedonic price indices and therefore underestimate value added growth (and thus labor productivity growth). The United States does use hedonic price indices, and the effects are considerable. To achieve international comparability, harmonized U.S. deflators are applied for two ICT-producing manufacturing industries (ISIC 30 and 321) in all countries. U.S. value added deflators are corrected for differences in overall inflation between each country and the U.S. Inflation is measured as the change in the deflator of all industries, excluding the ICT-producing manufacturing industries. One result which stands out very clearly is that when using only national deflators and comparing labor productivity levels, all countries start with a very high level of labour productivity for industry 10 "Office, accounting and computing machinery", and to a lesser degree also for industry 14 "Electronic components and accessories, and communications equipment" when compared to the U.S. However these levels tend to drop dramatically and all countries end with a very low labor productivity level compared to the U.S. To avoid these artefacts, we used labor productivity figures based on the harmonized US deflators for ISIC industries 30 and 321 and national deflators for all other industries. This practice is common to most publications based on GGDC's 60-industry database.

3. Descriptive Statistics

In this section, we present descriptive statistics that give a broad view of the patenting activity in the countries included in the sample. Table 1 starts off by giving indications of the number of patents granted by the U.S. patent office to inventors in these countries, irrespective of the industries that might manufacture the product innovations or use the process innovations.

Table 1: Raw patent counts per country

	No. of patents	No. of patents per hour worked*					annual growth
	1998	1979	1984	1989	1994	1998	(1979-1998)
AU	720	33.1	40.9	75.2	67.3	182.9	0.060
AT	387	70.9	170.0	260.1	141.6	312.5	0.042
BE	693	36.1	58.9	97.9	134.9	478.3	0.081
CA	2974	67.8	125.1	161.1	213.7	318.6	0.070
CZ	13	0.0	0.0	0.0	0.0	2.4	-
DE	9095	69.9	106.7	143.3	137.3	231.5	0.039
DK	392	36.4	43.9	108.2	71.8	118.8	0.046
ES	248	2.6	6.0	8.3	10.3	20.4	0.095
FI	595	23.1	50.3	68.2	160.0	281.1	0.115
FR	3674	58.0	94.1	148.5	145.0	212.0	0.052
GB	3464	36.7	54.4	84.9	87.9	127.9	0.049
GR	16	11.0	1.9	9.8	54.3	23.3	0.188
HU	50	0.0	0.0	0.0	6.4	10.6	-
IE	74	8.0	14.1	45.7	30.0	32.5	0.063
IT	1584	21.6	27.7	48.1	42.2	64.3	0.041
JP	30840	81.6	152.4	248.4	290.8	453.6	0.077
KR	3259	0.1	2.2	3.6	26.6	97.0	0.305
LU	20	80.5	105.4	187.0	49.4	164.6	0.041
NL	1226	114.8	165.0	254.4	246.6	405.7	0.047
NO	198	35.1	51.2	83.7	124.7	150.7	0.081
PL	15	0.0	0.0	0.0	0.4	1.0	-
PT	11	0.0	0.0	2.4	1.7	2.8	-
SE	1225	82.3	118.0	153.7	164.3	267.0	0.040
SK	2	0.0	0.0	0.0	0.0	0.1	-
TW	3100	3.2	5.1	30.6	58.0	111.4	0.196
US	80288	173.8	233.7	326.1	413.1	619.6	0.054

*The actual numbers were multiplied by 10,000 to arrive at the reported numbers.

The first column indicates that the bulk of the patents was granted to U.S. firms. The numbers in the column relate to 1998, but this results holds for all years. This result is not necessarily due to the technological superiority of U.S. firms, but is probably also partly reflecting "home market bias": the decision to apply for a patent is likely to differ between the home market and foreign markets (see Jung & Imm, 2002). It could well be that inventors decide first to patent at the domestic patent office to get acknowledged as being a 'technically capable inventor'. Applications for foreign patents are more often done after an evaluation of the potential commercial value of such a patent. Hence, domestic patents are often thought to be of an inferior quality, on average.

In order to correct for effects of scale, we decided to give indications of patents per hour worked. This ratio should not be considered as a productivity measure in a strict sense. Since we do not divide the number of outputs by labor inputs in innovative activities (such as R&D labor inputs would do), our measure should merely be viewed as "the number of patents corrected for the size of the country". For all countries included, the number of patents per hour worked rose considerably between 1979 and 1998. Differences across countries remain enormous. The U.S. have most patents, also after the size correction. In 1998, three other countries obtained more than 400 patents per ten thousand hours worked: Belgium, Japan and The Netherlands. The Eastern European countries are still largely unsuccessful in getting U.S. patents. Hungary is the only among these countries to have obtained more than 10 patents per ten thousand hours worked. Taiwan and Korea were ranked in the middle regions in 1998, with approximately 100 patents per ten thousand hours worked.

The last column indicates the average annual growth rates of scale-corrected patents. Here, a pattern of catching up is evident. While countries with "established" technological activity in the 1970s (such as the U.S. and most Western European countries) report growth rates of about 5% or slightly less, do other countries much better. In Europe, Finland, Norway and Spain, for example, managed to get their scale-corrected numbers of patents growing at a pace of around 10%. Such growth rates were even dwarfed by those of Taiwan and Korea, with 20% and 30%, respectively. Since most Eastern European countries did not get any U.S. patents in 1979 (for obvious reasons), their growth rates cannot be assessed.

The numbers of patents documented in Table 1 cover the entire spectrum from technologically unimportant patents applied for because of purely strategic reasons to patents associated with major technological breakthroughs. Table 2 attempts to shed some light on the frequencies with which countries managed to obtain patents of some importance. The leftmost columns refer to all patents. These numbers can also be found in Table 1, but are included for ease of reference. The columns to the right refer to patents belonging to different (industry-specific) quantiles of importance. From these columns, some interesting results follow. We will highlight a few. Within Europe, the worsening performance of The Netherlands is noticeable. In 1979 it was one of the leading four countries in producing top-5% patents. Although it succeeded in remaining one of the leaders in the corrected number of total patents granted, it did not concerning top-5% patents. Nowadays, countries such as Canada, Finland, Japan and Sweden produce approximately twice as many very important patents.

Table 2: Important patents per country

	No. of patents per hour worked*									
	Total		Top-50%		Top-25%		Top-10%		Top-5%	
	1979	1998	1979	1998	1979	1998	1979	1998	1979	1998
AU	33.1	182.9	11.3	89.0	4.3	36.4	1.2	9.0	0.5	2.5
AT	70.9	312.5	24.0	101.3	5.2	49.5	2.3	10.5	0.8	9.3
BE	36.1	478.3	20.1	161.1	10.7	47.6	5.5	17.5	4.1	13.3
CA	67.8	318.6	33.3	168.9	17.9	85.6	5.9	35.7	2.3	18.6
CZ	0.0	2.4	0.0	0.9	0.0	0.3	0.0	0.0	0.0	0.0
DE	69.9	231.5	28.6	85.2	12.6	33.6	4.6	10.9	2.1	5.0
DK	36.4	118.8	15.9	55.2	7.5	27.4	1.9	10.0	1.0	2.9
ES	2.6	20.4	0.9	7.6	0.3	3.2	0.1	1.0	0.0	0.4
FI	23.1	281.1	9.0	143.1	4.0	90.6	1.3	30.4	0.2	14.8
FR	58.0	212.0	26.8	75.1	12.7	32.6	3.9	9.3	2.2	3.8
GB	36.7	127.9	17.3	54.4	8.2	23.5	3.7	7.8	1.6	3.6
GR	11.0	23.3	2.2	4.3	1.8	3.1	0.0	1.9	0.0	0.0
HU	0.0	10.6	0.0	2.8	0.0	0.6	0.0	0.2	0.0	0.1
IE	8.0	32.5	6.9	18.7	0.6	7.5	0.0	4.8	0.0	1.2
IT	21.6	64.3	9.4	22.2	4.3	8.4	1.4	2.4	0.4	0.8
JP	81.6	453.6	39.8	218.4	19.3	100.7	7.5	37.2	3.8	17.2
KR	0.1	97.0	0.0	33.4	0.0	12.7	0.0	4.3	0.0	1.8
LU	80.5	164.6	24.7	99.5	17.8	91.0	0.0	5.9	0.0	0.0
NL	114.8	405.7	46.4	147.1	17.0	58.0	5.9	19.2	3.4	9.8
NO	35.1	150.7	17.0	64.3	10.8	36.4	1.7	16.7	0.0	2.5
PL	0.0	1.0	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0
PT	0.0	2.8	0.0	0.2	0.0	0.2	0.0	0.0	0.0	0.0
SE	82.3	267.0	34.3	119.9	15.5	62.1	5.3	28.7	2.5	16.5
SK	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
TW	3.2	111.4	2.1	52.8	0.7	26.2	0.0	9.8	0.0	4.2
US	173.8	619.6	91.9	347.2	47.8	187.7	20.1	81.2	10.3	42.1

*The actual numbers were multiplied by 10,000 to arrive at the reported numbers.

Great Britain and especially France (which has a certain reputation in achieving successes concerning technologically advanced products) were already taken over in terms of top-5% patents per hour worked by Taiwan in 1998, although this country did not produce enough top-5% patents in 1979 to record a positive entry in the rightmost-but-one column, corresponding to 1979. The Eastern European countries still encountered severe difficulties in producing very important patents. This result is also found for the Southern European countries (such as Spain, Portugal and Greece) that entered the EU in a relatively late stage. Finally, the numbers reported for the U.S. suggest that the technological dominance of the U.S.is responsible for the high scale-corrected number of patenst for this country found in Table 1, rather than the home market bias.

Table 3: Patents per hour worked, by industry*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AS	0.15	0.09	4.66	0.08	1.52	0.74	0.64	2.01	8.11	16.40	1.43	3.46	n.a.	5.27	0.77	1.10	1.52	2.06	17.35	1.08
AT	0.07	0.22	6.62	0.09	2.89	0.90	1.13	2.05	6.95	72.28	2.74	3.20	1.73	2.90	1.87	3.92	73.22	3.53	12.54	1.48
BE	0.18	0.37	7.74	0.43	6.48	1.34	0.37	1.33	7.39	46.97	6.27	1.74	1.82	11.53	0.27	1.71	0.94	2.35	36.03	1.45
CA	0.27	0.26	10.17	0.60	4.11	2.90	1.28	6.87	15.76	15.15	18.61	10.51	27.40	24.20	1.42	3.30	1.68	10.85	19.79	2.79
CZ	0.00	0.00	0.15	0.00	0.02	0.02	0.00	0.01	0.08	0.06	0.30	0.04	0.00	0.06	0.02	0.00	0.21	0.00	0.15	0.01
DE	0.15	0.74	13.07	0.34	5.10	2.05	1.01	3.11	8.04	12.81	13.20	4.97	3.71	26.12	2.27	1.13	10.52	8.67	12.95	1.55
DK	0.36	0.71	12.55	0.37	2.07	1.33	0.52	1.86	3.82	6.19	1.80	3.66	0.70	9.00	1.79	0.17	6.69	2.15	12.41	0.96
ES	0.02	0.01	0.93	0.01	0.23	0.07	0.04	0.27	1.09	0.92	0.52	0.39	0.08	1.11	0.10	0.08	0.95	0.48	1.63	0.18
FI	0.36	0.31	9.03	0.42	2.66	2.06	1.19	3.29	8.57	9.88	2.56	7.88	16.81	11.09	2.71	1.03	2.41	2.01	26.07	1.26
FR	0.17	0.27	13.32	1.24	3.04	2.03	1.49	2.32	8.23	27.37	5.94	7.95	8.23	22.41	1.12	1.27	3.54	6.38	11.86	1.52
GB	0.19	0.20	9.69	0.43	2.11	1.44	0.81	1.68	4.97	11.67	4.54	4.23	3.24	14.59	1.01	0.56	1.43	3.95	10.86	1.05
GR	0.00	0.01	0.41	0.02	0.12	0.02	0.05	0.07	0.20	9.09	0.10	0.30	2.27	1.19	0.21	0.04	0.13	0.09	1.68	0.03
HU	0.02	0.00	2.04	0.02	0.07	0.15	0.02	0.09	0.24	0.50	1.02	0.13	0.03	0.78	0.06	0.00	0.62	0.60	1.33	0.14
IE	0.07	0.05	1.88	0.06	1.09	0.26	0.23	1.41	2.62	1.61	2.36	1.61	1.37	5.95	0.70	0.34	n.a.	0.27	2.84	0.58
IT	0.07	0.03	5.50	0.17	1.55	0.29	0.28	0.54	2.99	7.29	2.02	1.66	3.38	5.37	0.58	0.33	1.58	1.37	4.71	0.55
JP	0.21	0.31	20.24	1.26	8.47	2.45	1.70	2.52	6.95	28.36	13.43	8.18	5.78	27.10	16.27	1.40	31.56	9.68	48.88	1.36
KR	0.02	0.01	0.72	0.02	0.21	0.16	0.10	0.39	0.67	4.14	0.66	1.19	1.26	4.00	0.16	0.01	2.13	0.42	3.56	0.20
LU	0.08	2.72	2.60	3.85	6.10	2.22	0.92	4.41	19.13	13.32	2.74	11.27	72.84	65.56	9.26	0.00	51.45	23.26	12.85	1.34
NL	0.59	0.61	9.77	2.24	6.63	2.40	1.02	2.41	10.41	24.57	14.56	29.71	2.25	72.40	1.65	0.45	1.71	2.84	29.86	0.79
NO	0.10	0.21	5.40	0.32	2.96	1.32	0.96	3.98	7.23	16.45	3.86	3.00	7.47	9.19	1.58	0.71	2.22	2.05	13.80	1.20
PL	0.00	0.00	0.21	0.00	0.03	0.00	0.00	0.02	0.04	0.00	0.00	0.03	0.00	0.08	0.00	0.00	0.00	0.03	0.20	0.00
PT	0.00	0.00	0.19	0.01	0.04	0.01	0.04	0.05	0.21	0.71	0.00	0.03	0.00	0.12	0.00	0.02	0.00	0.04	0.29	0.01
SE	0.58	0.95	11.18	0.93	5.81	4.19	1.56	6.06	13.43	22.93	6.47	13.62	7.30	15.02	2.00	3.91	4.56	6.92	24.37	2.05
SK	0.00	0.00	0.04	0.00	0.02	0.00	0.00	0.00	0.02	0.00	0.00	0.01	0.00	0.08	0.06	0.00	1.00	0.08	0.08	0.01
TW	0.02	0.02	0.68	0.06	0.54	0.42	0.11	2.07	2.83	1.28	5.50	2.07	0.53	3.79	0.79	0.32	5.05	1.52	8.27	1.97
US	1.07	0.80	32.98	2.67	11.76	7.33	2.44	13.19	21.29	49.92	19.34	17.87	35.01	53.22	5.08	4.37	3.38	17.91	35.64	6.12

*Averages over the period 1979-1999. The actual numbers were multiplied by 10,000 to arrive at the reported numbers. Industry classification: see Appendix.

We start investigating industry-level patterns in Table 3. This table presents numbers of patents (irrespective of their importance) per ten thousand hours worked, for each of the twenty industries. The numbers are computed for the entire 1979-1999 period. Interindustry differences in technological opportunities and/or patenting behavior show up clearly. For example, hardly any values above 1.0 are found in industries 1 ("food products") and 2 ("textiles"), while many double-digit values are reported for industries such as 10 ("office machines") and 14 ("electronic components").

For many industries, very high numbers are found for Luxemburg, which is mainly due to its very small size. One patent more or less have substantial effects on the numbers recorded for this country. In summarizing the results, we will therefore disregard the numbers for Luxemburg. The dominance of the United States emerges as being an across-the-board dominance. In 13 out of 20 industries the U.S. produces the most patents. A few countries are responsible for the exceptions to this rule. Sweden produced most patents per hour worked in industry 2 ("textiles"). The Netherlands scores highest in industries 12 ("electrical machinery") and 14 ("electronic components"), probably as a consequences of Philips' activities. Japan appears also as the strongest country in two industries, 15 ("motor vehicles") and 19 ("professional instruments"). In two more industries, an unexpected country tops the rankings. Austria would be best in producing patented innovations in industries 10 ("office machinery") and 17 ("aircraft"). Upon closer inspection, Austria turns out to have 'Luxemburgian' properties in these industries. Only very few people are working in these industries, which renders the scale-corrected patent numbers very sensitive to one or two additional patents. If we disregard Austria, the U.S. is the prime innovator in "office machinery" and Japan in "aircraft".[7] Korea and Taiwan do not play a significant role in any of the industries considered.

Table 4 focuses on the dynamics of patenting at the industry level. For many countries and industries, growth rates could not be computed, because the industry in these countries did not have any U.S. patent granted in 1979.

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7 Ironically enough, the Japanese aircraft industry was used as an example by Griliches (1990, p. 1667) to show how the assignment of multiple OTAF codes to technology classes can yield mistakes. In the early seventies, the Japanese aircraft industry showed fast increases in its aircraft patenting, but this was mainly due to engine-related patents being assigned to both "motor vehicles" and "aircraft". Our fractional counting procedue alleviates this problem. Furthermore, the Japanese aircraft industry has matured considerably in more recent decades (see Odagiri and Goto, 1996).

Table 4: Average annual growth rates of patents per hour worked, 1979-1998, by industry

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AS	**	0.053	0.100	**	0.041	0.051	0.048	0.033	0.066	0.125	0.034	0.077	**	0.099	0.089	0.068	0.076	0.122	0.075	0.065
AT	**	0.122	0.065	**	0.046	0.062	0.053	0.022	0.032	0.108	0.032	0.039	**	0.054	-0.003	**	0.062	0.119	0.036	0.034
BE	**	0.102	0.069	0.122	0.072	0.097	0.016	0.090	0.073	0.261	0.129	0.037	0.155	0.165	0.081	**	0.111	**	0.079	0.108
CA	0.031	0.102	0.086	0.011	0.035	0.077	0.034	0.041	0.040	0.132	0.085	0.090	0.143	0.071	0.025	0.124	0.040	0.052	0.065	0.070
CZ	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
DE	0.026	0.083	0.052	0.078	0.027	0.053	0.043	0.031	0.045	0.084	0.092	0.041	0.078	0.073	0.055	0.053	0.053	0.073	0.050	0.049
DK	0.035	0.127	0.122	**	0.011	0.047	0.038	0.071	0.063	0.018	**	0.029	-0.057	0.026	0.084	**	**	0.042	0.049	0.063
ES	0.003	**	0.078	**	0.114	0.055	**	0.106	0.049	**	**	0.167	**	0.135	0.036	0.033	0.042	**	0.142	0.146
FI	**	**	0.131	**	0.113	0.134	**	0.071	0.080	0.162	**	0.090	**	0.190	0.098	0.131	**	**	0.082	0.131
FR	0.066	0.093	0.074	0.061	0.057	0.054	0.055	0.044	0.043	0.081	0.081	0.048	0.093	0.066	0.061	0.070	0.077	0.030	0.067	0.047
GB	0.056	0.083	0.066	0.157	0.022	0.060	0.019	0.043	0.026	0.121	0.066	0.028	0.060	0.080	0.045	0.025	0.052	-0.006	0.064	0.043
GR	**	**	0.107	**	-0.063	-0.014	**	0.024	0.056	0.032	**	**	**	-0.004	**	**	**	**	**	0.041
HU	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
IE	**	**	0.023	**	**	**	**	**	0.093	**	-0.075	0.074	**	**	**	**	**	**	**	0.033
IT	0.045	0.165	0.061	0.108	0.016	0.046	0.033	0.063	0.046	0.050	0.081	0.066	0.022	0.110	0.078	0.080	0.002	-0.011	0.074	0.077
JP	0.032	0.111	0.073	0.111	0.071	0.094	0.072	0.077	0.062	0.122	0.140	0.090	0.124	0.083	0.080	0.155	0.046	0.078	0.113	0.082
KR	**	**	**	**	**	**	**	0.257	0.245	**	**	**	**	**	**	**	**	**	**	0.197
LU	**	**	**	**	**	-0.098	0.002	-0.064	-0.005	**	**	**	**	**	**	**	**	**	-0.150	**
NL	0.116	0.071	0.062	0.011	0.053	0.028	0.080	0.004	0.005	0.098	0.022	0.078	0.070	0.071	0.064	0.091	0.082	0.070	0.086	0.069
NO	**	**	0.085	-0.007	0.045	-0.011	**	0.051	0.043	**	0.049	0.048	**	0.153	-0.153	0.035	**	0.071	0.044	0.029
PL	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
PT	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
SE	0.046	**	0.059	**	0.023	0.032	0.051	0.014	0.023	0.132	-0.017	0.034	**	0.079	0.023	0.180	0.027	0.040	0.056	0.039
SK	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**
TW	**	0.166	0.245	**	0.223	0.247	**	0.153	0.173	0.099	**	0.225	**	0.244	0.147	0.071	0.091	**	0.270	0.202
US	0.023	0.074	0.050	0.018	0.023	0.046	0.036	0.035	0.033	0.141	0.050	0.045	0.079	0.069	0.035	0.057	0.044	0.034	0.067	0.046

**: growth rate undefined due to zero patents in initial year.

Among the cases in which growth rates could be computed, Taiwan emerged as the fastest grower in many cases. In fact, in no less than nine industries, the growth rate of the size-corrected number of patents was unparalleled by any other country. For another two industries (8, “fabricated metal products”, and 9, “other machinery”), South Korea appeared as the country with the highest growth rate. Regarding the European countries, the number of patents for Great Britain rose strongly in industry 4 (“Petroleum and gas”), while Belgium performed relatievly well in a number of high-tech industries (10, 13 and 17). In most of these cases, the level of Belgian patenting was rather low in 1979, however. Dutch patents increased in numbers in “food” (1) and “iron and steel”(7). Finally, Sweden recorded the highest average annual growth rate in “ships and boats” (16).

So far, the industry-level information we presented did not distinguish between degrees of importance of patents. Table 5 alters this situation. Here, we present information on the extent to which national industries specialize in important innovations. To this end, we will look at “Revealed Comparative Technological Advantages” (RCTAs), which are defined in the same vein as Revealed Comparative Advantages used in empirical analyses of trade patterns. For industry *i*, country *k*’s RCTA is defined as

$$\mathrm{RCTA}_i^k = \frac{n_i^{*k} / \left(n_i^{*k} + n_i^k\right)}{\sum_{k=1}^{C} n_i^{*k} \Big/ \sum_{k=1}^{C} \left(n_i^{*k} + n_i^k\right)} \qquad (1)$$

RCTAs defined as in equation (1) always yield nonnegative values in cases in which the industries has any patents (the denominator in the numerator may not be zero). Values smaller than 1 indicate “negative specialization” in the generation of important patents, values greater than 1 point to specialization. A problem with this conventional way of presenting degrees of specialization is that negative specializations are comprimed in the [0,1> interval, while positive specialization are spread over <1,∞>. To report degrees of specialization in a symmetric fashion, we will always present the natural logarithms of the RCTAs. The logs of the RCTAs in Table 5 refer to a categorization in which patents belonging to the decile with the most citations in an OTAF industry in a given year is considered to be important. The results are based on all patents granted by USPTO in the 1970-1999 period.

The most striking finding is that the United States has a positive specialization in all industries. This corroberates the result found by Akkermans *et al.* (2005) and proves empirically that the home market bias explantion for the high number of patents does not hold for the U.S. case. Many other (especially Western European) countries are negtively specialized in important innovations in all countries. This holds for Austria, Belgium, Germany, Spain, France, Great Britain, Italy and The Netherlands. Countries like Denmark show positive specialization in “food” (1) and “non-metallic mineral products” (6). Norway specialized positively in important innovations in “chemicals”(3) and “petroleum and gas”(4).

Table 5: Average Revealed Comparative Technological Advantages (in logs), 1970-1999

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AS	-0.47	-0.97	-0.31	-1.40	-0.07	-0.93	-0.35	-0.37	-0.53	-0.23	-0.94	0.04	-0.85	-0.10	-0.49	-0.20	-0.11	-0.56	-0.19	-0.33
AT	-0.26	-0.64	-0.53	#	-0.44	-1.04	-0.24	-0.73	-0.59	-1.78	-0.67	-1.31	-0.72	-1.69	-0.32	#	-0.02	-0.11	-0.96	-0.95
BE	-0.41	-0.08	-0.04	-0.28	-0.24	-0.30	-0.76	-0.12	-0.66	-1.01	-0.28	-0.18	-0.04	-0.47	-1.09	#	-0.19	-0.36	-0.81	-0.10
CA	-0.30	0.19	0.02	-0.61	-0.09	-0.11	-0.33	-0.27	-0.09	-0.05	-0.16	-0.05	0.16	0.17	-0.39	0.08	-0.38	-0.29	-0.12	-0.20
CZ	**	**	#	**	#	#	**	#	#	#	#	#	**	#	#	**	#	**	0.31	#
DE	-0.62	-0.82	-0.42	-1.22	-0.55	-0.44	-0.33	-0.36	-0.41	-1.30	-0.90	-0.61	-0.44	-0.94	-0.19	-0.87	-0.10	-0.08	-0.63	-0.46
DK	0.14	-0.20	-0.14	#	-0.31	0.19	-1.46	-0.60	-0.77	-0.65	#	-0.47	-0.16	-0.84	-0.55	#	-0.86	-0.56	-0.20	-0.41
ES	-1.49	-0.57	-0.87	#	-0.55	-0.53	-0.02	-1.14	-1.09	-0.27	-0.30	-1.60	#	-1.07	-1.14	#	-0.91	-0.19	-0.31	-1.05
FI	0.08	-0.01	-0.40	-1.11	-0.48	-0.75	-1.33	-0.57	-0.20	-0.96	-0.88	-0.76	0.85	0.34	-2.18	-1.54	-0.64	#	-0.59	-0.49
FR	-0.54	-0.86	-0.40	-0.19	-0.43	-0.47	-0.45	-0.42	-0.44	-0.66	-0.81	-0.42	-0.34	-0.80	-0.59	-0.83	-0.62	-0.59	-0.48	-0.24
GB	-0.08	-0.29	-0.07	-0.14	-0.22	-0.21	0.00	-0.28	-0.36	-0.22	-0.61	-0.22	-0.04	-0.37	-0.35	-0.54	-0.32	-0.38	-0.35	-0.14
GR	#	#	-1.69	#	-0.10	#	#	-1.34	-0.51	-0.76	1.60	0.30	#	0.52	#	#	#	#	-0.56	-1.22
HU	-1.14	**	-1.04	#	-0.61	-0.69	-1.51	-0.83	-0.73	#	#	-1.63	#	-2.25	-1.23	**	-0.63	#	-1.07	-1.46
IE	0.10	0.47	0.31	#	0.19	0.00	#	-0.68	-0.28	-0.44	0.26	0.41	#	-0.33	-0.87	#	0.01	-0.26	0.09	-0.10
IT	-0.76	-0.91	-0.72	-1.16	-0.66	-1.04	-0.48	-0.48	-0.63	-1.09	-1.11	-0.71	-1.31	-0.70	-0.55	-1.20	-0.46	-0.51	-0.83	-0.33
JP	-0.66	-0.30	-0.30	-0.26	-0.16	-0.13	-0.25	0.06	0.11	-0.95	0.13	-0.19	-0.22	-0.34	0.11	0.62	0.24	0.30	-0.52	-0.06
KR	**	-1.79	-0.89	**	-1.05	-0.39	-0.86	-0.05	-0.55	-1.88	-0.07	-0.46	-1.17	-0.40	-1.70	**	-2.89	-1.74	-1.22	-0.17
LU	#	-1.12	0.98	#	-0.55	-0.82	#	-0.36	-0.91	#	#	#	#	-0.11	0.04	**	#	#	#	-0.03
NL	-0.57	-0.65	-0.43	-0.19	-0.39	-0.85	-0.47	-0.67	-0.35	-0.65	-1.26	-0.45	-0.23	-0.69	-0.67	-0.76	-0.56	-2.34	-0.29	-0.42
NO	-1.06	-0.75	0.18	0.65	-0.54	-0.11	-0.38	-0.80	-0.92	-0.31	-0.46	-0.50	0.03	-1.30	-0.45	-0.97	-0.60	-0.84	-0.46	-0.58
PL	**	**	-0.40	#	#	-0.28	**	-1.05	-1.39	-0.48	1.20	-0.15	-0.27	-1.97	#	**	**	**	-1.29	**
PT	#	#	-1.33	#	1.40	#	#	0.62	#	#	**	-0.28	**	#	**	#	**	**	-0.39	0.06
SE	-0.97	0.25	0.28	-1.70	-0.49	-0.43	-0.72	-0.54	-0.43	-0.09	-1.09	-0.47	0.62	0.00	-0.52	-0.56	-0.49	-0.53	-0.28	-0.28
SK	**	**	#	**	#	**	**	**	#	**	**	#	**	#	#	**	#	#	#	#
TW	#	-0.90	-1.04	**	-0.11	-0.18	-1.25	0.22	-0.33	-1.21	-0.21	-0.58	-0.92	0.17	-1.14	-1.20	-0.64	0.00	-0.94	-0.06
US	0.20	0.27	0.20	0.08	0.16	0.16	0.24	0.10	0.16	0.36	0.14	0.20	0.26	0.23	0.11	0.04	0.05	0.04	0.25	0.09

#: log(RCTA) could not be computed due to no important innovation (top-10%) in this industry.

**: RCTA could not be computed due to no patents in this industry.

Table 6: Trends in Revealed Comparative Technological Advantages (in logs), selected countries

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DE	1970-74	-0.11	-0.60	-0.25	-2.11	-0.44	-0.16	-0.18	-0.37	-0.26	-1.12	-0.57	-0.40	-0.49	-0.54	-0.06	-0.68	-0.01	0.12	-0.73	-0.55
	1980-84	-0.92	-0.89	-0.46	-1.32	-0.50	-0.56	-0.25	-0.18	-0.41	-1.07	-0.79	-0.41	-0.63	-0.79	-0.14	-0.33	-0.18	-0.18	-0.52	-0.26
	1990-94	-1.10	-0.52	-0.53	-1.01	-0.52	-0.58	-0.74	-0.39	-0.51	-1.41	-1.34	-1.06	-0.41	-1.43	-0.35	-1.10	-0.09	-0.18	-0.66	-0.56
	1995-99	-0.64	-1.11	-0.39	#	-0.61	-0.58	-0.42	-0.41	-0.52	-1.76	-1.57	-0.88	-0.84	-1.21	-0.18	#	-0.04	-0.06	-0.70	-0.46
FR	1970-74	-0.43	-1.02	-0.31	-0.36	-0.41	-0.34	0.08	-0.49	-0.43	-1.28	-1.27	-0.24	-0.42	-0.67	-0.40	-0.96	-0.27	-0.15	-0.54	-0.33
	1980-84	-0.62	-0.24	-0.29	-0.38	-0.46	-0.59	-0.45	-0.44	-0.44	0.09	-0.36	-0.23	0.14	-0.69	-0.18	-1.25	-0.30	-0.67	-0.37	-0.15
	1990-94	-1.61	-2.62	-0.49	-0.40	-0.67	-0.55	-0.87	-0.57	-0.47	-0.66	-0.71	-0.29	-0.99	-0.91	-0.95	-1.21	-1.01	-1.80	-0.57	-0.20
	1995-99	-0.26	-0.81	-0.47	0.10	-0.48	-0.49	-0.72	-0.23	-0.54	-0.89	-1.10	-0.65	-0.54	-0.90	-1.15	#	-0.97	-1.00	-0.42	-0.01
GB	1970-74	0.24	-0.47	0.14	0.39	-0.07	-0.16	-0.12	-0.33	-0.48	-0.06	-0.93	-0.23	-0.99	-0.24	-0.17	-0.57	-0.11	-0.30	-0.33	-0.07
	1980-84	-0.19	-0.01	0.03	-1.28	-0.20	-0.03	0.25	-0.03	-0.30	-0.18	0.13	-0.15	0.68	-0.43	-0.59	-0.03	-0.46	-0.17	-0.33	0.01
	1990-94	-0.10	-1.14	-0.29	-0.38	-0.42	-0.54	0.01	-0.37	-0.33	-0.24	-0.78	-0.31	-0.24	-0.33	-0.29	-1.11	-0.47	0.18	-0.41	-0.25
	1995-99	-0.72	-0.04	-0.24	0.24	-0.22	-0.12	-0.47	-0.41	-0.31	-0.47	-1.42	-0.35	-0.30	-0.47	-0.69	#	-0.66	-0.09	-0.58	-0.29
IT	1970-74	0.10	-2.05	-0.68	#	-0.57	-0.64	-1.04	-0.05	-0.50	-0.59	-0.39	-0.53	-1.53	-0.44	-0.40	#	-0.01	-0.72	-0.74	-0.19
	1980-84	-0.15	-0.37	-0.67	#	-0.77	-0.84	0.49	-0.61	-0.36	-1.36	#	-0.59	-0.70	-0.33	0.06	0.14	-0.06	-0.57	-1.13	-0.51
	1990-94	-0.59	-0.71	-0.98	-0.15	-0.66	-0.55	-0.37	-0.63	-0.76	-1.67	#	-0.82	#	-1.29	-0.62	-0.58	-1.44	-0.73	-0.80	-0.51
	1995-99	-1.31	-2.24	-0.70	#	-0.71	-1.41	-0.32	-0.70	-0.92	-1.39	-1.45	-0.57	-1.62	-0.65	-1.71	#	-0.41	-0.42	-1.01	-0.27

#: log(RCTA) could not be computed due to no important innovation (top-10%) in this industry.

Table 6 (continued): Trends in Revealed Comparative Technological Advantages (in logs), selected countries

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
JP	1970-74	-0.90	-0.35	-0.13	-1.15	-0.01	-0.18	-0.11	-0.44	-0.02	-0.62	-0.73	-0.12	-0.23	-0.30	0.18	-1.03	0.22	0.29	-0.62	-0.31
	1980-84	-0.32	0.01	-0.06	0.17	0.14	0.13	-0.14	0.14	0.15	-0.39	-0.32	-0.14	-0.19	-0.13	0.20	0.43	0.17	0.36	-0.29	0.03
	1990-94	-0.69	-0.37	-0.51	-0.21	-0.36	-0.35	-0.44	0.03	0.05	-1.10	0.22	-0.33	-0.21	-0.37	0.03	0.56	0.28	0.18	-0.67	-0.18
	1995-99	-1.06	-0.47	-0.51	-0.56	-0.27	-0.09	-0.39	0.09	0.20	-1.22	0.23	-0.17	-0.31	-0.46	0.08	1.08	0.30	0.48	-0.49	0.00
KR	1970-74	**	**	#	**	#	#	**	#	#	#	**	#	**	#	#	**	**	**	#	#
	1980-84	**	2.29	-1.34	#	-0.18	#	#	-0.39	0.13	#	#	-0.38	**	#	2.08	#	#	**	#	-1.65
	1990-94	#	#	-1.20	#	-2.78	-0.23	-0.48	-0.32	-0.62	-1.53	-0.44	-0.64	-2.24	-0.44	-2.58	#	#	0.05	-1.44	-0.17
	1995-99	#	#	-0.79	#	-0.71	-0.48	-0.85	0.06	-0.51	-1.96	0.18	-0.39	-0.89	-0.39	-2.63	#	-2.66	-2.35	-1.16	-0.12
TW	1970-74	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	**	#
	1980-84	**	#	#	#	-0.07	#	#	-0.75	-1.62	#	0.20	-0.51	#	-0.42	#	**	#	#	#	-0.65
	1990-94	#	#	-0.97	#	-0.42	0.02	-2.13	0.10	-0.38	-2.53	-0.72	-0.84	-1.54	-0.14	-0.45	-0.28	-1.21	0.14	-1.80	-0.51
	1995-99	#	-0.72	-0.93	#	0.08	-0.25	-0.79	0.42	-0.19	-0.99	-0.06	-0.36	-0.60	0.27	-1.68	#	-0.39	-0.05	-0.57	0.14
US	1970-74	0.08	0.20	0.10	0.04	0.08	0.09	0.09	0.10	0.12	0.17	0.16	0.11	0.13	0.11	0.05	0.17	0.05	0.05	0.17	0.07
	1980-84	0.21	0.23	0.14	0.07	0.11	0.11	0.19	0.08	0.15	0.25	0.18	0.18	0.13	0.17	0.03	0.13	0.08	0.03	0.21	0.07
	1990-94	0.26	0.28	0.30	0.09	0.22	0.24	0.37	0.12	0.20	0.49	0.15	0.29	0.40	0.30	0.20	-0.06	0.01	0.07	0.32	0.13
	1995-99	0.25	0.32	0.24	0.11	0.20	0.19	0.36	0.07	0.16	0.37	0.08	0.24	0.41	0.29	0.16	-0.24	0.01	-0.06	0.26	0.06

#: log(RCTA) could not be computed due to no important innovation (top-10%) in this industry.
**: RCTA could not be computed due to no patents in this industry.

The remaining Scandinavian countries also appear to have specialized in important innovations in a few industries. Finland did so in industries (13) and (14), “radio and TV receivers” and “electronic components”, respectively. Sweden also stood out positively in “radio and TV receivers”, besides in “textiles” (2) and “chemicals” (3).

The East Asian countries reflect different stages concerning their technological achievements. While Japan specialized in important innovations in quite few industries (the most notable being industries, 15-18, which all relate to transport equipment), appeared Korea very despecialized in important innovations in virtually all industries. Taiwan has an intermediate position, with positive specialization in just two industries, 8 (“fabricated metal products”) and 14 (“electronic components”).

In Table 6, we study trends in technological specialization over time, for a few selected countries. The first panel, which presents results for the four traditionally most important industrial countries in Europe, depicts a rather gloomy picture. Although trends are not always monotonic over time, for almost all industries we find that Germany, France, Great Britain and Italy got more despecialized in important innovations between the early 1970s and the late 1990s. In industry 1 (“food”), for example, Great Britain and Italy were positively specialized in the early period, but quite despecialized in more recent times. Probably the most dramatic findings relate to Germany. This country witnessed a hardly noticeable increase in its specialization in important innovations in “instruments”, but apart from this exception it lost ground in each and every other industry, including technologically dynamic industries such as “office machinery” (10) and “electronic components” (14). For France, the results are a little bit less extreme, with positive trends in “petroleum and gas” (4) and “office machinery” (10). In a traditionally strong French industry, “motor vehicles” (15), it saw its log(RCTA) become much more negative than it used to be in the early 70s. Great Britain lost much ground in many industries, such as “iron and steel” (7) and “office equipment”(10). Its specialization patterns changed towards important innovation in “radio and TV receivers”(13) and “railroad equipment” (18). Italy improved its position in “iron and steel” (7), but lost much in traditionally strong industries as “metal products” (8) and “motor vehicles” (15).

The countries in the lower panel, which might be seen as Europe’s rivals (in some cases probably in the future) when it comes to becoming the most technologically dynamic economy of the world, show tendencies that are almost opposite to those of Germany and France. First, the U.S. managed to increase its already positive specialization in important innovations in almost all industries. These tendencies are particularly strong in industries with high technological opportunities such as “office machinery” (10), “radio and TV receivers” (13) and “electronic components”(14). The exceptions are mainly found in more mature industries, such as “shipbuilding” (16) and “railroad equipment” (18).

Japan did a good job in industries 8, 9, 11, 16 and 18, (“metal products”, “machinery”, “insulated wire”, “shipbuilding” and “railroad equipment”). It lost some ground, however, in high-tech industries like "office machinery" (10) and "electronic components" (14). The latter are industries in which Taiwan made up some of its lag. Furthermore, it managed to obtain a positive specialization in most recent times in "rubber and plastics products" (5) and "metal products" (8). South Korea is still lagging farther behind in terms of its specialization in important innovation, but also reports positive log(RCTA) values in "metal products"(8) and "insulated wire" (11) already.

The overall situation that emerges from the descriptive statistics on patenting is not very positive for most European countries. A big question, of course, is whether a declining patenting activity (relative to many other countries) and despecialization in important innovations are a problem or not. As is well-known, knowledge has some characteristics of a public good (although the degree to which this is the case is an issue of debate). Consequently, European countries could maybe make up a lot of lost ground by quickly and effectively assimilating knowledge pertaining to important generations elsewhere. This might be a sensible strategy, since it would avoid the high riskiness of often big projects aimed at important innovation and still give access to productive technologies. To see whether the relatively poor innovation performance by many European countries is matched by poor labor productivity growth results, we turn to Table 7.

The labor productivity growth rates by industry presented in the table show a dominance by two countries that were catching up in many industries, South Korea and Ireland. Korea managed to attain the highest growth rate in eight industries, among which industries 6-10. These industries mainly relate to metal products and several kinds of machinery manufacturing. Ireland did particularly well in industries 1 ("food"), 3 ("chemicals"), 12 ("electrical machinery") and in 20 ("miscellaneous manufacturing"). In the technologicall dynamic "electronic components" industry (14), the United States attained the highest growth rate.

We will not go to deeply into the performance of the European countries here, but a quick glance at Table 7 shows that the traditional economic powers did not very well. Especially in the high-tech industries, countries like Germany, France, Great Britain and Italy grew slower in productivity terms than many other countries. In industries in which these countries were traditionally strong, such as "motor vehicles" (16), the productivity growth rates fell well behind thos in countries like Korea and Japan. Within Europe, the Scandinavian countries seem to perform relatively well, with occasionally high growth rates for Finland and Sweden. The latter country even managed the highest productivity growth rate in "radio and television receivers" (13).

*Table 7: Average annual labor productivity growth rates (in %), 1979-2002.**

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
AS	1.71	0.38	1.56	4.01	2.43	2.66	2.56	2.24	1.62	31.74	3.35	3.27	n.a..	19.89	2.68	3.26	2.78	2.44	3.36	1.36
AT	3.85	3.36	5.06	5.99	5.25	2.15	6.33	3.68	3.70	40.97	1.07	3.92	5.63	13.75	1.64	8.29	5.07	5.31	6.13	4.14
BE	2.83	5.21	8.05	1.55	7.95	3.87	5.40	3.04	2.31	34.47	3.54	4.68	5.20	13.74	4.56	4.31	5.61	5.76	4.23	3.54
CA	1.07	1.38	3.68	0.86	2.94	1.18	4.35	0.67	2.59	34.43	0.71	3.33	0.81	12.23	2.13	0.95	2.72	0.51	2.05	1.72
CZ	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
DE	1.31	2.97	3.73	3.36	1.79	2.39	3.57	1.62	1.55	32.58	0.71	2.27	3.11	16.16	1.26	2.77	4.42	2.05	2.40	1.52
DK	2.00	2.05	4.61	10.59	1.03	1.64	3.45	2.32	1.20	34.42	0.21	3.12	4.69	17.82	1.79	1.00	-2.86	3.62	4.45	0.93
ES	2.13	2.62	3.45	2.02	1.88	2.70	3.97	1.91	2.10	35.11	3.37	3.57	2.29	13.25	2.38	1.54	3.14	3.41	3.41	2.10
FI	4.32	2.74	3.93	4.99	3.91	3.14	5.50	3.77	3.32	38.48	7.92	5.48	10.12	16.19	5.47	1.20	0.35	1.17	6.18	4.48
FR	1.01	2.71	5.21	-2.81	2.55	3.98	3.95	0.90	3.07	28.80	4.08	4.19	12.73	18.27	5.47	6.21	1.18	6.73	2.28	2.47
GB	2.55	2.68	5.64	7.12	2.70	3.31	6.68	4.19	1.85	35.44	-0.23	4.61	7.77	20.11	4.92	7.75	5.51	1.42	6.23	2.46
GR	2.79	-0.07	3.27	5.05	-0.44	1.65	-0.12	0.03	2.05	27.35	0.92	1.50	3.93	5.23	1.39	2.12	0.90	0.39	0.14	1.43
HU	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
IE	7.20	5.09	11.68	5.33	4.23	5.85	5.72	3.76	4.21	36.19	9.09	13.39	10.39	28.63	5.00	4.69	n.a..	8.41	8.90	6.20
IT	2.20	2.68	5.06	-1.95	1.09	1.33	4.60	2.64	1.36	31.10	2.77	3.00	6.93	15.50	3.35	0.43	-0.22	0.38	2.56	2.44
JP	0.15	0.53	4.50	4.74	0.28	3.03	0.70	2.69	2.64	34.53	12.17	9.74	8.66	25.75	5.83	7.41	5.94	2.94	4.49	2.30
KR	4.09	2.05	7.04	7.53	4.06	7.30	8.95	4.23	5.07	40.89	5.66	4.68	11.94	32.56	8.32	11.75	2.96	12.08	7.74	5.36
LU	-0.36	9.79	1.61	6.53	6.18	3.49	6.54	2.63	2.15	33.63	2.18	2.18	0.88	23.38	1.36	1.36	1.36	1.36	2.18	2.41
NL	3.66	4.64	4.66	0.55	4.04	3.56	2.50	2.34	2.68	33.85	3.52	2.86	2.80	10.73	4.46	3.58	3.81	6.58	4.95	3.02
NO	0.12	2.59	2.71	5.27	1.61	0.13	3.24	1.11	3.51	30.40	-2.67	-0.23	5.09	8.16	-0.90	1.04	-2.28	1.04	-0.37	0.98
PL	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
PT	1.86	3.05	2.88	4.57	-0.59	5.30	2.78	3.04	-0.18	32.63	-0.58	4.30	7.06	25.83	7.89	6.29	6.13	9.63	8.92	2.93
SE	1.98	2.39	4.27	3.78	2.47	1.53	5.51	2.19	2.87	33.89	6.44	2.67	13.78	8.63	5.11	-0.05	2.55	-3.04	9.19	2.25
SK	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
TW	-0.15	2.94	3.08	3.93	4.25	1.28	2.12	1.92	0.83	35.28	1.72	3.41	10.36	24.21	1.69	0.34	1.79	0.75	3.26	0.43
US	2.93	2.87	7.39	8.99	5.36	5.29	5.49	2.39	4.39	38.77	8.28	8.52	8.00	33.98	3.36	3.99	3.59	2.58	3.86	3.71

*US national deflators used for all countries for industries 10 and 14.

4. Empirics of the Patents-Productivity Relationship

In this section, we will present some provisional econometric work to assess the impacts of patenting activity on labor productivity growth. In future work, we intend to elaborate into these analyses much more deeply. Section 5 will give some directions in this regard. For now, we experimented with several variations on two themes. Because most variations within a theme (like including time dummies, experimenting with different lag structures and including a few additional explanatory variables) did not alter the results in a qualitative way, we will just present two sets of results.

In Table 8, we regressed average labor productivity growth in five-year periods on the growth of the patent stocks per unit of labor in the previous five-year period.[8] The hypothesis would be that access generation of many recent patents would enhance productivity growth in the years to follow. The stocks were computed by means of the perpetual inventory method. We assumed an obsolescence rate of 15%. The initial stocks for 1979 were computed on the basis of actual patent flows from 1970 onwards and estimated flows from 1963 onwards. We present results for the growth of two types of patent stocks, total patent stocks and stocks that belong to the worldwide most important 5%.

For many industries, we find a significant and positive relationship between patent stock growth and labor productivity growth. If we first turn our attention to total stocks, we find that the relationship is insignificant at commonly accepted significance levels in eight industries. Among them are high-tech "office machinery" and "aircraft". The estimated slope coefficients are generally in the range of 0.4-1.0. If we look at the growth of top-5% patent stocks, the coefficients are considerably smaller and often insignificant. In fact, we find a positive and significant rekationship in only a few industries: "rubbers and plastics", "fabricated metal products", "electronic components" and "miscellaneous manufacturing". For the "aircraft" industry, we even find a significant negative relationship. These results suggest that obtaining many very important patents is not of utmost importance for productivity growth. Activities aimed at more incremental, less important innovations might be more important. One industry that does not obey this provisionally apparent 'law' is the highly dynamic "electronic components" industry.

8 The periods are 1979-1983, 1984-1988, 1989-1993 and 1994-1998. Due to the lagged specification, productivity growth could only be addressed for the three most recent periods.

Table 8: Productivity growth regressions on growth of patent stocks per hour worked

	Growth of total stock			Growth of top5% stock		
Sectors	a (tstat)	b(tstat)	n_obs/R^2	a (tstat)	b(tstat)	n_obs/R^2
1 Food	-0.026	1.121	47	0.008	0.292	37
	-0.877	3.690	0.23	0.340	1.805	0.09
2 Textiles	0.062	0.423	52	0.096	0.077	38
	1.953	2.291	0.10	3.320	0.374	0.00
3 Chemicals	0.073	-0.008	63	0.069	0.102	51
	3.848	-0.039	0.00	4.745	0.862	0.01
4 Petroleum and gas	-0.083	0.968	32	-0.058	0.155	24
	-1.792	2.130	0.13	-2.223	0.779	0.03
5 Rubber and plastics	-0.006	0.608	60	0.023	0.258	52
	-0.276	3.042	0.14	1.360	2.334	0.10
6 Other non-metallic mineral products	0.042	0.462	57	0.057	-0.070	46
	1.870	2.480	0.10	3.182	-0.788	0.01
7 Iron and steel	0.094	-0.591	48	0.069	0.028	41
	2.723	-1.745	0.06	2.317	0.115	0.00
8 Fabricated metal products	-0.011	0.523	62	-0.001	0.269	58
	-0.581	2.601	0.10	-0.035	2.552	0.10
9 Machinery and equipment, n.e.c.	-0.010	1.057	65	0.051	0.092	59
	-0.622	5.867	0.35	3.331	0.925	0.01
10 Office machinery	0.146	0.020	54	0.135	0.305	33
	5.494	0.125	0.00	5.101	1.264	0.05
11 Insulated wire	0.073	0.118	42	0.072	-0.013	34
	2.096	0.467	0.01	2.166	-0.052	0.00
12 Other electrical machinery	0.017	0.585	57	0.034	0.173	50
	0.851	2.522	0.10	1.818	1.280	0.03
13 Radio and television receivers	0.026	0.545	40	0.107	-0.268	34
	0.680	2.691	0.16	3.115	-1.954	0.11
14 Electronic components	0.075	0.439	57	0.070	0.330	45
	3.022	2.554	0.11	3.708	3.052	0.18
15 Motor vehicles	-0.021	0.751	55	0.011	0.058	40
	-0.711	2.931	0.14	0.461	0.295	0.00
16 Ships and boats	0.069	-0.336	40	0.019	0.198	32
	2.136	-1.582	0.06	0.718	1.259	0.05
17 Aircraft and spacecraft	0.034	-0.172	51	0.042	-0.355	37
	1.252	-0.632	0.01	1.772	-2.061	0.11
18 Railroad equipment	0.066	0.285	45	0.042	0.219	37
	2.131	1.196	0.03	1.539	1.645	0.07
19 Professional instruments	0.065	0.193	60	0.067	-0.160	51
	2.894	1.075	0.02	4.714	-1.578	0.05
20 Manufacturing products, n.e.c.	-0.014	0.909	61	0.024	0.205	59
	-0.782	3.998	0.21	1.616	2.901	0.13

Table 9: Productivity growth regressions on patent stocks per hour worked in initial periods

	Initial total stocks			Initial top-5% stocks		
Sectors	a (tstat)	b(tstat)	n_obs/R^2	a (tstat)	b(tstat)	n_obs/R^2
1 Food	0.048	-0.001	58	0.047	-0.008	58
	1.806	-0.344	0.00	1.819	-0.356	0.00
2 Textiles	0.136	-0.009	63	0.124	-0.099	63
	5.016	-1.768	0.05	4.905	-1.330	0.03
3 Chemicals	0.074	0.000	83	0.073	0.000	83
	4.730	-0.422	0.00	4.753	-0.376	0.00
4 Petroleum and gas	0.044	0.000	43	0.042	-0.004	43
	1.404	-0.854	0.02	1.374	-0.789	0.01
5 Rubber and plastics	0.045	0.000	77	0.041	-0.002	77
	2.474	-0.604	0.00	2.503	-0.345	0.00
6 Other non-metallic mineral products	0.087	0.000	75	0.084	-0.006	75
	4.922	-1.072	0.02	4.923	-0.932	0.01
7 Iron and steel	0.068	0.000	63	0.068	-0.002	63
	2.604	-0.123	0.00	2.682	-0.121	0.00
8 Fabricated metal products	0.042	0.000	81	0.041	-0.001	81
	2.709	-0.353	0.00	2.711	-0.292	0.00
9 Machinery and equipment, n.e.c.	0.057	0.000	89	0.056	0.000	89
	3.900	-0.503	0.00	3.901	-0.383	0.00
10 Office machinery	0.125	0.000	69	0.122	0.000	69
	4.738	-0.418	0.00	4.844	-0.227	0.00
11 Insulated wire	0.123	0.000	55	0.114	-0.002	55
	4.526	-1.259	0.03	4.402	-0.759	0.01
12 Other electrical machinery	0.064	0.000	76	0.063	-0.001	76
	3.694	-0.587	0.00	3.688	-0.460	0.00
13 Radio and television receivers	0.116	0.000	50	0.114	-0.005	50
	3.305	-0.537	0.01	3.607	-0.665	0.01
14 Electronic components	0.116	0.000	75	0.110	-0.001	75
	5.892	-1.271	0.02	5.897	-0.893	0.01
15 Motor vehicles	0.050	0.000	71	0.049	-0.001	71
	2.204	-0.226	0.00	2.195	-0.140	0.00
16 Ships and boats	0.070	0.000	51	0.069	-0.005	51
	2.588	-0.542	0.01	2.610	-0.519	0.01
17 Aircraft and spacecraft	0.035	0.000	65	0.034	0.000	65
	1.530	-0.174	0.00	1.525	-0.143	0.00
18 Railroad equipment	0.124	-0.001	56	0.110	-0.011	56
	4.412	-1.975	0.07	4.195	-1.501	0.04
19 Professional instruments	0.084	0.000	80	0.083	0.000	80
	5.109	-0.609	0.00	5.119	-0.532	0.00
20 Manufacturing products, n.e.c.	0.051	0.000	82	0.051	-0.002	82
	3.698	-0.468	0.00	3.702	-0.410	0.00

The second set of results, associated with variations on the second theme, is documented in Table 9. In this case, we did not investigate if patent stock *growth* in the previous period was important, but whether a high level of the patent stock per hour worked at thebeginning of five-year periods mattered for labor productivity growth. Here, the hypothesis would be that access to a big stock of own patents would enhance productivity growth. Based on very preliminary estimation efforts, Table 9 shows that no evidence is found for this hypothesis. The model, which only contains an intercept besides the patent stock variable, has hardly any explanatory power. This result is robust for considering very important patents only.

5. Future Research

Although we think that the material contained in this paper gives some useful insights, it is definitely calling for improvements and extensions in several respects. This section is devoted to three, more or less distinct developments we have in mind.

5.a Specification issues

The specifications for the regressions reported upon in the previous section were very simple. Apart from the (sometimes purposeful) omission of many possibly important explanatory variables, there are more shortcuts that might affect the results. For example, we split the entire period of study into subperiods of equal length, without taking business cycle effects into account. This might well have an impact on the results.

A next step would be to use the full potential that our relatively long panel dataset offers us. Fixed-effects estimation should provide more insights, although some caveats might well apply. As Tables 1 and 2 showed, the number of patents per hour worked steadily increased over time. So did labor productivity levels. Consequently, standard fixed-effects estimations might well yield spurious correlation. In order to correct for this, it might be worthwhile to apply techniques that take potential cointegated relations into account. Techniques using 'error correction models' proposed in Los and Verspagen's (2000) study into the effects of technology spillovers at the firm level are candidates for such explorations.

5.b Industries-of-manufacture vs. industries-of-use

A second avenue of future research activity confronts conceptual problems in linking labor productivity levels and growth to patent stocks and flows as proposed in this paper. Most patents refer to product innovations. A problem associated with the most common ways of measuring productivity levels and growth is that deflation procedures do not take quality differences into account. This implies that product innovations will often show up as inefficient production of existing products. In view of this, it is not very surprising that we often did not find results in our regression analyses that met our expectations. In our perspective, there is only one mechanism that could cause measured productivity to increase with patented product innovation. If a country is the first to manufacture a new product, it is most likely to benefit first from "going down the learning curve". In other words, it would be the first to reap the fruits of process innovations that often follow radical product innovations. The estimation results presented in Table 8 do not offer much support for the empirical relevance of this mechanism, because even the lagged specification does not yield a positive relation between generating many top-5%

patents and high productivity growth. The only exception is the "electronic components" industry. This industry does not suffer from the measurement problems mentioned earlier, because we could use U.S. hedonic deflators for this industry.

In this paper, we used a concordance that linked patents to industries that are most likely to *manufacture* the patented product. In view of the measurement problems mentioned, productivity growth in industries that use patented products will generally enjoy overstated productivity growth rates (see, e.g., Los and Verspagen, 2005, for a discussion of such 'rent spillovers'). Therefore, it might be worthwhile to consider concordances that link patents to industries that are most likely to *use* the patented product in their production processes. Lach (1995) used the so-called 'Yale-matrix' in a study like ours, focusing on productivity growth rates across U.S. industries. More recently, Johnson (2002) extended previous work on the Yale-matrix (which was based on Canadian patent data) to OECD countries.

5.c Identification of important innovations: the Silverberg-Verspagen Approach

In the previous sections, we constructed indicators for the numbers of important patents granted to inventors in countries, at the level of industries. To this end, we ordered the patents that were assigned to an industry on the basis of citation-based scores. The patents that belonged to the upper quantiles were considered to be important. For each of the industries, we experimented with several quantiles in our estimations linking productivity growth to innovative activity. The specific quantiles considered were taken as fixed over time. Although the results might appear insightful, this "fixed quantiles-based" approach has a number of drawbacks. In this section we will reflect on these, and describe a possibly fruitful way forward to deal with a few of these problems.

First, industries vary considerably in terms of their propensity to patent inventions. Patents are meant to protect inventors from imitation, in order to stimulate innovative activity. Cohen *et al.* (2000) find that many innovators do not view the patents sytem as the most effective way to protect their intellectual property. Keeping their technology secret is often considered a more attractive option, and many firms just rely on first-mover advantages (lead time). Cohen *et al.* (2000) also stress that many patents are not applied for to preclude imitation, but rather to force other firms into negotiations (often about cross-licensing) or to have potential competitors changing their technological strategies by "fencing" or "blocking" strategies (see Granstrand, 1999). Opportunities to keep innovations secret or to force competitors into negotiations over cross-licensing are industry-specific. If few patents are granted to an industry, the few patents that are granted will, on average, receive fewer citations than the average patent granted to an industry in which patenting is popular.[9] By identifying important patents on the basis of industry-level frequency distributions we correct for interindustry differences in the numbers of citations

[9] Using a European dataset, Verspagen & De Loo (1999) find average received citations-to-patents ratios ranging from 0.39 in the shipbuilding industry to 1.16 in the computer manufacturing industry. Hall *et al.* (2002) present qualitatively similar results for USPTO patents.

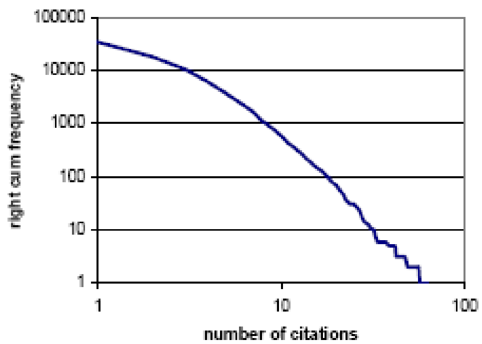
that correspond to specific quantiles, but we do not correct for differences in the shape of these frequency distributions.

Second, industries differ in terms of the technological opportunities they experience. Utterback and Abernathy (1975) identified innovation patterns that are quite strongly associated with stages in industry life cycles. In early stages, when no dominant design is in place yet and technological dynamism is huge, many product innovations are produced. Later on, upon entering the stage of maturity, the numbers of innovations are generally lower and cost-reducing process innovations tend to dominate over product innovations. Industry life cycles are often aligned with technology life cycles, or technological trajectories (Dosi, 1982). Interindustry differences with respect to the stage in the technology life cycle are taken into account by means of the year-specific identification of important patents. Again, however, this approach remains limited to a correction for differences in the numbers of citations received by the patent defining a specific quantile, but not for differences regarding higher 'moments' of the citation frequency distributions.

In summary, we feel that considering a patented innovation that received much more citations than a simultaneously granted patent as more important is justified. We admit, however, that it is probably unwarranted to consider the most heavily cited 10% of food-processing related patents granted in 1976 as equally important for this industry as the most heavily cited 10% of aircraft-manufacturing patents in 1995 was for that industry. A very recent empirical approach proposed by Silverberg and Verspagen (2006) could provide a way to overcome this problem.

The point of departure of Silverberg and Verspagen (2006) is the by now uncontested finding that the returns to innovation are very skewed (see, e.g., Scherer *et al.*, 2000). Only about one in every four innovation projects yields a positive return and only a few projects generate the big chunk of total returns to investment in R&D. The specific skew statistical distribution that is most able to describe the empirical distribution has been a topic of debate. Traditional goodness-of-fit tests suggest that lognormal distributions do a good job, but more thorough examination shows that Pareto distributions are superior in matching the observed frequency distributions in the right tail, i.e. the frequencies for the most valuable innovations. This phenomenon can also be observed for frequencies of numbers of patent citations (see Fig. 1).

Figure 1: Pareto plot of EPO 1989 patent citation data



Source: Silverberg and Verspagen (2006)

This graph was generated by ordering all patents issued by the European Patent Office with a priority date in 1989 according to the numbers of citations they received in the period up till and including 1999. These numbers of citations are depicted along the horizontal axis. The frequencies of patents with a higher number of citations than the value depicted on the horizontal axis is indicated along the vertical axis. Since both scales are chosen to be logarithmic, a Pareto distribution would look like straight downward sloping line. Exponential distributions would show curvature, that is, the absolute value of the negative slope would become higher for higher citation numbers. Figure 1 clearly shows that the frequencies of patents with more than approximately 70 citations tend to follow a Pareto distribution (the rightmost part of the curve is approximately linear). For less-cited patents, a lognormal distribution can be showed to fit the ever more steeply declining curve better.

Silverberg and Verspagen (2006) present evidence that a mix of lognormal (for less important innovations) and Pareto distributions (for the right tails of important innovations) can be used to describe observed frequency distributions for many indicators of patent importance. As they argue in a related paper (Silverberg and Verspagen, 2003), important innovations come about in a different way than less important ones. They derive part of their argument from Dosi's (1982) argument that radical innovations that constitute a 'technological paradigm' are almost always followed by swarms of more incremental innovations. Given that a dominant design is slowly emerging in such cases, the degree and nature of uncertainty surrounding innovation processes change over time. Changes in behavior by potential innovators caused by the changing environment they face could well yield different statistical distributions that govern innovation frequencies.

We intend to apply statistical procedures proposed by Silverberg and Verspagen (2006) to citation numbers for cohorts of industry-specific patents granted by USPTO. If successful, these exercises would provide us with a division into important and less important that is grounded in theory, as opposed to the rather arbitrary fixed-quantiles approach we have used so far. This would amount to removing part of the noise in our data that could play a role in the rather unsatisfactory regression analyses.

6. Conclusions

In this paper, we have studied the innovation performance of countries. We used patents as the output indicator of innovative activities. Unlike many older studies, we did not focus on raw patent counts alone, but tried to capture the enormous heterogeneity in importance of patents that is known to characterize them. To this end, we used patent citation data based on USPTO documents.

Our preliminary results indicate that the traditional powers in European manufacturing did not do well in terms of (important) patenting. The gap to the U.S. that existed already in the early 1970s seems to have widened in more recent decades. Simultaneously, other countries caught up. The East Asian 'Tigers' (Korea and Taiwan) do particularly well in this respect, but Japan also shows a performance that is superior to that of countries like Germany, France, Great Britain and Italy. Within Europe, the best innovation performance is found for Scandinavian countries such as Finland and Sweden, especially in cases in which the focus was on important innovation.

The provisional regression analyses we presented did not show that the generation of important patents has a stronger impact on labor productivity growth than the production of patents in general. As we indicated already, we should take such results with a grain of salt (to say the least), because the specification of our equations should be improved considerably. If these results would survive further scrutiny, however, they could imply that the relatively poor innovation performance of the biggest European countries could not be seen as the main determinant of the almost equally poor recent labor productivity growth performance of these countries.

In the final part of the paper, we focused on a few directions for further research that we would like to pursue. They relate to measurement issues of different kinds and improvements concerning the use of econometric techniques.

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Appendix

Industry Clasification

Nr.	Description	OTAF codes	EUKLEMS codes
1.	Food and kindred products	20	6,7
2.	Textile mill products	22	8,9,10
3.	Chemicals	28	15,16
4.	Petroleum and natural gas extraction and refining	1329	4,14
5.	Rubber and plastics products	30	17
6.	Other non-metallic mineral products	32	18
7.	Iron and steel	331+,333+	19,20
8.	Fabricated metal products	34-	21
9.	Machinery and equipment, n.e.c.	351,352,353,354,355,356,358,359,348+	22
10.	Office, accounting and computing machinery	357	23
11.	Insulated wire	364	24
12.	Other electrical machinery and apparatus, n.e.c.	361+,362,363,369	25
13.	Radio and television receivers	365	28
14.	Electronic components and accessories, and communications equipment	366+	26,27
15.	Motor vehicles and other motor vehicle equipment	371	31
16.	Building and repairing of ships and boats	373	32
17.	Aircraft and spacecraft	372,376	33
18.	Railroad equipment and transport equipment, n.e.c.	374,375,379-	34
19.	Professional and scientific instruments	38-	29,30
20.	Manufacturing products, n.e.c.	99	REST

Countries

1.	AS	Australia	14.	IE	Ireland
2.	AT	Austria	15.	IT	Italy
3.	BE	Belgium	16.	JP	Japan
4.	CA	Canada	17.	KR	South Korea
5.	CZ	Czech Republic	18.	LU	Luxembourg
6.	DE	Germany	19.	NL	The Netherlands
7.	DK	Denmark	20.	NO	Norway
8.	ES	Spain	21.	PL	Poland
9.	FI	Finland	22.	PT	Portugal
10.	FR	France	23.	SE	Sweden
11.	GB	U.K.	24.	SK	Slovakia
12.	GR	Greece	25.	TW	Taiwan
13.	HU	Hungary	26.	US	U.S.