The Evolution of Patent Thicket in Hybrid Vehicles.

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Abstract:

Most of the modern technologies are complex systems that require the assembly of several components. If these components are owned by different companies and inventors, the result is a technological landscape characterized by property rights interaction. This type of landscape is called by Shapiro (2001) patent thicket. This article argues that the increasing complexity in the architecture of hybrid vehicles and the use of patents as strategic devices, are taking shape in the sector as patent thickets. To prove the existence and evolution of the patent thicket a quantitative methodology, built from the USPTO is proposed. The results indicate that the hybrid vehicle industry is forming a network of interrelated patents. Results indicate that the hybrid vehicle industry is forming a network of interrelated patents.

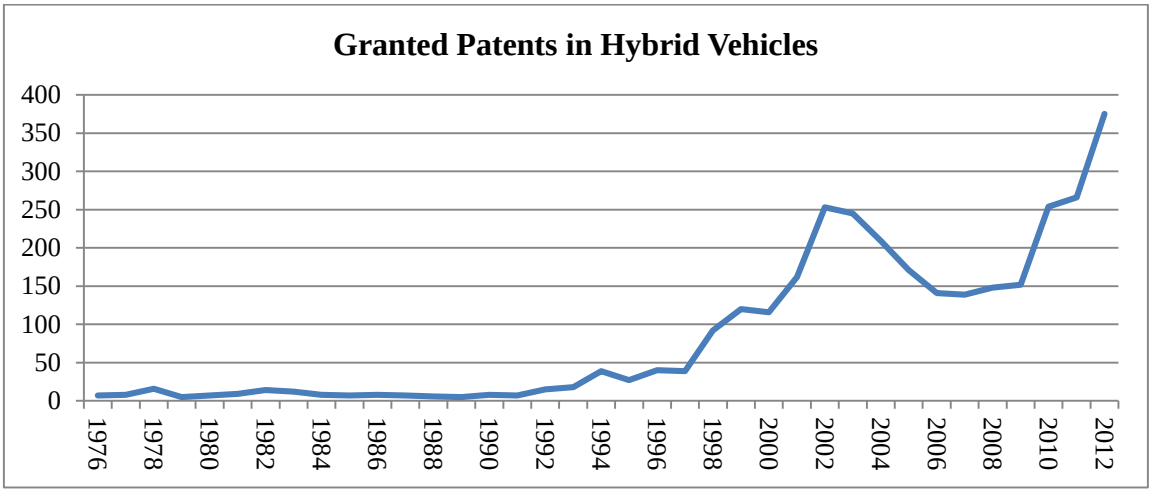
Keywords: Anticommons, Patent Thicket, Complex Systems, Automotive.

1. Introduction.

New environmental laws are requiring automotive companies the production of environmentally friendly vehicles. Biodiesel, natural gas, electric and hybrid vehicles and fuel cells have emerged as the most viable technologies. From this set of options, one of the most efficient is the hybrid vehicle. This vehicle offers a better performance than gasoline and diesel engines and posseses more autonomy than electric vehicles. (Raskin and Shah, 2006).

The hybrid vehicle is a complex system integrated by E/E (Electric /Electronic) and mechanical components. The combination of E/E and mechanical components has given rise to various vehicle architectures, such as in series, parallel, series-parallel and complex.
The search for a dominant architecture has meant automobile manufacturers to explore the frontiers of technological skills, creating new components or experimenting with different combinations of components. The expansion of technological borders in the automotive industry has opened a window of opportunities for software, electronics and energy specialized companies. The coexistence of automotive companies with firms of other technology areas has strengthened the sector's technological capabilities, but also has led to property rights fragmentation.

Likewise, the search of a dominant design has caused an increase in the number of patents granted over the last 20 years. In 1992 there were 15 patents registered, while in 2011 there were 266. The goal of this paper is to represent and measure the technological development of hybrid vehicles, in order to show that the technology landscape has evolved into a thicket patent situation. There are several studies that have developed methods in order to identify the phenomenon of patent thickets, however, these static views do not capture the sector´s technological evolution. The approach developed in this work includes a set of patent indicators that give a dynamic view of hybrid vehicles technological evolution.



Source: USPTO Database. CONACyT Proyect (156204).

In the first part of this paper the patent thicket nature is analyzed, stressing its importance for the rising of complexity and patenting strategic reasons. The second part describes the methodology and reviews the most relevant papers, which have advanced in the construction of a method for measuring the patent thicket. Finally, results are shown and analyzed, and conclusions are given.

2. - The nature of patent thicket.

Shapiro (2001) defines patent thicket as "a dense web of overlapping intellectual property rights that a company must hack its way through in order to actually commercialize new technology." Patent thicket describes a technological landscape in which major components are complementary and are owned by different agents. To understand the phenomenon of patent thicket, it is necessary to distinguish between complementary and substitute technologies. Substitute technologies are able to perform the same function, but its architecture and components are different. Complementary technologies require additional assembly to ensure end product functionality. For example, a computer consists on monitor, disk drive, hard disk, keyboard, etc. The patent thicket characterizes most modern technological fields, designing complex architectures requiring the assembly of a large variety of components. For example, microcontrollers or new cell phones.

If patent holders practice their rights of exclusion and not allow their components to be assembled with other manufacturers, it is obtained what Heller (1998, 2008) called tragedy of the anticommons[1]: "a situation in which agents underutilized a scarce resource because multiple owners are locked together." The tragedy of the anticommons can have negative consequences on economic efficiency and social welfare. Since it can slow innovation, raise costs associated with legal defense, discourage scientific research, shortage of essential medical products in the market or increasing monopolistic power of some companies. Due to the potentially negative effects of patent thicket, researchers have focused on identifying

[1] The patent thicket is a particular case of what Heller calls anticommon property regime, it is "a property regime in which multiple owners hold rights of exclusion Effective in a scarce resource." (Heller, 1990).

causes and proposing solutions that allow efficient exchange of rights. Patent pools and cross-licensing are some of the proposed solutions (Shapiro, 2001). Patents pools are agreements between companies to share a group of patents or sell them to other companies. Cross licenses are bilateral agreements that allow companies to share a set of patents. Regarding the causes of patent thicket emergence, academic literature generally identifies the following:

1. - The cumulative nature of science. The progress of science involves the reuse of existing knowledge in order to develop new one. In technological evolution, the cumulative nature of science is expressed in the reuse of methods and mechanical devices available in a culture. This development is an interrelated web of structuring where the most complicated components evolve from the simplest (Arhur, 2009). To represent technological change as a dynamic process that continually integrates new building blocks and new relationships between blocks, allows to understand patent thicket as a phenomenon inherent to all complex technological systems. Von Graevenitz et al. (2011) showed that in complex technological system, property rights have more interaction than in simple technological systems.
2. - The use of patents as strategic devices. Like any institution, the patent is an artifact (Ostrom, 1980; Hess and Ostrom, 2003) designed to meet some particular objectives, however, this does not mean that users are prevented from that institution to take advantage of it differently to what was created for. Regarding to patents, it is manifested in various motives for patenting. Blind Knut et al. (2006) identified the followings: a) traditional reasons (protection against imitation) and b) strategic reasons (defensive blocking, offensive blocking, reputation for competitors and customers, internal performance indicator, income from the sale of licenses, control of standards, and response to competition).

The complexity of modern technologies and incentives to use patents as strategic devices, have caused difficulty to develop an innovation without violating any intellectual property right. Therefore, the cooperation to meet the challenges posed by the patent thicket is one of the main dilemmas that companies must meet. In an ideal world of zero transaction costs, agents are always able to overcome the tragedy of the anticommons, by negotiating their property rights. However, in the real world agents must reconcile their strategic behavior and overcome their cognitive biases (Heller and Eisenberg, 1998).

To develop policies and to promote cooperation are essential tasks in order to ensure an efficient exchange of rights. However, it also requires a methodology that assists in the detection of a potential patent thicket. A methodology to represent and measure evolution of patent thicket may help governments and companies to design efficient strategies in order to avoid the tragedy of the anticommons.

3. - Methodology and description of indicators.

To measure the evolution of hybrid vehicles patent thicket, the database of the United States Patent and Trademark Office (USPTO) was used. Search fields (180/65.21-65, 29, 903 +) were taken from the classification of Environmentally Sound Technologies developed by the USPTO. The information of 3,155 patents was downloaded, they were granted in the period January/1976-October/2012. The information obtained from these patents were: number of

forward and backward citations, number of inventors, classes and claims, award year and company that the patent was assigned to.

In the past two decades, the advance of information technology has made easier to obtain and to sort the patent data. This has allowed to progress in the understanding of the dynamics of technology and processes related to the dissemination of knowledge. However, the use of patents as technology indicators is not yet widespread in the academic literature. That is why before going to the relevant literature review and analysis of the results, it is necessary to describe the indicators used in this paper, in order that the interpretation and analysis of the results be as clear as possible.

A) Citations forward and backward. Information contained in a patent is a public good and not rival, so that all innovators can appropriate this information to develop new inventions. Citations registered in a patent document indicate the information obtained from other patents to develop that invention. Citations have become a key indicator for the study of technological dynamics and the value of patent portfolios. The measurement of the effects related to the emergence of spillovers has been possible through citations analysis (Jaffe et al., 1993; Maurseth and Verspagen, 2002; Almeida and Kogut, 1999). In addition, studies show that there is a relation between the number of citations forward received by patents and its market value (Harhoff, 1999; Trajtenberg, 1990).

Apart from being a good indicator of the distribution of knowledge and valuing patent portfolios, citations are a good indicator to study the causes and effects of fragmented ownership (Ziedonis, 2001). For example, companies that recycle much knowledge of its competitors may face a situation of patent thicket. Also, citations indicate the manner in which various blocks are recombined to build a system and the emergence od complex architectures involving a large number of components. As the evolution of a technological sector, structures new designs and integrates new participants, the number of citations per patent tends to rise, this may indicate a potential patent thicket.

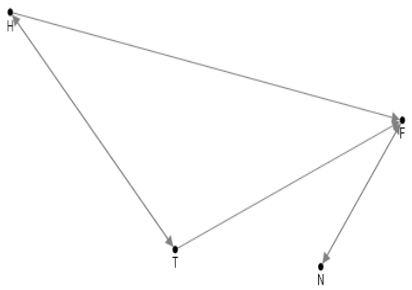
B) Claims. The patent system grants property rights over knowledge that is considered original, potentially useful and marketable. This right is enshrined in the claims that are spelled out precisely in the patent. A patent claim may be associated with a single product, for example, the active ingredient of a medicine. Claims describe the component characteristics and their relationship with a certain disease (Teutsch, 2010). Also, there are patents that describe methods, materials or information, that can be used in final products or as complex technologies, in this case the patent clearly recognizes the owner and knowledge claims, but the total products associated to this knowledge are not and can not be fully identified. Some authors, such as Tong and Frame (1994) suggest that claims are a better measure of technological performance of countries compared to the count of patents granted. Regarding patent thicket, claims can help us identify a potential patent thicket, because if the patents of a sector contain a large number of claims, they are very likely to overlap at some point intellectual property.

C) Gini coefficient. The Gini index shows the difference between the current distribution of a set of patents belonging to a technological domain compared to a perfectly equal distribution. A Gini index equal to 0 represents a perfect equality, while an index equal to 1

represents a perfect inequality. The Gini index helps to detect the existence of extensive patent portfolios within a sector. The existence of large portfolios may indicate that some companies are building huge intellectual property fences around key technologies.

D) Clustering coefficient. The complex network analysis is becoming increasingly important in recent years. Many of the complex structures we observe in the world can be represented in a network map; the brain is composed of many neurons interconnected, food chains in an ecosystem or social systems. Barabasi and Reka (2002) mention that these complex networks have some principles of organization and it is necessary to develop quantitative tools to unravel those principles. In recent years there have been a lot of concepts and measures that allow us to understand and think about complex networks.

In this study we used network analysis in order to represent how the dissemination of knowledge goes structuring a complex network in which property rights are overlaped. To determine the links, backward and forward citations are used. A property of networks is that nodes tend to form groups. This tendency to clump is quantified through the clustering coefficient (Watts and Strogatz, 1998). To illustrate how to construct this index we will draw a hypothetical network of four companies: Toyota (T), Honda (H), Ford (F) and Nissan (N).



In this network, the arrows indicate the flow of knowledge; such networks are called direct networks. If we see the node F arrows indicate that the F company is taking knowledge of nodes H, T and N. The direction of the arrows is determined on the basis of forward and backward citations of patents. The previous network may be represented as a non symmetric matrix, in which ones and zeros represent knowledge flows.

$$A_{ij} = \begin{array}{c|cccc} & \boldsymbol{H} & T & F & N \\ \hline \boldsymbol{H} & 0 & 1 & 1 & 0 \\ T & 1 & 0 & 1 & 0 \\ F & 0 & 0 & 0 & 1 \\ N & 0 & 0 & 1 & 0 \end{array}$$

Based on the data provided by the matrix, it is possible to calculate the clustering coefficient. We will calculate the coefficient of node H. In this network, the H firm is connected with T and F firms. In this case we see that the number of possible connections between T and F is equal to 2. In this case the existing link number is equal to 1. The clustering coefficient H is obtained from equation 1.

$$C_H = \frac{K_H}{N_H(N_H - 1)} = \frac{1}{2} = 0.5$$

Where N_H nodes are neighbors of node H and K_H is the number of connections that exist among neighbors of the node H. The clustering coefficient for others nodes is equal to:

T	0.5
F	0.33333333
N	0

The clustering coefficient is moved in a range of 0 to 1. A node with a coefficient equals to 1 indicates that its neighboring nodes are fully connected. A "0" coefficient indicates that none of the neighboring nodes are connected. The clustering coefficient of the entire network is equal to the average of all nodes. In this hypothetical network the coefficient is 0.33. This value indicates that if we take a random node there is a 33% chance that its neighboring nodes are connected. The clustering coefficient is a good indicator to detect a potential patent thicket. If the ratio is close to 1, it indicates that the companies have their property rights strongly intertwined.

E) Technological classes. Patents are classified according to the areas of knowledge that they belong to; this classification is assigned according to the standard built by patent offices. For example, in the USPTO, the class 701 makes reference to "Data processing: vehicles, navigation, and relative location." A patent may belong to several technological classes if it relates diverse knowledge areas.

Technological classes offer a window to track the inventive step of a technological sector or company, since classes let us identify exploration and exploitation patterns. The emergence of a new technology class or recombination of existing classes is an indicator of exploration activities. This process of emergence of classes and relationships between classes may be seen as something parallel to biological evolution, that is, as a process of variation and selection (Solé et al., 2013).

The indicator used to detect the existence of the patent thicket is the number of new classes and the total number of classes containing patents of the sector in a period. The coexistence of firms with different skills stimulates the emergence of new technology classes or combinations between classes, this knowledge can be recycled by other companies looking for more efficient designs, this fact interrelates property rights.

3.1. - The use of indicators and network analysis in order to detect the existence of the patent thicket.

Several papers have helped to develop a methodology to measure the patent thicket. Clarkson (2005) used a method based on the analysis of social networks which consists in measuring the density of the network. Patents represent the network nodes and connections are determined by forward and backward citations. However, Hall et al. (2012) considered that

the analysis of Clarkson is not a good indicator because it analyzes the patents, but the company is the central actor.

The Intellectual Property Office (2011) conducted an analysis of eight technological sectors. The following indicators were used: average citations and classes, patent family size and Herfindal index. Likewise, a patent map was developed, this to display the technological space of razors. The objective of the analysis was whether the patent thicket generated entry barriers for SMEs to technological areas. The study condenses a lot of technical indicators, and reveals the differences between the sectors analyzed. However, this analysis lacks a developmental perspective that helps to illustrate the change of a disconnected network to a connected network, and a potential patent thicket.

Graevenitz et al. (2011) introduced a measure based in the network analysis and triples counting. A triple is a citations relationship between three companies in a specific sector. Graevenitz et al. (2012) showed that in complex fields, a greater number of triples are found, compare to the ones in in discrete technologies.

4. - Evolution of the patent thicket in hybrid vehicles.

	1976-1982	1983-1988	1989-1994	1995-2000	2001-2006	2007-2012
Patents Granted	66	48	92	433	1175	1341
Countries	9	9	11	12	17	16
Companies patenting for first time	27	9	28	58	108	99
Total firms patenting in the period	27	16	35	75	152	169
Percentage of patents that have 1%, 5% and 10% of the leading companies. And percentage held by inventors						
	1976-1982	1983-1988	1989-1994	1995-2000	2001-2006	2007-2012
1% of companies	7.58%	12.50%	6.52%	21.25%	29.45%	31.32%
5% of companies	13.64%	12.50%	10.87%	40.88%	60.77%	57.27%
10% of companies	16.67%	16.67%	19.57%	54.27%	71.74%	68.53%
Percentage of patents granted to inventors	43.94%	54.17%	32.61%	11.32%	3.83%	5.37%
Percentage of patents registered companies from Japan, USA and Germany						
	1976-1982	1983-1988	1989-1994	1995-2000	2001-2006	2007-2012
Japan	11%	13%	34%	57%	59%	43%
United States	64%	46%	43%	29%	27%	39%
Germany	5%	23%	8%	8%	8%	10%
Otros	21%	19%	15%	6%	6%	8%
Gini coefficient and clustering coefficient						
	1976-1982	1983-1988	1989-1994	1995-2000	2001-2006	2007-2012
Gini coefficient	0.241	0.25	0.324	0.671	0.767	0.766
Clustering coefficient	0.092	0.022	0.031	0.257	0.369	0.381

Backward and Forward Citation analysis, Claims and inventors						
	1976-1982	1983-1988	1989-1994	1995-2000	2001-2006	2007-2012
Average patent inventors	1.38	1.46	2.11	2.77	2.91	2.6
Backward citations Average	7.06	8.13	8.98	9.54	12.25	23.08
Backward citations modal value	4	9	8	16	20	20
Forward citations average	33.24	28.9	36.51	34.24	13.38	1.79
Forward citations modal value	9	13	22	13	4	0
Average claims	10.64	10	13.43	14.11	14.75	14.13
modal value of claims	4	9	8	16	20	20
Technological classes						
New classes in the period	208	88	131	384	672	652
Total class that was patented	208	146	222	558	1084	1273

In the period 1976-1982 the average backward citations, claims and inventors were the lowest compared with other periods. At this stage of exploration, inventors were the main driving force behind innovation. The Gini index is 0.241 which indicates a more equal distribution of patents granted. The clustering coefficient indicates a highly disconnected network.

In the period of 1983-1988 the activity was lower than in the previous period, since the number of patents granted was 48. The patents in this period had more citations than in the last period. The number of claims and inventors remained relatively the same as in the previous period. The Gini index shows that the distribution of the property remained relatively symmetrical. The clustering coefficient shows that in this period, the network was very disconnected.

In the period 1989-1994 the number of patents granted was 92.52% more than in the previous period. The average number of citations increased slightly compared to the previous period, from 8.13 to 8.98. The number of claims is the indicator that showed the most dramatic change, patents from this period have 3 more claims than those of the two previous periods. The Gini index shows an upward trend, which is explained by the presence of large automotive companies. Furthermore, inventors were losing strength, the motor of innovations was weakened.

In the period 1995-2000 the average backward citations rose significantly. In the period before, the modal value was 8 citations per patent, in this period were 20. Likewise, patents contained one more claim than in the previous period. The Gini index has doubled over the previous year, indicating the presence of large automotive companies with large resources and skills. The clustering coefficient significantly increased from 3% to 25%. The significant increase in citations and the clustering coefficient indicates that in this period various components were combined, what leads to the design of new architectures. In this period arose the General Motors EV1 and the Toyota Prius. Japanese firms had a broad domain of the innovation in this sector.

In the period 2001-2006 the average citations per patent increased considerably. Patent citations contained 3 more than the previous period. Also, the number of claims is the highest of all periods. The increasing complexity of designs caused the inclusion of more inventors in research activities in this period, each patent used almost 3 inventors. The Gini index reached its highest level 0.767, which indicates a high concentration of patents by leading companies. In this period the number of companies involved in the sector increased significantly, compared to the previous period, 49% more companies patented. Japanese firms had a remarkable mastery: 59% of the patents were Japanese. The inventors become clearly a minor force, only 3.83% of patents were granted to them.

The period 2007-2012 shows a tendency similar to the previous period. The only indicator that shows a relevant change is the average backward citations, which rose form 12.25 to 23.08. This increase is explained by the patents granted to the alliance called Global Hybrid Cooperation, containing over 200 citations on average. This alliance is developing a new hybrid technology, so is recycling a lot of knowledge. In order to avoid such bias, the modal value of each period is included, if we take a look to this modal value, it is clear there were no change in comparison to the prior period: 20 citations per patent. During this period, the average number of claims and the inventors decreased somewhat. The Gini coefficient remained the same as in the previous period. Although, the clustering coefficient showed a more connected network, during this period, 169 companies participated and the number of patents between Japan and USA tended to balance out.

The analysis of indicators by each period identifies some variables that seem to be the ones that are driving the fragmentation of property rights in the sector:

1) The number of backward citations reflects the creation of more complex architectures that require a greater number of assembling components. Two factors explaining this increase in the number of citations are the amount of new technology classes and the increase in the amplitude of claims. Also, the increased complexity of designs is also expressed in the number of inventors by each patent.
2) The number of patenting firms in the sector has increased in each period, which has tended to fragment property rights. The new entrants to the sector can be explained by the opening of new opportunity windows. In addition, the indicators show how the nationalities of companies are becoming more diverse, indicating the growing environmental and economic importance of green technologies.
3) The clustering coefficient follows a similar trend to the Gini coefficient. The relationship between these indicators means that as some actors dominate large areas of technology in the sector, the probability that firms tend to cite between themselves, increases considerably. That is, if a few agents have extensive patent portfolios, it is highly likely an interrelation among their intellectual property.

Conclusions.

The set of indicators presented shows that the patent thicket is becoming a relevant phenomenon in hybrid vehicles. The new entrants to the sector, a raise in the number of citations and increased clustering coefficient show that the sector is very dynamic and is looking to consolidate a dominant design. It is necessary to note that this evolution of the

patent thicket is a result of the complexity of new vehicles and the strategic moves made by companies following their internal models. This interaction of strategies is outlining the technological landscape structure, creating new building blocks and by nesting property rights.

Also, this article highlights the importance of developing a methodology to measure the existence and evolution of the patent thicket. While there are several works that have made progress in the construction of a methodology, we consider it necessary to direct more efforts towards a dynamic representation of the patent thicket. That's why our method rescues many earlier proposals and includes new indicators that give extra strength to the analysis. It allows to recompose the historical process that originates the phenomenon of patent thicket. Moreover, we must take into consideration that there is no definitive methodology, the method is always perfectible and that no single indicator is able to provide a conclusive answer.

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