INVENTION MACHINES: HOW CONTROL INSTRUMENTS AND INFORMATION TECHNOLOGIES DROVE GLOBAL TECHNOLOGICAL PROGRESS OVER A CENTURY OF INVENTION

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Abstract

Inventions depend on skills, experience, and information exchange. Information is shared among individuals and organizations both intentionally and unintentionally. Unintentional flows of knowledge, or knowledge spillovers, are viewed as an integral element of technological progress. However, little is known about the overall patterns of knowledge flows across technology sectors or over long periods of time. This paper explores whether it is possible to identify "invention machines" – technologies that help create new inventions in a wide range of other sectors – and whether shifts in the patterns of knowledge flows can predict future technological change. In the spirit of big data we analyze the entire PatStat database of 90 million published patents from 160 patent offices over a century of invention and exploit variation within and across countries and technology fields over time. The direction and intensity of knowledge spillovers measured from prior-art citations highlight the transition from mechanical to electrical instruments, especially industrial control systems, and the rise of information and communication technologies as "invention machines" after 1970. Most recently, the rapidly increasing impact of digital communications on other fields may herald the emergence of cloud computing and the industrial internet.

Introduction

The history of invention is a history of knowledge spillovers. There is persistent evidence of knowledge flowing from one firm, industry, or sector to another, either by accident or by design, enabling other inventions to be developed (Frischmann & Lemley, 2007; Griliches, 1979; Jaffe, Trajtenberg, & Fogarty, 2000; Jaffe, Trajtenberg, & Henderson, 1993). For example, Thomas Edison's invention of the "electronic indicator" (US patent 307,031: 1884) spurred the development by John Fleming and Lee De Forest in early 20th century of early vacuum tubes which eventually enabled not just long-distance telecommunication but also early computers (e.g., Guarnieri, 2012). Edison, in turn, learned from his contemporaries including Frederick Guthrie (1876). It appears that little of this mutual learning and knowledge exchange was paid for and can thus be called a "spillover", i.e. an unintended flow of valuable knowledge, an example of a positive externality in the terminology of economists.

Breakthrough inventions and their spillovers may generate tremendous waves of technological change. In particular, general-purpose technologies (Bresnahan & Trajtenberg, 1995) such as the vacuum tube or its successor the microprocessor can be utilized in many different compound inventions, cumulatively leading to technological revolutions in the adopting sectors. Moreover, a special class of general-purpose technologies we call invention machines are not only applicable in many other sectors but facilitate invention in those other sectors. Our goal is to identify technologies that have such a broad and catalytic impact by enabling follow-on invention in many application sectors.

In economic terms, general-purpose technologies have been defined as being widely used, capable of sustained technical improvement, and enabling innovation in application sectors (Bresnahan, 2010), although others have not emphasized their innovation-spawning nature (e.g. Hall & Trajtenberg, 2004; Helpman & Trajtenberg, 1998). Innovation in application sectors combined with sustained technical improvement implies that there are dynamic complementarities between the general-purpose and application technologies: the returns to innovation in application technologies are enhanced by improvements in the general-purpose technologies, and vice versa, provided that knowledge spillovers or markets for technology enable such combinatory inventions.

Further, when the invention of general-purpose technologies is associated with fixed costs, there may be vast economies of scale via broad adoption by different application sectors. In such cases the impact of the enhanced innovation opportunities may be unusually long-lasting, in particular, due to the “superadditivity” of invention across sectors and over time: each invention in the general-purpose technology enhances the incentives to invent new applications, and each new application enhances the incentives to improve the general-purpose technology. General-purpose technologies are then capable of generating sustained aggregate growth (Bresnahan, 2010). There are also positive externalities because each inventor is likely to only consider their own inventive returns and not their impact on the inventiveness of other sectors. Such increasing returns to R&D investment are thus unlikely to be fully captured by the inventing organizations, for which reason investment in the development of general-purpose technologies should be of keen interest to policymakers.

Previous empirical studies have analyzed specific technologies such as steam engines (Crafts, 2004), electricity (David, 1990; Moser & Nicholas, 2004), and computers (Bresnahan & Greenstein, 1999) as general-purpose technologies through historical industry analysis. The study closest to ours is Hall and Trajtenberg (2004) who conduct analyses of patent citations to identify individual patents that can be characterized as general purpose because of their generality and association with rapidly evolving technology classes. Our approach is different in that, although we also conduct patent-level analyses, we are interested in sectoral differences in patterns of citation and cross-citation. We attempt to identify entire technology classes or fields that have generated sustained invention that was adopted and cumulatively invented upon by other technology areas. We suggest that this approach is more aligned with the notion of general-purpose technologies that are rarely single inventions but particularly generative and broadly applicable clusters and streams of inventions (e.g. electricity). Then, it makes sense to try to identify long-term patterns of invention and spillover generated by technological subfields that indicate exceptional impact on invention in a broad range of technology sectors.

Equipped with significantly enhanced computing power than Hall and Trajtenberg in 2004, we conduct a descriptive, comprehensive, and very long-term analysis of cross-sectoral patent citations over several decades and in many countries. We take a big-data approach – "N=all" – and consider the entire technological progress of the world for most of the past century. This allows us to describe relationships among fields of technology that are difficult to discover with a short random or industry sample. We find that the inventive impact of instruments[1] and information technologies[2] is exceptional and sustained over long periods of time. We highlight them as types of "Turing machines of invention": instruments enable the manipulation of physical matter (chemical substances, artifacts, physical processes, biological organisms), whereas information technologies enable the manipulation of information. Both are "invention machines" in that they are not only general-purpose technologies that can be adopted in a wide variety of other sectors, but they also provide essential ingredients for invention in the other sectors. Instruments, through the manipulation of matter, facilitate discovery of new physical properties; computers, through the manipulation of information, facilitate discovery of new information. Together, instruments and computers have been used to automate a wide range of industrial processes since early 1970s.

Method

An important aspect of technological change is the creation of public knowledge goods, associated with positive economic externalities. A new technology is potentially not only useful to its inventor but also to other economic agents, although these other agents do not always pay a price for the use of the invention. This insight has inspired a complete rewriting of the theory of economic growth that focuses attention on the role of knowledge accumulation in aggregate economic growth (Grossman & Helpman, 1991; Romer, 1990). Empirically, Griliches (1979) and Scherer (1982) suggested that the productivity of firms or industries is related to their own R&D spending, and also to the R&D spending of other firms and other industries.

[1] Standard Industrial Classification 38
[2] Standard Industrial Classifications 357, 367

Knowledge spillovers may take place through various mechanisms, such as through the mobility of R&D workers, the exchange of information at technical conferences or in scientific and technical literature (including patent documents), reverse engineering, and industrial espionage. Given the difficulty in measuring knowledge spillovers, patent citations have long been considered proxies for the flow of knowledge from the inventors whose patents are cited to the inventors making the citations. Empirical studies using patent citations have demonstrated the process of technological accumulation (Caballero & Jaffe, 1993), as well as a large body of research assessing the extent to which knowledge spillovers are geographically localized (Jaffe, Fogarty, & Banks, 1998; Jaffe et al., 1993; Maurseth & Verspagen, 2002). These authors find that knowledge spillovers between firms, or from (semi-) public knowledge institutes to firms, depend on geographical distance – that is, citing occurs more often the closer geographically situated the inventors.

Much economic research has attempted to measure and assess the implications of spillovers by analyzing citations made in patent documents to predecessor inventions. To verify this measurement strategy, Jaffe et al. (2000) surveyed the meaning of patent citations and concluded that a substantial part (but by no means all) of such citations involve actual flows of knowledge. Thus, patent citations are a noisy but meaningful indicator of knowledge spillovers in an economy. However, care must be taken with using patent citations, as citations can be added not only by the inventors, but also by the patent attorneys and the patent examiners involved with the patent application, with the final decision ultimately lying with the patent examiner. Thus specific controls for inventor versus examiner additions have shown not only that geographical distance but also cognitive distance and time influence the probability of knowledge flows (Criscuolo & Verspagen, 2008). This said, patent data remains a valuable, even if imperfect, tool with which to measure knowledge flows.

Our data source is PatStat, a comprehensive resource from the European Patent Office covering more than 170 publication authorities (patent offices), 90 million awarded patents, 160 million citations and more than 200 control variables covering the period from 1920 to

2014. Table 1 shows the PatStat organization for technology sectors (5 in total) and fields (34 in total).[3]

Table 1 Technology Sectors and Technology Fields in PatStat patent data

Technology Sector	Technology Field
Chemistry	Basic materials chemistry
Chemistry	Biotechnology
Chemistry	Chemical engineering
Chemistry	Environmental technology
Chemistry	Food chemistry
Chemistry	Macromolecular chemistry, polymers
Chemistry	Materials, metallurgy
Chemistry	Micro-structural and nanotechnology
Chemistry	Organic fine chemistry
Chemistry	Pharmaceuticals
Chemistry	Surface technology, coating
Electrical Engineering	Audio-visual technology
Electrical Engineering	Basic communication processes
Electrical Engineering	Computer technology
Electrical Engineering	Digital communication
Electrical Engineering	Electrical machinery, apparatus, energy
Electrical Engineering	IT methods for management
Electrical Engineering	Semiconductors
Electrical Engineering	Telecommunications
Instruments	Analysis of biological materials
Instruments	Control
Instruments	Measurement
Instruments	Medical technology
Instruments	Optics
Mechanical Engineering	Engines, pumps, turbines
Mechanical Engineering	Handling
Mechanical Engineering	Machine tools
Mechanical Engineering	Mechanical elements
Mechanical Engineering	Other special machines
Mechanical Engineering	Textile and paper machines
Mechanical Engineering	Thermal processes and apparatus
Mechanical Engineering	Transport
Other Fields	Civil engineering
Other Fields	Furniture, games
Other Fields	Other consumer goods

Notes: Technology fields consist of non-overlapping IPC codes that are available from the PatStat dataset.

Our analysis is based on a simple count-data model of the number of citations received by each patent, controlling for several confounding factors that may influence our estimates. The base model is of the type:

[3] Occasionally patent classification schemes are modified and patents can change their classification. For our analysis we use the most recent classifications. We do not believe that past reclassifications will influence our analysis, as most reclassifications happen at quite granular (3 or 4 digit) levels, and our analysis is at the rather coarse sectoral and field levels. Put differently, it is unlikely for a patent to be reclassified between technology classes.

$$C_i = \beta_{kt} F_{kt} + \gamma_i X_i + \varepsilon_i$$

where C_i is the sum of all citations received by patent i, F_{kt} is a binary variable equal to 1 for patents that belong to field k and were published in year t, and 0 otherwise. This model reports estimators at the field-year level conditional on a broad range of controls. These controls are included in X_i, the vector of patent characteristics, and ε_i is the error term. β_{kt} captures the number of citations received by each field and year, all other things being equal. Our analysis is done at the patent-year level allowing the maximum degree of flexibility in the estimates.[4]

There are a few factors that may drive patent citation counts. First, the number of citations is strongly linked to the procedures followed by publication authorities (national or regional patent offices) that oversee the application and grant process. This can change over time as new processes within patent offices may affect the ways to attribute citations. Second, prior art citations have generally been rising in recent years thus introducing a secular trend. We therefore control for year and patent office effects in our model allowing direct comparisons across jurisdictions and over time. Third, a patent may also belong to a family of inventions that are submitted to multiple patent offices. The size of such a patent family can affect the visibility of the invention and hence increase the likelihood of the patent being cited. We compute and control for the numbers of patents that belong to each family and each "extended" family.[5] Fourth, different technology sectors have varying publication and citation patterns. We control for the total number of inventions granted (annual patent flows) and the total number of citations within each patent class each year. These metrics correct for potentially inflated citation counts in sectors with more inventions (hence with a higher likelihood of being cited) and sectors that cite patents and non-patent literature more extensively than others. Further, we control for the citations made by patent examiners and the number of claims to capture the

[4] The cost of this decision is that the size of the dataset exceeds common computing capacities. Therefore, most of the analysis has taken place using c4.8xlarge compute optimized instances and r3.8xlarge memory optimized instances on the Amazon cloud service.

[5] This broader definition of a patent family takes domestic application numbers as additional connecting elements and includes patents having the same scope but lacking a common priority (www.epo.org).

extent and scope for protection sought. Lastly, we capture seasonal effects with controls for the month of publication.

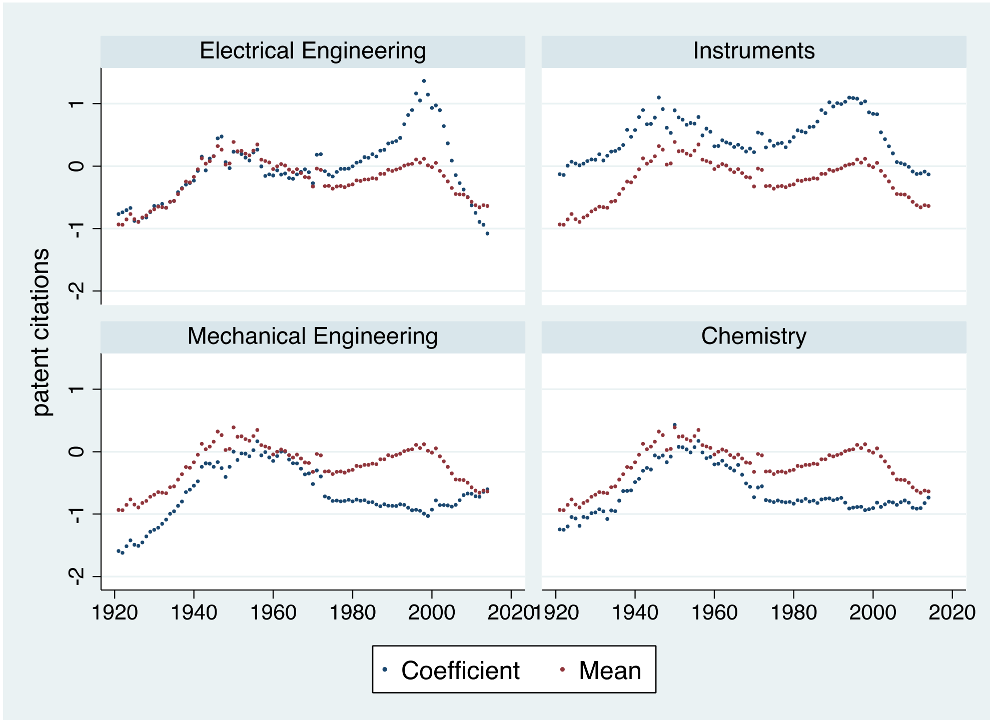
All these controls reassure us about the validity of comparisons over time, across patent offices, and across technology fields. Our assumption thus is that patents submitted in a patent office, at the same time, within the same field, and with the same family size will be treated equally by the authorities.

Results

We first look at the relative influence of the four primary technology classes (the highest level of classification within PatStat), namely electrical engineering, instruments, mechanical engineering, chemistry, and other fields over the period 1920 to 2014 (Figure 1). Given the shorter window of observations for recently published patents we observe that their citation counts drop quickly after 2000. To avoid a systematic bias, we consider results until 2000 in our analysis. Given the increasing patenting activity in recent years – for which we explicitly control – this choice reduces our sample to approximately 54 million.

Although the four technology classes display distinct citation profiles, all of them present a changing pattern starting around year 1970s. Prior to 1970 mechanical engineering and chemistry technology classes closely followed the general trend. Soon after this period their influence starts to drop. In contrast, the electrical engineering technology class also follows the mean until the 1970s, after which it begins to increase more rapidly, peaking just before the 2000s. Amidst these changes, the instruments class remains above the citation mean for the whole period of study, and, similar to electrical engineering, also begins to attract more interest after 1970. These patterns correspond to a shift from mechanical and chemical technologies to electrical ones.

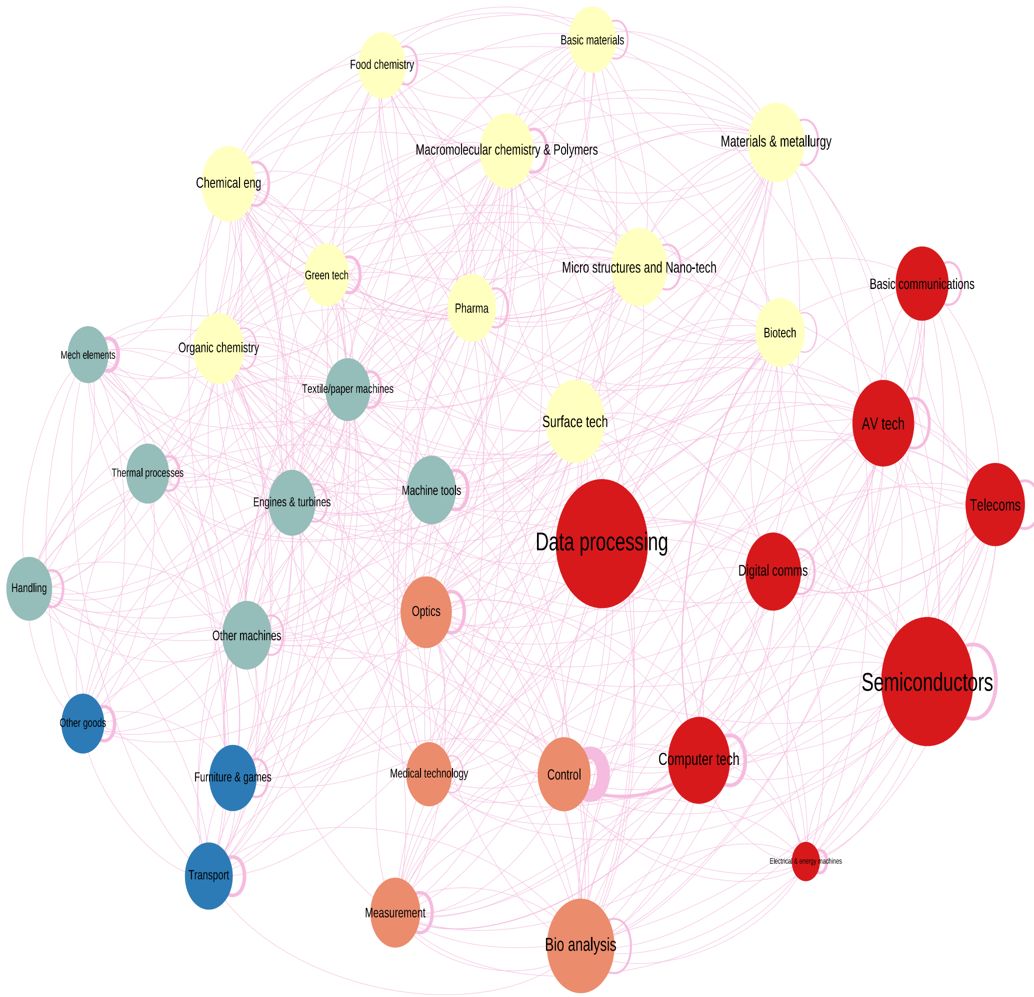
Figure 1 Predicted patent citation coefficients by sector and by year



Notes: Blue dots represent the sector-level coefficients β_{kt} while the red dots represent the mean of all technology classes (reported as a reference in all figures. These results control for year and publication authority fixed effects, citations added by examiners, publication claims, family and broad family size, stock of published patents by sector and year and stock of citations by field.

Digging deeper into technology classes within each sector at the time of this major technological shift, Figure 2 presents a graph of the citation flows among technology classes in 1970. The size of each node represents the number of citations received from all fields (in-degree), and the thickness of the edge represents the number of citations from each of the other nodes. Lines originating from and going back to the same node represent self-citations by the sector itself. This figure illustrates the beginning of the Information and Communication Technology (ICT) revolution, and the emergence of information technologies as invention machines. Semiconductors and Data Processing are the most cited classes with Surface Technology sending and receiving the most cites to and from Semiconductors.

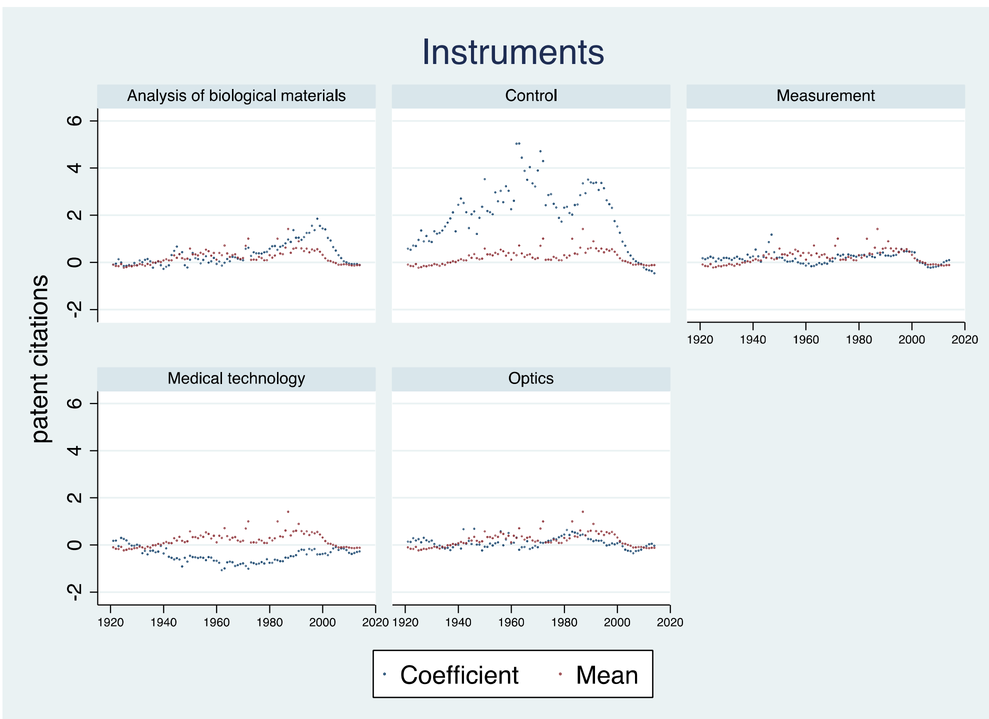
Figure 2 **Cross-sector citation flows in 1970**



Notes: 1) Color of the circle represents the broader sector of each technology field (Red: Electrical Engineering, Yellow: Instruments, Green: Chemistry, 4: Cyan: Mechanical Engineering, 5: Blue: Other sectors) 2) Size of the circle represents the number of incoming citations; 3) Thickness of the edge represents the magnitude of citations from one sector to another (only showing the links with statistically significant coefficients greater than 0; the full version is available in the Figure A4) 4) The curve of the edge indicates the direction of citations (origin of citation clockwise linked to destination) 5) These results control for year and publication authority FE, citations added by examiners, publication claims, family and broad family size, stock of published patents by sector and year and stock of citations by field.

To further explore the exceptional patterns of the instrument and electrical engineering sectors we discovered in Figure 1, we break down sector-level citations into more specific technology fields including analysis of biological materials, control, measurement, medical technology, and optics (Figure 3). The fields of optics and measurement generally track the mean of all technology classes while the other three fields show some distinct patterns. With the exception of the 1920s, medical technology appears to consistently receive fewer citations than other instrument fields; this points to the increasing specialization of medicine over the 20th century, whereby medical technologies are not frequently used in other fields. Analysis of biological materials generally follows the mean of all citations until the 1980s, when it appears to increase its overall influence. Whereas this could suggest the emergence of biological analysis as an invention machine, a closer analysis suggests otherwise: the rise of biological analysis appears to reflect the adoption of digital technologies within this field – the highly cited patents in this technology class tend to be co-listed in the digital communications and data processing classes (see Figure A1 in the Appendix for more detail).

Figure 3 Predicted patent citation coefficients by instrument field and by year

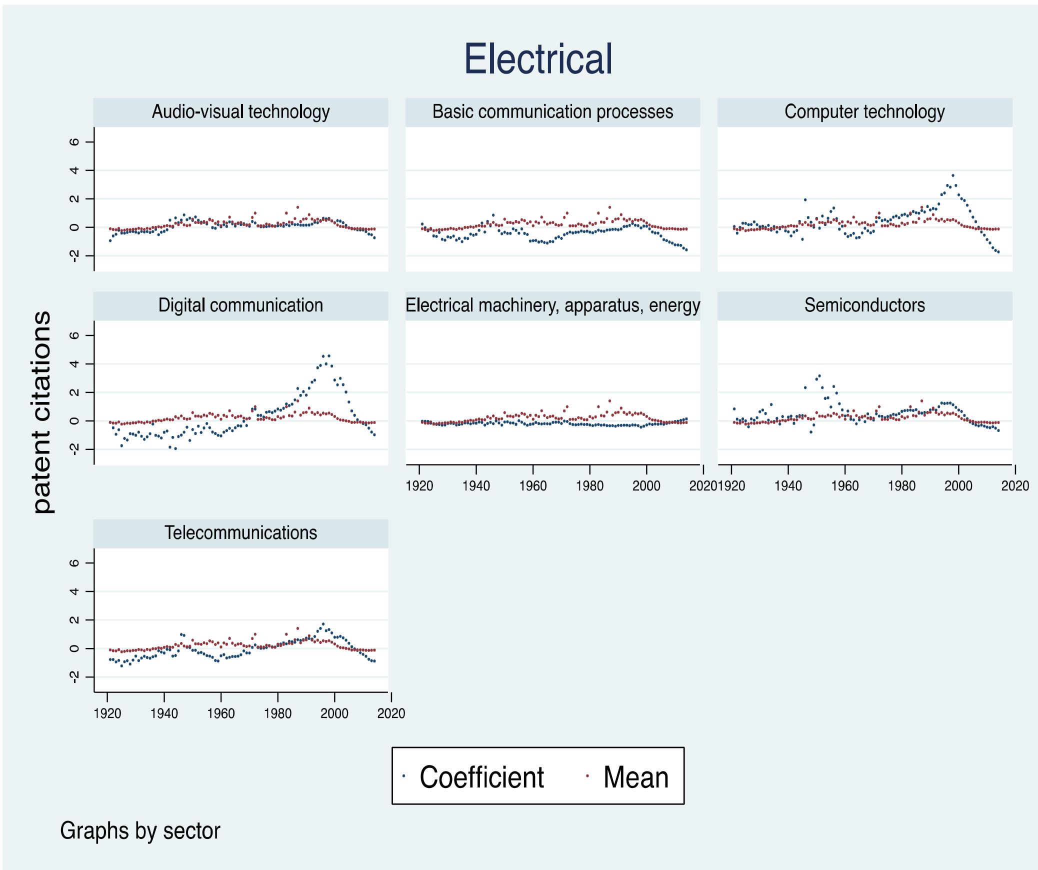


Notes: Blue dotted line represents the coefficients for the technology class in question while the red dotted line represents the mean of all technology classes. These results control for year and publication authority FE, citations added by examiners, publication claims, family and broad family size, stock of published patents by sector and year and stock of citations by field.

The most striking field of instruments is control technologies, which consistently receive more citations than the mean of all classes for the entire period. Control technologies relate to the electrical or mechanical manipulation and management of machinery (see Appendix A1 and

A2 for examples of each). The above-average citations to the instruments sector can almost entirely be attributed to this specific field. Control technologies thus appear to qualify as invention machines that enable the manipulation of information or physical properties in a broad range of applications, inciting follow-on invention in those application sectors.

Figure 4 Predicted electrical engineering patent citations by technology field and by year



Notes: Blue dotted line represents the coefficients for the technology class in question while the red dotted line represents the mean of all technology classes. These results control for year and publication authority FE, citations added by examiners, publication claims, family and broad family size, stock of published patents by sector and year and stock of citations by field.

We carry out a similar analysis of the subfields of electrical engineering. Figure 4 reports the yearly coefficients for these fields. Again, the red dotted line marks the average of all sectors and the blue dotted lines the coefficients of the specific field in question. AV technologies, basic communication, electrical machinery, and telecommunications are all not different from the average in any sustained pattern. In contrast, semiconductors had a long (albeit variable) spike prior to 1960; computer technology has been above average after 1970 and particularly in the 1990s; and digital communications have experienced a seemingly exponential growth after 1970 (ignoring the 2000s for which we do not yet have comprehensive data). Perhaps surprisingly, computer technologies have not been as impactful or persistent in their influence on other fields as have control technologies or digital communications. We have left out the field of IT methods for management which is included in the Appendix A3. Because of a relatively small number of patents in this field, its coefficients are very unstable and therefore difficult to interpret.

Next we exploit the fact that patents can be classified in multiple patent classes via co-listed patent classes. Figure 5 and Table 2 present analyses of those technology classes that instrument patents are co-listed with. We define as “mechanical instruments” those patents that list both mechanical engineering and instrument classes while “electrical instruments” list both electrical engineering and instrument classes.

To highlight the impact of “electronification” of production, we utilize a differences-in-differences approach around the year 1970, when Electrical Engineering patent citations counts first rose above the mean (cf. Figure 1). In Table 2 we estimate a model for both types of instruments, mechanical and electrical. Here we also consider a narrower definition of sectoral spillovers by estimating both models that include all citations (both within-sector and cross-sector citations) in specifications 1 and 3, and models that only include cross-sector citations in specifications 2 and 4.

We find that mechanical instruments are the most frequently cited patents across all instruments but electrical instruments gradually replace them after 1970. Specifically, prior to 1970 mechanical instruments receive on average 0.364 more citations (compared to other technology fields at the same time period) whereas electrical instruments increase their share after this milestone to receive 1.026 citations (columns 1 and 3, Table 2) more. Regarding cross-sector spillovers, we find that electrical instrument spillovers increase by 0.388 citations after 1970 whereas mechanical instrument spillovers drop by 0.307 during the same period (columns 2 and 4). This take-off of electrical instruments coincides with the information technology revolution since the early 1970s and continued in the following decades. Nevertheless, instrument technologies appear to have generated substantial and sustained knowledge spillovers over several decades regardless of the underlying technological base.

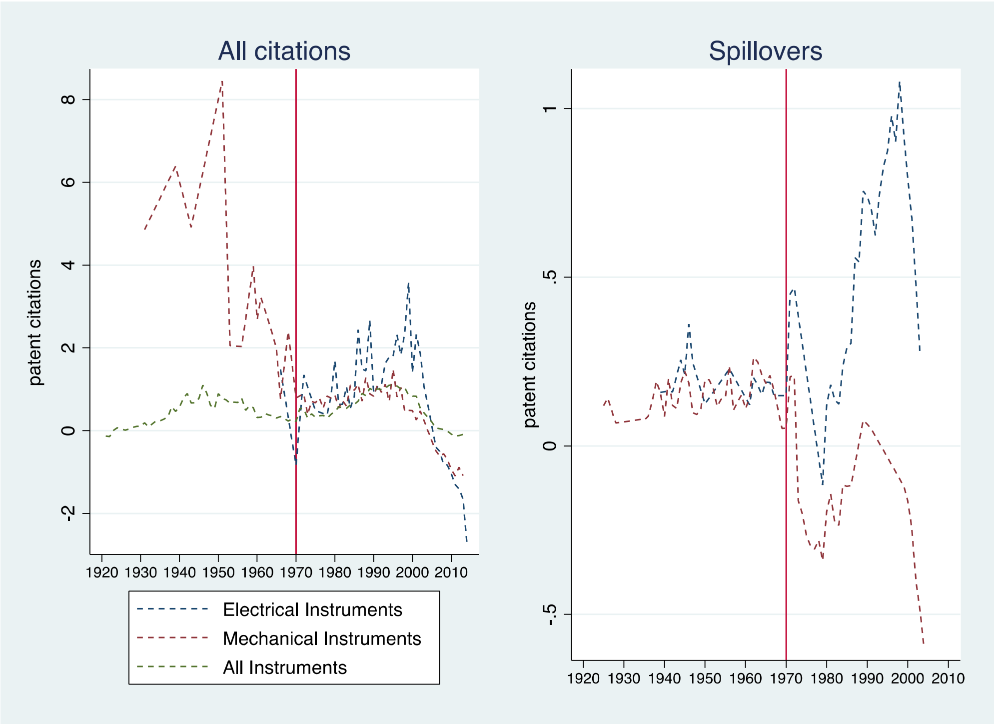
Table 2 Citations for electrical and mechanical instruments, before and after 1970

	(1)	(2)	(3)	(4)
Estimation method	FE	FE	FE	FE
Dependent variable	All citations	X-sector Spillovers	All citations	X-sector Spillovers
$Post_t$	1.735	0.096	1.706	0.095
dummy=1 after 1970	(70.18)**	(143.23)**	(68.86)**	(33.92)**
Electrical Instruments	4.23	1.32		
	(238.42)**	(432.28)**		
Electrical Instruments X Post	1.026	0.388		
	(56.24)**	(123.53)**		
Mechanical Instruments			5.14	1.39
			(346.00)**	(829.03)**
Mechanical Instruments X Post			-0.364	-0.307
			(23.53)**	(175.63)**
Observations	53,980,888	53,980,888	53,980,888	53,980,888
R^2	0.24	0.14	0.25	0.12
Year FE	yes	yes	yes	yes
Publication Authority	yes	yes	yes	yes
Stock of published patents by field & year	yes	yes	yes	yes
Family Size	yes	yes	yes	yes
Family Size Broad	yes	yes	yes	yes
Publication Claims	yes	yes	yes	yes
Citations (#) by examiners	yes	yes	yes	yes
Stock of citations by field&year	yes	yes	yes	yes

Notes: The dependent variable is the total number of citations per patent *i i*n year *t* (columns 1 and 3) and the number of citations from all other sectors excluding Electrical Instruments (column 2) and Mechanical Instruments (column 4). Standard errors clustered at the patent family level are reported in parenthesis below coefficients: *significant at 5%; **significant at 1%.
Source: Authors' calculations based on data from PATSTAT.

Figure 5 illustrates the dramatic switch to electric engineering as the basis of industrial instruments around the watershed year 1970. The difference between mechanical and electric instruments is particularly clear and consistent for the cross-sectoral spillovers post 1970 (panel on the right).

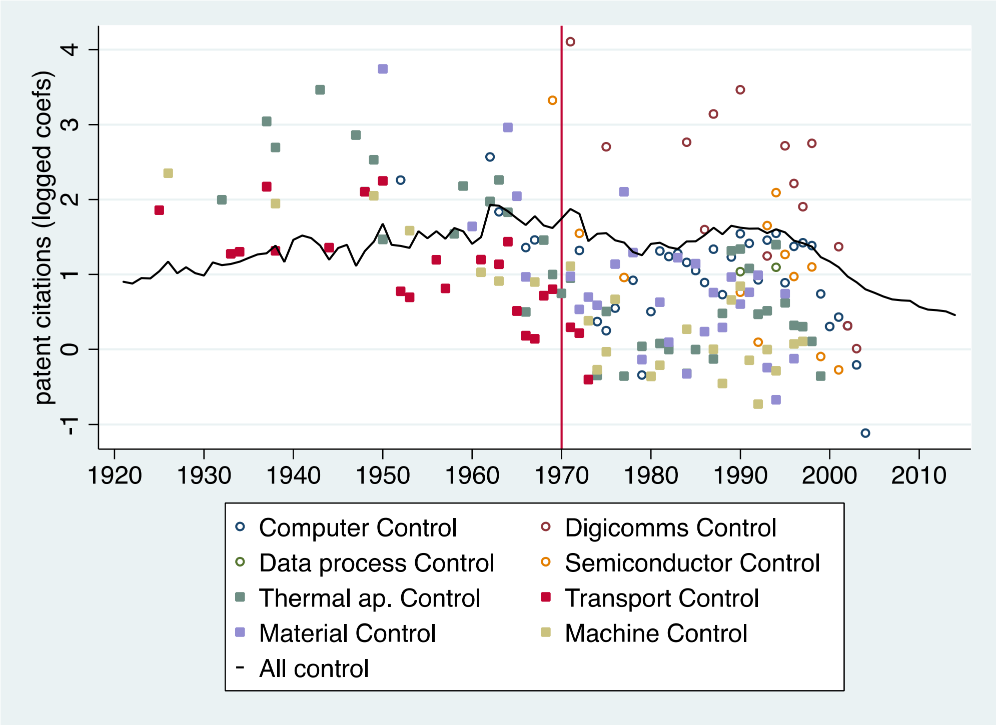
Figure 5 All predicted citations and cross-sector spillovers of mechanical and electrical instruments



Notes: These results control for year and publication authority FE, citations added by examiners, publication claims, family and broad family size, stock of published patents by sector and year and stock of citations by field.

In our final illustration of technological discontinuities involving industrial control and electronics, we delve into the technology areas cross-listed with control technologies (Figure 6). We find that pre-1970 the above-average knowledge spillovers from control technologies (above the solid line that represents average citation rate of control technologies) take place when inventions are co-listed with a variety of mechanical technology fields, including thermal, transport, materials, and machine tools (square symbols). In contrast, post-1970, the most frequent senders of control technology spillovers are co-listed with electrical engineering technology fields (round symbols) and dominated by digital communications. Although computer technologies have been assumed to play a central role in automation, it appears that communication technologies actually generate the most invention impact.

Figure 6 **Predicted control patent citations with co-listed technology fields**



Notes: The results presented include controls for year and publication authority FE, citations added by examiners, publication claims, family and broad family size, stock of published patents by sector and year and stock of citations by field. For clarity, hollow circles represent the Electrical X Control categories and the squares the Mechanical X Control categories. Colors indicate the relevant sup-group.

Discussion and Conclusion

Expanded data storage and processing capabilities allow social scientists to tackle ever-larger datasets in comprehensive and complex analyses of networks and dynamics. We analyzed the entire global history of patenting since about 1920 to detect long-term patterns of technological influence via prior-art citations of patented inventions.

The history of knowledge spillovers as measured by patent citations is dominated throughout the 20th century by instrument technologies and, after 1970, by electrical engineering, particularly information and communication technologies. We described these technologies as "invention machines" because they play critical roles in the processes of invention in many sectors of the economy. Thus, they are not only general-purpose technologies that can be utilized in many different sectors but also general invention technologies that facilitate the discovery of other technologies. Instruments enable the manipulation of physical processes whereas information and communication technologies enable the manipulation of data. Both capabilities are fundamental to most economic and industrial activity.

Our analyses imply that industrial automation technologies coming out of the subfield of control instruments have been the most generative (and probably the most valuable) general-purpose technologies over the past century of invention. Meanwhile, the sources and implications of control technologies have rarely been considered in the debates around computerization, digitization, and productivity. Our analysis suggests that automation actually requires a great deal of instrumentation which, to our knowledge, has not been studied in detail by historians or economists.

We also find a watershed moment around year 1970 when the modal invention trajectory switched from mechanics to electronics. Here we confirm the finding of Jovanovic and Rousseau (2005) of the ICT revolution commencing about this time. Electronics invention in technologies such as semiconductors and data processing, and later computer technologies and particularly digital communications paved the way for digitization and automation of production and economic coordination. In particular, digitized industrial control systems appear to have had a tremendous technological impact since 1970. We leave it for future research to connect these technological advances with effects on productivity and competition that probably continue to this day.

As the control and communication revolution appears to continue, we may wonder what is in store for the future. We investigated the conspicuous rise of biological analysis technologies but concluded that their initial rise is primarily caused by the adoption of electronics, not necessarily by the application of biological techniques in other industries. However, the convergence of digital communication technologies and control technologies may well prove to generate the next generation of invention machines. Advanced digital communications make it possible to simultaneously and immediately utilize information in a wide variety of contexts. This bodes well for the integration of techniques related to cloud computing, big data, and the industrial internet with control technologies such as different types of sensors and actuators that, together, allow observing and manipulating physical, chemical, biological, and social processes in connected industrial activities in a vast set of contexts. As the onslaught of automation may continue to create tremendous industrial value but also societal upheaval via creative destruction of jobs, occupations, and organizations, it is interesting to notice that the set of technologies that fundamentally enables this, control instruments, has gone relatively unnoticed in the economics of technology. In ongoing research, we examine the geographic origins and implications of these patterns of knowledge flows.

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Appendix

Figure A1 US Patent 9,268,320 B2: Wireless Industrial Control User Interface with Configurable Software Capabilities (2016)

US009268320B2

(12) **United States Patent**
Braun et al.

(10) **Patent No.: US 9,268,320 B2**
(45) **Date of Patent: *Feb. 23, 2016**

(54) **WIRELESS INDUSTRIAL CONTROL USER INTERFACE WITH CONFIGURABLE SOFTWARE CAPABILITIES**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 531 days.

This patent is subject to a terminal disclaimer.

(21) Appl. No.: **13/093,616**

(22) Filed: **Apr. 25, 2011**

(65) **Prior Publication Data**

US 2012/0109342 A1 May 3, 2012

Related U.S. Application Data

(63) Continuation of application No. 11/259,511, filed on Oct. 26, 2005, now Pat. No. 7,933,668.

(51) **Int. Cl.**
G05B 19/042 (2006.01)

(52) **U.S. Cl.**
CPC ***G05B 19/042*** (2013.01); *G05B 2219/24165* (2013.01); *G05B 2219/25186* (2013.01)

(58) **Field of Classification Search**
None
See application file for complete search history.

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Primary Examiner — Sean Shechtman
Assistant Examiner — Steven Garland
(74) *Attorney, Agent, or Firm* — Quarles & Brady LLP

(57) **ABSTRACT**

A user interface operable to connect to a device within an industrial control system includes a memory and a processing unit. The memory is operable to store a plurality of software applications for interfacing with the device and a configuration mask including access rights for at least a subset of the software applications. The processing unit is operable to establish a first connection with the device and disable selected software applications based on the configuration mask.

19 Claims, 12 Drawing Sheets

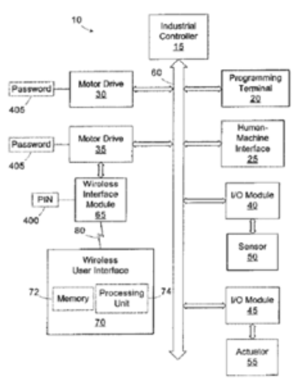

Figure A2 US Patent 3,444,896: Hydraulic Interval Timer (1969)

United States Patent Office

3,444,896

Patented May 20, 1969

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3,444,896

HYDRAULIC INTERVAL TIMER

William R. Van der Veer, San Antonio, Tex., assignor, by mesne assignments, to William B. Wilson, Iraan, Tex.

Filed Jan. 18, 1967, Ser. No. 610,146
Int. Cl. G05b *19/00;* F15c *3/00;* A01g *25/02*
U.S. Cl. 137—624.2 10 Claims

ABSTRACT OF THE DISCLOSURE

A hydraulically actuated timer including a plurality of pilot valves for sequentially operating a plurality of associated irrigation valves without having to resort to an external source of power other than that derived from the pressure and/or flow of the water being used for irrigation purposes.

The present invention relates to a hydraulically actuated hydraulic interval timer and more particularly to a hydraulically actuated timer for the remote control of pressure responsive diaphragm actuated valves. More specifically, the present invention relates to the provision of a novel construction for a hydraulic interval timer adapted to be utilized to sequentially operate diaphragm valves in agricultural irrigation systems and the like.

The prior art contains numerous examples of flow dividing and water distributing valves of the type which service a plurality of water outlets in timed relation to a water inlet as would normally be the case in a lawn sprinkler system or the like wherein it is desired to sequentially operate a plurality of sprinklers singly at full line pressure. However, in commercial agricultural irrigation systems, such as utilized for the irrigation of orchards, row crops and the like, no suitable device has been proposed heretofore which could perform the function of remotely controlling and timing the opening and closing of valves in irrigation hydrants and standpipes without having to resort to some auxiliary source of power, i.e., power other than that derived from the flow or static pressure of the irrigation water, such as compressed air, electricity, standby engines, or the like. Heretofore, the most common solution to the problem has been the use of electrically operated valves and an electrically actuated interval timer. Even then, such a system is not capable of operating large capacity valves directly but has to operate through additional electric operators, such as electric solenoid valves which in turn operate the large capacity water valves. This, of course, requires that electrical power has to be supplied to the operating site.

It will accordingly be appreciated that a need still exists for a hydraulic interval timer adapted to sequentially operate a plurality of irrigation valves without having to resort to an external source of power other than that derived from the pressure and/or flow of the water being used for irrigation purposes.

Another object of the present invention is to provide a hydraulic interval timer of a novel construction adapted to derive all its power from the water supply line used to supply irrigation water to the valves being controlled by the hydraulic interval timer.

Still another object of the present invention is to provide a novel construction for a hydraulic interval timer which is adapted to automatically sequence a group of irrigation valves wherein the valves are operated in series, one at a time, in a manner such that relatively large capacity irrigation water valves comprising a part of an irrigation hydrant, standpipe or the like are opened for a specific length of time to flood a field and then closed after which the next series valves in the system are similarly operated.

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Still another object of the present invention is to provide a simple, relatively inexpensive hydraulic interval timer which is adapted to be connected in series with one or more similar units so as to permit sequential operation of the hydraulic interval timer units per se as well as permitting the sequential operation of a plurality of valves controlled by each of the hydraulic interval timers.

Still a further object of the present invention is to provide a hydraulic interval timer constructed in such a manner so as to be adjustable to be self-terminating at the end of a sequencing cycle.

Still another object of the present invention is to provide a novel construction for a hydraulic interval timer wherein variable speed hydraulic motor means is adapted to drive a cam means in a step-by-step fashion so as to operate a plurality of pilot valves associated with the cam means whereby the pilot valves may sequentially operate diaphragm actuated valves comprising outlet valves in the irrigation system so as to insure desired distribution of irrigation water therefrom.

These together with other objects and advantages which will become subsequently apparent reside in the details of construction and operation as more fully hereinafter described and claimed, reference being had to the accompanying drawings forming a part hereof, wherein like numerals refer to like parts throughout, and in which:

FIGURE 1 is a schematic view of an exemplary embodiment of a hydraulic interval timer module constructed in accordance with the principles of the present invention;

FIGURE 2 is a fragmentary top plan view of a hydraulic interval timer constructed in accordance with the schematic device illustrated in FIGURE 1;

FIGURE 3 is a side elevational view of the hydraulic interval timer of the present invention taken substantially along the plane of the line 3—3 of FIGURE 2;

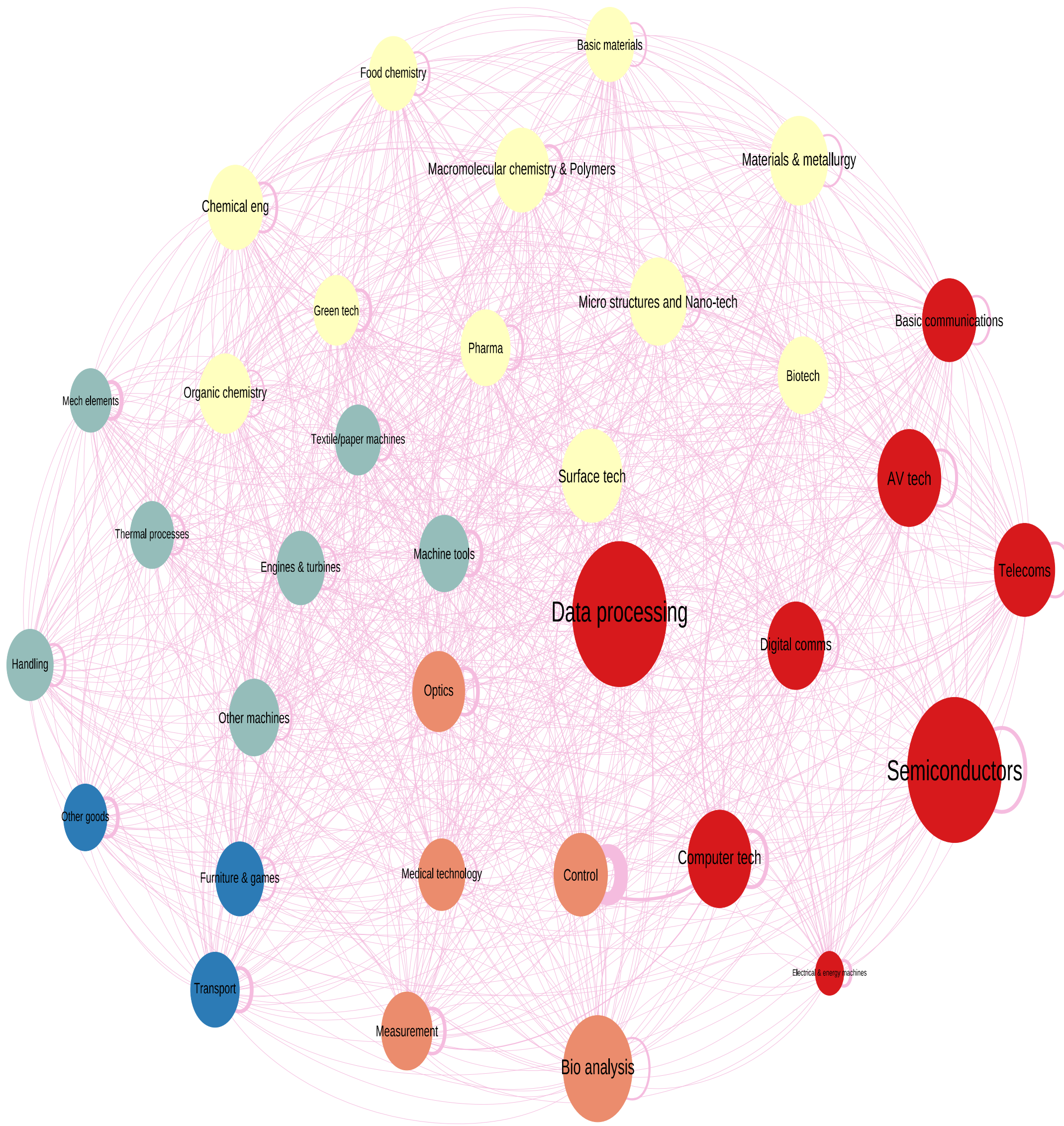
FIGURE 4 is an enlarged fragmentary view of the hydraulic interval timer of FIGURES 2 and 3 and further showing certain details of the gear means of the hydraulic timer;

FIGURE 5 is an enlarged vertical cross-sectional view taken substantially along the plane of the line **5—5** of FIGURE 3; and

FIGURE 6 is a fragmentary cross-sectional view taken substantially along the plane of the line **6—6** of FIGURE 3.

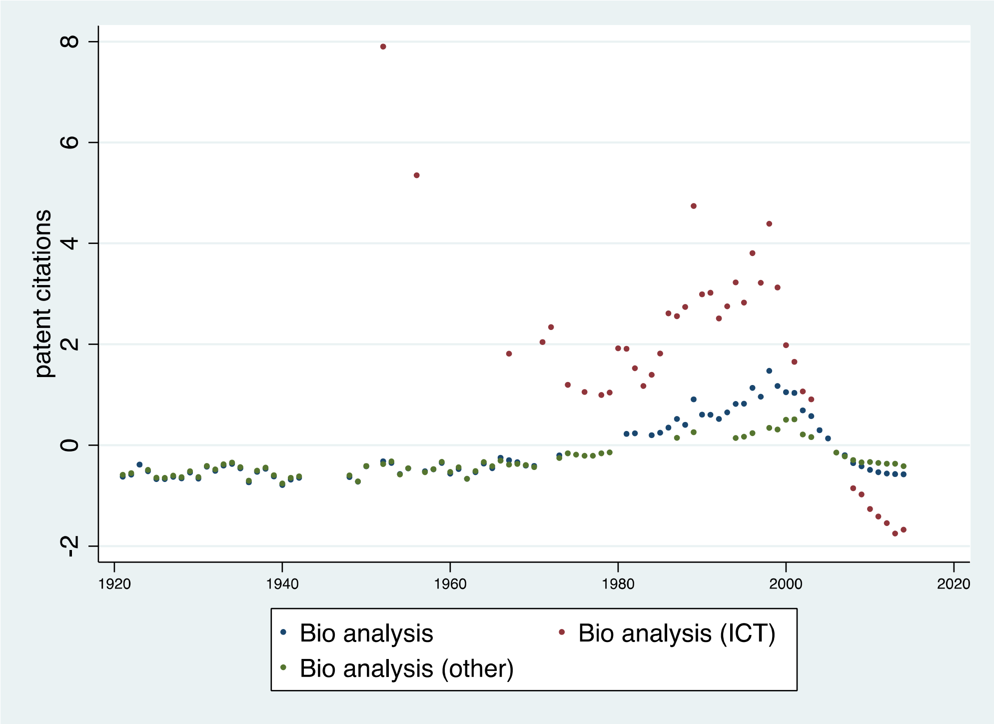
Referring now in detail to the drawings and particularly FIGURES 1 and 2 it will be seen that the exemplary embodiment **10** of a hydraulic interval timer constructed in accordance with the present invention includes a base means **12** which in the embodiment illustrated comprises an elongated rectangular metallic plate. A variable speed hydraulic motor means indicated generally at **14** is secured adjacent one end of the base means **12**. The hydraulic motor means **14** includes water inlet and outlet conduits **16** and **18** respectively. The hydraulic motor means **14** is of a conventional type wherein water or the like, under pressure entering through the conduit **16** impinges against a hydraulically driven turbine blade and is exhausted through the outlet conduit **18** while the rotation of the turbine is utilized to impart rotation to the output gear element **20**. It will thus be appreciated that the hydraulic motor means **14** comprises a conventional hydraulic motor. A pair of upstanding end bearing plates **22** and **24** provide a means of mounting a reduction gear means indicated generally at **26** in meshing engagement with the hydraulic motor output gear **20**. Toward this end, it will be seen that the reduction gear means **26** includes gear **28** fixed to a shaft **30** rotatably journaled in bearings **32** press fit into the hub **34** integral with and projecting laterally from the end plate **22**. The

Figure A3 Cross-sector citation flows in 1970 (no filtering)



Notes: 1) Color of the circle represents the broader sector of each technology field (Red: Electrical Engineering, Yellow: Instruments, Green: Chemistry, 4: Cyan: Mechanical Engineering, 5: Blue: Other sectors) 2) Size of the circle represents the number of incoming citations; 3) Thickness of the edge represents the magnitude of citations from one sector to another (showing all links with statistically significant coefficients) 4) The curve of the edge indicates the direction of citations: origin of citation clockwise linked to destination 5) These results control for year and publication authority FE, citations added by examiners, publication claims, family and broad family size, stock of published patents by sector and year and stock of citations by field.

Figure A4 Biological analysis patent citations with co-listed technology fields



Notes: These results control for year and publication authority FE, citations added by examiners, publication claims, family and broad family size, stock of published patents by sector and year and stock of citations by field.