‘OLD’ AND RECENT KNOWLEDGE IN A GLOBAL INDUSTRY; THE INTEGRATED CIRCUIT INDUSTRY AND FRANCE, 1970s-2013

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ABSTRACT

How important is ‘old’ knowledge for technological innovation? This paper addresses this research question focusing on the highly innovative semiconductor industry. Using a novel dataset of patents covering the period between the early 1970s and 2013, we highlight the relevance of age-old wisdom, as well as recent knowledge, to inventions produced by a cohort of world-leading semiconductor design multinational enterprises. Our analysis focuses on France and investigates the temporal dimension of recombinant search within the intellectual legacy of French entities in various high-tech industries.

Résumé

Quelle est l’importance des connaissances conventionnelles dans l’innovation technologique? Cet exposé tente de répondre à cette question en se concentrant sur l’industrie hautement innovante des semi-conducteurs. En utilisant un registre nouveau des brevets couvrant la période du début des années 1970 à 2013, nous soulignons le rôle du savoir classique ainsi que celui des connaissances plus récentes pour les inventions fabriquées par un grand nombre d’entreprises leaders mondiales dans la conception des semi-conducteurs. Notre analyse

examine la situation en France, et se penche sur la dimension temporelle de la recherche recombinante au sein de l'héritage intellectuel des entités françaises dans différentes industries de pointe.

I. Introduction

Up-to-date knowledge is one important factor that firms leverage to remain relevant in the ever-changing business environment, to gain early-mover advantage and sustain their competitive position. Very importantly, working at the knowledge frontier prevents firms from falling into obsolescence, their knowledge stock from becoming inadequate and their core capability becoming core rigidities.[1] Incumbents are recommended to experiment with novel and emerging and pioneering technologies and step out of the 'familiarity trap' and 'learning myopia' in order to produce technological breakthroughs.[2]

The keen attention to the new, nevertheless, might not justify the negligence of the 'old'. In light of this, recent studies have attempted to move away from considering dated knowledge simply as a source of inertia, and the role of 'traditional knowledge' in innovation is attracting renewed attention in scholarly and business communities.[3] The knowledge search and recombination informing innovation often spans the temporal dimension and encompasses knowledge from diverse domains.[4] The invention of automobiles, for instance, can be seen as a combination of the bicycle, the horse carriage, and the internal combustion engine; inventions from different times and industries.[5]

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[1] D. Leonard-Barton, "Core Capabilities and Core Rigidities: A Paradox in Managing New Product Development", *Strategic Management Journal*, vol. 13, Special Issue Summer, 1992, p. 111-125; D.A. Levinthal and J. G. March "The Myopia of Learning", *Strategic Management Journal*, vol. 14, Special Issue Winter 1993, p.95-112; A. Capaldo, D. Lavie and A. Messeni Petruzzelli, "A Quest in Time: How the Maturity, Distance, and Diffusion of Knowledge Affect Innovation" *Academy of Management Proceeding*, vol. 2012, No.1, July 2012.

[2] G. Ahuja and C.M. Lamper, "Entrepreneurship in the Large Corporation: a Longitudinal Study of How Established Firms Create Breakthrough Inventions", *Strategic Management Journal*, vol.22, No 6-7, 2001, p. 521-543; Levinthal and March "The Myopia".

[3] See for instance A. De Massis, F. Frattini, J. Kotlar, A. Messeni Petruzzelli and M. Wright, "Innovation through Tradition: Lessons from Innovative Family Businesses and Directions for Future Research", *Academy of Management Perspectives*, vol.30, No.1, 2016, p.93-116.

[4] R. Katila and G. Ahuja, "Something old, something new: a longitudinal study of search behaviour a new product introduction", *Academy of Management Journal*, vol.45, No.6, 2002, p.1183-1194;

[5] L. Fleming and O. Sorenson, "Technology as a Complex Adaptive System: evidence from Patent Data", *Research Policy*, vol.30, No.7, 2001, p.1019–1039, p.1020.

This paper focuses on an industry at the cutting edge of modern technology, the semiconductor design industry, and investigates its use of both 'old' and recent knowledge from various industries and entities. Examining the patent records of 28 semiconductor design multinational enterprises (MNEs) from the early 1970s to 2013, we study in particular the contribution of knowledge generated by corporations and research institutions in France.

II. "Old" knowledge in the innovation process

The importance of 'old' knowledge in innovation activity is grounded in theory and empirical evidence. Theoretical foundations can be found in the notion that technology is a cumulative, incremental and differentiated process.[6] In this notion the existing knowledge stock, both internal to the firm and in a specific location, is the foundation of technological process. However, for this very same reason, firms and regions may suffer from technological lock-in. Furthermore, a firm's internal stock of knowledge plays an important role for their absorptive capacity—a firm's ability to recognise and utilise external knowledge.[7] Thus, old wisdom is important in order to access, select and absorb new knowledge.[8]

A distinguished tradition of work, beginning with Gilfillan and Schumpeter in the 1930s, put forward an interpretation of innovation as a new combination of existing technologies and knowledge, which, through 'crucial steps' and 'gradual accretions', is brought to a new range of applications.[9] In their milestone work Nelson and Winter argued that "the creation of any sort of novelty in art, science, or practical life — consists to a substantial extent of the recombination of conceptual and physical materials that were previously in existence."[10] For instance, the early development of the steam engine can be traced back to the Savery engine of the last decade of the seventeenth century, which evolved, through a series of technical

[6] R.R. Nelson and S.G. Winter, *An Evolutionary Theory of Economic Change,* Cambridge, MA, Harvard University Press, 1982; K. Pavitt, "International Patterns of Technological Accumulation", in N. Hood and Vahlne J.E. (eds.), *Strategies in Global Competition*, London and New York, Routledge, 1988, p.126-157.
[7] W. Cohen and D. Levinthal, "Absorptive Capacity: A New Perspective on Learning and Innovation", *Administrative Science Quarterly*, vol.35, No.1, 1990, p.128-152.
[8] S.L. Cohen and M. Tripsas, "Managing Technological Transitions by Building Bridges", *Academy of Management Journal*, vol.61, No.6, 2018, p.2319-2343.
[9] J. Schumpeter, *Theory of Economic Development*, Cambridge, Harvard University Press, 1934, p.223. Gilfillan, S.C. 1935. *Inventing the Ship*. Chicago: Follett Publishing, p.275.
[10] Nelson and Winter, p. 130; A. Nerkar, "Old is Gold? The Value of Temporal Exploration in the Creation of New Knowledge", *Management Science,* vol.49, No.2, 2003 p.211-229, p.214.

improvements, to the Watts and later Trevithick engines.[11] In a similar vein, David Edgerton stressed how technology in use at any point in time has deep historical roots and, in most cases, acquired further importance throughout subsequent years. This is the case for automobiles and aeroplanes, for example. "Even the key novel technology of the late twentieth century, the electronic computer has been around for many decades. The post-modern world has 40-year old nuclear power stations as well as 50-year old bombers. It has more than a dash of technological retro about it …..".[12]

Innovation as a 'recombinant' search aiming at achieving better "combination and configurations of existing technologies" is well studied in contemporary business and management literature.[13] The recombinant search takes place along the three main dimensions of depth, breadth and the temporal dimension. The depth of search identifies the search for knowledge within a firm's own knowledge base.[14] The breadth of search takes place across different technological and geographical contexts.[15] Temporal search identifies the process by which a firm scans knowledge created at previous points in time in order to create a new product.[16] In his 2003 article, Nerkar maintains that "recombining knowledge from broad time periods is relevant as it can uncover valuable knowledge that is forgotten, under-utilised or whose time has not come."[17] Such knowledge may have not been utilised in full due to bounded rationality, path-dependence or lack of complementary knowledge and technology, which instead might be available when the under-utilised technology is revisited later in time. It is well known that Wilhelm Rontgen discovered X-rays in 1895. However, it was only several

[11] George. Basalla, *The Evolution of Technology*, Cambridge U.K, Cambridge University Press, 1988; A. Nerkar, "Old is Gold? The Value of Temporal Exploration in the Creation of New Knowledge", *Management Science*, vol.49, No.2, 2003, p.211-229, p.214; K. Frenken and A. Nuvolari, "The Early Development of the Steam Engine: an Evolutionary Interpretation using Complexity Theory", *Industrial and Corporate Change*, vol.13, No.2, 2004, p.419–45.

[12] D. Edgerton (2008), *The Shock of the Old. Technology and Global History since 1900*, London, Profile Books, p. xii.

[13] R. M. Henderson and K. B. Clark, "Architectural Innovation: The Reconfiguration of Existing Product Technologies and the Failure of Established Firms", *Administrative Science Quarterly*, vol.35, No.1, March, 1990, p. 9-30; L. Fleming, "Recombinant Uncertainty in Technological Search", *Management Science*, vol.47, 2001, p.117-132; L. Fleming, O. Sorenson / Research Policy, vol. 30, 2001, p.1019–1039, p.1020.

[14] A.S. Miner, P. Bassoff and C. Moorman, "Organizational Improvisation and Learning: A Field Study", *Administrative Science Quarterly*, vol.46, 2001, p.304–37.

[15] R. Katila and G. Ahuja, "Something old, something new: a longitudinal study of search behaviour a new product introduction", *Academy of Management Journal*, vol.45, No.6, 2002, p.1183-1194; L. Rosenkopf and P. Almeida, "Overcoming local search through alliances and mobility", *Management Science*, vol.49, 2003, p.751-766.

[16] R. Katila, "New Product Search Over Time. Past Ideas in their Prime", *Academy of Management Journal*, vol.45, No.5, 2002, p.995-1010, p.995.

[17] Nerkar, 'Old is Gold?', p.213-215.

decades later, with the development of hospital services due to the application of business technologies, that X-ray images became part of routine patient care.

Corporations and inventors might deliberately engage in ‘temporal search’ or ‘temporal exploration’ as a strategy to discover the underexploited or neglected potential of old technologies.[18] A case in point is the rediscovery of natural remedies in the pharmaceutical industry, in which Pfizer has been reported to have invested more than US$1 billion for research into traditional Chinese medicine. Similarly, the American chemical company W.R. Grace has developed a commercial drug based on a herb from India, Neem, the healing powers of which have long been known but not commercially exploited.[19]

The role of historical knowledge in the innovation process does not detract from the importance of the latest knowledge, which represents state of the art in a specific field and the best technological options that have emerged.[20] Researchers argue that by experimenting with technologies that are new to the firm and to the industry, established corporations can constantly renew their capabilities and generate breakthroughs.[21] The search for new knowledge and “of things that might come to be known” is defined in organisational learning literature as knowledge exploration, whereas knowledge exploitation indicates searching for and mastering old knowledge and developing technologies already known, with the aim of generating innovation.[22] Pursuing only one or the other would be a failing strategy for an organisation, as focusing entirely on exploration might mean that the organisation will never enjoy the return of its R&D, whereas focusing entirely on exploitation would lead to inertia,[23] lock-in and obsolescence.[24] Old-technology knowledge has the potential to serve as a valuable resource to be leveraged to keep abreast of radical technological change. The key condition for success with this is the strength of the corporation’s inventive performance with the old

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[18] Nerkar ‘Old is gold?’, p.213-215.

[19] A. Messeni Petruzzelli, D. Rotolo and V. Albino, “The Impact of Old Technologies on Innovation: the Case of the US Biotechnology Industry”, *Technology Analysis and Strategic Management*, vol. 24, No.5, May 2012, p.453-466.

[20] Nerkar, ‘Old is gold?’, p. 213-215.

[21] Ahuja and Lampert, “Entrepreneurship in the Large Corporation”; Leonard-Barton, “Core Capabilities”;

[22] R. Katila and G. Ahuja, “Something Old, Something New”.

[23] Leonard-Barton, “Core Capabilities”; M. Tripsas and G. Gavetti, “Capabilities, Cognition and Inertia: Evidence from Digital Imaging”, *Strategic Management Journal*, vol.21, No.10/11, 2000, p.1147-1161.

[24] J. G. March, “Exploration and Exploitation in Organizational Learning”, *Organization Science*, vol.2, No.1, 1991, p.71-87; S.J. Liebowitz and S.E. Margolis, “Path Dependence, Lock-in, and History”, *Journal of Law, Economics and Organization,* vol.11, No.1, April 1995, p. 205-226.

technology. If the firm has strong R&D its innovative performance in the new technology will be enhanced.[25]

As mentioned above, a further dimension of recombinant knowledge search is the "breadth" or "scope", which indicates a search that occurs across different technological and geographical contexts.[26] The search across different contexts aims at product development by expanding the pool of knowledge that enables firms to develop variations. Moreover, the "breadth" or "scope" of the search aims at broadening a firm's range of new products.[27] However, extensive searches also mean higher costs than narrower searches, which may therefore hinder innovation.[28] Despite acknowledging the cost of a search, incorporating knowledge across different technological, organisational and geographical contexts is considered of paramount importance for achieving technological breakthroughs.[29]

III. The Dataset

Our analysis is based on 28 world-leading corporations in the integrated circuit (IC) design industry, including multinational enterprises such as ARM and QUALCOMM, the leading suppliers of IC products for mobile devices globally. In the history of modern manufacturing industries, the rise of the IC design business is a recent phenomenon.[30] It started in the 1990s when vertical specialisation began to slice the semiconductor industry into a production network spanning countries and continents.[31] Semiconductor design companies outsource manufacturing, hence their idiomatic name of fabless, and focus on the development of algorithms and circuit design, striving for flexibility, product customisation and differentiation

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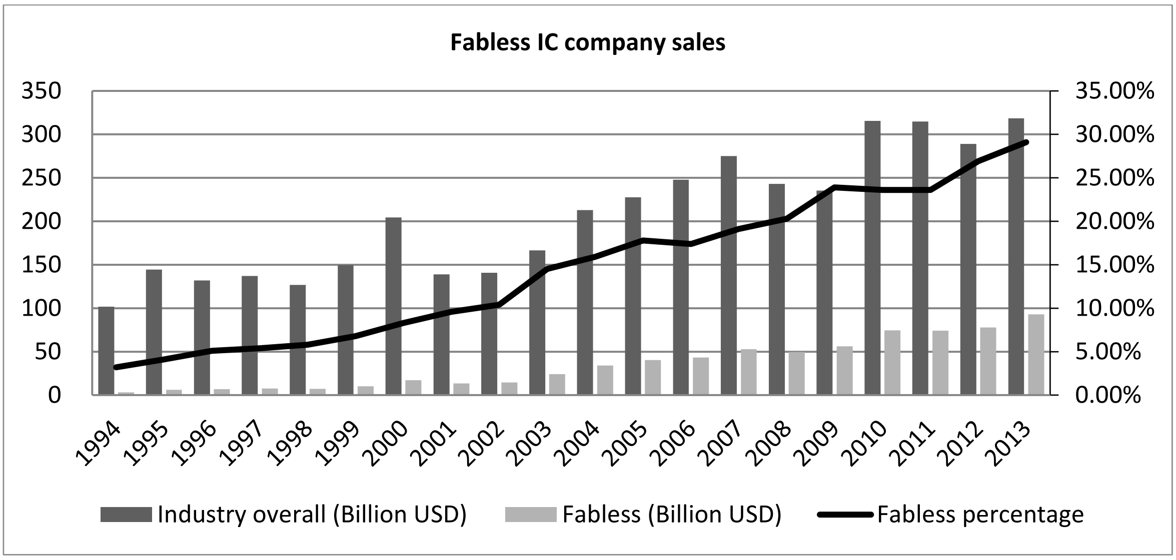
25 S.L. Cohen and M. Tripsas, "Managing Technological Transitions by Building Bridges", *Academy of Management Journal*, vol.61, No.6, 2018, p.2319-2342.
26 Katila and Ahuja, "Something Old"; L. Rosenkopf and P. Almeida, "Overcoming Local Search through Alliances and Mobility", *Management Science*, vol.49, No.6, 2003, p.751-766.
27 Katila and Ahuja, "Something Old".
28 L. Laursen and A. Salter, "Open for Innovation: the Role of Openness in Explaining Innovation Performance among UK Manufacturing Firms", *Strategic Management Journal*, vol. 27, 2006, p.131–150; A.Gkypali, D.Filiou and K.Tsekouras, "R&D Collaborations: Is Diversity Enhancing Innovation Performance?" *Technological Forecasting and Social Change*, vol.118, 2017, p. 143-152.
29 Different organizational forms include for instance public research and science institutions. Cohen and Tripsas, "Managing Technological", p. 2321; G. Ahuja and C. Lampert, "Entrepreneurship in the Large Corporation: a Longitudinal Study of How Established Firms Create Breakthrough Inventions", *Strategic Management Journal* vol.22, No.6-7, 2001, p.521-543.
30 D. Nenni and P.M. McLellan, *Fabless: The Transformation of the Semiconductor Industry*, SemiWiki.com Project, 2014.
31 J.T. Macher and D.C. Mowery, "Vertical Specialization and Industry Structure in High Technology Industries", *Advances in Strategic Management*, vol. 21, 2004, p. 317–355.

and the ability to enter new product categories, locations and national markets. Leading IC design companies tend to operate a global network of design centres. Internationalisation is paramount for semiconductor companies as a strategy to obtain access to country-specific engineering expertise, skilled labour and market demand. Subsidiaries of our 28 top IC design companies are located in important semiconductor clusters in Europe, namely Sophia Antipolis in France, the Dresden area in Saxony and the Cambridge cluster in the United Kingdom.[32]

Figure 1 below provides an overview of the growth of the IC design industry compared with the overall semiconductor industry.

Figure 1: Market size of the global IC design industry 1994-2013



Source: Global Semiconductor Association https://www.gsaglobal.org/gsa-resources/forecasts/actual-growth/ (accessed on 16 /07/2019)

To compile a sample of representative IC design companies, we reviewed industrial reports and industrial publications of the past two decades, and constructed a historical list of leading design companies between 2001 and 2008.[33] The primary source of reference is the Leading (Top) Fabless IC Suppliers' list published by IC Insights, an industry publication used in

[32] Nenni and McLellan, *Fabless*.

[33] We focus on the time period between the dotcom crisis in the 2001 and the financial crisis in the 2008 for two reasons: (1) the dotcom crisis fundamentally reshaped the landscape of the IT industry; (2) the financial crisis severely affected global R&D investment and resulted in the distortion of patenting records.

previous studies to identify prominent semiconductor companies.[34] In this list, we identified 41 design companies — that had accounted for more than one per cent of the global market share in at least one year — and further reviewed their suitability for subsequent analysis. We briefly checked corporate histories and firm patenting, and excluded one private firm, one founded in 2007, two with complex histories of mergers and acquisitions, one with its main source of sales revenues from other businesses, and several others with minuscule international patenting. While this process successfully selected 26 design companies based in North America and East Asia, we further included two western European firms — Dialog Semiconductors, based in Germany, and ARM, based in the United Kingdom. Overall, these 28 design companies and their global network of design centres span a wide geographical area across the globe.

We compiled the patent and citation records of these 28 design companies from the USPTO dataset and the EPO PATSTAT database 2018 Spring edition.[35] The semiconductor industry patents intensively and the IC design companies in particular benefit from an effective patent regime.[36] Both the trade and transfer of designs to external parties rely on the guarantee of intellectual property rights.[37]

We tracked and analysed the patenting records of these 28 firms from the early 1970s to 2013. This gave us a total of 30,964 citing and 137,691 cited patents. Within this group we identified 6,796 design company patents with citations to 61 France-based assignee organisations in 11,265 citations, including the French-American Alcatel-Lucent and the French-Italian STMicroelectronics. These 61 assignees include organisations in both public and private sectors (see Table A.1 in Appendix). For brevity, we refer to these organisations as French assignees in the remainder of the paper.

Figure 2 below shows the data that were extracted manually from each patent record. Information on patent assignees and residence of first inventor was used to identify the location

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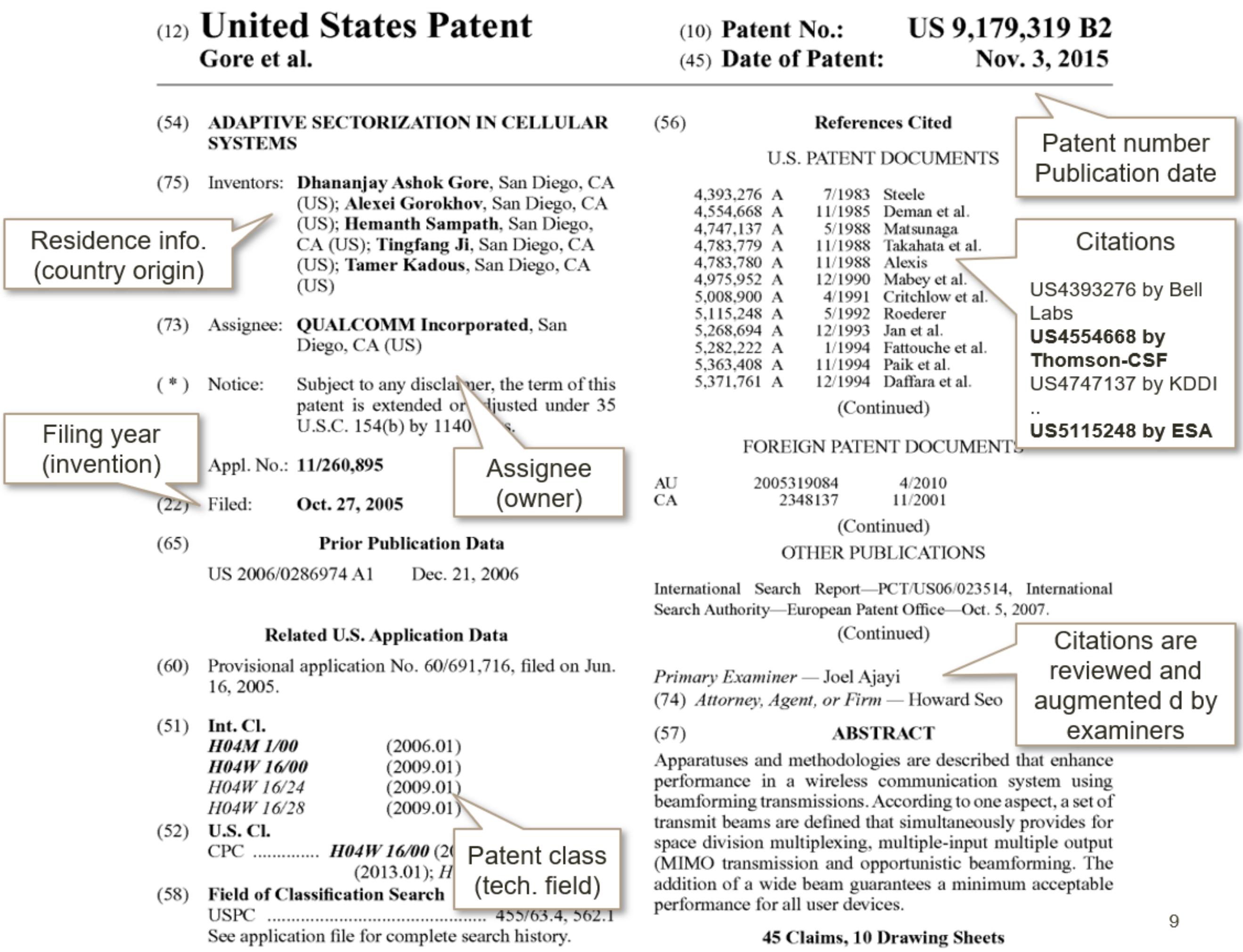
[34] D.H. Hsu and R.H. Ziedonis, "Resources as Dual Sources of Advantage: implications for Valuing Entrepreneurial- Firm Patents", *Strategic Management Journal*, vol.34, No.7, 2013, p. 761–781.
[35] https://www.epo.org/searching-for-patents/business/patstat.html
[36] B.H. Hall and R.H. Ziedonis, "The Patent Paradox Revisited: An Empirical Study of Patenting in the US Semiconductor Industry, 1979-199,." *RAND Journal of Economics*, vol.32, No.1, Spring 2001, p.101–128.
[37] C. Brown and G. Linden, *Chips and Change: How Crisis Reshapes the Semiconductor Industry*, MIT Press, 2009; R. Mazzoleni and R.R. Nelson, "The Benefits and Costs Of Strong Patent Protection: A Contribution to the Current Debate", *Research Policy*, vol.27, No.3, 1998, p.273–284.

of origin of the IC design invention.[38] Cited patents were identified from the USPTO database using the patent number and the same information was extracted from the cited patents, thus identifying the location of the assignee organisations. The example below shows a patent owned by one of the major corporations in our sample QUALCOMM, headquartered in San Diego CA. The patent was filed in 2015 and concerned an innovation that enhanced the performance of wireless communication systems. Reference to prior art includes a patent filed in 1983 by Thomson-CSF (Paris) concerning the frequency-hopping radio communications system between master and slave stations. Another citation refers to a patent filed in 1990 by the Agence Spatiale Europeenne (FR) concerning a device to feed multibeam antennas. The oldest citation in the 2015 QUALCOMM patent goes back to a patent filed by Bell Labs in 1980 that refers to a secure communication system for analog signals.

A caveat applies to patents filed by European corporations and inventors, as these might be less accurate for two reasons: European inventor and city name entries are often misspelt in US patent records; the high population density in western Europe implies that inventors could be hired in one country and live in a neighbouring one.

[38] Cantwell and O. Janne, "Technological Globalisation and Innovative Centres: The Role of Corporate Technological Leadership and Locational Hierarchy", *Research Policy*, vol.28, No.2–3, 1999, p.119–144.

Figure 2: Example of information extracted from patent records


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

(10) **Patent No.: US 9,179,319 B2**
(45) **Date of Patent: Nov. 3, 2015**

(54) **ADAPTIVE SECTORIZATION IN CELLULAR SYSTEMS**

(75) Inventors: **Dhananjay Ashok Gore**, San Diego, CA (US); **Alexei Gorokhov**, San Diego, CA (US); **Hemanth Sampath**, San Diego, CA (US); **Tingfang Ji**, San Diego, CA (US); **Tamer Kadous**, San Diego, CA (US)

(73) Assignee: **QUALCOMM Incorporated**, San Diego, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 1140 days.

Appl. No.: **11/260,895**

(22) Filed: **Oct. 27, 2005**

(65) **Prior Publication Data**
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H04W 16/00 (2009.01)
H04W 16/24 (2009.01)
H04W 16/28 (2009.01)

(52) **U.S. Cl.**
CPC .... ***H04W 16/00*** (2013.01); *H*

(58) **Field of Classification Search**
USPC 455/63.4, 562.1
See application file for complete search history.

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4,747,137	A	5/1988	Matsunaga
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4,783,780	A	11/1988	Alexis
4,975,952	A	12/1990	Mabey et al.
5,008,900	A	4/1991	Critchlow et al.
5,115,248	A	5/1992	Roederer
5,268,694	A	12/1993	Jan et al.
5,282,222	A	1/1994	Fattouche et al.
5,363,408	A	11/1994	Paik et al.
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(Continued)

Primary Examiner — Joel Ajayi
(74) *Attorney, Agent, or Firm* — Howard Seo

(57) **ABSTRACT**

Apparatuses and methodologies are described that enhance performance in a wireless communication system using beamforming transmissions. According to one aspect, a set of transmit beams are defined that simultaneously provides for space division multiplexing, multiple-input multiple output (MIMO transmission and opportunistic beamforming. The addition of a wide beam guarantees a minimum acceptable performance for all user devices.

45 Claims, 10 Drawing Sheets

A distinguished tradition of work uses patents as a proxy for innovation. Patents are publicly available and are a measure of inventive output. Measures of inputs, such as investment in R&D, be it human capital or assets, are less available to researchers and steeped into industry and firm routines. Thus, these measures of inputs do not take into account that some inventions and innovation are more resource-intensive than others and that some corporations might be more efficient than others in generating inventions and innovation from R&D expenditure.[39]

[39] See for instance the path-breaking work J. Schmookler, *Invention and Economic Growth*. Harvard University Press: Cambridge, MA, 1966.

The drawbacks of patents have been extensively discussed in the literature.[40] Examples of such limitations are that not every invention is patented and that not every patent corresponds to an innovation. However, surveys based on large samples have demonstrated that patents tend to follow the distribution of innovation, when the latter is more directly measured.[41] One can conclude that the large size of a dataset improves the accuracy of this proxy and reduces accidental biases. A related concern is that the economic and technological value of individual patents vary. Some work addresses this concern using data about the lifespan of patents and their renewals.[42] Other work, including this research, uses the number of citations received by a certain patent as an indicator of the same characteristics. This well-established indicator has the advantage of being correlated with patent renewals and the economic value of the underlying technology.[43] More recently, patents have been used as a "specific proxy for the creation of specialised knowledge inputs into innovation".[44] Our research is in line with this latest approach, while being aware that citations can only indicate codified specialised knowledge, and do not include tacit knowledge.[45]

IV. The input of 'old' French knowledge into innovation in IC design

Figure 3 below presents a stylised diagram of the directed network of citations from ten IC design MNEs with highest out-degrees to ten French assignees with highest in-degrees. The width of the connecting ties is proportional to the logarithm of citation counts. The out-degree of an IC design MNE suggests the intensity of its knowledge-seeking from the French assignees in our sample, whereas the in-degree of a French assignee indicates the extent to which the 28 IC design MNEs draw upon its patented knowledge.

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[40] See the overview J. Cantwell, 'Introduction' in J. Cantwell (ed.) *The Economics of Patents*, Edward Elgar Publishing Ltd., Cheltenham, UK, 2006.

[41] K. Pavitt, M. Robson and J. Townsend, "The Size Distribution of Innovating Firms in the UK, 1945-1983", *Journal of Industrial Economics*, vol.35, No.3, 1987, p.297-316.

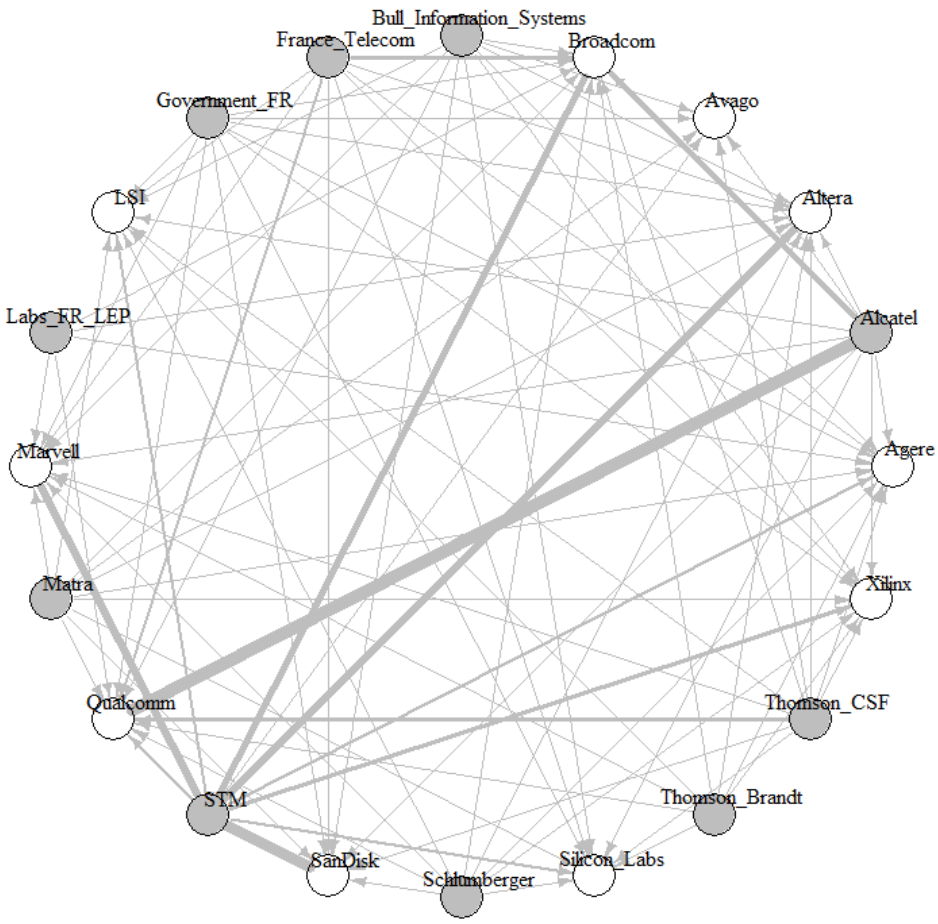
[42] On this point see the milestone work A. Pakes, "Patents as Options: some Estimates of the Value of Holding European Patent Stocks", *Econometrica*, vol.54, 1986, p.755–784.

[43] B.H. Hall, A.B. Jaffe and M. Trajtenberg, "Market Value and Patent Citations", *Rand Journal of Economics,* vol.36, No. 1, 2005, p.16-38.

[44] Cantwell, 'Introduction' p.6.

[45] S. G. Winter, "Knowledge and Competence as Strategic Assets", in Teece D.J. (ed.), *The Competitive Challenge: Strategies for Innovation and Renewal,* Cambridge, MA, Ballinger Publishing Company, 1987, p.186-219.

Figure 3: Citation network of ten IC design MNEs and ten French assignees with highest in- and out-degree centralities



Source: French patent assignees included in the original dataset.

Keys: Grey nodes represent French organisations and clear nodes represent citing IC design MNEs. The thickness of connecting ties is proportional to the logarithm of citation counts.

The diagram shows that the IC design MNEs have drawn to a great extent from the technological knowledge created by STMicroelectronics (STM in the graph), one of the leading semiconductor companies in Europe, and Alcatel, one of the world's leading telecommunication equipment supplier. In particular, inventions produced by Alcatel are extensively cited by QUALCOMM. The corporation established in 1985 has been a leading developer and supplier of CDMA-based communication IC products. This technology became the primary technological standard behind the third generation (3G) mobile telecommunication and various mobile services. Among more than a thousand citations made by QUALCOMM to Alcatel patents, around half are in *multiplex communications* (USPC370) and a quarter in *telecommunications* (USPC455).[46]

STMicroelectronics. formed from the merger of the Italian SGS Microelettronica and the French Thomson-CSF semiconductor business in 1987, was an early pioneer in Smart Card and mobile phone IC.[47] Marvell and SanDisk are both renowned designers of flash memory storage devices. These corporations cited STMicroelectronics' patents in *static information storage and retrieval* (USPC365). The California-based corporation Altera focuses on communications, electronic data processing, industrial, and consumer applications with high-density re-programmable logic devices (PLD). Altera cited STMicroelectronics patents in *electronic digital logic circuitry* (USPC326).

Bull Information Systems, a computer company incorporated in the 1930s, is also widely cited by our IC design companies. Lastly and not surprisingly, these semiconductor design companies have also drawn upon technological inventions produced by Thomson-Brandt, Thomson CSF and Matra in the French aerospace and defence industries, which are usually considered as the advanced knowledge sources alongside public and private research institutes. The technological development of the aerospace and defence industry has a close relationship with the semiconductor industry, as both the early source of technology and the earliest clientele.[48]

Three of the semiconductor design companies, ARM, Broadcom and CSR, and many of the French organisations identified in this analysis, have operations in the cluster of Sophia Antipolis, including Dassault, France Telecom, STMicroelectronics, Schneider and Thales. High technology activities started in Sophia Antipolis in the 1970s particularly in the industries of Information Technology and Life Science. These included investment from MNEs that wanted to adapt their products to the requirements of the European markets, but also investment

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[46] In the classification of technological fields adopted by the United States Patent and Trademark Office (USPTO) multiplexing is defined as "The simultaneous transmission of two or more information signals in either or both directions over a common (same) transmission medium in such a manner that the information signals may be discretely recovered" (https://www.uspto.gov/web/patents/classification/uspc370)

[47] http://www.fundinguniverse.com/company-histories/stmicroelectronics-nv-history/

[48] Langlois R. N., and Steinmueller W. E., The evolution of competitive advantage in the worldwide semiconductor industry, 1947-1996. *The Sources of Industrial Leadership,* New York, Cambridge University Press, 1999, p.19–78.

from the French government that wanted to promote less industrialised regions. The early arrival of France Telecom was particularly important as it provided internet infrastructure.[49] From the initial dominance of MNEs, followed the emergence of several technologically advanced small- and medium-sized enterprises. This development resulted from the crisis in the 1990s when a number of large international firms abandoned this location leaving behind a pool of expertise, which generated a number of spin-offs and start-ups.[50] From the mid-1980s, the Information Technology industry was further reinforced by the establishment of public and private education and research institutes. Indeed, the intensive interaction among private firms and research institutes is an important characteristic of Sophia Antipolis.[51] Education and research institutes include the University of Nice Sophia Antipolis, INRIA (National Research Institute on Informatics and Automation) and CNRS (National Centre of Scientific Research). Moreover, the European Telecom Standardization Institute (ETSI), located in Sophia-Antipolis since 1989, has also been critical to the development of telecommunication technologies.[52]

We aggregated the French assignee organisations of the cited patents into 23 industries (see classification of industries in table A.1 in the Appendix). Admittedly, many organisations in our list were at some point highly diversified conglomerates. Our categorisation is thus inherently limited. This limitation notwithstanding, the 23 industries represent sources of codified knowledge mentioned in our 30,964 IC design patents. In order to assess the ‘age of knowledge’ cited in our IC design patents we computed the time lag between the filing date of the cited patents and the filing date of the IC design citing patent (see citation lag in Table 1 below). We computed this indicator for French cited patents and non-French counterpart, i.e. rest of the world (RoW in parentheses in Table 1).

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[49] R. Parker, ‘Evolution and Change in Industrial Clusters: An analysis of Hsinchu and Sophia Antipolis’, *European Urban and Regional Studies*, vol.17, No.3, 2010, p.245-260; A.L.J. Ter Wal, “Cluster Emergence and Network Evolution: a Longitudinal Analysis of The Inventor Network in Sophia-Antipolis”, *Regional Studies*, vol.47, No.5, 2013, p.651-668.
[50] M. Queré, “Sophia-Antipolis as a Reverse’ Science Park: from Exogenous to Endogenous Development”, in Frenken K. (ed.), *Applied Evolutionary Economics and Economic Geography*, Cheltenham, Edward Elgar Publishing Ltd., 2007, p.48-66.
[51] Ter Wal, “Cluster emergence”.
[52] A. Di Minin and M. Bianchi, “Safe Nests in Global Nets: Internationalization and Appropriability of R&D in Wireless Telecom”, *Journal of International Business Studies*, vol.42, No.7, 2011, p.910.

Table 1: Average age of French cited patents by the industry of origin

Industry category	Oldest patent cited	Latest patent cited	Average citation lag [RoW] 2,3	Median citation lag [RoW]2	Citation count
IC	1975	2011	7.19 [7.16]	6.44 [6.26]	5178
Telecom-Infrastructure	1967	2010	6.97 [7.08]	6.47 [6.42]	2400
Defense[1]	1965	2001	16.25** [12.89]	14.32 [10.43]	805
Telecom	1991	2006	8.38** [7.71]	8.47 [6.95]	766
IT	1974	2002	11.27** [8.61]	9.55 [7.26]	724
Government (FR)	2000	2000	10.5** [11.48]	9.69 [8.66]	341
Energy-Petrol	1971	2004	11.61** [16.4]	10.2 [15.03]	279
Aerospace-Spacecraft[1]	1970	2007	9.11** [12.87]	9.49 [10.58]	225
Machinery	1975	2007	10.42* [12.1]	6.04 [9.77]	99
Labs	1978	1989	14.58** [12.95]	14.29 [10.94]	96
Defence-Communication[1]	1981	1989	12.23* [11.18]	12.27 [9.09]	76
Instrument	1978	2003	6.56** [9.18]	4.46 [7.53]	46
Energy-Electrical	1987	2006	8.82** [13.23]	9.71 [11.59]	44
Aerospace-Communication	1976	1994	13.17** [8.79]	12.17 [7.66]	43
Broadcast	2000	2000	3.35** [10.08]	3.82 [8.73]	39
IC-Smart	1997	2007	6.21** [10.21]	6.64 [9.84]	31
Aerospace-Aircraft[1]	1980	2000	8.06 [7.17]	7.15 [5.89]	18
Broadcast-Distribution	1980	1988	20.61** [6.76]	22.04 [6.45]	15
Med	1982	1997	14.85** [9.95]	14.46 [7.91]	12
Chemical	1989	2004	9.06 [11.06]	7.4 [7.71]	9
Motor	1971	2000	12.97 [9.52]	13.35 [8.02]	8
Universities (FR)	1965	2001	4.87** [9.07]	4.95 [8.12]	4
IT-Service	1994	1998	9.95 [8.18]	11.12 [7.79]	3

Source: original dataset

Keys: 1: Most aerospace companies are also defence product suppliers. Here the defence categories refer to specialised defence product suppliers; 2. The average and median ages of citations to rest of the world [RoW] patents are in parenthesis; 3: The average and median ages of citations to rest of the world [RoW] patents are in parenthesis; 4: ** t-test with $p<0.05$;* t-test with $p<0.1$.

Table 1 shows that the input of codified knowledge, i.e. citations, varies considerably across industries. The importance of within-industry knowledge flow, indicated by more than 5000 citations in the IC industry, is not surprising in this highly competitive and knowledge-intensive industry. The 'age' of knowledge is rather recent, suggesting that IC design firms need to be at the forefront of technological advances in the industry in order to sustain their competitive positions. The 'age' of citations to IC inventions generated in other countries is also recent and very similar to the French counterpart, suggesting that intra-industry knowledge flows occur globally and almost concurrently. The network graph also shows that French-Italian STM is a major source of knowledge in this industry. The company has built and operated state-of-the-art semiconductor manufacturing plants in Grenoble and remains a world-leading firm in the semiconductor industry to this day.

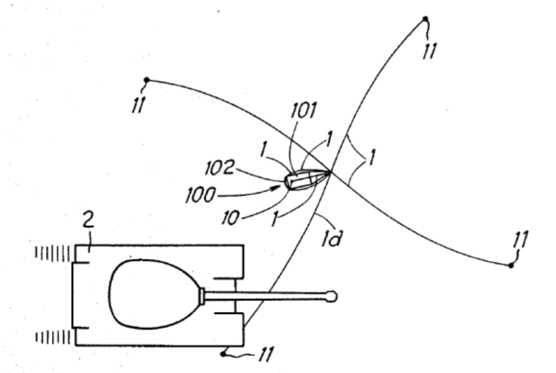
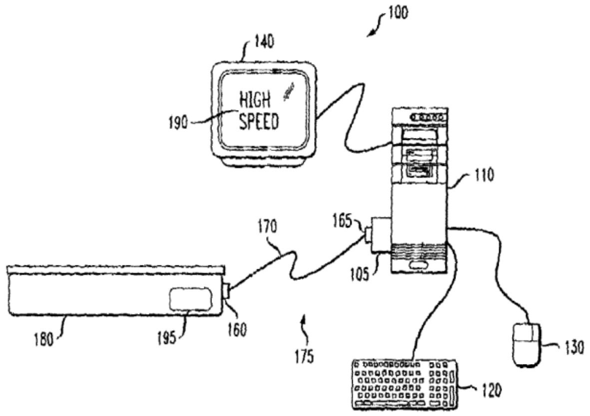
Similarly to the IC industry, citations to Telecom Infrastructure have a relative short time lag, despite spanning over a long period of time, which indicates that IC design firms need to consult the legacy as well as the latest innovations and technological standards in this industry. Telecommunication is one of the most important sources of knowledge for the semiconductor industry, both in France and globally. The IC design industry, like many other branches of the electronic industry, relies on telecom infrastructure. Very importantly, the standard set in the 1990s by the European Telecommunications Standards Institute (ETSI), based in Sophia Antipolis, played a key role in defining the technological trajectory of the entire industry, and created the conditions for great commercial returns for those corporations the intellectual property of which was included in the ETSI standards.[53] Moreover, the telecommunication industry has been one of the most important clientele for semiconductor design companies, because IC products are used widely in the land-based telephones, internet equipment as well as mobile devices and infrastructure of 2/3/4G networks.

[53] R. Bekkers, G. Duysters and B. Verspagen, "Intellectual Property Rights, Strategic Technology Agreements and Market Structure. The case of GSM," *Research Policy*, vol.31, No.7, 2002, p.1141–1161; Di Minin and Bianchi, "Safe Nests", p. 913.

Patents produced in the Defence sector cover a long timespan and the ‘age’ of French patents is significantly higher than the non-French, or international, counterpart. This latter feature is shared with Labs and the IT industry, to mention only those industries with around 100 citations and above. The ‘older age’ could imply that French knowledge source entities are earlier pioneers in these industries and that they produce ‘base’ research and inventions that lay the foundations for inventions and innovation in the commercial electronics industry. Lastly, the t-test rejects the difference between the average time lags of citations made to French knowledge source entity in the IC industry and those to the rest of the world. In other words, in terms of the innovation in the semiconductor industry, the French semiconductor industry appears to be on par with the rest of the world.

Several cases could be mentioned to highlight the importance of the Defence sector as a source of knowledge for the IC design industry. Figure 4 below displays, on the right, a patent filed in 2007 by one of our 28 MNEs, Agere Systems Inc. (Allentown, PA). The company was established in 2000, as a subsidiary of Lucent Technologies. However, it spun off from Lucent in the following year and, after going through restructuring and consolidation, Agere gradually became focused on IC products for storage devices, mobile phones, high-speed communications systems and personal computers. The patent in Figure 4 below protects a detection system that uses peripheral devices (i.e. mouse, keyboard) to diagnose the USB connection. The prior art in the Agere’s patent includes a patent filed by the Société Européenne de Propulsion in 1983 and protecting the invention of an anti-tank mine. The likely explanation of the relevance of this military invention to the Agere’s patent is that the military invention embodied a detection system that used cables to detect tanks movement and guide and trigger the anti-tank mine.

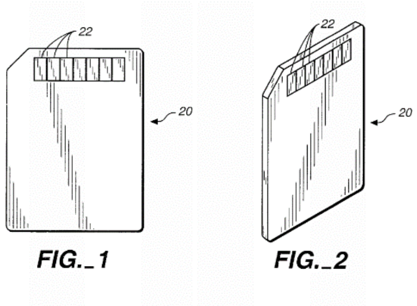
Figure 4: Signal data detection system

Patent filed by the Société Européenne de Propulsion (1983)	Patent filed by Agere Systems Inc. (2007)
	

Source: United States Patent and Trademark Office, Patent Nos. 4402271 (1983) and 7272740 (2007)

The importance of the IT industry as a source of codified 'old' knowledge for the IC industry is exemplified by the patent below filed by SanDisk in 2002. SanDisk Corporation was founded as SunDisk in California in 1988; in 1996, the company went public and changed its name to SanDisk. SanDisk has since its early years focused on flash memory storage devices for consumer electronic devices as well as industrial and aerospace applications. The technology of flash memory storage allows digital information to be stored in durable and compact solid-state devices based on IC products. The advantages of such devices — smaller dimension, lower power consumption and high tolerance to shock and vibration — make flash memory storage devices ideal for applications in small and portable electronic devices. As the market pioneer and technological leader of flash memory storage devices, SanDisk led the industry and supplied some of the earliest flash memory storage devices to IBM and NASA. For instance, by the end of 2013, one of its key patents filed in 1989 — US Patent No. 5,602,987 — had received more than 400 citations.

Figure 5: Integrated circuit memory card design by SanDisk



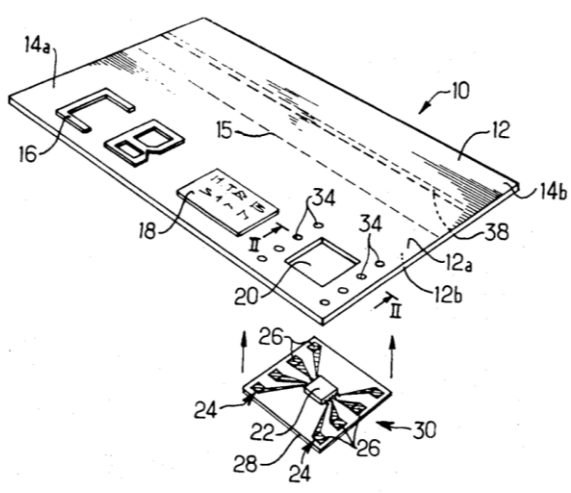
Source: United States Patent and Trademark Office, Patent no. 6410355 (2002)

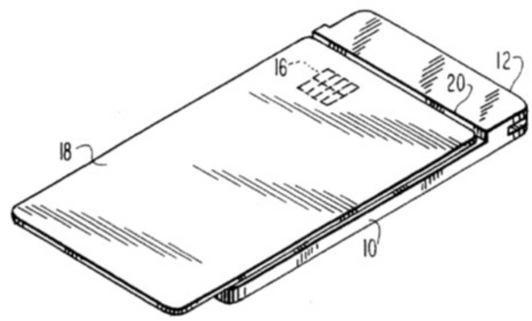
This specific patent refers to the packaging for a flash EEPROM memory, using terminals that are part of a conductive layer of a circuit board. The patent refers extensively to prior art, including a patent filed by Bull Information Systems in 1979, concerning a standardised information card (on the left in Figure 6), and a patent filed by Gemplus Card International in 1992, concerning an exchangeable memory card having several integrated circuits for personal computers (on the right in Figure 6).

Figure 6: Examples of prior art cited by SanDisk (Patent no. 6410355, 2002)

Standardized information card by Compagnie Internationale pour l'Informatique Cii-Honeywell Bull (1979)

Exchangeable memory cards by Gemplus Card International (1992)





Source: United States Patent and Trademark Office, Patent nos. 222516 (1979) and 5375037 (1992).

V. Conclusions

This paper set forth to assess the importance of 'old knowledge' in a technology-intensive and modern industry such as the semiconductor industry, with particular emphasis on knowledge generated by organisations based in France. We find that the age of codified knowledge, produced in France and adopted by MNEs, varies across industries. The industries that were major sources of codified knowledge, IC and Telecom-infrastructure, display a relatively short citation lag, an indicator of the age of knowledge. Cited patents from these industries are between six and seven years old, which is in line with the average of cited patents produced in the same industries in the rest of the world. Thus, IC and Telecom-infrastructure industries, in France and globally, support the 'recency' argument discussed in the management and business literature and corporations seem to engage in knowledge exploration more than knowledge exploitation. However, various industries represented in our dataset display an average 'age' of knowledge well above ten years. In the Defence and IT industries in particular, the age of cited knowledge is even greater in France than in the rest of the world. Thus, these industries support the argument in favour of exploitation of 'aged knowledge'.

The value of 'old wisdom' might be contingent on the specific industry where knowledge originates. In cases where knowledge originates in industries that undertake base research with a wide range of applications, such as Defence, its knowledge might be of great value to corporations and industries for long periods of time. Moreover, for its very nature, the Defence industry might only disclose advances and inventions after extended periods of time, upholding secrecy in the first place. In other instances, the protracted value of knowledge might be related to the high quality of research and inventions generated in that industry and country. The 'older age' of citations of IT patents in France, as compared to the rest of the world, might be related to the high quality and pioneering role of inventions produced by that industry in that country, possibly in Sophia Antipolis in particular.

The study of citations to French assignees reveals the multitude of French industries that pioneered various technological fields and produced innovations that benefited the IC industry for extended periods of time. Inventions generated in the same IC industry are by far the most cited. An additional and very important source of knowledge is Telecom Infrastructure, followed at distance by the Aerospace and the Defence industries, which are also very innovative but have a smaller propensity to patent. These findings demonstrate the considerable ‘breadth’ of knowledge search undertaken by IC design MNEs.

There remain pending issues for future studies concerning in particular the firms and individuals who rediscovered these aged technologies, who they were and under what circumstances the rediscovery occurred. Technological inventions, especially those disclosed in patent documents, have the virtue of diffusion across time and space, borders, cultures and knowledge domains. The analysis in this research found the traces of aged French inventions that inspired new inventions in North America and East Asia. Economic historians suggest that the process of diffusion and repurposing of technology could, in some cases, take decades until the true impacts of technologies are revealed.[54] For future studies, one may look into the motivations and processes of these firms and individuals who embarked on the temporal search for knowledge.

[54] Edgerton, “*The Shock of the Old*”.

APPENDIX

Table A.1 List of French knowledge sources identified in this research

French assignee	Industry category	French assignee	Industry category
Adret Electronique	Instrument	Oberthur Card Systems	IC-Smart
Aérospatiale	Aerospace-Spacecraft	Pierre Fabre Medicament	Medical
Alcatel	Telecom-Infrastructure	Renault	Motor
Alcatel-Evolium S.A.S.	Telecom-Infrastructure	Rhone-Poulenc	Medical
Alstom	Machinery	SA Telecommunications	Aerospace-Spacecraft
Areva	Energy-Electrical	SAFT	Defense
Biscosa Societe de Recherche	n/a	SAGEM	Telecom-Infrastructure
Bull Information Systems	IT	Sagem-Autoliv	Motor
Canal Group	Broadcast	Saint-Gobain	Chemical
CEPE	Instrument	Schlumberger	Energy-Petrol
CII	Defense	Schneider Automation	Machinery
CIMSA	Aerospace-Aircraft	Schneider Electric	Energy-Electrical
CP8 Transac	IC-Smart	Sextant Avionique	Aerospace-Aircraft
Dassault	Aerospace-Aircraft	SFR	Telecom
EADS	Aerospace-Spacecraft	SLE-Citerel	Conglomerate
Elf Aquitaine	Energy-Petrol	SNECMA	Aerospace-Spacecraft
Elf Atochem	Chemical	Societe Europeenne De Propulsion	Aerospace-Spacecraft
ESA	Aerospace-Spacecraft	Societe NEO-TEC	n/a
ETA SA	Instrument	SODERN	Aerospace-Spacecraft
Etablissements Caillau	Machinery	Sofamor	Medical
Framatome	Energy-Electrical	Sofradir	Defense
France Telecom	Telecom	Solaic	IT-Service
Giat Industries	Defense	STM	IC
Jeumont-Schneider	Machinery	TDF Group	Broadcast-Distribution
Labs (FR-LEP)	Labs	Telemecanique	Machinery
Labs (FR-SCART)	Labs	Thales	Aerospace-Spacecraft

LMT Radio Professionnelle	Defense-Communication	Thomson-Brandt	Defense
L'Oreal	Chemical	Thomson-CSF	Defense
Matra	Aerospace-Spacecraft	Thomson-CSF Semiconducteurs	IC
Merlin Gerin	Energy-Electrical	Government (FR)	Government (FR)
		Universities (FR)	Universities (FR)