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How did traditional MedTech integrate ICT: a new methodological approach

Monica Coffano
EPFL
CEMI
monica.coffano@epfl.ch

Dominique Foray
EPFL
CEMI
dominique.foray@epfl.ch

Abstract

How did traditional MedTech integrate ICT: a new methodological approach- Monica Coffano- EPFL – year enrollment: 2011- expected final date: 06/2016, monica.coffano@epfl.ch Since the beginning of the '90s, patent data are the most used proxy for innovation thanks to amount of heterogeneous information that they can provide. In particular, patent backward citations are shown to be a good mean to trace spillovers (Jaffe et al. (1993)). From the very first time that backward citations were introduced as measure of knowledge spillover, any scholar who has to deal with patent data has calculated this index at least once in her carrier. One aspect that has been neglected so far in the literature is the relation between knowledge spillovers and the different rate of adoption at which any technology can be assimilated by other sectors. The rate of adoption is also strongly related with the rate of technological progress in all the industries which are reached by its spillovers (Shapiro, 1985). This paper contributes to the literature that wishes to unpack the black box of the knowledge generation and technological spillovers between different sectors. The index of backward citations is redefined to better meet the different speed at which industries adopt new technologies. So far, the most common method to calculate patent backward citations was simply to count the number of prior patents. For any focal patent, the references are counted. But there are many options that can be added to this simple count, like the origin of the patent citation, the dimension of the family who's the patent belongs or the patent authority where the patent was filed. Due the recognize complexity of the topic discussed, the literature on patent citations includes also few works concerned about the possibility that knowledge spillovers and knowledge flow could be captured correctly by looking just at the first stage of backward citations. They do believe that important technological relations are embedded in the connection between the focal invention and its 'parents', and that this phenomenon can be captured with patent citations, but that is something more complicated than a simple count. The hypothesis that brings to the need of a different way to calculate in different way knowledge spillovers through backward citation is the following: some technologies become 'common knowledge' faster than others. As fast the speed of adoption is, as fast the knowledge spills over and the new technology becomes embedded in a new sector. From a backward citations point of view, this phenomenon leads to an underestimation of the knowledge spillovers from all those technologies that are easier to be adopted by other sectors. In fact, if a new technology is very easy to be acquired and used by a specific sector, it will be massively included in the references of the first patents citing this technology. The data used to calculate the new backward citation index are patent data extracted from the version of December 2014 of Patstat. I retrieved all the patents belonging to a Suisse applicant or a Suisse inventor, applied in the patent office of Switzerland, EPO, WIPO and US. Only the orthopedics subgroup of Medical devices has been analyzed in order to minimize the possibility to have results driven by the size effect of a particular subgroup and to fit the assumption of homogeneity of the sample. De facto Nieto and Quevedo (2005) demonstrate how firms that belong to the same sector are experiencing very similar industrial activities and so their knowledge should be similar. This leads to a sample of 9300 patents from 1980 till 2013. The speed of adoption has been calculated instead on a dataset that includes the patents in all technologies in the same period of time. The results show that the fastest technologies to be adopted are the ones in nanotechnology and computer science, followed by surface technologies and audio visual technology. Moreover the technologies that disappear sooner are the ones that have a higher speed of adoption. So patents in technologies like nanotechnologies and computer science are the fastest to be adopted and the fasted to disappear from the citations. The calculation of the second stage of the new backward citation index focuses on the patent cited in the first stage, with a combined IPC code, weighed. The results show that the second stage citations capture perfectly the real nature of the invention. Technologies do not behave all in the same way when interact with other sector, they have different intensity and especially a different speed. As consequence, knowledge spillovers of different technologies cannot be expressed in their totality using a single stage of backward citations of patent data.

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How did traditional medical technologies integrate ICT: a new methodological approach

Monica Coffano, Dominique Foray

Ecole Polytechnique Fédérale du Lausanne (EPFL)

Introduction

One of the main question for policy makers interested in the future of a traditional industry is about its potential for modernization, diversification and transition that would allow this industry to generate new and more competitive specialties. Foray's work on smart specialization involve the analysis of these various logics of transformation (Foray, 2015).

- Transition is characterised by a new domain emerging from an existing industrial base (a collection of R&D, engineering, and manufacturing capabilities that sustain innovation). The case of traditional ceramics moving to technical ceramics exemplifies such a transition pattern from traditional technologies for old declining markets to new technologies allowing these firms to enter new markets.
- Modernisation is manifest when the development of specific applications of a general purpose technology produces a significant impact on the efficiency and quality of an existing (often traditional) sector. Cases in point are the development of nanotechnology applications to improve the operational efficiency of the pulp & paper industry or the integration of new information technologies into the footwear industry. In these instances, the intersection between the development of applications of a *general purpose technology* and a mature sector defines a space of opportunities in which entrepreneurs' experiments and discoveries can be expected to produce socially useful knowledge.
- Diversification, in a narrow sense, is a third pattern. This is for example the case of mould manufacturing companies specialised in the production of moulds for glass makers, which diversified towards plastics products. In such cases potential synergies (economies of scope) are likely to materialise between an existing activity and a new one.

Works on smart specialization and related variety (Foray and Frenken, 2015) as well as the broad literature on the historical economics of GPTs suggest that such a transformation potential is fundamentally determined by the capacity of the traditional industry to recombine the existing knowledge base with new applications of a general purpose technology (such as electricity in the XX° century or the information and communication technologies – ICTs - in the end of XX° and the beginning of the XXI° centuries) (Rosenberg and Trajtenberg, David and Wright, Bresnahan).

In fact, the characteristics of a general purpose technology (GPT) are horizontal propagation throughout the economy and complementarity between invention and application development. Expressed in the economist's jargon, the invention of a GPT extends the frontier of invention possibilities for the whole economy, while application development changes the production function of one particular sector. The basic inventions generate new opportunities for developing applications in particular sectors. Reciprocally, application co-invention increases the size of the general technology market and improves the economic return on invention activities related to it. There are therefore dynamic feedback loops in accordance with which inventions give rise to the co-invention of applications, which in their turn increase the return on subsequent inventions. When things evolve favorably, a long term dynamic develops, consisting of large scale investments in R&D whose social and private marginal rates of return attain high levels.

Anecdotal evidence as well as case studies suggest that the new ICTs are clearly a source of innovation in medical technologies: the development of ICTs provides opportunities to increase productivity and improve quality of a broad range of medical devices. This may happen through the so-called process of co-invention of applications which is the process by which the new ICTs diffuse across a wide range of sectors and specific applications are generated.

It is therefore important to try to observe and measure such a dynamic of knowledge recombination or co-invention between the existing industrial technologies in a given sector and the new ICTs' applications. Measuring these *knowledge recombination* should provide new insights about the dynamics of industrial change that an industry has experienced in the recent past and should help to predict its near future.

Producing such a measure and applying it to the case of the Swiss medical technology sector are the two objectives of this paper. While we started our empirical analysis by using the standard backward citation index, our preliminary findings suggested that this methodology requires major revisions and improvements (in short first stage count of citations - even if improved with a weighted count of the second stage citation - does not allow to capture the full process of recombination between the traditional knowledge base and the new ICTs). Because of the need for a major improvement of the measurement tools, this paper turned out to be more "methodological" than expected – meaning that the building of a new measurement approach is an important result of this paper, as important as the empirical findings about the industry considered.

In the next section, we explain our choice to analyze the medical technology industry in Switzerland. The next two sections overview the literature on patent citations to measure knowledge flows and the cumulativeness of innovation. Section 4th presents the data set. Section 5th exposes our initial findings (based on the standard backward citation index) and discuss them. In section 6th we show in a qualitative manner why the standard method is not satisfactory and fails to capture most of the recombinant effects. Section 7th and 8th present our new method as well as an application. In conclusion we discuss these findings and put our work in perspective.

The economics of innovation in medical technologies and the case of Switzerland

Medical device innovations are characterized by interesting features which make them a good case to study and measure the process of knowledge recombination and cumulativeness. As Rosenberg et al (1995) observed, medical device innovations do not depend heavily on the exploitation of basic knowledge generated upstream in medical schools but rely on the transfer of capabilities already generated outside of the medical sector and indeed more commonly generated in the industrial world rather than in the academic world. So medical device innovations are not only inherently interdisciplinary but also outward-looking by nature. This first feature points the centrality of transfer into medicine of advance in electronics, optics, computers or material sciences. This has an important implication for the timing of innovation. For example, the realization of the first endoscope, which had been conceptualized already in the Middle Age – had to await advances in areas of science and technology over which the medical profession had little to no control. Some innovations which were "intellectually ready" did not emerge because of the slowness of the technical knowledge. From this feature one can expect typical phenomena of development blocks and sequence of complementarities. We know also instances where the need to accelerate the timing forced the medical community to take the lead for solving manufacturing problems. This was the case for fiber optics: the major innovation not only came into the world through medical instrumentations but the medical world itself made significant contributions to the advancement of that technology.

Medical device innovation represents therefore a domain in which the process of knowledge integration and recombination between the traditional knowledge base of the sector and new technologies coming from outside have played a central role in the generation of technological change and innovation.

Studying the dynamics of medical device innovation in Switzerland is motivated by the fact that the Swiss medical technology industry is a tremendous success, as documented in many books[1]. By any measure (number of firms, employment, added value, number of global innovators, export performance), this industry stands in a very high position and presents itself as a strong knowledge-driven industry involving several global leaders. It is also a very innovative activity characterized by a high density of inventors and innovators as well as a high degree of innovativeness of the main customers which are medical schools and hospitals.

Patent citations: the measure

A patent is a legal document that offers exclusive rights to the owner and to the inventors in exchange of the public disclosure of the invention. In order to prove the novelty and non-obviousness of any invention, this must be compared with the previous existing knowledge. The applicant before, and the examiner after list the existing literature (patent and non-patent literature) in order to have a benchmark to judge the effective novelty of the invention. The existing literature has been called in literature 'backward citations'.

So far, the most common method to calculate patent backward citations was simply to count the number of prior patents. For any focal patent, the references are counted. But there are many options that can be added to this simple count.

In Patstat, it is possible to differentiate between patent and non-patent literature. Non patent literature includes articles, papers, academic works, and presentations, everything that is not a patent. For each patent citation all the usual information can be added, like priority year, or the authority where the patent application was filed or technological classification. The technological classification is a hierarchical system codification named 'International patent classification code' or simply 'IPC'. It provides the technological area correspondent to the new invention. It has entered in enforcement in 1971 after the Strasbourg agreement and since then, it has always kept updated. An IPC code is composed by a mix of letters and numbers. The first position of the code is always a letter and identifies the section. Following, there are numbers and letters that explain more in detail the technological class to which the invention belongs. Technically these subsequent numbers are defined as class (letter of the session plus two digits), subclass (a class plus a letter), and group (a

[1] - See for instance "Der diskrete Marsch der Schweizer Medizintechnik an die Weltspitze", in R.Breiding and G.Schwarz, *Wirtschaftswunder Schweiz*, Verlag NZZ, 2011

subclass plus two digits). The IPC divides technology into eight sections with approximately 70,000 subdivisions. Moreover, since the 2013 a new classification has been added. It is based on the industrial sectors and it is called 'TECHNICAL FIELD'[2]. The aim is to provide a unique classification in order to enable country comparison and try to translate technological classes in industrial sectors. There is a total of 35 sectors.

Again since 2013, it is also possible to identify the origin of the citations. Citations could come from the examiner or from the applicant. This information helps to capture more accurately the cumulativeness of knowledge because it becomes possible to distinguish between the knowledge which was really known by the inventor (the applicant) from the one added by the patent examiner for a legal purpose, and that can be unascertained by the applicant of the patent (Alcacer, J., & Gittelman, M. (2006), Criscuolo, P., & Verspagen, B. (2008)).

But above the selection of the different variables requested for a specific analysis, 'a thorough understanding of patenting practice is needed in order to interpret patent citations data properly' (Meyer, (2000)). There are many differences between patent authorities that should be taken into account to develop a correct patent analysis. The major one is the content of the search report of Europe versus US patent office. The search report is the document written by the patent examiner that includes among other information, the technological classification, the approval of the claims and the missing references to prior art. In US the two thirds of the total citation is added by the examiner (Alcacer, J., Gittelman, M., & Sampat, B. (2009)) while EPO colleagues include less of them. Also the average citations count per patent changes between the two patent offices. The result is that the same measure computed from two different data sources can lead to very different results (Bakker, Varhoeven, Van Looy (2014)).

The last point to be taken into account should be the level of analysis. Many analysis are limited to the patent level, counting the number of backward citations for each focal patent. Others prefer to look at the families. There are two types of family: DOCDB and INPADOC. The DOCDB family groups all the patents who share the same priority date. In other words all those patents who are exactly the same invention filed in different patent authorities. The INPADOC family instead has a less stringent definition and includes patents that are still protecting the same invention but they can also have different priority application (Dernis, H., & Khan, M. (2004)). In this situation the count of citations can be again different: one could count the total number of citations of the entire family, or otherwise, in order to eliminate the risk of bias create by large patent families, the count will not be any more at the level of application but at the family cited.

Literature on multistage citations

The literature on patent citations includes also few works which are concerned with the possibility that knowledge spillovers and knowledge flow could not be accurately captured by looking only at the first stage of backward citations. These authors believe that important technological relations are embedded in the connection between the focal invention and its 'parents', and that this phenomenon can be captured with patent citations, but that is something more complicated than a simple count.

[2] Schmoch, U. (2008). Concept of a technology classification for country comparisons. Final Report to the World Intellectial Property Office (WIPO), Karslruhe: Fraunhofer ISI.

To identify the technological impact of a patent on another one Trajtenberg et al. (1997) add to the original count of citations a weighted count[3] of the second stage citations (in other words, the citations of the patents cited by the focal patent). In this way he wants to capture the technological impact of all the previous knowledge on a specific patent. Very often patents citations are used as proxy for the value of a patent. With this aim Von Wartburg at al. (2005) creates the network of citations. They look not only at the direct ties of the network (in other words the usual backward citations) but also at second stage. Specifically they used 'the probability weighted direct Freeman out-degree times the probability weighted direct Freeman out-degrees of the cited patents'. Han and Park (2006) propose a new method to measure knowledge flow between industries. Using patent data and citations data, they build two matrixes: the first one represents the amount of knowledge belonging to an industry and the second one the degree of interaction between industries. Therefore the knowledge flows are represented as the product of the two matrixes. They show that IT-based sector turned out to be the most active actor in the network of knowledge flows. IT both spreads and absorbs knowledge to and from other sectors. The authors also show the intense link between IT-based sector and more traditional ones as manufacturing.

In short the literature developing multistage citations methods suggests that knowledge relations and flows can be traced more properly and precisely while looking not only at the count of the first patent citations.

The data

We are using patent data extracted from the version of December 2014 of Patstat. We retrieve all the patents belonging to a Suisse applicant or a Suisse inventor, applied in the patent office of Switzerland, EPO, WIPO and US.

Medical device is anyway a very complex sector. A Medical device can be the bed of the hospital but also a surgeon robot, or prosthesis or a tube for endoscopy. All these inventions have clearly different knowledge bases. Given such a huge heterogeneity, we decided to focus our work on a subgroup of medical devices. The homogeneity of the sample is important because firms belonging to the same sector are experiencing very similar industrial activities and so their knowledge should be similar (Nieto and Quevedo 2005).

We decided to focus on the orthopedics medical devices, because of the history of Medical device sector in Switzerland. It has been shown by many reports (Swissmedic 2014) that the specializations in precision mechanics and watches have led the Medical firms to develop orthopedics instruments. The identification of the 'orthopedics' technological codes has been conducted searching for keywords suggested by one of our expert, inside at the definition of each International patent classification code (IPC). We identify 58 IPC codes. This leads to a sample of 9300 patents from 1980 till 2013. In all the results we propose we have converted the IPC to TECHNICAL_FIELD in order to have them more readable.

Initial findings: ICT entered medical technologies at a glacial pace

We calculate all the possible variation of the backward citations used in literature so far. Initially we computed the simple count of backward citations made by medical device patents, divided by application authority, the office where the application of the patent was filed.

[3] The weight is fixed and equal to 0.5

Figure 1 about here

Figure 2 about here

Figure 3 about here

Figure 4 about here

These initial results were very surprising. We were expecting to find a quite high percentage of ICT technologies as anecdotal evidence, interviews of experts as well as previous cases studies showed. One central highlight from these various informative sources is the centrality of ICT integration as an engine for innovation and technological change in the medical device sector during the last 10 years[4]. However the figures above show that backward citations to ICT are very scarce. This share never overcomes the 3,5% a part in very few years that appear to be not relevant. The figures show also that in many years there were 0 citations to ICT even in the historical years of great impetus of the IC technologies. For example in figure 3 there are no citation to any ICTs in 1992.

To explore further these puzzling findings we thought to calculate the backward citations index by family. There are many papers that discuss which of the two families is better to use (Bakker, Varhoeven, Van Looy (2014). This is not the aim of this paper so we propose the two.

Figure 5 about here

Figure 6 about here

In these cases the results are even "worst". The share of backward citations of medical patents to ICT do not overcome the 1,8%. We decided at last to use the new variable added to Patstat one year ago: the citations origin. We take only those citations that were referenced by the applicants.

Figure 7 about here

Also in this case the result does not change. A part from a 4.2% in 1988, the share of citations remains incredibly low. In order to figure out the effect we were expecting, we show the share of citations to pharmaceutical and mechanical inventions.

Figure 8 about here

Table 1

The pharmaceutics citations, even if they do not show a precise trend, are always present at a high level; displaying an average of 18% over the period while the mechanical citations shows an average of 4% that don't seem impressive but if compared with ICT, is definitely higher. In Table 1 we rank the top ten most cited technologies by medical devices patents. We see that the innovativeness of the medical device sector seems to rely very much on "traditional connections" with sectors like Mechanics, Chemistry and Pharma.

Based on these findings, one could conclude that the potential of this industry to regenerate through the integration of new ICT's applications is very low. However, such results are inconsistent with what experts and case studies suggest. We decided therefore to look at a few patents more in detail and we selected carefully those medical device patents that seem to be very much ICT's intensive just by reading the technology description.

Qualitative overview of the problem

In order to better understand our results we selected randomly 10 patents within our sample and we analyze their content, the technologies used and the backward citations. Let's take as an example the EPO patent titled 'Surgical cassette'[5] (see Graphic 1).

This patent is classified as a medical device (techn_field_number for medical device is 13) but in the abstract it is clearly stated that it contains 'Radio frequency identification…and pressure sensors, having a mean for automatically identifying unique information specific to an individual cassette which may affect operation of the surgical system…'

We expected to find at least two citations to ICT technologies. When we looked at the backward citations we found 8 patents which are related to the main patent through a backward citation. No one of them relates to another technology than medical technology. Just three out of the 8 patents have multiple IPCs – that is to say they combine the medical device IPC with another IPC (see the three patents in colour at level 1). One of the three combines the medical device IPC with two other IPCs: F04B43/12 defined as 'Machine, pumps having flexible working members having peristaltic action *[Mechanical elements]'* and F04B49/02 defined as 'Control for machine pumps (stopping, starting, unloading) *[Mechanical elements]'.* The second patent combines the medical device IPC with G02B23/24 defined as 'Fiberscope, instruments for viewing inside of hollow bodies *[Optics]'.* The third patent combines the medical device IPC with G06K 7/10:' Methods or arrangements for sensing record carriers by electromagnetic radiation, e.g. optical sensing; by corpuscular radiation *[Computer technology]'*

Surprisingly only one of the four "other" IPCs is related to ICT. Reading more in detail the definitions of the IPC cited, what we notice is that ICTs should be also present in the other three IPCs (such as sensors to control machine pumps or audiovisual technologies to develop fiberscopy).

We decided to look more in detail at the three patents which exhibit a combination of different technologies in their classification. When we looked at the backward citations of these three patents (level 2 on the graph 1 corresponding to the second stage of backward citations) we found that the technological classifications of these patents explain incredibly well the focal Medical device innovation (the surgical cassette). In fact we have patents that identify drugs based on the barcode, or devices for conversion from a pharmaceutical identification number to a standardized number, or peristaltic pump having means for reducing flow pulsation.

When we looked at the other patent selected, the situation just described repeated itself. Consequently we state that the problem in calculating backward citation in ICT is twofold:

1) When the backward citations approach is reduced to 'first stage' or direct ties observations, then a large part of the external knowledge that explains the new invention and comes from the second stage remains unobserved.

[5] EP1787606A1

2) As a process of knowledge cumulativeness develops, the knowledge used and absorbed at the initial steps become invisible. It does not disappear as a substance but it becomes invisible.

The new method - 1: the measure of the speed of adoption

The new approach is based on the concept of speed of adoption. Our hypothesis is the following: the faster the speed of adoption, the faster the new technology becomes common knowledge and is made invisible in terms of backward citations. From the backward citations point of view, this phenomenon leads to an underestimation of the knowledge recombination and integration between the technologies of the traditional sector and the new technologies which are rapidly adopted. In fact, if a new technology is rapidly diffused in a specific sector, it will be massively included in the references of the first patents citing this technology. This will lead to think to this innovation as 'given' and it will not be needed to cite it anymore in the following inventions. One exaggeration of this assumption could be: for how long do you have to cite the wheel when you invent new cars? There are technologies that are part of the common knowledge nowadays and that are not cited anymore. We want to understand how the speed of adoption of a given new technology may influence the measure of knowledge recombination (including this new technology) using backward citations.

To calculate the speed of adoption, it is necessary to calculate the rate of adoption. It is the percentage of firms that, at a certain point in time, decide to adopt a new technology over the total number of firms present in that moment on the market.

So speed of adoption and rate of adoption will be calculated as:

$$(1)\quad SpeedAdoption_{z,t} = \frac{RA_{z,t}}{t_z(t_1 \dots T)}$$

$$(2)\quad Rate\ adoption_{z,t} = \left(\frac{N_{CA,z,t}}{N_{PA,z,t}}\right)$$

Where t is the year of the birth of a new technology, z is the technology, $N_{CA,z,t}$ is the number of firms adopting the new technology z , $N_{PA,t,z}$ is the number of potential firms adopting the new technology z and finally $t_z(t_1 \dots T)$ is the time occurring from the moment in which the new technology is available since the moment when it was adopted. The explanation of speed of adoption is very similar to the classic formula of the speed that expresses the amount of space treaded in a certain amount of time. So the higher speed of a technology in the respect of another one indicates the fact that this technology spreads faster than another one.

Starting from the concept of speed of adoption we develop a specific measure. We use both the standard IPC classification and the sector classification (technology field). The technology z is identified as the combination of the first 4 digits of the IPC, the time t is the priority date of the birth of the invention (priority date). $N_{CA,t,z}$ is the number of sectors adopting the new technology z and has been calculated as the number of cumulative distinct sectors who cite (backward) the technology z at time t. $N_{PA,t,z}$, the number of potential sectors adopting the new technology z at time t has been calculated as the total number of distinct sectors that are present on the market at time of the invention t, so it is fixed at 35 . We decide to take a fixed number of potential sectors because in this way the 'distance to walk' will be the same for all the technologies and the different results will be comparable. Finally $t_z(t_1 \dots T)$, the time occurring from the moment in which the new technology is available since the moment when it was adopted is calculated as the lag of time between the priority date of the invention and the date of the patent that cites the invention. The calculation has been computed by two different application authorities, US and EPO. We got a random sample of patents, without caring about specific country of origin, in order to have a sample as heterogeneous as possible. We choose 100 patents for each IPC (4 digits). The total amount of patents is 104963 for EPO and 125789 for US. Then we look at the citations received by these patents up to this moment in time (2015). The aim of this exercise is to look, for each invention its technology, how many sectors the invention was able to touch and in how much time. Then we compute an average speed of adoption per year, in order to see if a particular technology has changed its speed of adoption over time.

The results show that, over time, the speed of adoption of different technologies remains quite constant. In order to make the results more readable, we have translated the IPC into the sector classification, but only with the aim to understand which kind of technologies are represented by the IPC codes. The analysis was conducted using IPC codes at the level of single patent, so single invention. Some technologies have a slightly increasing trend over time as for example the technologies related with Environmental technology, or Nanotechnologies, or basic communication process, or other special machines or Pharmaceuticals. Other technologies show a decreasing speed of adoption, like the ones related with Food chemistry or Machine tools, or Measurements. The technologies related with telecommunication inventions represent an exception for what concerns the constancy of the trend over time: they reach a peak in 2002, increasing of 6 times its usual speed. The differences in the speed of adoption among the different technologies can be also quite big. In Table 2 we report the list of the 35 technologies in order of decreasing speed of adoption. We see that the fastest technologies to be adopted are the ones in nanotechnology and computer science, followed by surface technologies and audio visual technology. In the top 10 fastest technologies we find three of the four technologies that we have defined before as ICT. The difference in the value of speed between different technologies can go very big, like in the case of electrical machinery and computer science, or so small that taken alone is difficult to interpret. For this reason we went more into detail with the analysis. In Table 3 we show, for each category of technologies, the average time after which a patent is not cited anymore. All the patents in our sample, by construction, have received citations by some other subsequent patents. In this table we show after how much time the patents are not cited anymore. This variable has been calculated as the difference between the year of the last citation (priority year of the patent citing the patent in our sample) minus the year of the priority date of the focal patent. Not surprisingly, the technologies that disappear sooner are the ones that have a higher speed of adoption. So patents in technologies like nanotechnologies and computer science are the fastest to be adopted and the fasted to disappear from the citations. But are they also the technologies that are able to reach the large amount of other sectors? Table 4 we see that it is like that. Again, an invention in nanotechnologies is able to been absorbed by, on average, 5 other sectors while an innovation in Computer technologies is able to reach 4 other sectors. These results suggest us that the technologies do not behave all in the same way that interact with other sector with a different intensity and especially a different speed. As consequence, knowledge spillovers of different technologies cannot be expressed in their totality using backward citations of patent data. Some sector as ICT and Micro-structural and nano-technologies are so fast in been adopted by other sectors that they could also disappear very fast from the history of the prior art. Based on the qualitative and quantitative evidence presented so far and on the previous literature, we propose a new method to calculate backward citations.

The new method – 2 : application

Coming back to the example of the surgical cassette, we found that just three of the cited patents have a medical technology IPC combined with some other technology. Thus we looked at the entire sample of medical device innovation in Switzerland to calculate how many patents have the same structure. We find 2795 patents that have a combined IPC, so around the 30% of the total patents. When we look inside the backward citations of the sample we find that the total number of backward citations is 33735 of which 5470 are patents with a combined IPC, 9040 are patents that belong entirely to another field and the remaining 19225 are medical technology patents. When we look at the origin of the 9040 patents that belong to another field we find that in 84% of the cases these citations are made by medical technology patents with a combined IPC. Just in the 16% of the cases a pure medical technology patent cites a patent of another field.

So we can differentiate two cases: the first one is when the focal patent is a pure medical technology invention (all its IPC are medical technology). The second one is when a focal patent has a combined IPC, so it has medical technology IPC combined with some IPC of other sectors. Usually in the works using patent data the level of analysis is the application itself or the priority year, when the evolution of a field or a technology is under investigation. This second is our case, since we wanted to study the recombination of ICT with medical technology. For each year we have a set of patents that where filed in that year and that can be pure MedTech or MedTech combined with other technologies. When we find this second case we proceed to the normal calculation of the backward citation measure. The novelty of our method relies on the treatment of those patents that are pure medical technology (as the surgical cassette proposed in the example). In those cases we calculate the first stage of backward citations as usual and we add to them a second stage of backward citations, weighted by the size of their family in order to minimize the effect of big families. So if a cited patent belongs to a family with 10 patents, its weight will be 0.1. The total number of backward citations will be calculated as:

$$
\begin{aligned}
&Total\ backward\ citations\ patent_i to\ technology_z \\
&= \sum \Big(\sum backward\ citation\ of\ patents\ with\ 'pure'\ IPC \\
&+ \sum weighted\ by\ family\ size\ 2nd\ stage\ backwars\ citations\ of\ patent\ with\ a\ combo\ IPC \Big)
\end{aligned}
$$

The new results are strongly different from the previous ones, even if just the 30% of medical device patent had a combined IPC and so just these 30% was undergone to the new method.

Figure 9 about here

Figure 10 about here

Figure 11 about here

Figure 12 about here

The first thing that it is observable is that the trend of the curves is continuous and not interrupted as before. Some of the technology that composed the big group of ICT, like 'Basic communication process' and 'Digital communication' remain still low, and this makes sense due to the sector we are looking at, but they are anyway present and constant. In all the four graphs we can recognize some picks especially for what concerns ‘Computer technology’. Not surprisingly these picks are localized at the end of the ‘80s and at the middle of the ‘90s. In the EPO subsample there is an increasing of the backward citations to ‘Computer technology’ till almost 10% and the average over time is about 5%. The USPTO patents show a particular interest to the ‘Audio visual technology’, having an average over time of the 4%. It has to be notice that these results are not raising impressively the amount of backward citations to ICT, compared to other technology cited. For example Mechanics and Chemistry remain with the higher percentage, as it should be, since we decide to analyze the Orthopedics medical device sector. These new results have the only aim to show that there is a new, not negligible help from the ICT technologies in Medical devices. If we had stopped at the results based on the classic measure of backward citations, we would have concluded that Medical device sector is still a very traditional field, still based on its classic knowledge. While looking at these new graph we can say that Medical device is taking advantage of the new technologies coming out from other sectors, even if very distant, in terms of final products, by it.

A last point to be discussed is related to the number of different stages to compute to get the complete information on knowledge spillovers. Even if the previous literature focuses only to the second stage of citations we try also the following, in order to understand if it was correct to stop at the second stage, or if the flowing would have add important information. In Table 2 we report the result of the first three stages of the patent taken as example, the surgical cassette.[6]

Table 5 about here

We can see how the second stage citations capture perfectly the real nature of the invention. The share of citations to Computer technology rises from 5.5% till 13%. Also the percentage of Engines and pumps rises of 4 points. Another important change is the slight decrease of Optics in favor of the adjunction of new technologies like ‘Audio visual technologies’, ‘Measurement’ and ‘Controls’ that describe perfectly the invention but that where not present in the first stage citations. There is an addition of four others technologies cited, with a very low percentage: Basic materials, Machine tools and Mechanical elements. Of these three technologies, all of them are actually the top 10 technologies cited by Medtech, so in any case they go to reinforce a trend that was already very clear, and they cannot to be considered as not noise.

The third stage adds an incredible amount of other technologies with a general decrease of the share of all the technologies. We think that the third stage, if taken into account, would not even add noise because the citations are spread over 22 technologies and, considering that they would have been weighted even more strongly than the one at the first stage, their effect would disappear completely.

Conclusion

The importance of knowledge spillovers for the economic growth of a sector or a country is universally recognized. The way in which the knowledge spillovers can be measured has been a hot topic in the economic literature. In the past 20 years a big role in the attempt to answer to this

[6] The three stages are not weighted in Table 1

question has been played by the patent data. From Hall et al.(2001) the calculation of the patent backward citations has been the most popular way to capture the displacements of knowledge

The aim of this work is to analyze in deep this measure in order to understand if it works to all the technologies. To do that, we calculate the speed of adoption for each technology

The results show how the speed of adoption of a technology influences the measure of knowledge spillovers using backward citations. We make a comparison between the original measure of backward citations and a new one, inspired by the different behavior of the technologies in terms of speed of adoption. We conduct both a qualitative and a quantitative analysis on a sample of Medical device patents. We argue that those technologies that have a higher speed of adoption are easier to understand and use and for this reason, they disappear faster from the list of references in the patents legal data. We calculate the speed of adoption of each technology, the time after which the technology has not cited anymore and the amount of sector that each technology is able to reach to be absorbed. The results show that the technologies with a higher speed are also the ones with a higher capability to be adopted by different sectors and the ones that disappear first from the list of patents backward citations. Our belief is that this brings to the difficulty to trace knowledge correctly spillovers from 'fastest' technology like ICT or Nanotechnologies.

We propose a modification of the original measure of backward citations that meet this new finding. It is based on the calculation of the weighed second degree of backward citations only for those patents that have an IPC combined. A patent with an IPC combined is a patent with IPC that belong to different sectors. We show that more than the 80% of backward citations to another sector comes from this typology of patents. When we add the second degree of backward citations to the first one we see how the percentage of the core technologies persists, with an addition of the technologies that before were invisible but that are components of the invention.

There are many possible improvements related with this work. For example it would be interesting to study the speed at which a technology reach a certain fixed number of sectors, to understand the possibility of recombination of a specific sector. This new measure offers the possibility to see new emerging stream of recombination of technology inside a sector that otherwise would remain too difficult to read.

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REFERENCES

Agrawal, A., & Henderson, R. (2002). Putting patents in context: Exploring knowledge transfer from MIT. Management Science, 48(1), 44-60.

Alcacer, J., & Gittelman, M. (2006). Patent citations as a measure of knowledge flows: The influence of examiner citations. The Review of Economics and Statistics, 88(4), 774-779.

Alcacer, J., Gittelman, M., & Sampat, B. (2009). Applicant and examiner citations in US patents: An overview and analysis. Research Policy, 38(2), 415-427.

Almeida, P., & Kogut, B. (1999). Localization of knowledge and the mobility of engineers in regional networks. Management science, 45(7), 905-917.

Audretsch, D. B., & Stephan, P. E. (1996). Company-scientist locational links: The case of biotechnology. The American Economic Review, 641-652.

Balconi, M., Breschi, S., & Lissoni, F. (2004). Networks of inventors and the role of academia: an exploration of Italian patent data. Research Policy, 33(1), 127-145.

Bakker, Varhoeven, Van Looy (2014): 'Patent citation Indicators: One size fits all?' Druid

Batz, F. J., Peters, K. J., & Janssen, W. (1999). The influence of technology characteristics on the rate and speed of adoption. Agricultural Economics, 21(2), 121-130.

Breschi, Stefano, and Francesco Lissoni. (2003)"Mobility and social networks: Localised knowledge spillovers revisited." Milan: University Bocconi, CESPRI Working Paper 142.

Cohen, W. M., Goto, A., Nagata, A., Nelson, R. R., & Walsh, J. P. (2002). R&D spillovers, patents and the incentives to innovate in Japan and the United States. Research policy, 31(8), 1349-1367.

Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: a new perspective on learning and innovation. Administrative science quarterly, 128-152.

Criscuolo, P., & Verspagen, B. (2008). Does it matter where patent citations come from? Inventor vs. examiner citations in European patents. Research Policy, 37(10), 1892-1908.

Dernis, H., & Khan, M. (2004). Triadic patent families methodology.

Fleming, L. (2001). Recombinant uncertainty in technological search. Management science, 47(1), 117-132.

Foray, D. (2015), Smart specialization, Routledge

Foray D. and Frenken K. (2015), Related variety and smart specialization, draft

Griliches, Z. (1957). Hybrid corn: An exploration in the economics of technological change. Econometrica, Journal of the Econometric Society, 501-522.

Griliches, Z. (Ed.). (2007). R&D, patents and productivity. University of Chicago Press.

Hall, Bronwyn H., Adam B. Jaffe, and Manuel Trajtenberg (2001). The NBER patent citation data file: Lessons, insights and methodological tools. No. w8498. National Bureau of Economic Research

Han, Y. J., & Park, Y. (2006). Patent network analysis of inter-industrial knowledge flows: The case of Korea between traditional and emerging industries. World Patent Information, 28(3), 235-247.

Hoisl, K. (2007). Tracing mobile inventors—the causality between inventor mobility and inventor productivity. Research Policy, 36(5), 619-636.

Jaffe, Adam B., Manuel Trajtenberg, and Rebecca Henderson. (1992)Geographic localization of knowledge spillovers as evidenced by patent citations. No. w3993. National Bureau of Economic Research,.

Jaffe, Adam B., Manuel Trajtenberg, and Michael S. Fogarty. (2000) "KNOWLEDGE SPlLLOVERS AND PATENT CITATIONS: EVIDENCE FROM A SURVEY OF lNVENTORS." NBER/Sloan: 21.

Marshall A., 1890: Principles of Economics. Macmillan, London.

Maurseth, P. B., & Verspagen, B. (2002). Knowledge spillovers in Europe: a patent citations analysis. The Scandinavian journal of economics, 104(4), 531-545.

Meyer, M. (2000). What is special about patent citations? Differences between scientific and patent citations. Scientometrics, 49(1), 93-123.

Nieto, M., & Quevedo, P. (2005). Absorptive capacity, technological opportunity, knowledge spillovers, and innovative effort. Technovation, 25(10), 1141-1157.

Pavitt, K. (1985). Patent statistics as indicators of innovative activities: possibilities and problems. Scientometrics, 7(1-2), 77-99.

Richerson, P. J., & Boyd, R. (2008). Not by genes alone: How culture transformed human evolution. University of Chicago Press.

Shapiro, C. (1985). Patent licensing and R & D rivalry. The American Economic Review, 25-30.

Spence, M. (1984). Cost reduction, competition, and industry performance. Econometrica: Journal of the Econometric Society, 101-121.

Strumsky, D., & Lobo, J. (2015). Identifying the sources of technological novelty in the process of invention. Research Policy, 44(8), 1445-1461.

Trajtenberg, M., Henderson, R., & Jaffe, A. (1997). University versus corporate patents: A window on the basicness of invention. Economics of Innovation and new technology, 5(1), 19-50.

Von Wartburg, I., Teichert, T., & Rost, K. (2005). Inventive progress measured by multi-stage patent citation analysis. Research Policy, 34(10), 1591-1607.

Zander, U., & Kogut, B. (1995). Knowledge and the speed of the transfer and imitation of organizational capabilities: An empirical test. Organization science, 6(1), 76-92.

Appendix

Figures

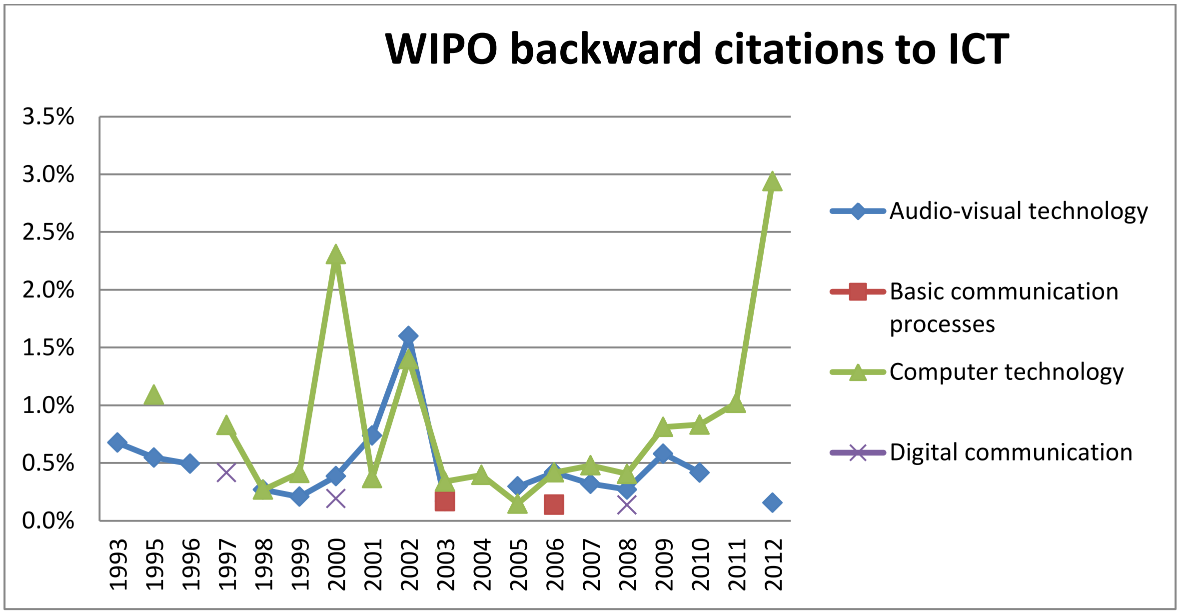


Figure 1: Share of ICT backward citation of Medtech patents filed at WIPO

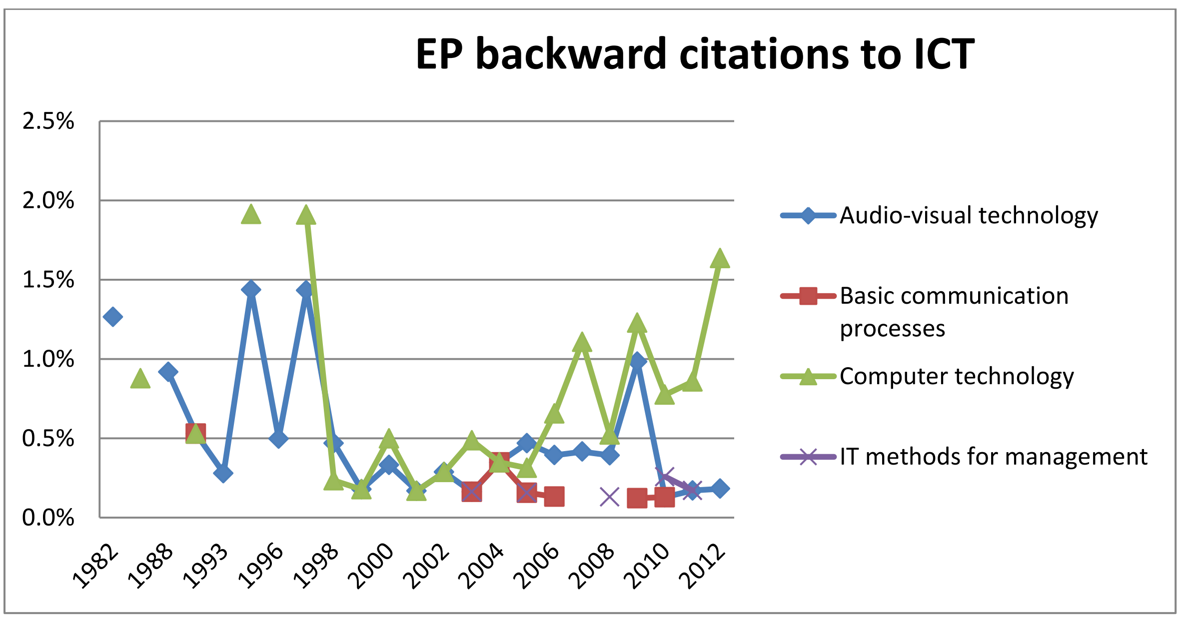


Figure 2: Share of ICT backward citation of Medtech patents filed at EPO

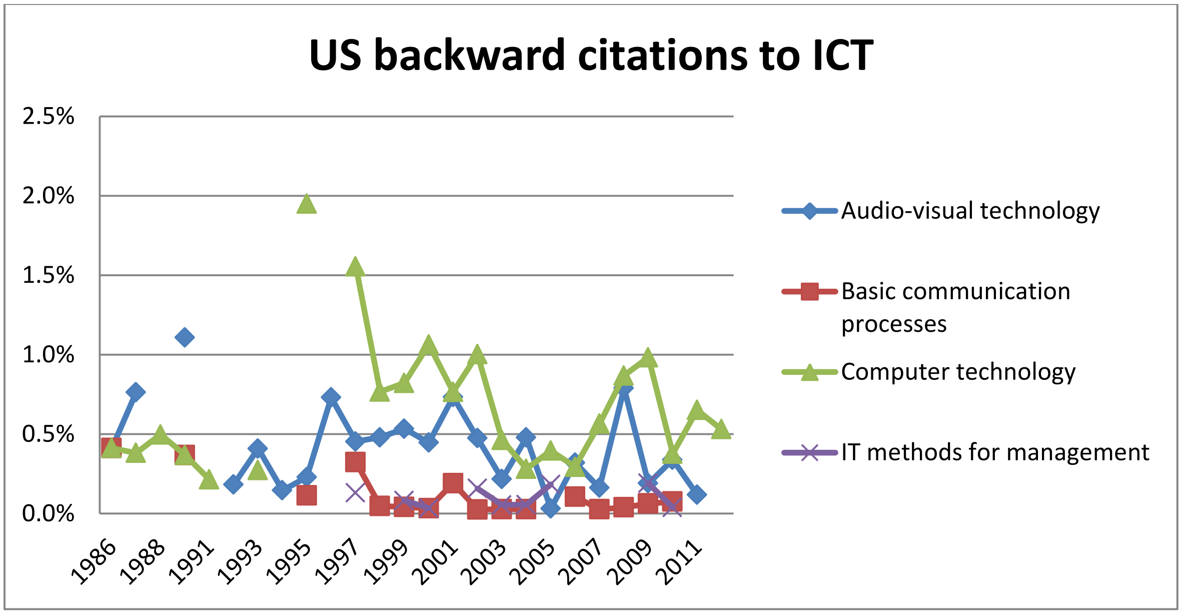


Figure 3: Share of ICT backward citation of Medtech patents filed at US

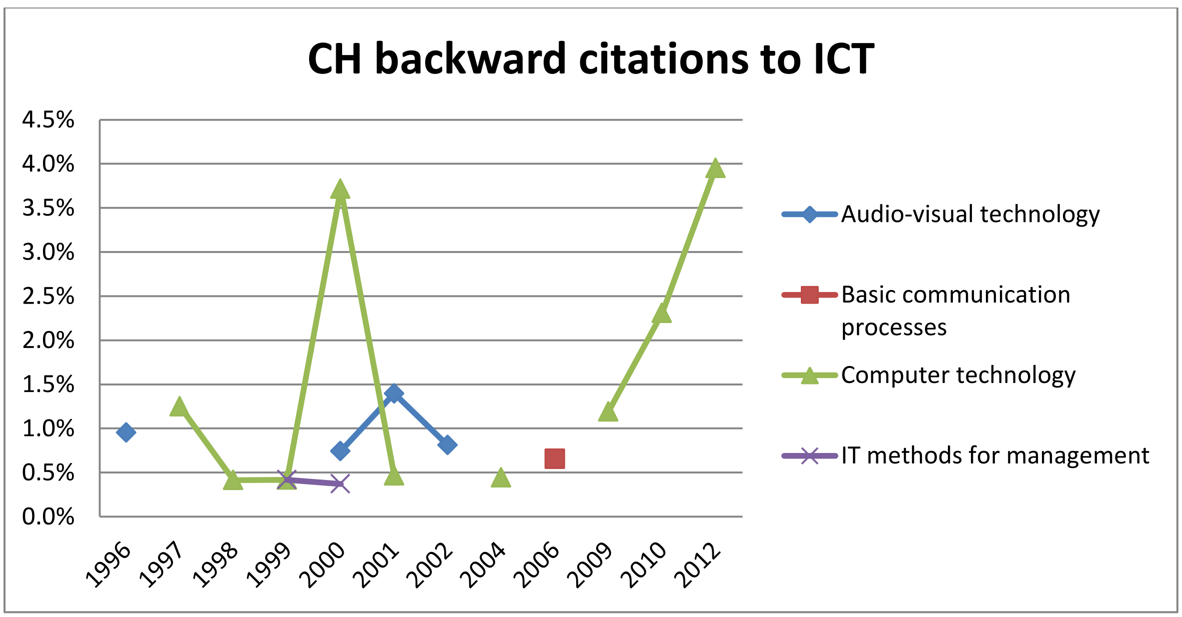


Figure 4: Share of ICT backward citation of Medtech patents filed at Suisse patent office

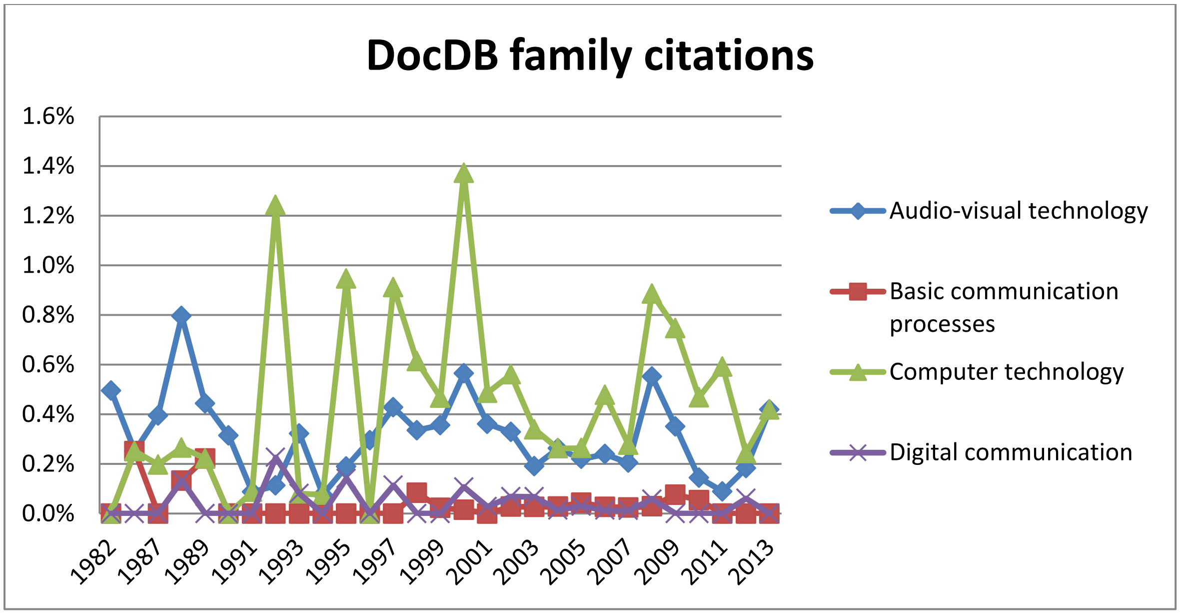


Figure 5: Share of ICT backward citation of DOCDB families of Medtech patents

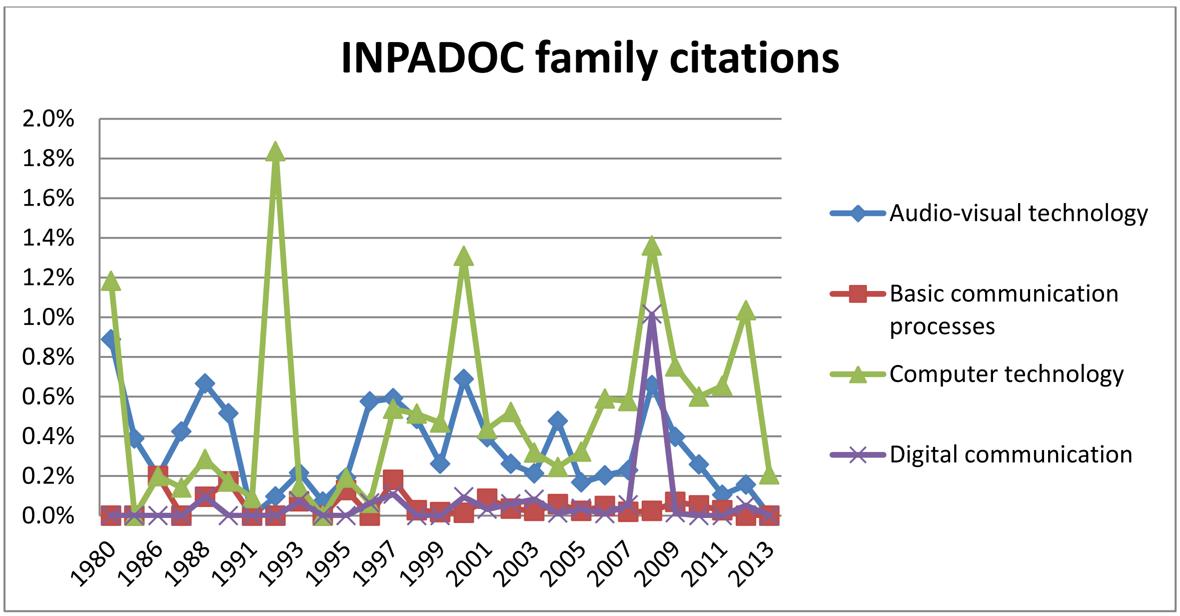


Figure 6: Share of ICT backward citation of DOCDB families of Medtech patents

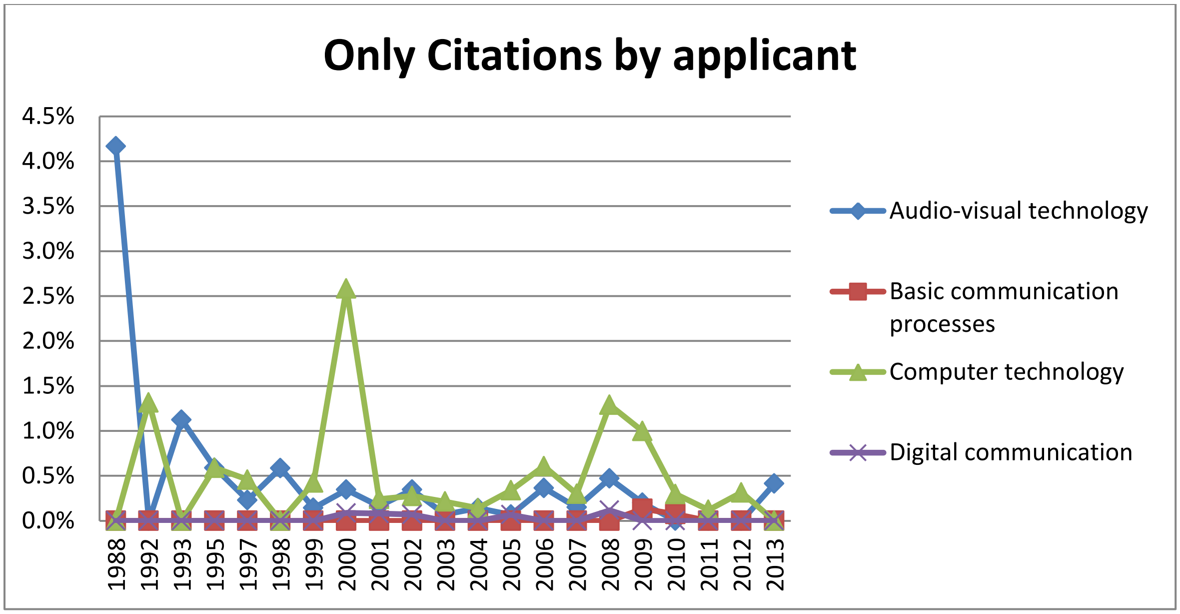


Figure 7: Share of ICT backward citation made by MedTech applicants

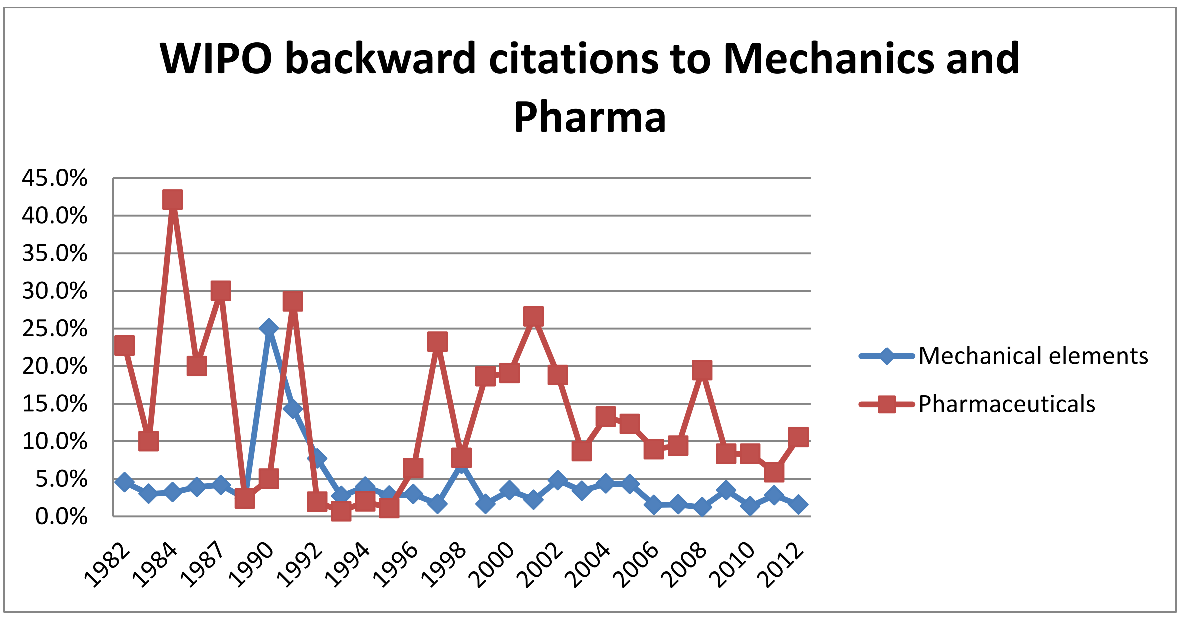


Figure 8: Share of Mechanical and Pharma backward citation made by MedTech applicants

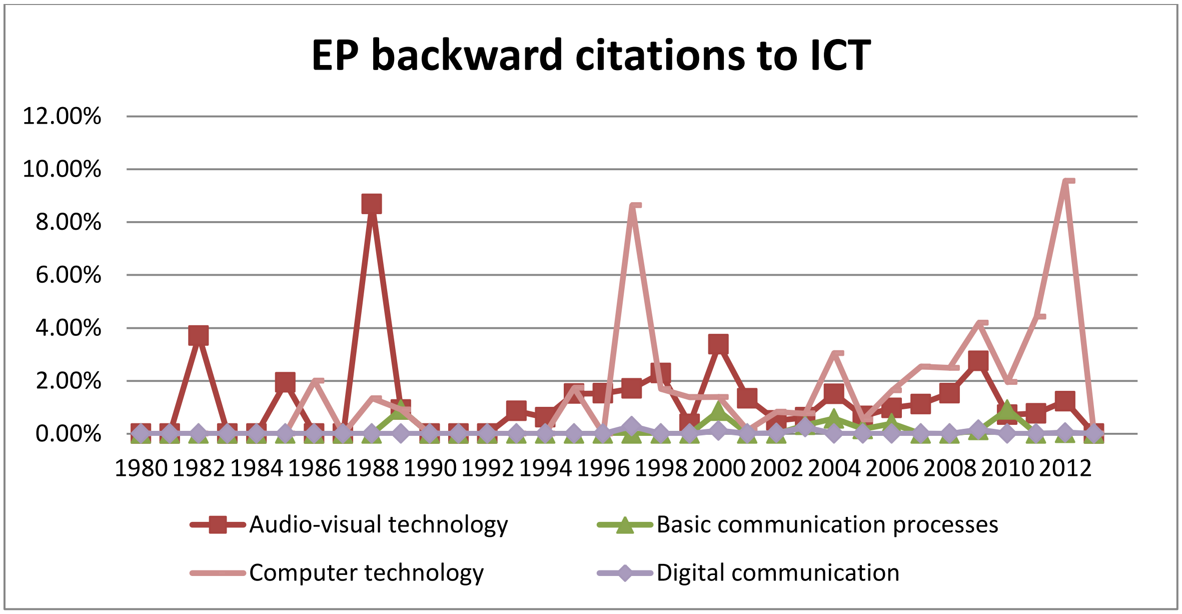


Figure 9: Share of ICT backward citation of Medtech patents filed at EPO: new method

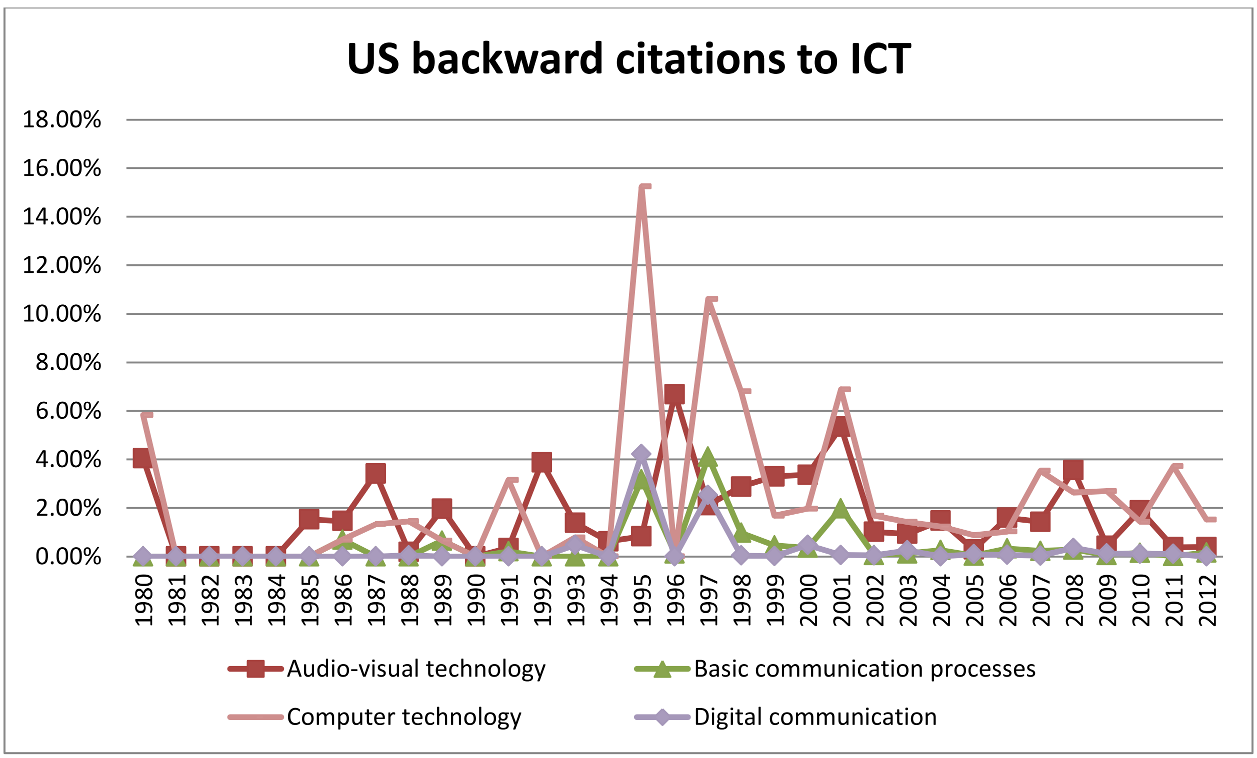


Figure 10: Share of ICT backward citation of Medtech patents filed at US: new method

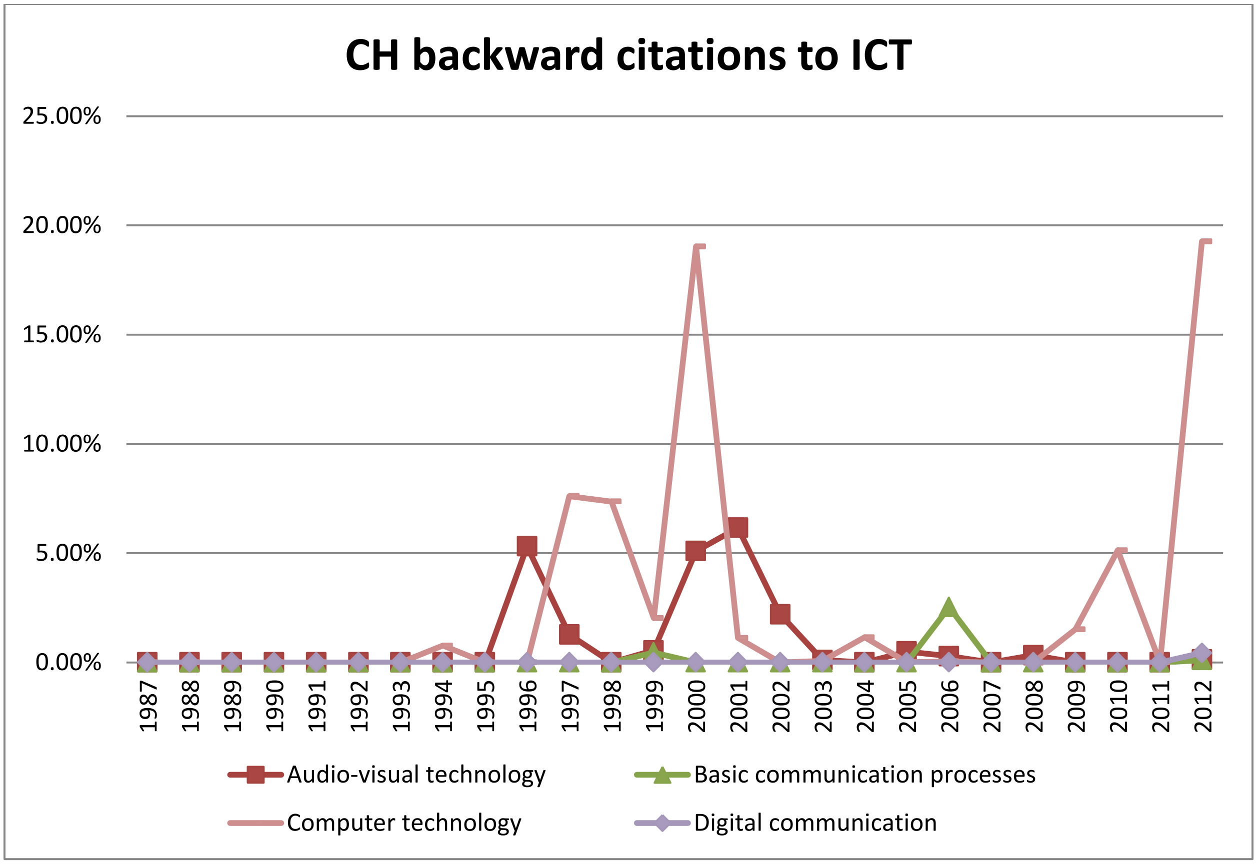


Figure 11: Share of ICT backward citation of Medtech patents filed at CH: new method

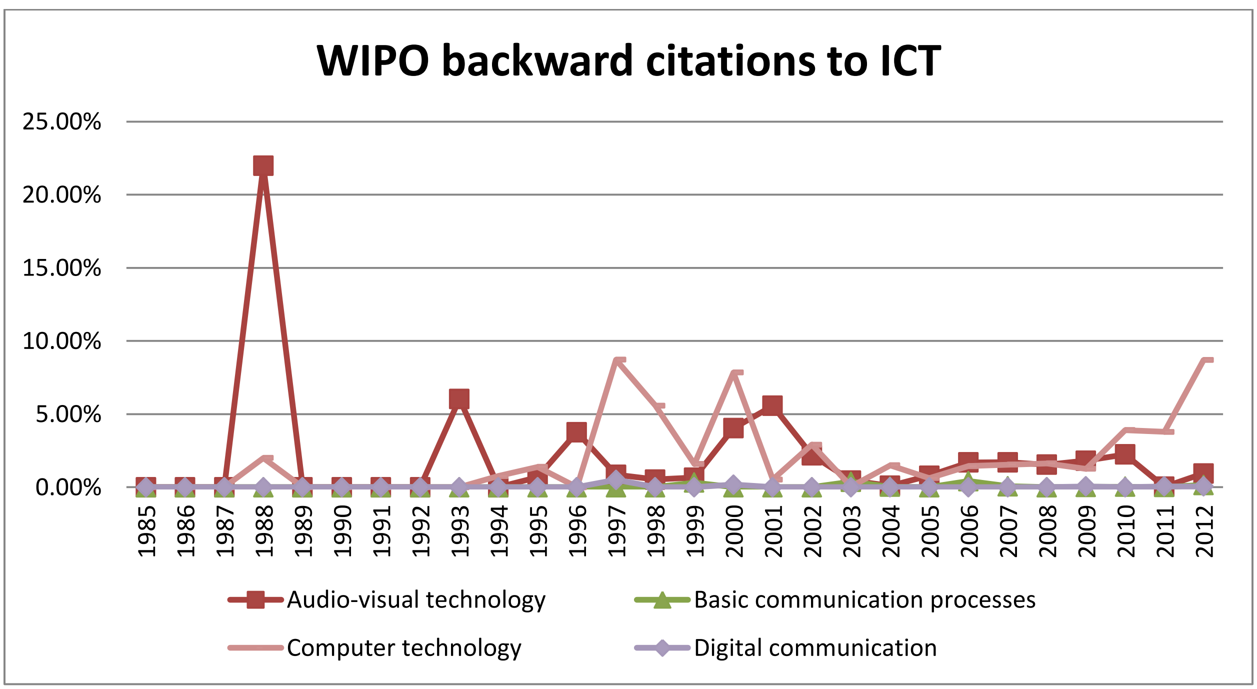


Figure 12: Share of ICT backward citation of Medtech patents filed at WIPO: new method

Tables

Table 1: Top ten technologies cited by Medtech

Top ten cited Technologies	
1	**Pharmaceuticals**
2	**Mechanical elements**
3	**Machine tools**
4	**Other special machines**
5	**Basic materials chemistry**
6	**Materials, metallurgy**
7	**Electrical machinery, apparatus, energy**
8	**Chemical engineering**
9	**Macromolecular chemistry, polymers**
10	**Handling**

Table 2: Absolute Speed of adoption of different technologies

Technologies	Speed of adoption
Micro-structural and nano-technology	3.51278552
Computer technology	3.29454233
Surface technology, coating	3.1737498
Audio-visual technology	2.99461899
Optics	2.95263987
Measurement	2.95142554
Other special machines	2.75183467
Semiconductors	2.69498699
Telecommunications	2.6269757
Control	2.6219856
Chemical engineering	2.56481576
Materials, metallurgy	2.51757247
Other consumer goods	2.45011299
Thermal processes and apparatus	2.44560092
Analysis of biological materials	2.3537335
Environmental technology	2.32940599
IT methods for management	2.30342264
Machine tools	2.27040347
Textile and paper machines	2.23274166
Basic communication processes	2.17644449
Furniture, games	2.15454082
Medical technology	2.15130527

Handling	2.13123476
Macromolecular chemistry, polymers	2.11806198
Civil engineering	2.11774589
Mechanical elements	2.11421272
Transport	2.06314635
Basic materials chemistry	1.87971643
Engines, pumps, turbines	1.82687641
Electrical machinery, apparatus, energy	1.68661383
Digital communication	1.5747299
Biotechnology	1.43882896
Organic fine chemistry	1.40724125
Pharmaceuticals	1.20386883
Food chemistry	0.04770575

Table 3: Average time after which a patent is not cited anymore

avg(time)	techn_field
4.9697	Micro-structural and nano-technology
5.3671	Computer technology
5.6977	Basic communication processes
6.1091	Optics
7.1202	Telecommunications
8.1267	Biotechnology
9.3368	Digital communication
9.3485	Semiconductors
9.5807	Audio-visual technology
10.3462	Measurement
10.3495	Surface technology, coating
10.477	Textile and paper machines
10.5313	Basic materials chemistry
10.566	Organic fine chemistry
10.6859	Other special machines
10.7518	Control
10.8847	Thermal processes and apparatus
11.2423	Mechanical elements
11.2866	Handling
11.2868	Environmental technology
11.2901	Macromolecular chemistry, polymers
11.3465	Chemical engineering
11.3738	Materials, metallurgy
11.43	Other consumer goods
11.4327	Engines, pumps, turbines

11.4358	Machine tools
11.4726	Transport
11.7872	Analysis of biological materials
11.9011	Civil engineering
12.0888	Pharmaceuticals
12.3832	Furniture, games
12.4259	IT methods for management
12.9483	Food chemistry
13.2367	Medical technology
16.7391	Electrical machinery, apparatus, energy

Table 4: Average number of sector reached by any technology

avg(max_num)	techn_field
5.0152	Micro-structural and nano-technology
4.91	Computer technology
3.8328	IT methods for management
3.547	Macromolecular chemistry, polymers
3.2422	Basic materials chemistry
3.2305	Surface technology, coating
3.155	Materials, metallurgy
3.116	Environmental technology
3.1155	Chemical engineering
3.0888	Pharmaceuticals
3.049	Control
2.9167	Biotechnology
2.8918	Measurement
2.8897	Food chemistry
2.7967	Semiconductors
2.7489	Optics
2.6892	Medical technology
2.6827	Audio-visual technology
2.6375	Telecommunications
2.6336	Other consumer goods
2.5842	Digital communication
2.5757	Other special machines
2.5544	Thermal processes and apparatus
2.5535	Organic fine chemistry
2.5322	Textile and paper machines
2.5308	Analysis of biological materials
2.5261	Basic communication processes

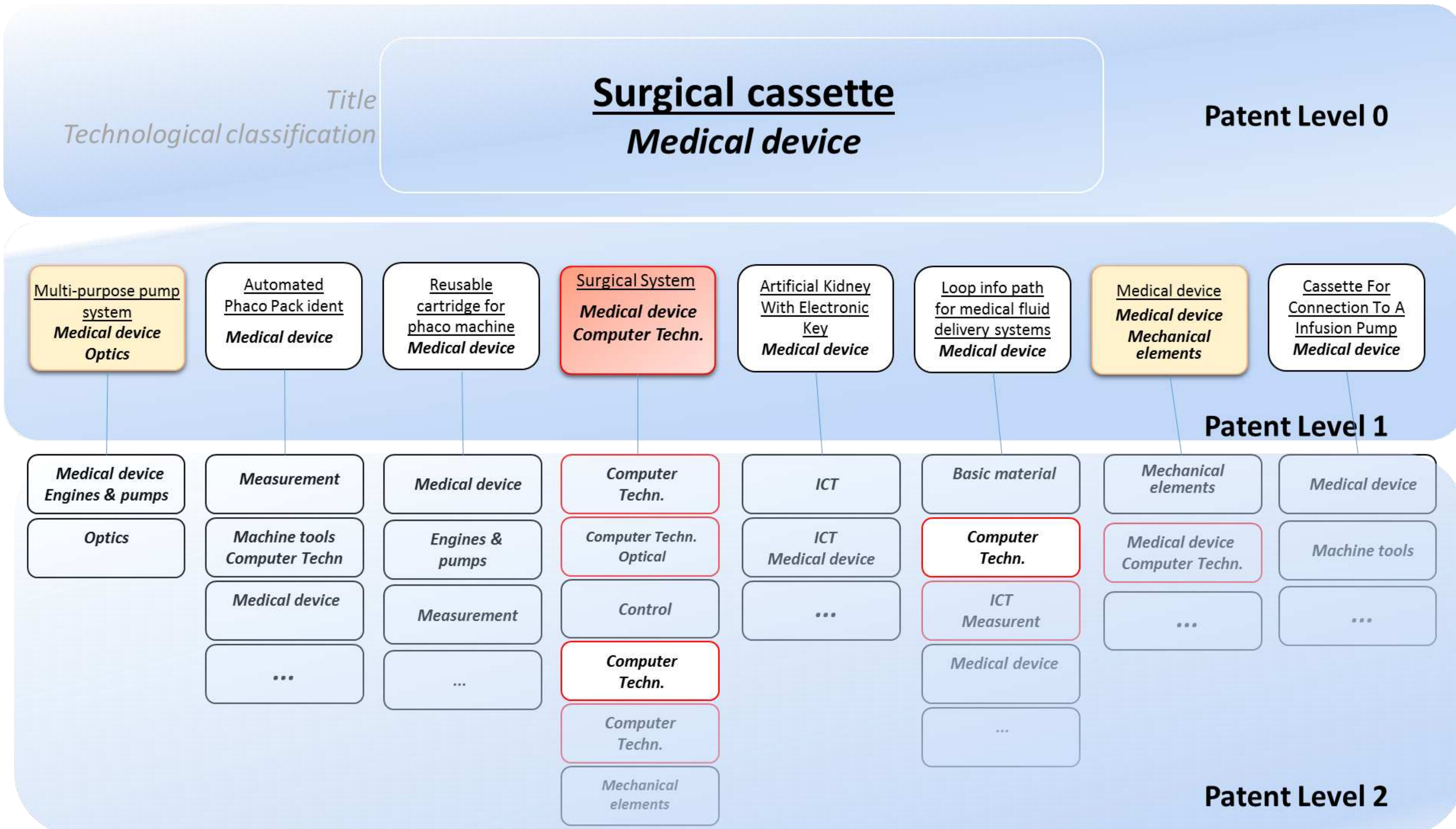
2.5217	Electrical machinery, apparatus, energy
2.4343	Machine tools
2.2934	Mechanical elements
2.2879	Engines, pumps, turbines
2.2859	Furniture, games
2.2083	Handling
2.1462	Transport
2.1365	Civil engineering

Table 5: First three stages of backward citations, Surgical cassette

First stage		Second stage		Third stage	
%	Field	%	Field	%	Field
5.56%	Computer technology	3.77%	Audio-visual tech.	0.23%	Analysis of biological materials
5.56%	Optics	13.21%	Computer tech.	2.53%	Audio-visual technology
83.33%	Medical technology	3.77%	Optics	0.12%	Basic communication processes
5.56%	Engines, pumps, turbines	1.89%	Measurement	0.12%	Basic materials chemistry
		5.66%	Control	0.35%	Biotechnology
		54.72%	Medical tech.	2.42%	Chemical engineering
		1.89%	Basic materials	10.24%	Computer technology
		1.89%	Machine tools	7.25%	Control
		9.43%	Engines, pumps, t.	1.04%	Digital communication
		3.77%	Mechanical elements	0.12%	Electrical machinery, apparatus, energy
				8.77%	Engines, pumps, turbines
				0.23%	Environmental technology
				0.81%	Furniture, games
				4.83%	Handling
				2.19%	IT methods for management
				1.15%	Machine tools
				0.12%	Macromolecular chemistry, polymers
				0.12%	Materials, metallurgy
				4.37%	Measurement
				2.65%	Mechanical elements
				36.82%	Medical technology
				0.58%	Optics

Graphs

Graph1: Qualitative description of the problem: the surgical cassette patent


Title
Technological classification
Surgical cassette
Medical device
Patent Level 0
Multi-purpose pump system
Medical device
Optics
Automated Phaco Pack ident
Medical device
Reusable cartridge for phaco machine
Medical device
Surgical System
Medical device
Computer Techn.
Artificial Kidney With Electronic Key
Medical device
Loop info path for medical fluid delivery systems
Medical device
Medical device
Medical device
Mechanical elements
Cassette For Connection To A Infusion Pump
Medical device
Patent Level 1
Medical device
Engines & pumps
Optics
Measurement
Machine tools
Computer Techn
Medical device
...
Medical device
Engines & pumps
Measurement
...
Computer Techn.
Computer Techn.
Optical
Control
Computer Techn.
Computer Techn.
Mechanical elements
ICT
ICT
Medical device
...
Basic material
Computer Techn.
ICT
Measurent
Medical device
...
Mechanical elements
Medical device
Computer Techn.
...
Medical device
Machine tools
...
Patent Level 2