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A Cinderella Story: The Early Evolution of the American Tractor Industry

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Abstract

The arrival of motorization, from before the beginning of the twentieth century, has changed agricultural production and the whole economy by dramatically reducing work force and improving productivity. Yet the negligence of research on the history of farm mechanization is surprising given that the history of economic growth has been strongly affected by farm mechanization. In this paper we study the evolution of a major agricultural input, and the cause for much of farm development, the farm tractor. We explore the history of the early tractors and the mechanism behind the birth of new technologies that pushed agriculture forward. We use a unique data set of the United States tractor industry through which we analyse the evolution of the tractor industry, its major innovations and identify fundamental breakthroughs. We believe that our paper is the first where the history of the development of tractors is presented in the fundamental context of innovation, where we use the industry life cycle and technology evolution.

Keywords: Agriculture, Industry Life-cycle, Innovation, Tractors, History

JEL classification: N6

I. Introduction

Agriculture is seldom viewed as an innovative sector, and what is considered innovation is mostly due to developments in the input industries, or happens not in the product but in the processes involved in agriculture. More generally, the importance and contribution of agriculture in overall economic growth and development is often ignored. Nevertheless agricultural innovation and technological change over the 20th century has globally improved food security and helped lower food prices. Another important result of change has been the raising of yield per unit of labour, thus freeing labour for other areas of the economy (Mundlak, 2000).

The advances in agricultural productivity enable the release of labour to manufacturing industries that account for most economic growth. Most benefits from agricultural technological change are captured outside agriculture (Mundlak 2000). This therefore is not conducive to promoting an environment that provides incentives to innovate in agriculture, hence the often felt need for public research and development in agriculture.

The negligence of research on the history of farm mechanization through an innovation point of view is surprising given that the history of economic growth was affected by farm mechanization. Farm mechanization and other technological advances such as agro-chemicals made possible the increase of productivity to such an extent that while in 1910 a farmer in the United States supplied food for 8 people; in 1990 he or she could supply food for 90 people (White, 2000). The arrival of motorization, from before the beginning of the twentieth century, has changed agricultural production and the whole economy by dramatically reducing work force and improving productivity. And in this productivity growth, tractors, one of the most important components of a farm, played a fundamental role.

We believe that the study of evolution in the tractor industry may provide us with valuable insights into the productivity growth in the agriculture industry as a whole. Thus the paucity of research on the technological evolution of the early tractor industry is surprising with economic historians relegating tractors much like Cinderella, marginalized and neglected.

In this paper we study the evolution of a major agricultural input and the cause for much of farm development, the farm tractor. Our work aims to understand the mechanism behind the birth of new technologies that pushed agriculture forward. While tractor industry shares a common history with the automobile industry, owing much of the advances in mechanics from it, the main advances in tractors are innovations specific to the industry such as the hydraulic (Ferguson) system.

We have selected the United Sates tractor industry because of the fundamental importance of tractor innovation in agriculture development. This is the case of a large market where models have been developed to face costumer needs, where there is a variety of agricultural systems that can affect tractor development, and where the main technological advances have been made in a relationship with the spread of agriculture through the continent. We created a unique data set on the United Sates tractor industry that we then use to analyse the evolution of the tractor industry, major innovations and identify fundamental breakthroughs. We believe that our paper is the first where the history of the development of tractors is presented in the fundamental context of Innovation, where we use the industry life cycle and technology evolution.

Our paper is organized as follows. In the following section, we describe some key aspects of technology evolution in industries. This understanding provides the theoretical underpinnings in which to view the evolution of the different innovations in the tractor industry. Then in section three, we describe first the radical and incremental innovations of tractors (section III.I) and then the evolution of the tractor industry in the United States (section III.II). In section IV, we present a view of the

industry evolution through the perspective of industry life-cycles and analyze the influence of major innovations in the survival of firms and in industry sales.

II. Industry life cycles

The major early innovations of the tractor along different dimensions, and the development of the tractor industry can be best understood in the theoretical light of technology evolution, which we discuss in this section.

One broad analysis of technology evolution was made by Anderson & Tushman (1990) which also included the emergence of dominant designs as part of a technology cycle (figure 1). These authors observed that industries evolve mainly via incremental innovations, disturbed at intervals by technological discontinuities. Technological discontinuities have the same effects as the concept of disruptive innovations (Christensen 1997). They break the continuous line of incremental change in an industry or product. Anderson & Tushman (1990) noted that these phenomena can happen both on products as well as on production processes.

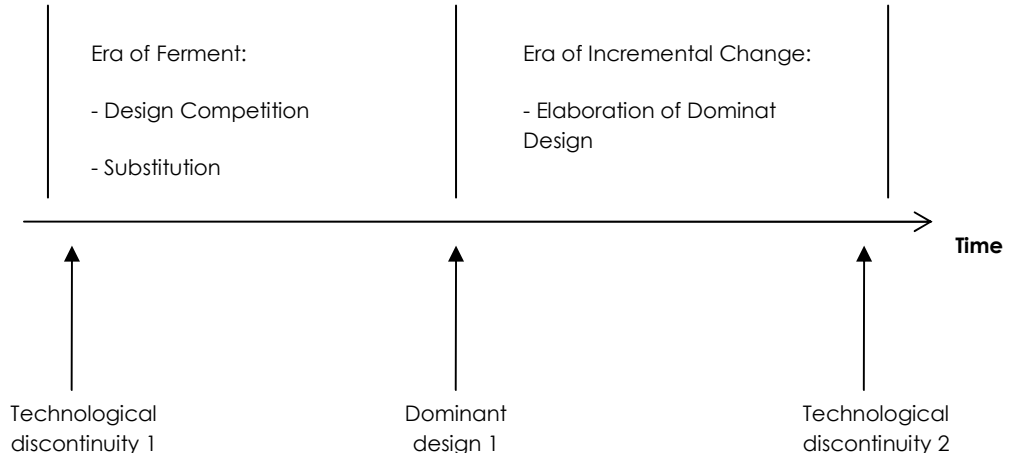

Fig.1- The technology cycle (Source: Anderson & Tushman, 1990).

Product discontinuities consist in a new product that has a radical advantage in at least one dimension - cost, quality or performance. Process discontinuities are new ways of making the same product that offer that same radical advantages. Discontinuities can be further characterized as competence enhancing or competence destroying, relating to the effects they have on the users of the new technology.

A technological discontinuity is generally an experimental product that still has many characteristics to improve. But the technological advance it represents tends to

encourage further experimentation from other competitors. Anderson & Tushman (1990) call it the Era of Ferment; which is characterized by strong competition both between new and old technology and within the new. The older technologies are further enhanced to surpass the threat posed by the new one, other authors found important advances in industries like typewriters and lighting after some technological discontinuity threatened them (Utterback, 1996). The battle between new and old technology implies an initial low rate of adoption of the innovation, but as the new technology proves its superiority its adoption accelerates. Substitution of old by new or the diffusion of the new technology can be represented by a logistic curve (Rogers, 2003).

Competition between several models of the new technology also happens, until a version of the discontinuity is so perfected and/or accepted by consumers that it becomes a standard, a dominant design.

The path that leads to industry technological dominance is influenced by technological factors and also market factors that act both at the firm level and at the environmental level (Suarez & Utterback, 1995; Suarez, 2004). Firm level factors are technological superiority (1), complementary assets (2), strategic manoeuvring (3) and the firm's installed base (4). These are the factors managers can control and the most broadly studied. However environmental factors, such as industry regulation (5) can be decisive on which technology would eventually dominate, network effects and switching costs (6) appropriability (7) and characteristics of the technologies (8) can moderate the influence of firm level factors, each of which are briefly explained below.

III. A history of early tractor industry innovations

Tractors are one of the most important components of a farm. The arrival of motorization, since the beginning of the twentieth century, has changed agricultural production as well as economic growth of countries, by dramatically reducing the work force and improving productivity.

White (2000) identifies three major agricultural advances since 1850: harvest mechanization with the reaper and the steam thresher, the replacement of horses by tractors and the development of chemical fertilizers and genetic crop selection. In his thesis White estimates that the introduction of the farm tractor in United Sates farms was responsible for the reduction of the farm work force, the reduction of draft animals and accounted for an increase of 8.4% of the US GNP in 1954. From 1910 to 1955, the fraction of total workforce applied in agriculture was reduced from 30% to 10% and the number of horses and mules decreased from 24 million to 4.3 million in the same period.

We next describe the technological innovations, both radical as well as incremental, and then explore the growth of the tractor industry in the United States over the previous century.

The early history of the tractor owes a lot to the development of the steam engine. As far as we could trace back, the first ever steam engine mounted on a vehicle, dates to 1769, when Joseph Cugnot, a French military engineer, presented his “fardier a vapeur” (AGEON, 1989). Cugnot was the first inventor to convert the alternate motion of a steam piston into rotary motion. He built a second wagon, dating from 1771, which was able to transport 5 tons at a speed of 3.5 km/h. This was a very heavy vehicle, hard to manoeuvre with two rear wheels and one in the front, supporting the steam boiler. The wagon’s many constraints together with the political environment in France, led to the French army ending this project. This machine remains preserved today at the Conservatoire National des Arts et Métiers, in Paris.

The steam engines were adapted and evolved for agricultural use. Many of the first steam traction engines of the 1800’s were mounted on wheels, transported to the field by horses and standing still would haul ploughs and other implements by cable. British soil scientists welcomed these innovations for they prevented soil compression associated with horse cultivation. The aim of farmers though was to create a machine capable of pulling implements or cultivating the soil directly, turning the soil more efficiently than a traditional plough. To encourage such a development, in 1854 the Royal Agricultural Society of England offered a 500 pound prize for the most efficient and economic steam cultivator.

Inventors competed for four years until an innovation was worthy and the prize was finally awarded. John Fowler was the winner, presenting a machine that could draw an agricultural implement, like a plough, back and forth across the field using a windlass (figure 2). The Fowler Company kept improving their machines through the 19th century, expanding their market to Eastern Europe (Lane, 1998). Another inventor, Thomas Rickett, developed a rotary steam cultivator, which was an enormous 10 ton machine designed to break and aerate the soil, that became popular at the time.

Fig.2- Fowler´s traction engine pulling a plough (Source: Steam Plough Club, www.steamploughclub.org.uk/pictures.htm)

Self propelled steam tractors, intended to pull implements were heavy and uneconomical given that they were more expensive than horses. Different soil characteristics meant these tractors were mostly unviable in the soft soils of England or Germany, but useful in the United States, especially in the drier soils of California, where they were further developed to directly haul ploughs or other implements.

In 1886, Case was the most important steam traction engine producer in the world. But its importance in world agriculture was residual. In the United States, the biggest producer, steam tractors production never exceeded 4000 units a year. And the growth of animal power during the last decade of the 19th century was greater than the growth of steam power in farms (White, 2001).

It was in North America that tractors were to be further developed. Since the end of the American civil war, many farmers moved to a large area of steppe and prairie east of the Rocky Mountains. These large areas of grassland were primarily used for cattle grazing. The vegetation was well established and demanded a lot of animal power to break the sod and allow agricultural production. Unlike European countries, where agriculture was established for hundreds of years based on animal power, powerful engines were needed to plough and break the soil in these areas. This was a major force for invention and the development of mechanization in agriculture.

The evolution of the tractor and automobile industries in the United States shared much common history. The initial years of the development of the internal combustion engines and the vehicles motorized by them were similar in these two industries, with some firms marketing kit conversions to adapt automobiles to do tractor work in the 1910's (Wendell, 2001).

The first plans of an internal combustion engine are attributed to seventeenth century Dutch physician and mathematician Christiaan Huyghens, who designed an engine, powered by gunpowder but however never actually built it. During the 19th century many inventors attempted to create a successful internal combustion engine. The first to succeed was Nikolaus Otto, who patented a four-stroke engine in 1876 called the "Otto Cycle engine". Otto's design became the forerunner of every motor to be built later on and was even used to power a motorcycle. This engine was further improved by Gottlieb Daimler and Wilhelm Maybach, and was adapted to a stagecoach to build the first ever four-wheel automobile in 1886 and in 1889 these inventors designed the first automobile.

In 1892, in Iowa, John Froehlich built the first traction engine equipped with an internal combustion engine, two of these were sold. This first attempt to produce a traction engine may be considered the one of the last developments in the traction engine industry. The first to successfully commercialize internal combustion tractors were Hart-Parr in the United States and Ivel in Great Britain, both around 1902 (Funenga, 2004; Baldwin & Morland, 2004). It was in 1906 that the word "tractor" was used for the first time to describe Hart-Parr's machine. The Hart-Parr tractor is the technological discontinuity that launched the United States tractor industry, starting an era of ferment lasting twenty years during which a variety of models and technological improvements were proposed.

The internal combustion engine had many advantages over steam: it was safer, needed 10 times less fuel, 40 times less water, produced 30% more energy and were lighter and easier to manoeuvre, needing only one operator when steam engines usually needed three men (Gray, 1954). Nevertheless the enumerated advantages, older companies that thrived with the steam engines were not willing to change, and some like Fowler kept producing steam tractors and rollers until the late 1920´s, yet also investing in gas tractors. Other British companies like Sentinel, Foden and Mann kept improving their lightweight steam tractors, until the 1930´s, but none was able to survive longer. The decision to change to gas tractors made cleavages inside companies such as the Canadian Sawyer-Massey, breaking some old business alliances and creating new companies.

The first internal combustion tractors had models very similar to the steam traction engines; many of them simply adapted the structure to the new engine. Those early tractors were still very heavy machines, weighing around than 10 tons (White, 2001). During the first two decades of the 20th century manufacturers improved their models, reducing their size and cost up to 10 times, while increasing the power needed to plough or pull other implements.

After the First World War, companies that had been manufacturing war machinery turned to producing agricultural tractors. Buenstorf (2006) analysed the United Sates

tractor industry and found 319 firms entered the industry until 1940. Only a small fraction was start-ups, most came from the engine industry or from the implement industry. The last was the most successful group, including companies like Ferguson, International Harvester and John Deere. These data shows the importance of the knowledge about customer needs and marketing capacity as success factors as or more important than technological capabilities.

As the development of farm mechanization happened, engineers developed lighter, smaller integrated cultivators such as the Somua "rototiller" of 1919 or the Fendt "motormower" of 1928. Until 1920 there was a huge variety of models and mechanical solutions for tractors, a characteristic of an era of ferment (Anderson & Tushman, 1990). Gray (1954) describes 20 different ignition systems, 8 lubrication systems, 11 cooling systems, 17 carburetting systems, 15 power transmission mechanisms and 27 different wheel arrangements that emerged in the first two decades of the 20th century. From then on tractor design tended to standardization.

Figure 3 presents the example of wheel arrangements. Based on data from Gray (1954) and Wendell (2001), it compiles all documented wheel arrangements proposed by tractor manufacturers year by year. A peak in the number of different combinations happens in 1920 and then in 1941, from then on the number of different wheel or track arrangements tends to stabilize to the present three types: two-wheeled garden tractors, four-wheeled common agricultural tractors and tacks.

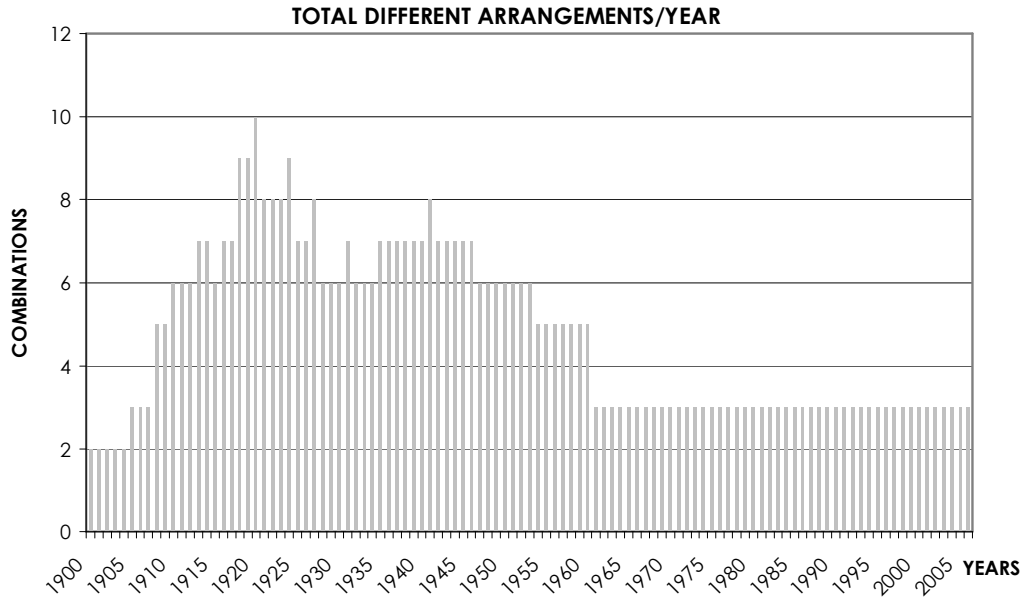

Fig.3- Number of different wheel arrangements displayed in North American tractors.

In 1917, was launched the Fordson, a newcomer, a crossover from the automobile industry, the tractor built in England by Henry Ford. The first Fordsons were ordered by the British government in an effort to mechanize British farms in a time when most

men and horses were engaged in the war. This was a small, inexpensive tractor aimed to be affordable enough to substitute the horse, an expensive animal at those days. In the United States the only manufacturer able to match Fordson's low price was International Harvester. The competition between these two manufacturers was fruitful for the development of tractors. In 1922 International Harvester introduced the modern power take-off in its tractors and in 1924 this company introduced the Farmall, one of the most successful models ever built. It was the first general-purpose tractor, designed for cultivating, ploughing and mowing. It was attractive to the average farmer and could work in a great range of crops. Soon other United Sates companies followed the trend and the general-purpose tractor replaced the one-purpose tractors like the Fordson. In fact Fordson´s production in the United States was discontinued in 1928, as Ford was concentrating efforts in the production of the model-A car. Figure 4 shows the two models, Fordson F and Farmall.

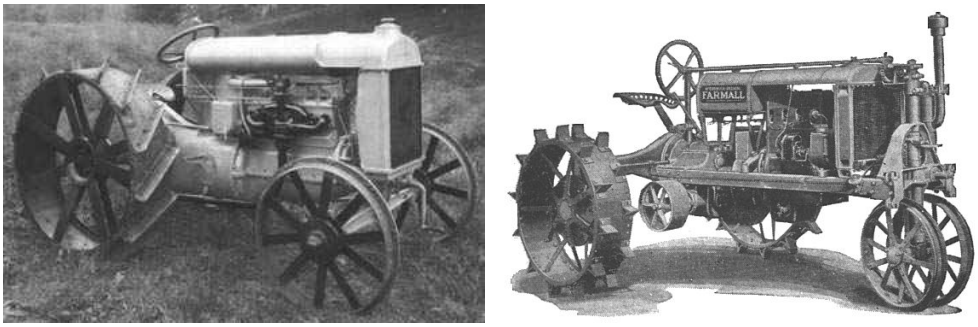

Fig.4- The 1917 Fordson F (Source: http://www.iol.ie/~manister/tractortrouble /history4.html) and the 1924 International Harvester Farmall Regular (Source: http://home.att.net/~klossner/ reginfo.htm).

Some reasons for the success of the Farmall model were International Harvester's marketing networks, proximity to the farmers, knowledge of their customers' needs, credibility and a range of implements and accessories compatible with the tractor. The era of incremental change set by the development of the Farmall had many improvements in the performance and cost of tractors. Three important tractor features were introduced in the 1930´s: tyres, the Diesel engine and the three point hydraulic hitch system invented by Irish tractor maker Ferguson. As tyres were broadly adopted to replace iron wheels, Ferguson's system was patented and only available on this make until 1938, when a gentlemen's agreement with Henry Ford allowed Fordson tractors to use the system (Brock, 2004).

The history of tires begins in 1844 with the development of rubber vulcanization by Charles Goodyear. In 1888 Irish veterinary J. C. Dunlop adapted a rubber tube to the wheels of his son's tricycle. The tire had been invented. The Michelin brothers in

France developed it further to be easier to change when damaged. In the United States, Henry Ford promptly adapted the new invention to his automobiles.

Early tractors were equipped with steel wheels. These had to be very large in the rear to support the weight, which made it hard to turn the tractor. Steel wheels were equipped with spikes that were capable to provide good traction in the field, but were very damaging to paved roads. Spikes were also damaging to superficial tree roots, and the citrus farmers of Florida were the first to adapt truck tires to their tractors. In 1930 Firestone presented the first tires specially conceived for agricultural uses.

Another alternative to steel wheels were crawler tracks. The first agricultural traction engine with crawler tracks was made by Holt in 1904 (see figure 5). It soon became known as the caterpillar. In 1908 Holt commercialized its first crawler with an internal combustion engine. In 1925 Holt and the Best Traction Company merged to form the Caterpillar Tractor Company. The price wars of the 1920´s lead this company to focus on the construction market and leave the agricultural tractor industry. Today crawler tractors are still more popular in construction than in agriculture.

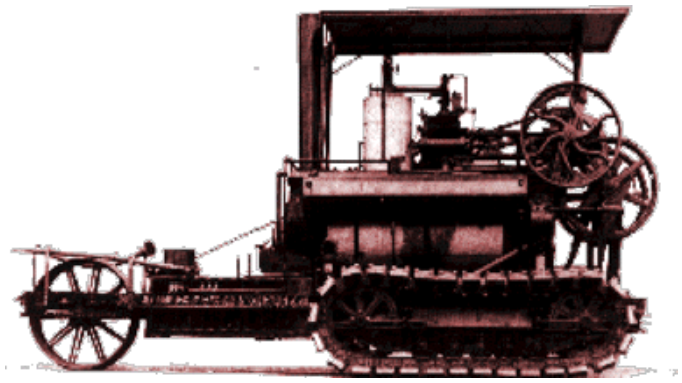

Fig.5 - Steam powered Caterpillar tractor built by Holt in 1904. (Source: www.txfb.org/AgClass/resource/AITCrg37.htm)

The first internal combustion tractors, starting with the Froehlich, used gasoline or other fuels like petrol or kerosene. Some tractors were equipped with all-fuel engines that allowed the farmer to use the cheapest fuel at the moment. Engines used different spark ignition systems from which the magneto became the most popular.

At the same time the Otto-cycle engine was being developed another kind of internal combustion engine appeared. In 1892 Rudolf Diesel patented an engine where fuel ignition was made by pressurizing the air until the temperature would ignite the fuel.

The first engines tested used coal dust, but proved unpractical. Oil however proved to be a good fuel and the system could work with a four-stroke engine. Further developments in the diesel engine mostly depended on fuel injection technology.

Tractors equipped with diesel engines first appeared in Germany. In 1922 Benz developed the Benz-Diesel. One of the first companies to build diesel engines was Deutz that equipped many other German tractor constructors. From the thirties on diesel became more and more common in tractors in Europe, but in the United States they were mainly used in large crawler tractors and only became widespread after the seventies. Since then almost every tractor model in the world is equipped with a diesel engine and gasoline is only used in small lawn tractors.

The third innovation of the thirties settled the design for tractors. Harry Ferguson had already patented a duplex hitch and a draft control principle; he also invented the first wheel-less plough, the Belfast Plough, that was adapted to work with the Ford Eros, a Model T conversion into a tractor. The three-point hitch system was designed in 1928. The first prototype had two upper hydraulic arms and the third hitch down, forming a V-shape. Soon it was turned upside down to the characteristic A-shape (figure 6). Ferguson system was revolutionary as the implements were mounted on the tractor instead of being dragged behind it. The two hydraulic arms could control depth and if the attached plough would hit an object it could be lifted easily, preventing the tractor to topple backwards (Ferguson Family Museum, 2006). The first tractor to be commercialized with the complete three-point hitch was the Ferguson Black Tractor in 1933, manufactured in Northern Ireland.

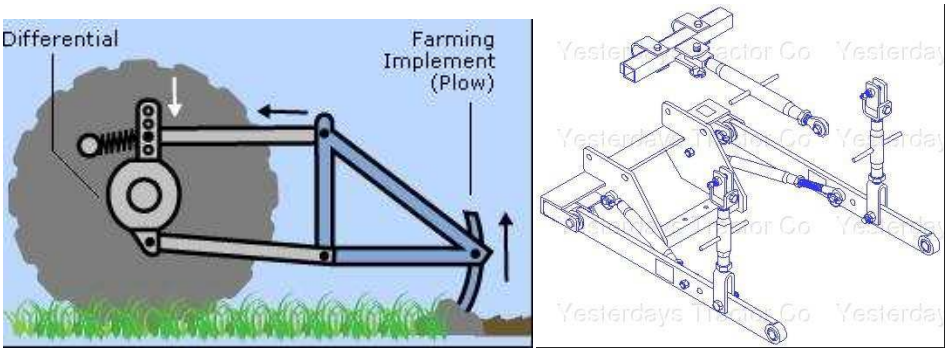

Fig.6 - The Fergusson system: a) Side view (source: http://www.fordmuscle.com/archives/2006/02/8NFordTractor/Images/hitch.gif); b) Scheme (source: http://www.ytmag.com/store/parts/pics/wm_HK305.jpg)

Over fourteen patents, registered from 1917 to 1939, cover the Ferguson System (one of the most important is the hydraulic regulation of working depth from 1926). As the patents expired the system was generalized to the whole industry and standardized to five sizes according to tractor drawbar horsepower (The Friends of Ferguson Heritage, 1994). The standardizing of the Ferguson system revolutionized agriculture. Before every tractor maker had a different linkage system for implements and when a farmer

changed his tractor, he would have to buy new implements or adapt the old ones at his own risk. Furthermore the Ferguson system allowed new implements to be mounted on the tractor, allowing endless uses for tractors, in cultivating, mowing, transporting, manure spreading, among other uses.

The Second World War had most European and United Sates tractor factories developing army tanks and represented a slowdown in the industry growth and development and delaying the emergence of a dominant design. After the war another growth era arrived for the industry. Mechanization and motorization became a priority as a part of policies to increase agricultural production around the world. In the beginning of the 1950´s the number of tractor producers reached a peak and since then has been dropping, although new companies have entered the market.

The fifties may mark the consolidation of the tractor design. Until then many small local makers experienced different ways to improve tractor performance. Different fuels such as kerosene, petrol, gasoline ethanol and diesel were used in different regions of the globe according their availability and price. Different implements were developed according to local agricultural conditions, and each maker had its particular attachment system but as the patents over the Ferguson design expired it was widely adopted across the industry and became a standard or dominant design, based on the architecture of the Fordson 9N.

In the sixties and seventies, the improvements on Diesel technology lead to its generalized adoption by the industry. At the same time, Asian countries entered the tractor industry; factories that had started by making models for other western companies began developing their own models and later exporting them.

Since the eighties, tractor manufacturers have improved safety structures and comfort together with electronic technology, from which the most advanced example is precision agriculture. Other innovations have had opposite paths once more regarding local agricultural systems. In Europe some makers have specialized in small vineyard and orchard tractors, same happening in Japan. The improvement of herbicides allowed the development of reduced-tillage and non-tillage systems that worked with low power tractors. In an opposite direction the United Sates developed high power tractors designed for the large farms of the Corn Belt, Australia or Argentina. Figure 7 summarizes the most important innovations that influenced the development of tractors.

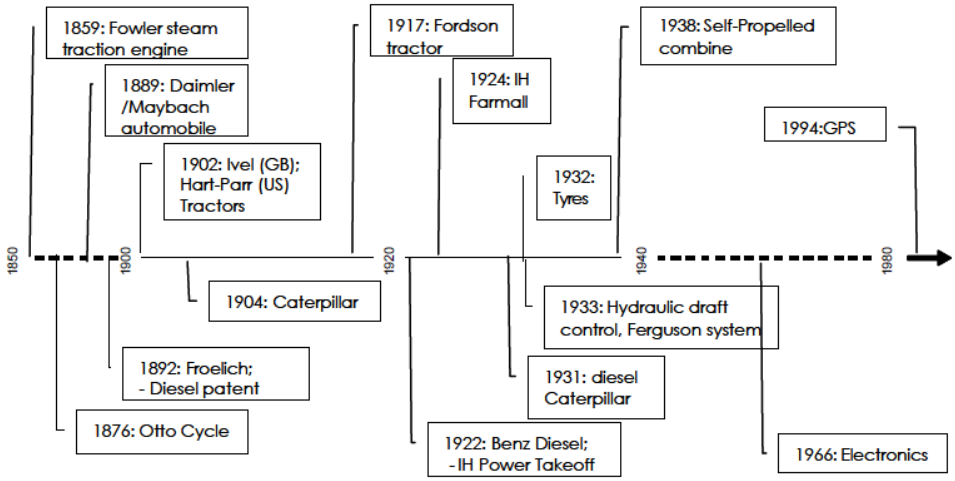

Fig.7- Timeline with the most important technological advances affecting tractor development.

Buenstorf (2006) compared the evolution of the tractor and automobile industries in the United States. The initial years of the development of the internal combustion engines and the vehicles motorized by them are similar in these two industries, with some firms marketing kit conversions to adapt automobiles to do tractor work in the 1910's. As the industries evolved, differences emerged. This author found that until 1940 most automobile firms were spin-offs of other incumbent firms and other producers were firms primarily engaged in producing wagons, carriages and bicycles. In the tractor industry, however, most prominent firms entering before 1940 were originally implement manufacturers, indicating that technological similarities were less important than markets.

IV. The emergence of the United Sates tractor industry

Since the early tractors, the industry has evolved in different ways, depending on different national and regional conditions. To conduct an analysis of the tractor industry in the world without analyzing regional differences could mask these effects. This way the analysis will be held for the United States industry, for which there is a very complete data set.

Data collection was made with the help of collector books (Gray, 1954; Baldwin & Morland, 1998; Carrol, 1999; Wendell, 2000), institutional web pages, and web forums of farm tractors collectors (please see list of web pages). Only firms developing original tractors were included in this research. From an initial list of 1012 United Sates firms only 760 were included.

An exhaustive list of tractor firms available in Wendell (2000) was complemented with data from Gray (1954). Based on this list all firms were researched for original models

developed and those that did not develop originals, were excluded from analysis. Further selection was made for firms that specialized in farm tools, lawn mowers, cultivators, combine-harvesters, adaptations or kits to transform automobiles into farm tractors, but did not develop tractors. These were not included in the final list of tractor manufacturers. The books on historical tractors used cover manufacturers and models until 1960.

More recent companies and models were looked for in the internet. The list of tractor manufacturers from Wikipedia was a starting point. From this list all United Sates companies that develop and manufacture original tractors were included in our set of data; multinational companies with headquarters in the United States or Canada were also included.

Farm mechanization in the United States and Canada is deeply connected with the spread of agriculture through the continent. Most United Sates regions had never experienced agriculture previous to European colonization; also many of the settlers had never experienced such soils, which meant a lot of experiencing and innovation. To break the prairie soils required a lot of animal power and ingenious solutions for new machines. Two of the most important inventions in farm mechanization came from the United States and were the beginning of two of the most successful tractor manufacturers. The first was the 1837 self-scouring steel plough from John Deere, the second was the 1842 combine thresher from Jerome Case (Carroll, 1999).

Specific characteristics of United Sates agriculture already mentioned and also the different economic situation meant a faster development of farm motorization compared to Europe and the rest of the world. For the group of 760 firms studied, dates of entry and exit in the industry were collected when available. In Figure 8 the data on the number of companies entering the industry and exiting is presented together with firm density. As we can see there are two peaks, the first in 1920, with 209 firms and the second in 1948, with 104 firms. During the period from 1920 to 1943 the number of firms decreased, with a slight recovery from 1933 to 1940 (between the end of the Great Depression and the beginning of World War II) and a decrease until only 43 firms were still producing tractors in 1943. This may indicate that a new cycle has begun after 1943 and a new industry standard has been set around the time of the second peak. The context of the time has influenced this rebirth of the industry; in fact, after World War II was over agriculture undertook a revolution. Productivity was the main priority in agricultural policies in the Western countries in order to feed a growing population that was increasingly moving to the cities. Family farms were being substituted by entrepreneurial farms of greater dimensions, the first organic pesticides were developed and a new era for agriculture was happening, where almost every task in a farm was becoming mechanized.

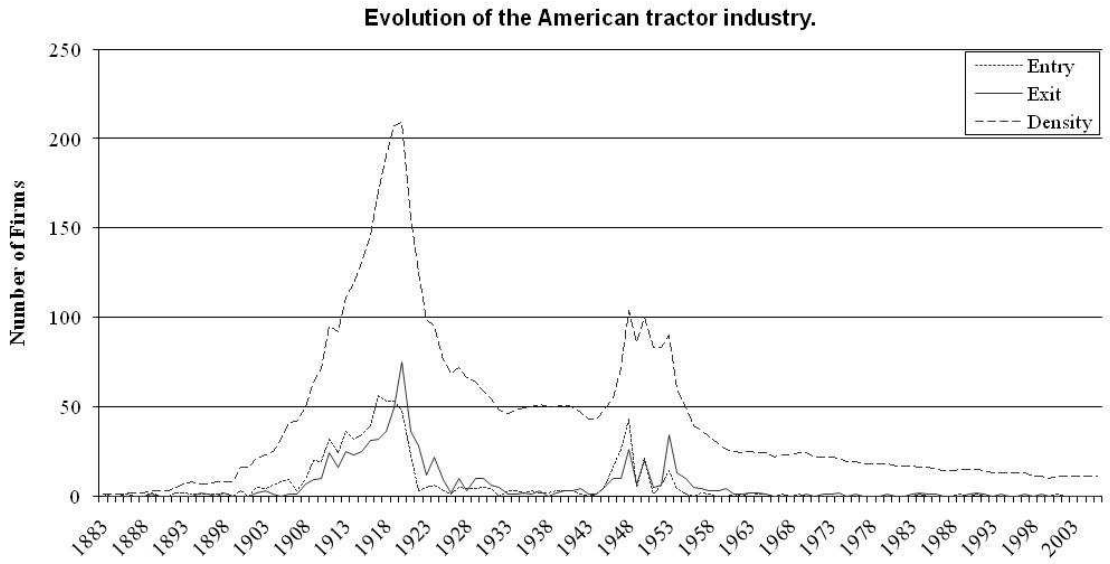

Fig.8- Evolution of the American tractor industry 1900 – 2006.

In the beginning of the 20th century there were 16 tractor manufacturers in the United States, this number rapidly grew to 71 manufacturers in 1910 and 209 in 1920. In 1921 the number suddenly dropped to 156. The number of manufacturers would only recover after World War II.

The tractor industry in the first two decades followed a pattern of evolution similar to other industries, an S-shaped curve, also common to the growth of biological populations. We can connect the beginning of the tractor industry lifecycle with the technological discontinuity represented by the development of the Hart-Parr, the first tractor powered by an internal combustion engine to be successfully produced. The first 10 years showed a slow growth, and a lot of experimentation. During this *era of ferment* that lasted until the 1920's, there was not a standard model of tractor. Besides the competition inside the new tractor industry, steam engines were still in use and being further developed to improve weight, strength, power and price and competing with internal combustion engines. The first gasoline tractors were heavy machines based on the structure of the steam traction engines and the manufacturers intended them for belt work and a source of power such as the steam engines. One of those massive machines was the International Harvester Type A Mogul, built between 1907 and 1911. However many other makers were developing smaller tractors and testing different characteristics. Gray (1954) reports at least eight different ignition systems, 18 power transmission mechanisms, 27 wheel and track arrangements and many other characteristics, like lubrication, carburetting and cooling systems varying from manufacturer to manufacturer, consistent with an era of ferment.

From 1910 on there was an exponential growth on the tractor manufacturer population until a peak in 1921. The increase in demand was associated with the emergence of smaller, less expensive machines that clearly surpassed steam traction

engines and were becoming an efficient alternative to horse power, that were presented through a series of contests and tractor demonstrations in the Mid-West from 1915 on. The adoption of tractors and the substitution of the horse become more rapid as soon as the new technology surpassed the old steam traction engine.

World War I came to further stimulate the growth of the tractor industry, in 1917, as the United States entered the war, the number of tractors produced doubled. Still many of the manufacturers had irrelevant productions. After the Fordson F was present 1917 it soon took over the market to reach 75% of the United Sates tractors sold in the beginning of the 1920's. Several factors came to help this domination, the Fordson was a small, affordable machine designed to be the model T of tractors, Ford had a large chain of distributors all over the country and was known for the reliability of its products.

Reliability was one of the major problems for farmers. With a rising number of firms in the market it was difficult to choose. An influent farmer from Nebraska, William Crozier, after buying two poor quality tractors sponsored a bill to force tractor testing in his state. This way, starting in 1920, the Nebraska State University tested every model to be commercialized in that state. The results had a deep impact in the industry. In 1920 only 15.4% of the tractors tested really accomplished their manufacturer's claims. The next two years percentage of realistic claims would rise to 40% in 1921 and 80% in 1922 (Baldwin & Morland, 1998). While non-accomplishing manufacturers were leaving the industry the small manufacturers presenting interesting innovations were being absorbed by the larger companies. This reduction in the number of companies also helped Fordson's success, but its dominance was brief.

In the mean time, competition at a higher level was taking place among Fordson, International Harvester and John Deere, as Fordson was dropping the prices of its models. These "price wars", as were referred to in those days, led to more product innovation and cutting down costs of production. The I H Farmall model of 1924 was the first tractor designed to work with an agricultural innovation: crops planted in rows, or row-crops. The light tractor, designed in a tricycle way, could safely run along the rows of cotton or maize without damaging them.

Following the methodology of Suarez and Utterback (1995) an industry dominant design was searched for with help of industry experts. According to White (2001) the Farmall tractor of International Harvester, commercialized in 1924 synthesizes the characteristics that became a standard in the tractor industry. It was a light tractor prepared to work in crops planted in rows that could perform a variety of tasks and be attached to pull various kinds of implements, in contrast with earlier tractors that were made for a finite set of uses, such as cultivating or harvesting. This tractor could perform a variety of agricultural operations in contrast to most previous models that were tending to specialize. It also featured previous innovations, such as the power

take-off, introduced in 1922. Even though it was not the first attempt to produce an all-purpose tractor, it was the first successful one and while it could loose to some competitors in specific operations on the Nebraska tests, in general it could perform all agricultural operations it claimed. In line with Anderson & Tushman (1990) the key performance parameter to define this dominant design is the number of possible tasks performed by the tractor. The Farmall was in production until the 70's with several incremental improvements made, such as the possibility to use tires since the 30's, different front axle distances and different models (the "letter series") according to horse-power.

An all-purpose, row-crop tractor type was soon presented by most of the top makers, and it was important in shaping agriculture, for as one single tractor could perform a variety of operations, more operations were mechanized. Until 1930, the number of tractor variations dropped, as an industry standard emerged.

The price wars and the Great Depression continued to reduce the number of manufacturers into the 30's. In 1929 Fordsons were discontinued in the United States, this same year the industry sales peaked to 229.000 tractors. According to Gray (1954) in 1933 the top 9 firms in the United Sates industry had 90% of the total market: International Harvester, John Deere, Case, Massey-Harris, Oliver, Minneapolis-Moline, Allis-Chalmers, Cletrac and Caterpillar. The dominant design tractor was by now a very different version of the first internal combustion tractors developed in the beginning of the 20th century to essentially plough the soil through belt work.

One can say that the period from 1930 to the end of Second World War represents an era of incremental change in the tractor industry, when most innovations were increases in size and horse-power. In 1939 the agreement between Ford and Ferguson for the use of the Ferguson system had Ford returning to the United Sates industry. The breaking of the war in Europe provided an opportunity for United Sates firms to export their tractors. But as the war continued there was little change or innovation in the industry.

The three-point hitch or Ferguson system results of the combination of several inventions developed by Harry Ferguson for over twenty years as an attempt to improve both the quality of work and safety. The first tractors with this system were built in England by Ferguson in 1933. The implements were no longer pulled behind the tractor, but instead they were mounted on it, providing control over them. This system combines a number of innovations into one part of the tractor - the three-point hitch -and can control the depth at which implements work and prevent the tractor to roll over when the implement hits an obstacle. Instead the integrated hydraulic lifts force the implements up allowing the tractor to proceed forwards.

Before the Ferguson system every tractor maker had a different linkage system for implements. Furthermore the Ferguson system allowed new implements to be mounted on the tractor, allowing endless uses for tractors besides cultivating, mowing, transporting or manure spreading. The technological discontinuity featured by the early designs of the Ferguson system meant an advance in the performance parameter earlier defined as the number of tasks performed by the tractor.

We identify the Ferguson Black Tractor of 1933 as a technological discontinuity developed outside the United Sates market. In 1939 an agreement with Henry Ford allowed Fordson 9N tractors to use the Ferguson system The patents protecting Ferguson's inventions prevented his system to become an industry dominant design, but as the patents ran out this system eventually became the standard already described, especially after 1948, when the agreement between Ford and Ferguson was broken and at the time many Ferguson patents were dropping and farm mechanization would greet a system that could perform a great number of tasks in farm using only a tractor (tractors were even used to power washing machines by the PTO). Presently every agricultural tractor model features the three-point hitch and hydraulics as a part as obvious as the internal combustion engine. The system is standardized in five sizes of linkages, adapted to the tractor size and horse-power, as presented in table 1.

Type	Top link size	Lift arm size	Lift arm spacing	Tractor drawbar horsepower
0	5/8 inch	5/8 inch	20 inch	less than 20
I	3/4 inch	7/8 inch	26 inch	less than 45
II	1 inch	1 1/8 inch	32 inch	40 to 100
III	1 1/4 inch	1 7/16 inch	38 inch	80 to 225
IV	1 3/4 inch	2 inch	46 inch	180 to 400

Table 1- The standard sizes of the three point hitch. Source: Ferguson Family Museum (2003).

Following Suarez & Utterback (1995), a direct interview with engineers and agronomists at CHN Portugal was performed and a general idea of what a dominant design is and what were the objectives of this work were presented. These experts promptly identified the hydraulic system of the three-point hitch as a dominant design.

The history of this innovation was researched for the technical bases of the system, the year it reached the United Sates market and what influence it had in agriculture. After the war the industry began recovering and again new companies entered the market offering new models. In figure 9, the sales evolution until 1950 is presented. A complete set of data is available from 1909 to 1950, from the Agricultural Statistics of the Bureau of Census of the US Department of Commerce (Gray, 1954). More recent data were not available. These years cover the first peak in industry density and the emergence of a dominant design. Sales growth is also included, this data can be used

to analyze the industry growth in the year of exit of each firm and provide insight to the external conditions affecting firm failure.

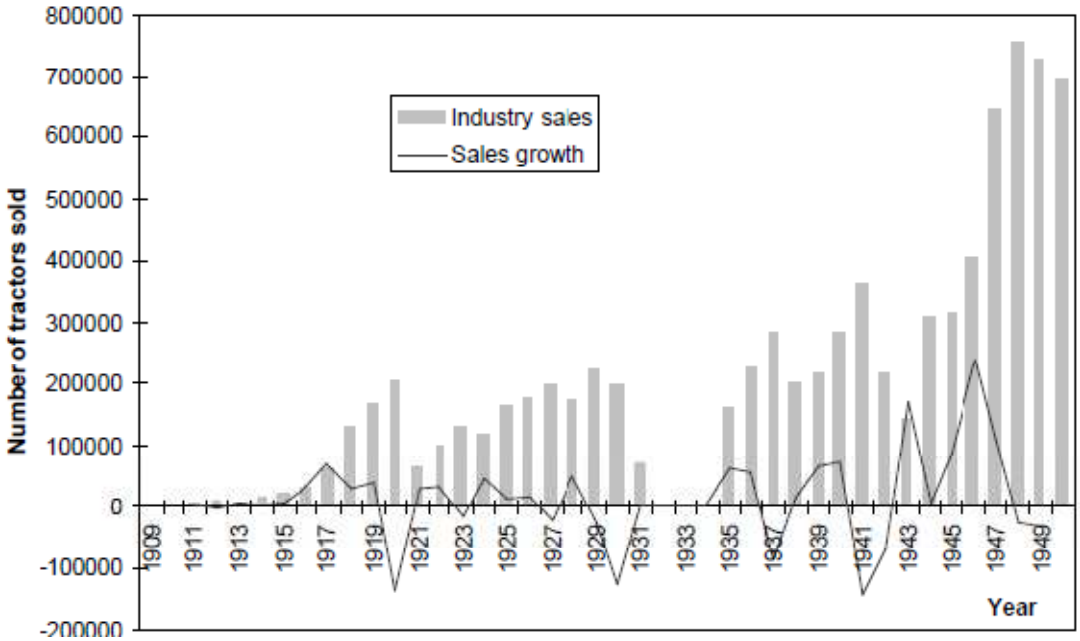

Fig.9- Number of tractors sold in the United States from 1909 to 1950.about here

The year 1951 (not presented in figure 9) marks the peak of sales of the United States tractor industry (White, 2001). Since 1948 the number of manufacturers has been decreasing, consistent with the emergence of a second era of incremental change that lasts until today. In Figure 10 we summarize the life-cycle of the United Sates tractor industry, based on Anderson & Tushman (1990).

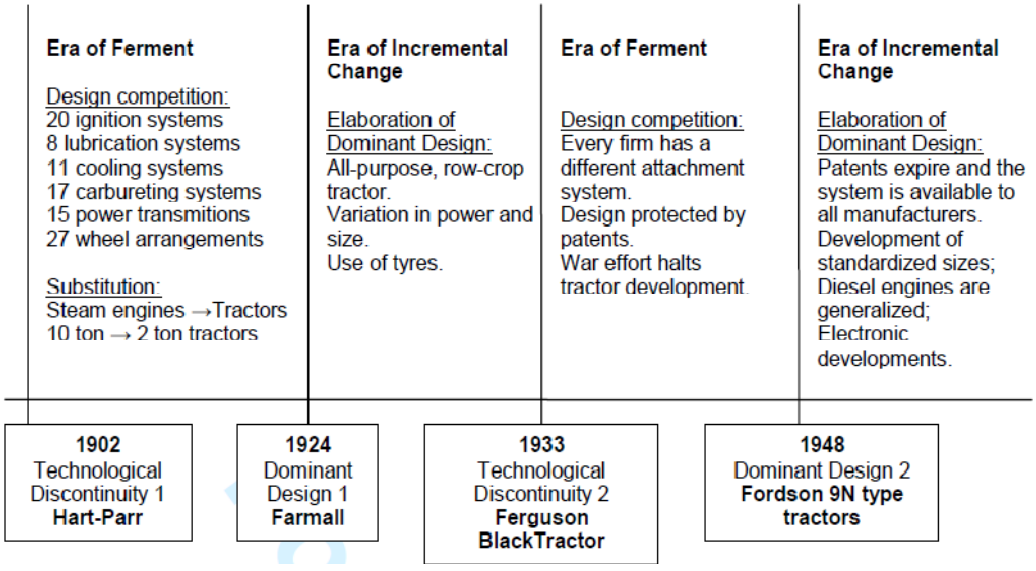

Fig.10- The life-cycles of the United Sates tractor industry.

When analysing the post-war period on the perspective of disruptive innovation, we can see other innovations taking place, such as the evolution of a parallel industry to that of the agricultural tractor. While the four-wheeled tractor equipped with a hydraulic three-point hitch was becoming a standard, smaller two-wheel tractors were becoming popular for vegetable garden owners and for lawn cutting work.

Garden tractors can be considered a disruptive innovation for this is the case of a product that has less traction power, less applications and is in general a very small and fragile version of the agricultural tractor. But its smaller size and price make an advantage for gardeners that were a low-end market for which the big firms never paid attention.

The first two-wheel tractors were developed in the era of ferment of the tractor industry, since 1913 (Fig. 11), but remained as experiments for most of the time until the after the Second World War. Between 1945 and 1955 there were 64 firms entering the market most of them exited in the same period. The increase in farm size and cheap manual labour from a growing immigration combined to make the acquisition of a small tractor uninteresting. The garden tractor industry in the United States virtually ended after this period.

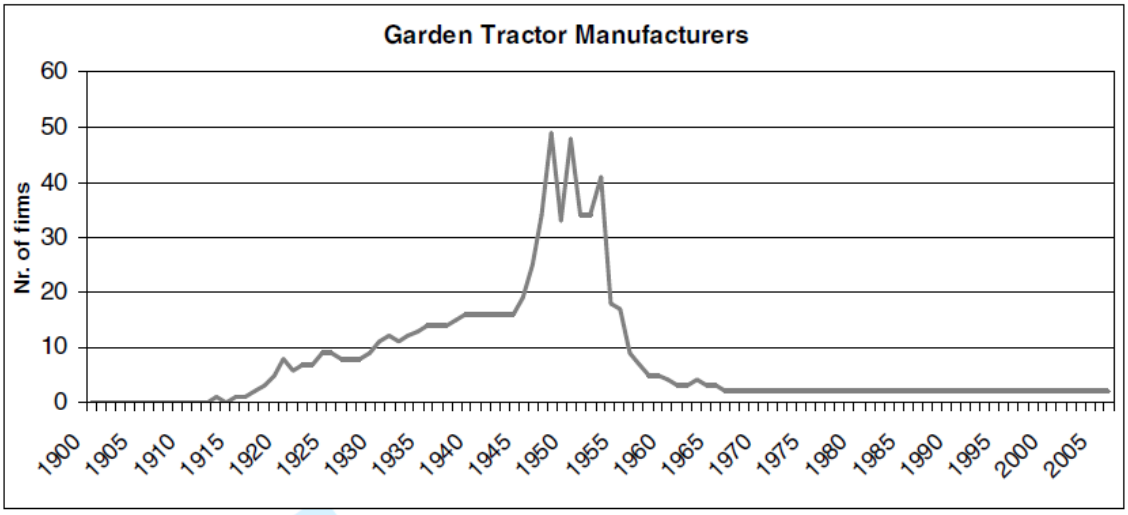

Fig.11- – Evolution of the garden tractor industry.

Most developments on small tractors in the world have been made by Asian firms. The smaller farm size and high intensity farming systems of Japan dictated the development of four-wheel models adapted to rice fields and vegetable gardens. Other Asian countries developed tractor industries from 1960 on. From them India and South-Korea emerged as exporters.

V. Conclusions

The farm tractor has been described as a "hero" (White, 2000; 2001) because of its importance in the economic growth of the United States in the 20th century. Here we present a historical perspective of its evolution from the earlier steam traction engines to the development of the first tractors featuring an internal combustion engine and its subsequent development. Specific characteristics of United Sates agriculture concurred to an earlier and greater development of the industry in this country. In the first two decades of the 20th century the number of tractor producers in the United States rose to 209. These numbers include a diversified group of producers, from the big implement firms (such as Deere) that entered the tractor industry to the small firms that made two or three tractors, and also include companies that came from the automobile industry and the motors industry. This diversity also meant a great deal of experimentation and models.

After the First World War, the United States entered an agricultural crisis that affected tractor firms. To increase sales, Fordson reduced the price of its tractors to nearly half, starting a price war with the major firms that forced more small competitors out of the industry and led to technological advance that culminated with the development of the first multi-functional tractor: the Farmall. This model has been described as an industry dominant design, for it changed competition and eventually even forced Fordson type tractor producers out of the industry. The companies that remained in the United Sates tractor industry were mostly producing flexible light tractors that could perform a variety of tasks, including ploughing, cultivating, spreading and harvesting cereals, in the same way the Farmall did.

In this paper we studied the evolution of the farm tractor. Our work aimed to understand the mechanism behind the birth of new technologies that pushed agriculture forward. While tractor industry shares a common history with the automobile industry, owing much of the advances in mechanics from it, the main advances in tractors are innovations specific to the industry such as the hydraulic (Ferguson) system. We presented the evolution of the tractor industry in the light of major innovations in the course of its development. The major early innovations of the tractor along different dimensions, and the development of the tractor industry can be best understood in the theoretical light of technology evolution as developed by Anderson & Tushman (1990). This paper therefore presents the framework for future research not just of new developments in the tractor industry, for instance the growth of small tractors that hold the promise of being a disruptive innovation, but for other industries as well.

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