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How to create conducive institutions to enable agricultural mechanization: A comparative historical study from the United States and Germany

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Agricultural mechanization is now high on the policy agenda of many developing countries. History has shown that successful mechanization depends on an enabling environment providing various supporting functions, for example, knowledge and skills development and quality assurance. This paper analyses how this enabling environment was created during the mechanization history of two today's mechanized countries, the United States and Germany, thereby distilling lessons for today's mechanizing countries. The paper highlights the different roles played by government agencies (public sector), manufacturers of agricultural machinery (private sector) and farmers' organizations (third sector) for the creation of this enabling environment. The study finds that both the United States and Germany witnessed the emergence of an institutional support landscape for mechanization. Yet, while mechanization benefitted from this support landscape in both countries, the organizations that created this support landscape differed largely. In Germany, the authors found more evidence of orchestrated public sector support and support from third-sector-actors to promote mechanization. In the United States, private actors played a larger role. For today's mechanizing countries, the findings suggest that public, private and third sector can all contribute to create a conducive environment for mechanization. The results indicate that the appropriate role of public, private and third sector depends on the strengths of each of these sectors and the strength of the driving forces for mechanization. While the study suggests that the enabling environment can be created by different actors, the study also shows that dedication will be key as mechanization is unlikely to unfold without certain key functions being fulfilled.

Keywords
Agricultural Mechanization, Knowledge and Skills Development, New Institutional Economics, Africa, United States, Germany

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How to create conducive institutions to enable agricultural mechanization: A comparative historical study from the United States and Germany

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Key Words

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1. Introduction

During the last decades, agricultural land and labour productivity have grown steadily around the world. In Sub-Saharan-Africa (SSA), land productivity has also increased, but labour productivity—a major determinant of farmers' incomes—has grown at a far lower rate in SSA than on any other continent (Fuglie and Rada, 2013). While productivity has always been a concern, policymakers, donors and private actors across Africa have, in recent years, rediscovered agricultural mechanization as a potential way to raise both labour and land productivity and started major mechanization efforts (Daum and Birner, 2017; Diao et al., 2016).[1] In these countries, a variety of mechanization patterns can be observed, ranging from purely state-led to market-led mechanization supply chains. For example, in Ghana, Nigeria and Zimbabwe, among others, the government has imported tractors and sold them at subsidized rates to farmers. In other countries, including Benin, Ethiopia, and Cameroon, mechanisation services are provided through state-led-hire-schemes.[2] A third strategy is the provision of mechanization through private service providers, which receive state-subsidised tractors. Examples comprise the "Agricultural Equipment Hiring Enterprises" in Nigeria, the "Agricultural Machinery Service Stations" in Kenya and the "Agricultural Mechanization Service Centers" in Ghana.[3] Where sufficient demand exists, small entrepreneurs dealing with used tractors and private service providers are also mushrooming. In addition, global players such as AGCO and the Deere and Company promote business models around emerging medium-scale farmers who service smallholders.

While these mechanization supply chains have different characteristics, they all have one challenge in common: they depend on supportive institutions, particularly, institutions for operational and technical information and skills development. Service providers, tractor operators, technicians, and farmers need knowledge and skills on how to operate, maintain, and repair tractors. A lack of these skills reduces the profitability of mechanization. Houssou et al. (2013) analysed the operations of 136 Ghanaian tractor-service providers. They found that 86% of them were not able to use their tractors during the entire cultivation period due to frequent and long-lasting breakdowns. These were due to lack of maintenance and a shortage of skilled operators and qualified mechanics (see also Daum and Birner, 2017; Diao et al., 2016). Besides affecting profitability, lack of knowledge and skills can also lead to operating errors, which may result in accidents and injuries. Moreover, lack of knowledge and operating skills can also affect soil fertility, e.g., if it leads to soil compaction or erosion (Senayah et al, 2012).

Setting up organizations and institutions to supply information and provide support for skills development is essential for successful mechanization, but such institutional development is a major and often neglected challenge. Ghana is an example. Although ffthe country has, according to the World Bank's aggregate governance indicators, a more effective government than many other countries in SSA (World Bank, 2017), the Ghanaian government has not been

[1] The effects of mechanization on yields are debated. Mechanization has the potential to raise land productivity because it allows timelier planting, cultivating heavier and more fertile clay soils, coping with weather risks during land preparation and harvesting and better seedbed preparation.

[2] Recent literature confirms the historically bad track record of such schemes (Daum & Birner, 2017; Diao et al., 2016; Houssou et al., 2013; Scoones, 2013; Takeshima et al., 2015; Pfebve, 2015).

[3] These schemes are not immune to governance challenges (Daum & Birner, 2017; Benin, 2015; Bymolt and Zaal, 2015; Takeshima et al., 2015).

able to generate the needed knowledge and skills for operators, technicians and farmers—potentially because of political economy reasons (Aikins and Haruna, 2012; Aikins, 2012; Daum and Birner, 2017; Houssou et al., 2013). Scholars have made the same observation about the lack of knowledge and skills for other countries, such as Kenya, Tanzania and Ethiopia (Bymolt and Zaal, 2015), Nigeria (Takeshima et al., 2013) and African countries in general (Ashburner and Kienzle, 2011; Diao et al., 2016; Houmy at al., 2013). A lack of qualified operators and technicians was also identified as an important reason for the failure of past mechanization programmes in SSA (FAO, 2016; Mrema et al., 2008).

As a look into history shows, countries that are mechanized today, such as the United States and Germany, faced similar challenges that developing countries are struggling with today. Some examples from Germany illustrate this point. In the 1920s, Thebis (1926) complained about lack of knowledge about maintenance and incorrect handling of tractors. In 1930, Schlange-Schöningen (1930, p. 139) wondered "how many expensive repairs could be avoided and how could the lifetime of machines be increased, if small repairs were done immediately." Likewise, Schlie (1935) observed that a large number of farmers purchased tractors merely based on how heavy they were. These observations raise important questions: How did the countries that successfully mechanized their agricultural sector solve these challenges? What was the role of government agencies (public sector), the manufacturers of agricultural machinery (private sector) and farmers' organizations (third sector) in this regard?

Answering these questions may lead to valuable insights on how developing countries, such as Ghana, that aim to mechanize their agricultural sector can develop institutions for tractor sales and repair and some type of program to provide owners and operators with training for the operation, service, and maintenance of machinery. The historical, political, agronomic and socio-economic conditions of each country are different—therefore, there is no "one-size-fits-all" solution. Yet, the authors of this study believe that examining the history of agricultural mechanization in two different countries, Germany and the United States, will provide valuable insights on the institutions that could facilitate agricultural mechanization in developing countries. Moreover, a comparative historical study may also inform the debate about the roles of the public, private and third sectors. In the words of Chang (2009, p.511), there is a "lot that developing and transition economies can learn from the history of agricultural policy in today's rich countries".

The paper proceeds as follows: In section 2, a conceptual framework is outlined. Section 3 describes the evolution of agricultural mechanization in the United States and Germany, focusing on technological change. Section 4 then highlights the institutional change in these two countries with particular focus on the institutions for developing the required knowledge and skills. Section 5 discusses and derives lessons for developing countries. Section 6 concludes.

2. Conceptual Framework

The profitability of new agricultural technologies depends on various determinants. These include the characteristics of the technology, which is influenced by capital requirements, effects on productivity, operability, and frequency of breakdowns. Profitability also depends on system-wide characteristics such as land abundance and labour scarcity (Hayami and Ruttan, 1971), the length of the growing season, topography, and soil types. In addition, the profitability of new technologies depends on farm-level characteristics such as farm size and types of crops grown (Feder et al. 1985, Sunding and Zilberman 2001, Huffman 2001). However, even if the agro-ecological, technological, and economic factors are conducive to the adoption of a new technology, there is also a need for an enabling institutional environment. The conceptual framework, which is shown in Table 1, identifies key components of an enabling institutional environment for mechanization. The framework distinguishes between two dimensions of the enabling environment: (a) the functions that need to be fulfilled by the institutions involved, and (b) the type of activities by which these functions are achieved. They are displayed in columns (functions) and rows (activities) of Table 1.

A basic function is the provision of information about the new technology. Farmers need access to information about the machinery that is available on the market and the ways in which it can be used. As shown in Table 1, different activities can fulfill this function, including provision of extension services, media such as farmers' magazines and exhibitions. In the case of agricultural machinery, provision of information to farmers is not sufficient to ensure the profitable use of this technology. Farmers need to develop the skills to use agricultural machinery, and there is a need for skilled technicians who can service and repair agricultural machinery. In fact, providing facilities for knowledge and skills development are most important functions of an enabling environment for agricultural mechanization. Schultz (1964) has shown early on that the adoption of new technologies can be constrained if users lack knowledge and skills on how to use them. As mentioned above, Houssou et al. (2013) and Daum and Birner (2017) found that a lack of maintenance, skilled operators, and qualified mechanics cause frequent and long-lasting breakdowns, which undermine the effective use of machinery. Daum and Birner (2017) also have shown that farmers often lack the capacity to assess the quality of used and new machinery and that the quality of machinery can vary widely without standards and certification. Hence, there is a need for facilities where farmers, farm workers and technicians can be trained. Other activities, such as ploughing competitions, can also contribute to skills development.

As shown in Table 1, an enabling institutional environment for agricultural mechanization also includes other functions, such as quality assurance, the promotion of competition within the machinery industry and the promotion of innovation. Activities to deliver these functions include exhibitions and field days, which may involve the award of innovation medals. Other activities are machinery testing and the publication of farm magazines that report on agricultural machinery.

There are other components of an enabling institutional environment for mechanization, which are, for reasons of scope, not addressed in this paper. These include applied research on the use of machinery, land consolidation as well as access to roads and fuel and a conducive regulatory and business environment. Some of these aspects have been discussed elsewhere: Gisselquist and Jean-Marie (2000) provide an overview on the influence of import regulations on technology adoption. Evenson (2001) shows the importance of applied research. Hulme and Mosley (1996) discuss the role of finance for agricultural development. Binswanger et al. (1995) highlight the role of land consolidation and land markets. The functions discussed in this paper (see Table 1) have received less attention in the literature, so far.

Table 1. Components of an enabling institutions for agricultural mechanization

Activities \ Functions	*Provision of information*	*Developing knowledge and skills*	*Quality assurance*	*Promotion of sales*	*Promotion of competition*	*Promotion of innovation*
General training of farmers		✓				
Specific training of operators		✓				
Training of technicians		✓				
Extension	✓	✓	✓			
Media	✓	✓		✓		
Exhibitions	✓			✓	✓	✓
Award of medals			✓	✓	✓	✓
Ploughing competitions		✓				
Machinery testing	✓		✓	✓	✓	✓

Types of institutions to carry out activities / fulfill functions of the enabling environment		
Private sector	**Public sector**	**Third sector**
Manufacturers and dealers of agricultural machinery; technicians; consultants Publishing companies	Government agencies, e.g. public extension service, farmer training centers or schools	Farmers' associations; cooperatives; machinery rings;

What is important to highlight from an institutional perspective is the fact that each of the activities listed in Table 1 can be provided by three types of institutions, as shown in Table 1: (1) institutions of the private sector, such as companies involved in manufacturing and sale of machinery); (2) institutions of the public sector, such as government agencies that provide extension services or operate training centres; and (3) institutions of the "third sector", that is institutions based on collective action, such as cooperatives and machinery associations. Importantly, some activities may be also provided informally, e.g., within the family or among neighbours.

These different types of institutions have different comparative advantages to provide each of the activities listed in Table 1. These comparative advantages may vary across countries and time. As a result, these activities may be provided by different types of institutions (private, public and third) in different countries and at different points in time. In section 4, we will present the findings of a comparative historical analysis that aims to find out how and by what type of organizations these activities were carried out in the United States and in Germany.

Before presenting these findings, we will outline how mechanization has unfolded in these two countries (section 3).

3. Technological Change: Evolution of Mechanization in the United States and Germany

The United States and Germany followed different pathways to agricultural mechanization. The United States was founded in 1776 along the Atlantic seacoast, and thereafter the frontier moved slowly westward opening up vast new lands as the U.S. government purchased new lands and cleared up ownership rights with Spain, France, and Mexico. During this era, the U.S. was rich in land and natural resources and short on labor, which spurred the use of animal power and later machinery. First, animal power (oxen, horses, mules) replaced manpower for turning and smoothing (harrowing) the soil for seedbed preparation. By the mid-19th century, steam power was introduced for threshing grain. Later came steam plows. Tractors with internal combustion engines were produced by Hart and Parr in the U.S. from 1901 to 1914. Horses were no longer needed to cart large volumes of fuel and water that steam engines and tractors used, which was a major advantage. However, they had many of disadvantages of the steam engines—heavy weight (10 tons), slow moving, and difficult to start internal combustion engines. The first successful small (about one-half ton) gasoline-powered tractor was the Bull. Other companies entered the race, and in 1910, there were 15 private companies manufacturing tractors in the U.S. The number of companies manufacturing tractors peaked at 186 in 1921, but rapid industry consolidation followed. A major factor was undoubtedly the establishment of the Nebraska Tractor Testing Station in the early 1920s (see 4.2.8). However, it was 1920 before small versatile farm tractors became available. However, rapid adoption of farm tractors did not occur until the late 1930s, and adoption was greatly disrupted during the early 1940s by World War II. After the war, new interest in farm tractors mushroomed.

In Germany, prototypes of tractors were produced, but unlike in the United States, they did not enter mass production, mostly because of relatively high prices and low demand (Franz, 1969). The first wave of tractorization started during the 1920s after a ban was lifted, which made the import of inexpensive and good-quality American Fordson tractors possible (Kayser, 1948). This development gave German tractor manufacturers a crucial push (see 3.2.) During the 1920s and 1930s, German companies caught up, often by learning from the developments of the U.S., and by producing small, inexpensive, reliable, and multi-use tractors themselves. Between 1925 and 1933, the number of tractors increased from 7,000 to 24,000, but these were mainly used on large estates (Klein, 1973, Wendler, 1994, p.247). In 1933, only 1% of the farms used tractors (Statistisches Reichsamt, 1934). Nevertheless, institutions for skill and knowledge development for mechanization evolved step-by-step. Many of them were parastatal (Franz, 1969; Wendler, 1994). In the 1930s, mechanization slowed down due to the Great Depression, the establishment of the Nazi Regime, which blamed mechanization for rising unemployment, and later the Second World War. A second wave of mechanization only started in the 1950s, triggered by industrialization, economic growth, and raising wages (Hermann, 1985; Renius, 1994). The number of tractors on farms jumped from 60,000 in 1945 to 1.16 million in 1965 (Franz, 1965, p.9). During this second wave of mechanization, small-scale farmers were among the beneficiaries (Hudde and Schmiel, 1965). The fast breakthrough of mechanization benefitted from the institutional foundations that had been laid in the 1920s and early 1930s, but it still took a decade for the institutional landscape to fully develop.

As mentioned above, stationary steam systems were developed and used around the same time in the United States and in Germany. However, the United States spearheaded the developments of self-propelled and gasoline tractors during the late 19th and early 20th century. Even during the 1930s and 1940s, the main agricultural engineering contributions such as the power-take-off (PTO), the use of pneumonic rubber-tires and the three-point hitch were developed in the United States. American manufactures often sold considerable quantities and thus reached economies of scale, allowing them to sell tractors at comparatively low prices and to generate revenues that they could invest in innovation. In 1920, 246,000 gasoline tractors were used on American farms (Olmstead and Rhode, 2008). The following sections discuss these developments in more detail for the United States (see 3.1.) and Germany (see 3.2.).

3.1 USA

The U.S. was founded in 1776 with 13 states, which had their origins as the Thirteen Colonies, stretching along the Atlantic Coast from Massachusetts to South Carolina. In 1880, the U.S. frontier started moving northeast into New England, South into Georgina and Florida, but more important, it was moving westward, as the U.S. settled land ownership disputes with other countries and acquired new territories, e.g., the Louisiana Purchase in 1803. By 1840, the western frontier of the U.S. included the southern half of Michigan, a small sliver of southern Wisconsin and eastern Iowa, then south near the western borders of Missouri, Arkansas and Louisiana (Cochrane 1979, pp. 29).[4] The new lands of the eastern Midwest were much flatter richer prairie soils compared to the hilly, sometimes mountainous, rocky timber soils of the northeast. As the frontier moved west, famers frequently faced new production problems, e.g., turning the heavy prairie soils of the Midwest relative to the rocky, timber soils of the East. In addition, these farmers acquired larger areas of land suitable for cropping, which was enhanced by the 1862 Homestead Act which gave a husband and wife 320 acres (160 acres each) if they would live on the land for five years and improve it (Cochrane 1979). In addition, as water transportation improved, grains produced in the Midwest could be shipped by the Great Lakes and the Ohio and Mississippi Rivers to the large cities on the U.S. East Coast. These changes increased the demand for invention by farmers and blacksmiths to solve new production problems of these new lands.

3.1.1 The Beginning of Mechanical Power

A particular bottleneck in the production of grain was its harvesting and threshing. Until 1850, farmers used sickles, scythes, cradles, and later improved scythes, to cut the wheat straw just above the plant roots (Cochrane 1979, pp. 193). Even with the improved cradle, the harvesting of grain remained slow and hard work. However, Cyrus McCormick and Obed Hussey were working on developing a horse-drawn reaper to harvest wheat. McCormick obtained the first patent on a reaper in 1831, but it did not perform in the field. Hussey obtained a patent on a slightly improved reaper in 1833, and McCormick obtained a second patent in 1834. After moving his business to Chicago, McCormick developed a reaper combining the best features of both machines in the early 1850s. It was horse drawn cutting the wheat straw a few inches above the ground, then letting it fall onto a table where a worker walking beside the reaper to

[4] By 1860, the main extensions of the frontier were to include all of Wisconsin, Iowa, and southern tip of Minneosta, and a sliver of eastern Kansas (Cocharane 1979, pp. 86).

rake wheat shafts in to piles on the ground (Cochrane 1979, pp. 194). These piles of straw and grain were later collected by farm workers using pitchforks and loaded the stocks with grain onto a horse-drawn flatbed wagon. The reaper greatly increased the speed of small grain fieldharvesting (Cochrane 1979, pp. 68).[5]

A second bottleneck in wheat production was the separation of the grain from the straw. It was very time consuming to beat the grain-laden wheat heads against a hard surface by hand. Advances in steam power were needed before this could occur.

In 1769, James Watt obtained a patent on a steam engine making use of a separate condenser and produced steam engines from 1774-1800. The contributions of Watt were so great that he is frequently referred to as the inventor of the steam engine. The early steam engines were used to power large water pumps, boats and railroad locomotives. By the 1830s, Hiram and John Pitt patented a stationary grain-threshing machine, which was powered by a steam engine using a belt to run from the belt pulley of the tractor to a receiving belt pulley on the threshing machine. Although the machine required horses to pull it rom farm to farm,by the 1840s the use of mechanical threshers was commonplace in the East and much of the Midwest.

Self-propelled steam engines became available later. At first they were just portable engines, needing chains or gears connecting the crankshaft and the rear wheels to power them. They could not be steered by an operator; horses were needed to pull them off a straight line. However, their power could be used to pull a threshing machine from farm to farm in a straight line, but this was time consuming and a great inconvenience. The Forty Niner, first built in 1849, was one of the first portable steam farm engines produced in the U.S. It was built in the 4, 10 and 30 belt horsepower sizes. The engine in the 4 weighed two tons.

A third bottleneck was land-surface preparation needed before planting spring crops. Aroiund 1855, Obed Hussey invented the first steam plow. It was successfully demonstrated at the Illinois State Fair in 1858. However, the invention of a steering device in 1880 enabled engines to turn themselves. This greatly improved maneuvererability of steam engines, steam tractors and plows. A steam engine that could be used for plowing, general pulling, belt power, and other farm work became known as the Steam Traction Engine.

Self-propelled steam traction engines or steam plows were first sold to U.S. farmers in the 1870s. In 1880, the invention of a steering mechanism made steam engines and tractors so that they could be steered by an operator. In 1890, approximately 3,000 steam traction engines and 2,661 steam threshers were built. In 1894, several plow manufactures advertised multiple bottom steam plows or gangs. By 1900, more than 30 firms were manufacturing some 5,000 large steam traction engines (Peterson 2009). By 1900, the gearing, shafting, and other wearing parts had been substantially improved for durability. These steam traction engines were largely used on large wheat farms in the Great Plains. Not only were these machines large in size and weight, but they generally required several individuals to operate them successfully.

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[5] Cyrus and his bother William developed innovative marketing and sales techniques for their reaper. They developed a wide network of salesmen trained to demonstrate operation of the machines in the field, as well as to get parts quickly and repair machines in the field if necessary. Their machine was widely adopted.

Huffman (2014) presents the economics of the demand for labor and capital service by farms, including substitution possibilities between labor a capital services and labor-saving technical change. He illustrates a number of important relationships, showing especially the importance of the wage for labor relative to the price of capital services. He also discussed the economics of the adoption of labor-saving technologies in the U.S. during the 20th century and how it has been a major factor in changing farm structure.

3.1.2 Origins of the Gasoline Farm Tractor (Internal Combustion Engine)

The first gasoline tractor was invented in 1892, but considerable additional innovations were required before versatile light-weight farm tractors were developed and available to American farmers.[6] Many innovations were occurring about 1910, and sales started to increase rapidly in the mid-1910s.

John Froelich is credited with inventing the first gasoline tractor in the U.S. In 1892, he mounted a gas engine on a steam tractor engine chassis and added a drive arrangement of his own design. This tractor had the five key attributes of a gasoline farm tractor. It was: (i) self-propelled, (ii) produced drawbar pull (horsepower), (iii) produced belt power (horsepower), (iv) had a clutch to engage and disengage the drive train, (v) had a reverse gear, and (vi) was steered by the operator. It was the first gas tractor to operate successfully. It had a single cylinder and generated 20 horsepower (most likely belt power). Froelich's tractor was smaller and much lighter (less than one ton) relative to the large cumbersome steam traction engines. The following year (1893), Froelich with partners founded the Waterloo Gasoline Traction Engine Company, Waterloo, IA. In 1895, the company's name was changed to the Waterloo Gasoline Engine Company. In 1914, it produced the first Waterloo Boy Tractor, which burned primarily kerosene; the Model R single-speed tractor. It later offered a new model "LA" tractor having two cylinders. Twenty of these tractors were produced and sold.

C.W. Hart and C.H Parr entered the University of Wisconsin in 1892 to better learn how to adapt crude gas engines to farm purposes. After graduating in 1896, they built several successful stationary gasoline engines. In 1900, they moved their operation to Charles City, IA, and then perfected their ideas for a gasoline traction engine, which was built and successfully operated in 1901. Their second model, a 22-45 horsepower (HP) (i.e., 22 horsepower at the drawbar and 45 horsepower on a belt) version was successful enough that 15 were built and put up for sale in 1903.[7] Hart and Parr continued to make improvements, introducing an 18-30HP traction engine in 1903, and a 17-30HP traction engine from 1903 to 1907. In 1907, Hart-Parr introduced its 30-60HP, named Old Reliable. Its advertising manager wanted a shorter name than a "traction engine" and eventually hit upon the word "tractor" for the first time, meaning a machine for pulling or hauling (The Tractor Guys). This name was rapidly adopted for all later gasoline-powered tractors, including those of the Waterloo Gasoline Engine Co.

However, the trademark of the Hart-Parr tractors was that they had much in common with steam traction engines: They were heavy, flywheels weighing 1,000 pounds or more, and the total

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[6] At the same time, the adult public was learning to drive cars. After learning to drive a car, learning to drive a gasoline tractor would have been more difficult, but it may not have been such a big step.

[7] These early tractors had much larger stationary horsepower for powering belt-driven threshing machines than drawbar horsepower reflected in power to pull things such as plows.

weight of tractors being about 10 tons. They had two cylinders and could burn any liquid fuel, but most generally kerosene. They were cooled by oil (not water); and had a tricky ignition system. The tractors were driven and steered by chains and moved slowly, about two miles per hour (Lettingwell 1991). In 1908, Hart-Parr introduced the 40-80HP tractors that had an improved ignition system and was marketed through 1914. However, they experienced major problems with untrained tractor drivers failing to maintain the engine properly, leading to breakdowns and costly repairs. A common problem with early gasoline engines was that they did not have an air-intake cleaner for air going into the combustion chambers. When field and road dust entered these chambers, the steel engine valves would quickly obtain burned-on carbon and the engine would lose power.

The first successful small farm tractor was the Bull introduced to American farmers in 1913. Standard features included a single "bull" wheel, weighing several hundred pounds, a two-cylinder 5-12 engine.[8] It had a cone clutch rather than the more common transmission gearbox. The Bull was a fraction of the weight of the early steam farm tractors, which frequently weighted 10-15 tons, and it was more easily maneuverered. The Bull Tractor Company did not actually manufacture these tractors but instead contracted with the Minneapolis Steel and Machinery Company to manufacture them. Sales skyrocketed in 1914 and 1915, but there was insufficient innovation and the Bull tractor soon became inferior to tractors made by more innovative companies. The production of the Bull tractor in the U.S. ended about 1918 (Olmstead and Rhode 2001).

In 1914, Hart-Parr introduced its first small tractor, the 15-22HP Little Red Devil. It was a peculiar tricycle rig propelled by a large single rear wheel with a direct-drive reversible two-cycle two-cylinder engine. This model sold in significant numbers until 1916. In 1918, Hart-Parr introduced two new much more practical small tractors, the 15-30HP Type A and the 12-25HP type. Both ran with two-cylinder engines. However, in 1921, the 10-20HP Model B two-cylinder was offered as a 20-40HP model, described as two 10-20 HP engines operating side-by-side.

Sometime in 1919, Hart and Parr sold their share of the tractor business to their financial partner M.W. Ellis. However, they continued be employed by the company and to engineer improvements in the Hart-Parr tractors, introducing disk clutches, forced-lubrication system, a high-energy magneto, water injection and three speed transmissions. However, Hart and Parr eventually retired, and in 1929, Ellis sold out to the Oliver Tractor Company.

3.1.3 Other Significant Technical Innovations in Tractors

Standardized testing of tractors and power take-offs and the introduction of pneumatic rubber tires were important innovations in the history of farm tractors. In 1924, tricycle type general purpose farm tractors suitable for row crops were first introduced. They had higher clearance, an advantage for cultivating corn and cotton, and better maneuverability compared to earlier steam and gas tractors.

The first power-take-off (PTO) was offered on tractors in 1922. It was a metal shaft turned by the rotation of the tractor engine, and it allowed implements in tow to have power directly from

[8] Although introduced about the same time, the U.S. Bull tractor is unrelated to the German Bulldog tractor.

the tractor engine. Earlier power of machines in tow, e.g., the reaper, spreader, mower and combines, was by power generated from a wheel rolling along on the ground. The PTO quickly became a standard feature of farm tractors after the American Society of Agricultural Engineers adopted a uniform standard for PTO arrangement on all new tractors in 1927. This was a major step forward because no particular tractor make was required to power a machine in tow. In 1928, the first mechanical lift for a farm tractor was invented.

In 1930, the first two-row mounted corn picker was introduced (Colbert 2000). It was a major technical advance over earlier pull-type corn pickers because the tractor operator could look ahead and to the side of his tractor seat to monitor the performance of the machine. With pull-type corn pickers, farmers were continually looking backward to monitor performance. Also, with a pull-type machine, operators had difficulty harvesting all of the rows of corn in a corn field; some of the outer rows had to be picked by hand or were lost. However, due to the Great Depression, 1929-33, and depressed farm incomes, farmers did not start to purchase two-row mounted corn pickers in significant numbers until the late 1930s. However, tractor-mounted corn pickers with their husking rollers and gathering chains located near the operator posed significant hazard to the fingers and arms of the machine operator.

In 1932, Allis Chalmers was the first to successfully introduce low-pressure pneumonic rubber tires for the rear wheels of tractors. Rubber tires were also added for the much smaller front wheels of tractors. The new rear tires greatly improved the performance in the field by reducing slippage of the rear wheels, where the power was delivered, and made the machine easier to ride both in the field and on roads and reduced tractor vibration, which could cause machine breakdowns. It also increased fuel economy, since it eliminated significant slippage of the rear wheels. By the mid-30s, there was a rapid change to the new rubber tires on all new farm tractors. In 1933, the first commercial use of diesel engines in wheel tractors occurred. They were known for their large lugging power at low revolutions per minute and fuel efficiency. In 1939, Ferguson introduced the first draft response three-point hitch. This was a major innovation and enabled attachment of rear-mounted plows, including a hydraulic lift system. This innovation was extended first to Ford tractors built by Henry Ford and eventually to almost all new farm tractors.

In 1959, the first fully power-shift transmission was introduced to farm tractors. The operator could shift from one gear to another without disengaging the clutch. And, in 1967, the first hydrostatic transmission was introduced to farm tractors. In this system, fluid from an engine-driven hydraulic pumping system is routed to a hydraulic motor, which then drove the wheels, making it is easy to change the speed of tractors while running the engines at a constant speed.

Tractor quality and versatility kept improving between 1919-1960 and, more important, only when real wages of farm labor increased did it become relatively unprofitable to operate a farm with labor-intensive horse and mule power and implements. Little evidence exists of an early emphasis on teaching farmers and farm workers how to smoothly and safely operate farm tractors and implements.

3.1.4 Work Animals and Tractors on U.S. Farms

The number of horse and mule working stock on U.S. farms peaked about 1920 at about 23 million, but thereafter numbers steadily declined (Table 1). In 1950, there were about 6.6

million working horses and mules on farms, but in 1960, the number had declined to only 2.5 million. As tractors were introduced after 1910, farmers replaced work horses and mules. However, early tractors lacked versatility and, hence, farmers generally needed both horses

Table 1. The Number of Tractors and Horses on U.S. Farms: 1920-1970

	Tractors [a/]		Horses and/or Mules [b/]	
Year	**Number**	**Share of farms**	**Number**	**Share of farms**
1910	~ 2	<0.1	18,010	85.0
1920	246	3.6	20,300	84.2
1925	505	7.4	20,060	79.9
1930	920	13.5	17,330	73.4
1935	1,123	nd	15,030	71.5
1940	1,567	23.1	12,215	63.8
1945	2,422	34.2	11,290	54.0
1950	3,609	46.9	6,630	46.9
1955	4,345	60.1	4,000	37.6
1960	4,688	72.3	2,500	30.6
1965	4,787	76.6		
1970	4,619	80.8		

[a/] Estimate of number of tractors on farms in 1,000s. Olmstead and Rhode (2001).

[b/] Working stock of horses and mules on farms 3 years of age and older in 1,000s. Brodell and Jennings (1944), and Olmstead and Rhode (2008, p. 374).

and tractors to complete their farm work. There were few gasoline tractors on farms in 1910, but by 1920, the number had grown to 246,000 with 3.6 percent of the farms having gasoline tractors (Table 1). The growth in number of tractors was steadily upward and by 1930, there were 920,000 tractors on farms with 13.5 percent of farms having a tractor, and in 1940, there were 1.6 million tractors on farm with 23 percent of the farms having tractors. By 1950, almost half of U.S. farms had tractors, with a total of 3.6 million tractors on farms. In Table 1, we see the phenomenon that Olmstead and Rhode (2008) emphasize; as tractors became more versatile after the 1920s, and were adopted more rapidly, the number of working horses and mules on farms declined, and tractors were used for plowing, disking, harrowing, and planting. The tricycle type tractors were also used for cultivating row crops of corn and cotton. Hence, animal power was rapidly replaced by gasoline tractors. By 1960, only 30 percent of U.S. farms had working horses and mules.

Although Griliches (1960) was to first to apply statistical methods to estimate the demand for farm tractors, Manuelli and Seshadri (2014) were the first to explain the long adoption lag over 1910-1960 for U.S. farm tractors. They argue that the slow rate of adoption was due to the steady increase in quality of tractors, which reduced early demand for new tractors. It the farmer waited a couple more years, he/she could purchase a significantly better tractor frequently at a lower real price. But, more importantly, it was not until U.S. farm real wage rates increased dramatically over the World War II years of 1940-44 (figure 2) that tractors rapidly replaced labor intensive horses and mules for power. For example, in 1930, 13.5 percent of farms had tractors, about 920,000 tractors; in 1940, 23 percent of farms had tractors, about 1.6 million tractors, but by 1950, the share had risen to 50 percent, and about 3.6 million tractors.

It is estimated that sales of tractors in the U.S were 14,000 in 1914, 36,000 in 1916, 164,500 in 1918, and 203,204 in 1920 (Wik 1983). As indicated above, by the mid-1910s, there was a rapidly growing number of firms that produced tractors. However, many of the tractors were of poor quality—frequently breaking down with no repair parts or service available, and no warranty. Some farmers were taken for suckers by enterprising makers of new makes of farm tractors in this era (Lettingwell 1991).

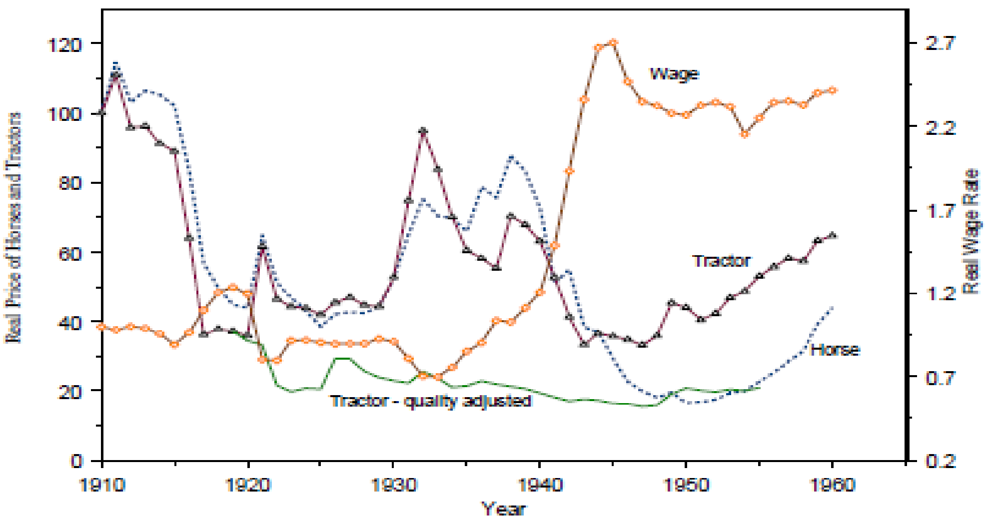

Figure 2. Real Prices for Tractors, Horses and Labor: 1910-1960 (Manuelli and Seshadrai 2014)

3.1.5 **Major Suppliers of U.S. Farm Tractors Over Time**

In the 1910s, the supply of farm tractors was dominated by International Harvester and Ford, a total of 41.5% (Table 2). See Lettingwell (1991) for examples of early American farm tractors by manufacturer. These two manufacturers were also dominant in the 1920s, accounting for a very large 72.8%. John Deere and Allis Chalmers first became significant suppliers of farm tractors in the 1930s, replacing Ford. In the 1940s, International Harvester and John Deere were the two leading sellers of farm tractors in the U.S. (66%). Also, Allis Chalmers for the first time had a double digit share in this decade (12.6%). During the decade of the 1940s, the market share of International Harvester and John Deere declined to 50%, with significant gains by the new and combined Massey-Ferguson (14.7%). In the 1950s, International Harvester, John Deere and Ford accounted for 64% of U.S. farm tractor sales.

International Harvester

In 1902, J.P. Morgan and Company purchased the McCormick Harvesting Machinery Company and the Deering Harvester Company, plus two small harvester companies. These businesses were merged to form the International Harvester Company. International Harvester began manufacturing small tractors in 1906. Because of anti-trust concerns, International Harvester was required to operate two companies for several years. The Titan model was built in Milwaukee, WI, and introduced in 1908 and sold by the Deering dealers. The company's Mogul line followed in 1910 and was manufactured at the Chicago plant and sold by McCormick dealers. It was a single cylinder tractor, rated 8 horsepower on drawbar and 16 horsepower on the belt. The claim was that it was relatively easy to maintain, repair and operate. The International Harvester Company was among the first to make the power take-off standard on farm tractors (Olmstead and Rhode 2001). The live power take-off was used to power equipment being towed by a tractor, e.g., a mower.

In 1923, International Harvester first field tested its new "all-crop" tractor that it named the "Farmall," and first offered it for sale in 1924. It was billed as the first light-duty, all-purpose, row-crop tractor. Farmers for the first time could eliminate horses, along with the need for large quantities of oats and hay to feed them and for workers to care for them, and still be able to complete their farm work (Olmstead and Rhode 2008). The Farmall model was marketed into the 1960s.

Table 2. Market Share in the U.S. of Leading Wheel Tractor Manufactures, by Decade, 1910-1955

Make	1910s	1920s	1930s	1940s	1950-55
John Deere	4.0%	6.4%	21.7%	17.0%	14.5%
Farmall/International Harvester	21.4	28.6	44.3	32.7	30.6
Ford	20.1	44.2	0.0	7.9	19.3
Massey-Ferguson	2.9	1.9	2.9	14.7	9.1
Case	7.2	3.6	7.4	5.1	6.2
Allis Chalmers	6.2	3.5	12.6	9.7	10.1
Oliver	2.1	2.2	5.0	4.8	5.4
Minneapolis Moline	8.0	0.7	2.9	3.2	3.6
Others	28.0	9.0	3.2	2.5	0.2

Source: White (2000).

John Deere

In 1804, John Deere (the individual) was born in Vermont but moved to Central Illinois in 1836. Here he discovered, as many other farmers, that the cast iron plows used successfully on the rocky and light sandy soils of the Northeast and Appalachian regions would not turn the heavy, sticky prairie soils of the Midwest. Deere visited a friend's sawmill and spotted a broken steel saw blade that was highly polished from sawing logs. He took the blade back to his shop and cut off the teeth and fitted it to a wrought iron mouldboard and wooden handle. A farmer tried it and proved Deere's new steel plow cut through and turned the heavy prairie soils, and Deere invented the first plow with a steel cutting shear (1837). Deere first produced plows on his own, but in 1843, he formed a partnership to produce and sell steel plows. However, this business was dissolved in 1848, and Deere moved his Deere plow business to Moline, IL, on the Mississippi River. This had the major advantage of reducing the cost of production and distribution. By 1850, the company was also producing other farm implements complementary with plows. However, by 1910, it became apparent that the John Deere Company needed a tractor to complete its line of farm machinery. In 1918, Deere and Company paid $2.35 million for the Waterloo Gasoline Engine Company, which manufactured the Waterloo Boy tractor at its facilities in Waterloo, and John Deere because a full service farm tractor and implement business. From 1918-1923, Deere and Company continued to make tractors under the Waterloo Boy name, but in 1923, the John Deere Model D was introduced. From this date forward, the John Deere name was affixed to all of their new tractors. However, this happened long after the founder John Deere passed away. In 1927, John Deere released the first of several models falling under the category of General Purpose Tractors with a narrow front end, including the John Deere Models A and B, that competed well with the Farmall. These models were marketed through 1952, when a new series of larger tractors were released—the models 70, 60 and 50.

3.2 Germany

Although the technical evolution of agricultural machines was largely influenced by preceding developments from the United States (and the United Kingdom), Germany followed its own unique pathway of agricultural mechanization.

3.2.1 The Beginning of Mechanical Power

In Germany, mechanization evolved from large estates that used stationary steam systems pulling light plough carts along ropes around the 1870s. Stationary steam system was developed 1832 by Georg Heathcote from the United Kingdom but became popular only with a version using two steam machines developed by John Fowler in 1862. However, these systems were expensive and became profitable only for estates with farm sizes of more than 400 hectares (Bauer, 2007; Herrmann, 1985). Around 1900, 3,000 such steam plow systems were used but then their popularity declined again (Kaiser, 1994, p.143). What was more popular was the use of these stationary steam machines to power threshing machines and also the use of autonomous steam threshing machines – both were pulled by horses from farm to farm. In the United States, such machines had been built since 1849. Its German counterparts were constructed from 1860 onwards by Rudolf Wolf and from 1879 onwards also by Heinrich Lanz (see 3.2.5). They usually had one or two cylinders and there power was approximately 10HP. In 1907, steam threshing machines were used on 488,867 farms (Kaiser, 1994, p. 143)

3.2.2 Origins of the Gasoline Farm Tractor (Internal Combustion Engine)

As indicated above, the development of gasoline tractors was spearheaded in the United States. Germany followed a different pathway. In 1907, the Gasmotorenfabrik Deutz experimented with such tractors. The 40HP-*Deutzer-Pfluglokomotive* had a four-wheel-drive and equally large iron wheels. Cable controlling ribbing ploughs were mounted in the back and the front of the machine. At the same time, Deutz also developed the *Deutzer-Automobilpflug*, which was powered by a 25HP gasoline engine and could be used mainly for ploughing but also to power threshing and shredding machines. The *Automobilpflug* had large driving wheels in the back and small steering wheels in the front and looked comparable to today's tractors. While both prototypes are considered milestones of German agricultural mechanization, they never entered serial production and there was little demand. The machines were too heavy, technologically complicated, frequently got stuck in muddy fields, and expensive. Also, they had a low energy transmission and high fuel consumption (Herrmann, 1985). The high fuel consumption was not only a financial problem but also an organizational one, as organizing and supplying several hundred liters of gasoline per working day was difficult because of missing infrastructure.

The pathway towards gasoline tractors, therefore, came to a halt before it could really take off. Instead, for a long time German producers relied on steam-run engines, which required only water and coal. Small machines (*Motortragpflüge*) dominated mechanization (Franz, 1969). The first *Motortragpflug* was presented by Robert Stock in 1910. The machine had two large front driving wheels, one small back steering/carrying wheel and three plough blades in between. The machine had a one-speed transmission and 8 to 28HP. The engine (and weight) was placed in the front and, therefore, the machine had a good energy transmission and was easy to navigate (Bauer, 2007). The success of these machines led to more imitated versions, most famously a version developed by Hanomag (with 50, 65 or 80 HP) (Franz, 1969). Although later developments made it possible to use different implements, the *Motortragpflüge* were mostly used for self-propelled land preparation.

This trend of using *Motortragpflüge* instead of gasoline tractors was also supported by the fact that the government banned the import of the inexpensive, light and multi-purpose 22HP Fordson tractors from the United States. *Motortragpflüge* costed between 5,000 and 10,000 Reichsmark whereas the Fordson tractors costed merely 2,000 to 4,000 Reichsmark (Wendler, 1994, p.248). The import ban may have slowed down mechanization, but allowed Germany to develop its own tractor-industry after the end of the First World War. The first company to produce gasoline tractors was Pöhl-Ackerbaumaschinen, which constructed a 30HP, four-gear tractor in 1918. These machines worked reasonably well but were slower and more expensive than the American Fordsons. They costed 7,000 Reichsmark (Franz, 1969, p.30). In 1924, the government eventually allowed the import of some Fordson tractors, which immediately encountered a large demand (Bauer, 2007; Wendler, 1994). To compete with the price and advanced technology of the Fordsons, German producers were forced to produce at lower costs and therefore reorganized the manufacturing process according to the principles of Ford (Franz, 1969, Wendler, 1994). The 26HP Hanomag WD tractor, which was sold from 1924 onwards and also the Hanomag RD 28 were considered as the "German Fordsons." From 1921 onwards, Lanz produced heavy-oil-fueled tractors of its Bulldog series, which became very famous later. While these tractors were celebrated by agricultural experts, they were still expensive and few were actually sold. Only after Lanz reduced production costs by using assembly lines, the tractors became finally affordable for a large share of the farmers (Hermann, 1985).

What is noteworthy is the parallel trend of developing and using motor movers (*Motormäher*), which took place in the South of Germany driven by small manufacturers. The small and simple self-propelled motor mowers were developed for harvesting hay, an activity that was the main bottleneck of the pasture-dominated farming systems in Southern Germany. These machines also became widespread among smallholders. Farmers also attached trailers and run other machines using the pulleys of the mowers (Wendler, 1994). Initially, these mowers were not strong enough for land preparation and thus not common in other areas of Germany. However, many of the *Motormäher* became, step by step, more sophisticated and powerful and eventually these mowers were indistinguishable from tractors. The tractor brand Fendt, which is still very popular among German farmers (now part of AGCO), has its roots manufacturing these mowers.

3.2.3 Other Significant Technical Innovations in Tractors

During the first decades of agricultural mechanization, German manufacturers largely adopted innovations in tractors made in the United States. One of the few exceptions was the engines of the tractors. As gasoline was more expensive and less readily available than in the oil-rich U.S., producers developed engines that needed less fuel and could cope with cheap and low-quality fuel (Wendler, 1994). This led to the use of hot-bulb-engines, which could run with heavy fuel oil, diesel, natural gas, kerosene and crude oil. Among the first tractors worldwide that had this type of engine was the 12HP Lanz-Bulldog developed in 1921. To kick off the engine, the hot bulb had to be heated with a blowtorch, a cumbersome but reliable method. Other manufacturers used more robust diesel engines, such as the *Motorpferd S7* (motor horse) of Benz-Sendling, which was produced from 1923 onwards. Klöckner-Humboldt-Deutz started to use diesel engines in 1926. The first American tractor with a diesel engine was produced by Caterpillar in 1931 (Herrmann, 1985).

3.2.4 Work Animals and Tractors on German Farms

In Germany, causal linkages between the number of work animals and tractors are difficult to establish because both the First and Second World War affected stocks of working animals and tractors. Moreover, numbers differ considerably between sources (Franz, 1969). However, evidence clearly shows that tractors and working animals co-existed during the first decades of agricultural mechanization (Hermann, 1985). Initially, agricultural machinery was used by large estates only. Mechanization focused on labour bottlenecks during ploughing and threshing and, thus, had little effect on the number of working animals that were still used for lighter tasks, such as weeding (Wendler, 1994). Between 1900 and 1910, the stock of horses even increased from 4 million to 4.5 million (Tornow, 1955, p.36). During the First World War and a subsequent wave of the hoof-and-mouth disease, the stock of working animals dropped massively (Franz, 1969, Lachenmaier, 1985).

Between 1925 and 1933, when tractors became cheaper, more powerful, versatile, and could be used for multiple purposes, their number more than tripled from 7,000 to 24,000 (Wendler, 1994, p.247). As mentioned above, during the 1930s, mechanization slowed down and the use of horses dropped slightly from 1.5 million to 1.4 million between 1930 and 1940 (Hermann, 1985, p.115). The Second World War must have affected the stock of working animals at large but there are no statistics available for this time period. In the mid-20th century, working animals still dominated German agriculture as smallholder farmers continued to use horses, oxen and even cows (if they could not afford specialized draft animals). Around 1950, this pattern changed and tractors started to displace working animals on a large scale. While the stock of tractors rose by 800,000 between 1950 and 1965 (Franz, 1969, p.9), the stock of horses dropped from 1.2 million in 1950 to 0.2 million in 1970 (Renius, 1994, p.263). Between 1960 and 1965, the stock of working oxen declined from 29,000 to 5,000 and the use of working cows decreased from 690,000 to 166,000 (Franz, 1969, p.9).

3.2.5 Suppliers of German Farm Tractors over Time

In the 1910s and 1920s, small *Motortragpflüge* produced by German manufacturers such as Stock and Hanomag dominated agricultural mechanization (see 3.2.2.). When the ban of inexpensive Fordson tractors was lifted, the tractor market was dominated by imports from the UK and the United States (Hermann, 1985). During the 1920s and 1930s, some German companies caught up and started producing small, reliable, and inexpensive agricultural machinery as well. In 1925, Hanomag was the leading agricultural machinery producing company (Hermann, 1985). Besides Hanomag, the Lanz AG and the Deutz-Werke AG dominated agricultural machinery production. In Southern Germany, companies such as Fendt produced simple *Motormäher* (motor mowers) (see 3.2.2.). After the Second World War, many tractor producers had to start from scratch. This gave foreign producers such as International Harvester and Massey-Ferguson an advantage. However, German manufacturers started producing again, as well. In 1950, Deutz, followed by Lanz and Fendt were the largest German tractor manufacturing companies (Renius, 1994). Besides these large players, there were around 50 additional producers of tractors—some of them which simply assembled tractors with parts purchased from other manufactures (*Konfektionsschschlepper*). With decreasing numbers of new tractors sold after the 1960s, the industry consolidated quickly as many of the producers had to step out of the agricultural machinery business or merged together (Franz, 1969; Wendler, 1994).

Heinrich Lanz AG

In 1859, Heinrich Lanz started working for the haulage company of his parents and shifted the focus towards agricultural machinery. Initially, the company was dealing with British agricultural machinery, e.g., Clayton steam engines. Soon, the Lanz AG began repairing these machines, and based on these experiences they started developing their own machines. From 1879 onwards, Lanz manufactured stationary steam machines and steam threshing machines and soon became the largest German agricultural machinery company. Until 1909, the company produced 24,000 stationary steam machines and 610,000 agricultural machines overall (Herrmann, 2000, p.242).

In 1921, the Heinrich Lanz AG shifted from producing heavy steam machines towards producing self-propelled tractors. The company presented a 12 HP heavy-oil-fueled tractor at an exhibition of the German Agricultural Society (DLG) (4.2.6). As mentioned above, this tractor was the first of Lanz Bulldogs series, which became very famous later. In 1923, Lanz presented a more powerful successor, the HP-Ackerbulldog, which was considered as a promising model by many agricultural engineers; however, only less than 800 machines were sold (Hermann, 2000, p.244). More economically successful was the first assembly-line-produced and inexpensive HR2, which was presented in 1925. Lanz sold more than 7,000 tractors within three years. By 1942, Lanz had sold 100,000 tractors (Herrmann, 2000, p.247).

During the Second World War, 90% of the tractor manufacturing capacity was destroyed (Herrmann, 2000). Despite selling its 200,000th Bulldog in 1956, the company never recovered. One reason was the damage caused by the war, but another reason was making decisions on technology that failed to meet customers' demands, which resulted in continuous financial problems (Herrmann, 2000). In 1956, John Deere and Company from the U.S. bought 51% of the Heinrich Lanz AG, which marked the end of the Lanz era in the history of German agricultural mechanization. Still, more than half a century later, the word "Bulldog" is still used as a generic term for farm tractors in Germany.

Hannoversche Maschinenbau (Hanomag) AG

The product portfolio of Hanomag mirrors developments of agricultural mechanization in Germany. Originally, the company, which was founded in 1871, mainly produced locomotives and steam engines. Hanomag entered the agricultural business in 1912 with its "Motortragpflug" (see 3.2.2.). In the 1920s, Hanomag developed the 26HP Hanomag WD and the Hanomag RD 28, which were considered as the "German Fordsons." These tractors were more expensive than the Fordson, but were able to use cheap petroleum (Hermann, 1985). In 1925, Hanomag was the leading company producing agricultural machinery (Hermann, 1985). In 1934, Hanomag introduced the first German tractor with pneumonic rubber tires (Herrmann, 2000).

After the Second World War, Hanomag started from scratch, as the factory ground was destroyed and the production line was outdated (Hermann, 1985). Nevertheless, Hanomag became again one of Germany's most successful agricultural machinery company and sold its 100,000th tractor in 1954 (Hermann, 2000, p.166). Hanomag then heavily invested in tractors that had two-cycle diesel engines and that had the possibility to attach equipment on the sides of the tractor. Customers did not appreciate either of these decisions. Attaching of equipment on the side of the tractor was cumbersome and farmers could not use existing equipment for this purpose. Moreover, the two-cycle diesel engines were very loud. Consequently, Hanomag lost market shares and ran into financial problems. Eventually, the company was sold to Massey Ferguson in 1974 (Hermann, 2000).

Deutz AG / Klöckner-Humboldt-Deutz AG

Another major tractor company was Deutz, which was founded 1864. Deutz started as a manufacturer of steam engines (later also petroleum engines for stationary farm engines). Over the decades, the company ventured into other business areas and merged with Maschinenbauanstalt Humboldt AG in 1930, which produced locomotives for trains. In 1938, it merged with the steel company Klöckner-Werke AG. In 1907, Deutz presented the prototype of a self-propelled 25 HP plough and a 40 HP plough locomotive. Both prototypes pushed the boundaries of German agricultural engineering, but they failed from an economic perspective.

During the First World War, Deutz produced artillery trucks. Making use of this experience, the company again developed tractors from 1919 onwards. The first of these tractors, which ran with benzene and diesel, were used by farmers for transportation and land clearing, but they were oversized and not used for other agricultural activities (Herrmann, 1985). The MTH, Deutz's first serial-produced tractor, which was manufactured from 1927 onwards, was basically a stationary farm engine on wheels (Herrmann, 1985). This changed with the introduction of the MTZ, Deutz's first real tractor, which was presented and awarded during a DLG exhibition in 1931 (see 4.2.6.). In 1936, Deutz presented the 11HP diesel-fueled F1M414, a tractor that was also called *Bauernschlepper* (peasants' tractor). The F1M414 costed only 3,000 Reichsmark and came to be the first German tractor that was widely used by small and medium scale farmers (Hermann, 2000, p.82). Until 1942, Deutz sold 10,000 of these tractors, the largest number of tractors sold in Germany prior to the Second World War (Hermann, 2000, p.82).

During the Second World War, the company had to devote large parts of its production capacities for military purposes. After the war, Deutz continued to be one of the major German producers of agricultural machinery. In 1962 onwards, Deutz purchased the Maschinenfabrik Fahr AG and in 1985, it bought the American agricultural machinery manufacturer Allis-Chalmers. Deutz-Fahr now belongs to the Italian SAME Group.

4. Institutional Change: Evolution of Institutions Supporting Agricultural Mechanization in the United States and Germany

In this section, we apply the framework developed in Section 2 to identify the different types of institutions that were developed in the US and in Germany in support of mechanization. Table 2 provides an overview that shows which activities were provided by which types of institutions (private, public and third-sector).

4.1 Overview

As shown in Table 2, the development of knowledge and skills in the United States was largely driven by private initiatives. Although public agencies, such as extension services and vocational programs, also helped support mechanization, they did so at a later mechanization stage and to a less important degree than in Germany. In Germany, one can identify a larger set of activities carried out by parastatal or public agencies that aimed at promoting mechanization. However, private and third-sector organizations also played a role. In the following sections, the specific efforts to create an enabling environment for mechanization in the U.S. (see 4.2) and Germany (see 4.3) will be described in more detail.

Table 2. Classification of enabling institutions for agricultural mechanization

	USA			Germany		
	Private	**Public**	**Third-Sector**	**Private**	**Public**	**Third-Sector**
Type of activity						
General training of farmers		Agricultural colleges and land-grant universities			Agricultural and vocational schools, RKTL	
Training of operators	Tractor manufacturing companies	Limited, exception: California State Polytechnic		Limited, tractor manufacturing Companien	DEULA school caravans	
Training of technicians		Agricultural colleges		Tractor manufacturing companies	After World War II: dual vocational system, DEULA	
Extension		Federal-state public extension		Private providers	Agricultural chambers and mechanization advisory centers	Self-help extension, farmer organizations
Media	Publishing houses			Industrial association, publishing houses and machinery companies	RKTL, extensions system	Farmer organizations
Exhibitions	Tractor Manufacturers Association	Field days of public extension	Shows, field days		Field days of public extension	Shows, German Agricultural Society (DLG)

Award of medals						DLG
Ploughing competitions			Agricultural societies		Youth programs of agricultural extension	
Machinery testing		University of Nebraska		Private magazines	Until World War II: RKTL and later Prüfanstalten (with DLG)	After World War II: KTBL and later DLG

4.2 USA

In the U.S., a diverse set of institutions supported mechanization (Table 2), and some of their activities are discussed below.

4.2.1 General training of farmers

The Smith-Hughes Vocational Education Act (national legislation passed in 1917) promoted vocational agriculture training for people "who have entered upon or who are preparing to enter upon the work of the farm," and provided federal funds for this purpose. Moreover, it is the formal legislation supporting vocational education in high schools in the United States. This legislation had the somewhat unusual requirement that vocational education in schools must be isolated from the rest of the curriculum in public schools. For example, vocational agriculture training in high schools was to focus on the practical but not the scientific dimensions of farming.

College short courses for farmers first emerged in 1867, when the state agricultural society in Michigan urged Michigan Agricultural College to start a program. In 1871, the Agricultural College of Pennsylvania inaugurated a four-day course that was devoted to trials of agricultural equipment and lectures by the agricultural faculty. During 1874-1899, the Illinois Industrial University experimented with special courses for farmers that ranged in length from three months to two years. Wisconsin was the leader in developing short courses in their modern form. The first session was offered in 1886 and proved to be a continuing success.

Despite frequent false starts, college short courses were a fixture on most agricultural college campuses by 1914. They varied greatly in length, content, and subject matter, but their purpose was always to reach and instruct rural adults, primarily farmers. By 1907-1910, college short-courses were being enthusiastically accepted by farmers (Huffman and Evenson 2006).

Traveling college short courses in Illinois (1893-94) and in other states were initially unsuccessful. Iowa State College’s traveling short course started in 1905 and was one of the early successes. A faculty member at Iowa State College developed the Iowa program, which was a carefully planned activity—produced on request and with a guaranteed fee. Local groups provided the facilities and advertising. Other states that followed the lead of Iowa State College in developing traveling short courses were Indiana, Ohio, and Virginia. Also, the railroads were a key means of transportation for these short-course speakers and their materials.

4.2.2 Specific training of operators

In contrast to Germany, in the literature on early farm tractors in America, one cannot find any evidence of a specific education program for tractor drivers or operators. Gasoline tractors in the U.S. were frequently sold to untrained individuals, and these untrained operators frequently overlooked regular service of the tractors and misused them causing major harm to the engines and costly repairs.[9] The Hart-Parr company was the first to register concerns about poor tractor maintenance and damage by tractor operators.

[9] Two major problems were common: (i) failure to maintain proper oil levels in tractor engines crankcases and (ii) failure to maintain a radiator that was full of water. Operating a farm tractor with low level of either oil or water quickly and seriously damaged the engine.

Early issues of *The Agricultural Education Magazine* discussed farm mechanics, including the repair and maintenance of gasoline engines (Pollom 1930), but not training of individuals to drive or operate farm tractors and machinery. However, in 1940, there is an enlightening article written by James Merson, Agricultural Mechanics Department, California State Polytechnic, San Luis Obispo, entitled: "Can you Drive a Tractor?" At this time, the article indicates that Cal Poly (see further information on this institution below) required all students graduating from the agriculture division to be able to operate, service and make the necessary field adjustments on several common types and makes of tractors and to operate these tractors with various pieces of available farm machinery and equipment. The training focused on: (i) fundamental principles of gasoline and diesel engines and students were then expected to start the various tractor engines, to service and adjust them, (ii) the function and care of the various parts of the running gear of tractors—clutches, brakes, gears and other controls, (iii) students practice driving tractors in a practice lot—learning to stop and start tractors and finally to manoeuvre them in and out of different situations, (iv) students learning to use various farm implements hitched to a tractor—during the fall quarter, it was ploughing, disking, harrowing, seeding and land levelling; in the winter term, it was road grading, ditching and contour work; in the spring term, it was cultivating row crops and hay-making. Hence, students not only learned to drive tractors, but they also learned to operate all of the various implements used behind the tractors in California in this era.

Merson indicated that for students who had never driven a tractor, it was amazing how difficult it was for them to master all of the controls on a big tractor and to develop the hand-eye coordination necessary to operate a tractor and implements safely, smoothly and efficiently. A final driving test involved a student hitching a tractor to a given implement, backing a two-wheel trailer or a four-wheel grader into a stall, or cultivating an "orchard" of stakes against time. Points are awarded for accuracy and time required, together with the number of times the operator received a penalty for mistakes in tractor operation. Also, there was a final written test on the care and maintenance of farm tractors and knowledge of common field adjustments of equipment.

In this setting, Cal Poly, San Luis Obispo, is an unusual institution. It was founded as a vocational high school in 1901 with a learning-by-doing philosophy (California Polytechnic State University). In 1924, Cal Poly was placed under the control of the California State Board of Education, and in 1933, the Board of Education changed Cal Poly into a two-year technical and vocational college. The institution began to offer Bachelor of Arts degrees in 1940, and in 1947, its name was changed to California State Polytechnic College. In 1949, it was authorized to offer a Master of Arts degree in Education. In 1960, control of Cal Poly and all other state colleges in California were transferred to the Board of Trustees of the State of California, which became the California State University system. In 1967, the college was authorized to offer Master of Science degrees. As the curriculum grew and become organized around three Schools, the California Legislature changed its name in 1971 to California Polytechnic State University, San Luis Obispo. It continues to have a relatively applied, i.e., learning-by-doing, focus compared to the universities in the University of California System, e.g., Berkeley, UCLA, Davis, Riverside, Santa Barbara, Santa Clara, Irvine, and even today it does not grant Ph.D. degrees. Cal Poly-Pomona is another technical university in California that got its start as a satellite campus of Cal Poly, San Luis Obispo. It also has a heavy focus on agriculture. In 1966, it became California State Polytechnic University, Pomona. However, the Cal Poly experience with training of tractor drivers or operators is unusual in the United States.

A more general theme for farm tractors has been tractor safety (e.g., Jones and Aldred, 1980, pp. 420-430). These authors described the environment of tractor field operations as being quite different from engines operated in factories or even saw-mills and pumping operations. The operator of an agricultural tractor is frequently in remote areas where there is no direct supervision. The operator must rely upon the design of the machine, his or her own knowledge and experience, and the information provided by operator manuals on how to perform field tasks. Of considerable concern has been the possible rollover of tricycle tractors on steep hillsides. Also, the use of a tractor's power take-off to power farm machinery in tow was a hazard for getting operator's clothing caught in them.

Early tractor manufacturing companies initiated programs to help farmers operate and maintain their tractors. Without this help, the expected benefits from investing in these new machines would not materialize, and this could greatly dampen future sales. In particular, Hart-Parr initiated a program in 1908 to help new owners operate and maintain their tractors. The reason was they found new owners experienced problems because they lacked knowledge about how to maintenance and service their tractors, and this sometimes caused major engine problems. Consequently, in 1908-13, they initiated an operator education program, including sending instructions by mail to owners of their tractors on how to operate and maintain them successfully (Lettingwell 1991). They covered general information for operating, servicing, and maintaining tractors. From then on, most new tractors came with an "operator's manual." However, these manuals were written at a general level, and furthermore, were frequently kept in the farm shop but not on the farm tractor. Hence, we do no find evidence of early involvement of the U.S. agricultural experiment stations, extension service, or high school vocational agriculture programs on training owners of tractors in the operation, maintenance, and repair of these machines.

4.2.3 Specify training of technicians

Community colleges or technical schools are the main institution for training individuals in agricultural mechanics leading to certificates and associate degrees. These programs teach skills in operation, repair, and maintenance of farm machinery and equipment, including principles of diesel and internal combustion engines, hydraulic and electrical and computer systems, and farm machinery. Instruction is on-site and includes classroom studies and laboratory sessions with on-hands experiences. These programs typically establish a partnership with one or more manufacturer of agricultural machinery and equipment. This insures that students have experiences with up-to-date agricultural technology. Programs frequently require students to complete an internship at an approved agricultural machinery dealership or business. Colleges offering certificates in agricultural mechanics include Black Hawk College (Moline, IL), Morrisville State College (Morrisville, NY), and Delta College (University Center, MI). Colleges offering 2-year associates (AA) degrees include Kirkwood Community College (Cedar Rapids, IA), Montana State University-Northern (Havre, MT), University of Northwester Ohio (Lima, OH), and Utah State University (Logan, UT). (Anonymous 2018).

4.2.4 Extension

In the U.S, the Morrell (Land-Grant College) Act of 1862 established public land-grant colleges to focus on the science of agriculture (including home economics) and mechanical arts (Huffman and Evenson 2006). However, the faculty in these colleges found little scientific information on agriculture (and engineering). In an attempt to boost the scientific base of land-grant colleges, federal legislation in the Hatch Act of 1887 was passed. It established an agricultural (and home economics) experiment station with federal funding in each of the U.S. states to advance scientific knowledge in these areas (Huffman and Evenson, 2006).

It took several years to work out the development of the new institution called public extension. It provided a form of adult education. Before the extension service, early agricultural societies in the U.S. sought to collect and distribute information among their members, to improve their member's farming practices, and to affect farming practices of their neighbours by example. The farm press, local agricultural clubs and societies, county farms, and pioneering instruction in agriculture appeared before 1861. Farmers' institutes and college short courses for farmers were initiated on a broad scale starting in the 1880s. The USDA started to distribute bulletins to farmers in 1889. Other USDA extension activities started shortly after the turn of the century (Huffman and Evenson, 2006).

In the USDA, extension work with farmers began about 1900. Early work in the U.S. South was led by Knapp and in the North and West by Spillman. These two individuals developed very different but successful approaches to extension education. The approaches were tailored to different social structures and information demands in these regions. The USDA's extension work in the South was prompted by a serious cotton boll weevil infestation during the early 1900s. In 1889, the USDA's Bureau of Plant Industry hired Knapp and in 1904 assigned him to a special agent to conduct boll-weevil control activities in the South. His USDA extension work expanded to other states as the weevil spread. He developed a successful control program built around field demonstrations. Moreover, he sought cooperation with state and local organizations, worked with and through local farmers, and used local demonstration fields to illustrate selection and better management practices.

The USDA's extension work in the North and West developed under less-pressing circumstances. In 1901, the Bureau of Plant Industry established Farm Management Branch and started surveys and studies of arms there to identify practices of successful farmers. In 1902, they hired Spillman, an agronomist from Washington State College, and he began shortly to conduct farm management research and associated extension work. Studies were made of farming conditions and practices, especially of successful farms, in various regions. In 1908, studies had been made of business management on the most successful farms, including farm records, farm equipment, livestock feeding systems, and general farm records. These were early cost-of-production studies. Publications were prepared showing how farmers could improve their management practices, such as to diversify their crop plan (Huffman and Evenson, 2006).

The first extension bill introduced in the U.S. Congress was in 1909, but in 1913, a new bill passed that authorized cooperative extension work between land-grant colleges and the USDA. The land-grant colleges established extension departments as units within their institutions with the objective of giving instruction and practical demonstration in agriculture and home economics through field demonstrations, publication, and other methods. The federal government agreed to help provide the resources to fund the new extension programs.

As the knowledge base for agriculture grew and farmers experienced new an unusual production problems, a need arose for an institution to interpret and disseminate this information for farmers and homemakers. The new federal legislation came in the Smith-Lever Act of 1914, which established a new federal-state public extension service to carry out these activities (Huffman and Evenson, 2006). In addition, as mentioned above, the Smith-Hughes Act of 1912 and its Future Farmers of America Program increased the opportunity for high school students to take practical courses in farm production. Hence, the FFA provided high school students with practical training in agriculture and the Cooperative Extension service provided farmers with scientific information to manage production problems.

4.2.5 Media

Early farm magazines (or newspapers) include the *American Farmer* established in 1918, *Prairie Farmer* in 1841, and *Wallaces Farmer* in 1855. Three generations of the Wallace family from central Iowa owned and operated *Wallace Farmer* for an extended period of time Over time the *Prairie Farmer* affiliated with the Farm Progress Company became the publisher of 22 agricultural and ranching magazines. In addition to the three magazines mentioned above, they also include: the *Carolina-Virginia Farmer*, *Dakota Farmer*, *Indiana Prairie Farmer*, *Michigan Farmer*, *Mid-South Farmer*, *Missouri Ruralist*, *Nebraska Farmer*, *The Ohio Farmer*, *The Farmer*, *The Farmer-Stockman*, *Western Farmer-Stockman*, *Western Farm Press*, and *Wisconsin Agriculturist*. These magazines regularly carried stories, columns, editorials, and advertisement of interest to farmers. However, since each of these publications, except for Farm Futures, has a coverage of one or a few states or a region of the U.S., their stories were different. In reflecting on the past 150 years of *Wallace Farmer* publications, Editor Swoboda, stated: "Our mission remains much the same today -- to provide Iowa farmers with accurate, useful information to help them profitably manage their farming operations, improve their quality of life and contribute to the prosperity of the agricultural community." In addition, Farm Progress' *Prairie Farmer* and *Wallaces Farmer* have been major sponsors of the Midwest Farm Progress Show since the early 1950s, thereby helping to insure that Midwest farmers have an opportunity to regularly see new agricultural machinery and equipment, crop technologies, agricultural chemicals, corn and soybean varieties, tillage systems, and management systems up close and in field experiments and conditions.

The Agricultural Education Magazine, established in 1927, is a long-term publication devoted to helping teachers of vocational agriculture in high schools and community colleges to better communicate with one another on curriculum and related issues.

4.2.6 Exhibitions and award of medals

Interest in farm tractors grew rapidly in the 1910s in the U.S., and this led to a series of tractor shows in the period from 1913 to 1919. Although tractor shows were held in many locations from Texas to Canada, one location—Fremont, Nebraska—held a special position in these events (Wik 1983). In 1913, forty tractors were on display and also demonstrated their ability for plowing. Roughly 4,000 people attended this multiday event, which featured considerable site entertainment. In 1914, 30 companies presented 60 tractors. The number of visitors was significantly larger than in 1913. In 1915, 60.000 people were attracted to Fremont for the Third Annual National Power Farming Demonstration. The crowds were so large that congestion became a major problem. It was generally difficult for participants to get into the exhibit and to see any field ploughing operations or tractor parades (Wik 1983). There were 43 companies displaying 84 tractors of various models, makes and sizes. Tractor sales were significant at the first show and increased with each show.

In 1916, eight tractor shows conducted in eight states replaced the one large Fremont show. However, the Fremont show attracted the most attention. There were 50 tractor companies displaying 250 tractors. Crowds at Fremont were even larger than the year before, despite competition of the other tractor shows.

When the U.S. entered World War I in 1917, the demand for tractors increased significantly with many men diverted to directly fighting the war. An increase in production of food was needed, but with less farm labor, horses and mules being available for work on farms. Consequently, the Tractor Manufacturers Association limited its shows to one in Fremont in 1917, one in Salina, KN, in 1918, and a final one near Wichita, KN, in 1919. However, there were many other smaller tractor shows sponsored by local implement dealers in most of the grain-growing states.

The Farm Progress Company, currently a publisher of 18 regional farm magazines with local coverage of each community, initiated four farm shows in 1953 including the (Midwest) Farm Progress Show. For the 1953 Midwest Show, Prairie Farmer teamed with the WLS Radio Station in Chicago to host a field day where farmers could see first-hand the progress in farming equipment, along with crop varieties and agricultural chemical. This farm field day was held in Vermillion County, IL. In subsequent years, the Show evolved to include seed test plots and field demonstrations. This show typically was held annually at different sites in Illinois, Iowa, and Indiana. As the event grew in size and sometimes experienced rainy weather and muddy field conditions, it became apparent semi-permanent locations were needed so that investments could be made to improve water run-off and pave streets in the main exhibition areas. Long-term contracts were signed for about 600-acre sites near Decatur, IL, and Boone/Ames, IA. The Decatur site held the first Midwest Farm Progress Show on new grounds in 2005, and the Boone/Ames site held the second Farm Progress Show the next year. The Midwest Farm Progress Show alternates annually between these two sites. The Midwest Farm Progress Show is the oldest and largest outdoor agricultural equipment and farm technology exhibition in the U.S.

4.2.7 Plowing Competitions

Given the central role of the moldboard plow in breaking the soil and turning it as part of seedbed preparation, local groups organized plowing competitions or matches, sometimes in conjunction with other events—field days, conservation days, farm progress shows and fairs. The first reported field trials of farm implements in America was the plowing match at the Fifth Semi-Annual Exhibition of the Columbian Society on May 20, 1812 (U.S. Department of Agriculture). Also, the agricultural society of Massachusetts, established in 1816, offered a plowing match with prizes for horse- and mule-drawn plows. The Wheatland Plow Match

Association, Will County, IL, started holding plowing matches in 1877. Judging was on straightness and uniform depth of the furrows and the coverage of surface weeds, and small prizes were awarded to the winners. Plowing successfully with horses and mules using a walking plow required a strong man with skill in managing horses and mules and the plow. With the shift to tractors in the 1910s and 20s, physical strength of the plowman was deemphasized, but skill in driving the tractor and in maintaining a uniform plowing depth became important (Smith 2014). Spector (1983) suggests that the objective of plowing matches was to encourage proper soil-tillage methods.

The Wheatland Plowing Match Association continued to provide locally organized plowing matches until 1977, only occasionally were matches cancelled—a total of eight in 100 years. The event promoted competition in plowing skill but over time became similar to a county fair, providing an array of recreational activities. It is estimated that attendance reached 18,000 in 1921, and attached people from as far away as Arizona.

In Iowa, the Pilot-Rock Plowing Match was first held near Cherokee in 1908. It was patterned after the Wheatland Plowing Matches. Attendance rapidly grew in size—4,000 people attended in 1914. As it grew, the event expended its range of activities and from being one to two days in 1919. By 1940, the plowing matches had gained a reputation as places where farm tractor and machinery companies could show and test their products. Wilson (2014) claims that it was good for sales for winning brands of plows.

The first national plowing matches and field days in the U.S. were held at Mitchellville, IA, in 1939. They were halted between 1941-1944 due to World War II, but resumed in 1945. In the late 1940s, they became known as the National Soil Conservation Fields Days and Plowing Matches. Standard plowing was in a straight line, but with new soil conservation concerns, contour plowing—plowing around a sloping field rather than up and down the slopes—was introduced.

The World Ploughing Organization (WPO) was established in 1953 to coordinate international competition in plowing matches. The U.S. Plowing Organization was established in 1964 to coordinate plowing competitions in the U.S. and with the World Plowing Organization. Guidelines to judges in the WPO included the following: Good (level land) plowing is expected to be straight and even, but judges are looking for more. They also consider the "opening split;" the crown of the plow ridges (should be uniform height, symmetrical, and connected furrows); weed control (should bury stubble, trash and wheel-marks so no weeds, stubble or surface trash showing); suitable for a seedbed with minimal field work; visual uniformity of furrows, neatness, positioning; uniform engagement and disengagement of plow furrows so minimal work is needed to straighten ends of field), and general appearance—neatness and symmetry.

The introduction in the 1970s of reduced seedbed preparation—called "reduced" or "conservation" tillage and "no-till farming,"—and complementary new herbicides, resulted in a dramatic decline in intensive field preparation previously associated with mouldboard plowing and heavy disking (Rahm and Huffman, 1984). Since the mid-1990s herbicide-tolerant crops have further reduced the need for the weed-control aspects of plowing and seedbed preparation. In the Midwest, field cultivators that stir the first few inches of the soil, leaving trash and waste on the surface, are now common for preparing fields for corn and soybeans

(Horowitz et al 2010). However, in 2005, conventional tillage, including use of the moldboard plow, was used on 29 percent of all U.S. corn acres and 75 percent of cotton acres (Horowitz et al., 2010).

4.2.8 Standardized Tractor Testing

To combat fraud by tractor manufacturers, a set of standards for testing farm tractors was needed. A Nebraska farmer named Wilmot Crozier purchased a Minneapolis Ford Model B (not a Henry Ford product) and barely got it back to this farm before it broke down. It never worked as advertised. He then purchased a Rumely Oil Pull tractor, which performed far superior to its claims. He decided to inject some honesty into the advertising of new farm tractors. With the help of L.W. Chase of the Department of Agricultural Engineering at the University of Nebraska, he authored a bill in the Nebraska Legislature in 1919 that required firms that wanted to sell tractors in Nebraska to have their tractors first tested in a prescribed way. This was the origin of the Nebraska Tractor Testing Program, including horsepower testing. The law was designed to test farm tractors to see that they met manufacturers' advertised claims of performance. The first tractor to be tested was the Waterloo Boy Model N, 12-25 HP, in April 1920. It passed but many other new tractors did not (Lettingwell 1991, p. 18). The firms that had tractors that failed these tests largely exited the industry, or went back to their shops and undertook efforts to improve them. The Nebraska Tractor Test Laboratory at the University of Nebraska continues to be the official tractor tester for all tractors sold in the United States (and some other countries).

4.3. Germany

Compared to the United States, Germany benefited from a more systematic public-sector support for mechanization. In the 1920s, the government created a special committee for this purpose, the Imperial Committee on Technology in Agriculture (*Reichsausschuß für Technik in der Landwirtschaft - RKTL)*. In addition to the RKTL, one farmer organization contributed largely to the enabling environment for mechanization, both before and after the World War II: the German Agricultural Society (*Deutsche Landwirtschafts-Gesellschaft - DLG*). Given their unique role in the mechanization landscape of Germany, these two organizations are briefly characterized here.

Farmer organizations – the DLG

In the 19th century, farmer organizations were expanding across Germany that were supported by the state and kingdoms (Lehmann, 2005). These organizations acted as discussion forums and platforms to jointly purchase inputs and hire extension agents (Lehmann, 2005). The country-wide Moving Collection of German Farmers and Foresters (*Wanderversammlung deutscher Land- und Forstwirte)* was founded in 1837; through conferences, practical demonstrations, excursions, exhibitions and, reports it generated and diffused knowledge, including knowledge on mechanization,. However, it stopped functioning in 1872 because of political reasons (Haushofer, 1960; Lehmann, 2005). This gap was filled by the agricultural engineer May Eyth. From 1862 to 1882, Eyth worked in the United Kingdom, the United States and Egypt for machinery companies. He was reportedly shocked about the backwardness of German agricultural machines and the high share of imports (Haushofer, 1960). In 1885, Eyth founded the German Agricultural Society based on the model of the English Royal Agricultural

Society (Achilles, 1993; Seidl, 2006). To ensure political and financial independence, the DLG had high membership fees (Lachenmaier, 1985; Uekötter, 2010). In 1886, DLG had 12,000 members and 38,000 members in 1934, among which 25,000 were farmers – mostly owners of estates (Lachenmaier, 1973, p.61). The DLG supported mechanization in many ways, but two of them were particularly important: its agricultural exhibitions (see 4.2.5) and its machinery tests (see 4.2.8).[10]

Special committee to promote mechanization - RKTL

Given the patchy institutional infrastructure of mechanization in the 1910s, the *DLG* (see above), the German Industrial Association, and other organizations lobbied to have a committee, which had the task to systematically support mechanization (Lachenmaier, 1973). In 1920, the *Reichsausschuss für Technik in der Landwirtschaft* (RATL, Imperial Committee on Technology in Agriculture) was founded and chaired by the Prussian agricultural ministry. The RATL struggled with erratic financial support and bureaucratic difficulties and was soon transformed into the parastatal *Reichkuratorium für Technik in der Landwirtschaft* (RKTL – Imperial Curatorium for Technology in Agriculture) - pro-forma an association but financed by the state (Franz, 1969; Tornow, 1955). RATL and RKTL greatly contributed to the set-up of a supportive agricultural mechanization system: they organized machinery tests, conducted cost-benefit-calculations on different types of mechanization, funded applied research, and supported agricultural finance[11] (Franz, 1969). Most importantly, they emphasized skills development, which was seen crucial to prevent mechanization from ending in a fiasco (Haushofer, 1963; Lachenmaier, 1973). In 1929, Dr. Willi Schlabach, the chief executive of the RKTL, argued that "theoretical and applied technical capacity is a precondition to enable (…) mechanization" (as cited in Lachenmaier, 1973, p.54). In 1931, the RKTL added that "not the machines and the methods are missing but the minds who use, properly apply and exploit its benefits" (as cited in Uekötter, 2010, p.291). RKTL advised individual farmers and from 1930 onwards also groups to reach more people. RKTL also trained and informed extension officers and supported the set-up of DEULA-schools for operators (see 4.2.2). After World War II, RKTL was refounded as the *Kuratorium für Technik und Bauwesen in der Landwirtschaft* (KTBL – Curatorium for Technology and Construction in Agriculture), an independent association, which focused on re-establishing the institutional landscape. KTBL supported the re-introduction of the DEULA-schools and conducted machinery tests until 1967 (Krombholz, 2015).

4.3.1. General training of farmers – agricultural schools

Formalized agricultural education in Germany dates back to the early 19th century, but the initial focus was placed on training the managers of large estates. This only changed with the emergence of the agricultural *Winterschulen* (winter schools) in the 1860s, which targeted regular farmers (Hudde and Schmiel, 1965; Seidl, 2006). In South Germany, these schools were

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[10] In 1934, the DLG was integrated into the Reichsnährstand, a unitary organization that the Nazi regime created to bring the different organisations dealing with food and agriculture under their control. In 1946, DLG was re-constituted again (Lehmann, 2005).

[11] The Financing Society for Agricultural Machinery (*Finanzierungs-Gesellschaft für Landmaschinen AG - FIGELAG*) was founded in 1924. Farmers buying German machines had to pay 10% on the spot, 15% with delivery and 75 % after harvest via low-interest credits. From 1924 to 1926 the FIGELAG had a credit volume of 36 million Reichsmark (Wendler, 1994, p.253).

financed directly by the state. In North Germany, they were financed by agricultural chambers, provinces, municipalities and farmer organizations (Aereboe, 1928). Courses were inexpensive and held during off-season, which allowed many farmers to participate (Hudde, 1965; Strauch, 1903). During summer time, the directors and teachers worked as agricultural extension officers (Aereboe, 1928). In 1920, there were 293 winter schools, which trained 20,000 students and in 1927, there were 636 winter schools (Achilles, 1993, p.373; Hudde, 1965, p.105). Besides the *Winterschulen,* farmers were also trained at rural schools for continuous education (*ländliche Fortbildungsschule*). In 1912, there were 6,191 such schools in Prussia, which held lectures (four to six hours each week) in the evening and on Sundays during winter time (Biehler, 1959; Hudde, 1965, p.113). The quality of these schools was mixed as a large share of teaching effort was devoted to general education and teachers were often not specifically trained in agriculture (Biehler, 1959; Exner, 2000; Haushofer, 1963; Hudde, 1965; Lehmann, 2005; Uekötter, 2010). Around 1910, only 10% of farmers had a formal agricultural education, but few of them were smallholders (Biehler, 1959; Achilles, 1993).

The integration of mechanization into the agricultural education domain was slow. In the 1910s and 1920s, most schools (winter schools or rural schools for continuous education) did not include mechanization in their teaching program. Moreover, teachers from domains such as business administration and plant production often covered the large field of agricultural engineering *en passant* (Exner, 2000; RATL, 1921; Landwirtschaftskammer Ostpreußen, 1919 as cited by Uekötter, 2010). Winter schools that had mechanization in the curriculum offered two to four hours each week on this topic out of a total teaching time of 35 – 37 hours (Strauch, 1903). However, the skills of the lecturers were so limited that in 1932, the RKTL, jointly with the German Association of Engineers (*Verein der Deutschen Ingenieure - VDI),* decided to train 200 teachers by offering six-day courses on applied engineering (Schlabach, 1932).

The situation had changed in the 1950s, when the fast spread of tractors did not allow the agricultural educational institutions to disregard mechanization any longer (Exner, 2000). Stepwise, the typical German "dual system" involving on-the-job training and training in schools emerged. Three-year mandatory agricultural vocational schools (*landwirtschaftliche Berufsschulen)*, which succeeded the rural schools for continued education, were set up (Biehler, 1959; Hudde and Schmiel, 1965). In 1954, these schools trained and examined 185,000 apprentices during winter time, who worked on farms during the summers (Christensen, 1965, p.219). The curriculum included five to ten weekly hours on mechanization (out of a total teaching load of 35 to 45 hours). The curriculum on mechanization included lectures on physics, economics, and also the use and maintenance of machines (AID, 1960; Hudde and Schmiel, 1965). The quality was initially mixed though as often three batches were trained at the same time (Christensen, 1965).

With the completion of vocational schools, students were entitled to visit the more theoretical and economic farm schools for two years (*Landwirtschaftsschulen,* the successors of the winter schools*)* (Exner, 2000; Schmiel, 1965). In 1954, there were 531 farm schools, which were supported by the state, municipalities and agricultural chambers, but participants still had to pay 50 DM per season in 1951/1952, which was equivalent to 17% of the average monthly salary (Exner, 2000, p.66; Schlögel, 1950; BGBI, 2002; BMEL, 1964). In the 1950s, around 30,000 students, some of them supported by scholarships, visited these schools annually

(Schmiel, 1965, p.269). Between 16 and 23% of the curriculum was related to mechanization topics such as physics mechanics, engineering and the use and maintenance of tractors (AID, 1960, p.48). Students also attended one-week courses on mechanization organized by the DEULA-schools and by the agricultural chambers (AID, 1960). Lecturers were mostly trained at universities and received continuous training at the DEULA-schools (AID, 1960).

4.3.2. Specific training of operators – the DEULA - school-caravans

Unlike in the United States, German policymakers explicitly pushed for widespread tractor driving trainings.[12] In 1926, the RKTL founded the independent school for operators of agricultural machinery *(Deutsche Landkraftführerschule - DEULAkraft*) close to Berlin. In 1927, the school offered nine four-week courses and trained 429 students on how to operate and handle tractors and how to fix breakdowns (Hirlinger, 2008, p.15). *DEULAkraft* soon realized that one central school was not sufficient and set up six school-caravans (*Wanderschulen*) which migrated from farm school to farm school and provided two-days practical training on mechanization for operators and technicians (DEULA Rheinland, 2008). Until 1933, these schools trained 11,200 students (DEULA Rheinland, 2008, p.8) and were widely seen as indispensable (Franz, 1969; Uekötter, 2010). The political support for the DEULA-schools deteriorated with the rise of the National Socialist Party (*NSDAP)* (DEULA Rheinland, 2008). During the late 1930s, its importance was again acknowledged in view of the reduced numbers and high fluctuation of farm workers and horses due to World War II. The DEULA-schools were decentralized and non-iterant schools were set up across Germany, which were supported by agricultural ministries and chambers (Tornow, 1955).

In the 1950s, the concept of the *DEULA*-schools was revived as non-iterant agricultural machinery schools *(Landmaschinenschulen*) in several federal states (Lohde, 1965). Until 1960, more than 100,000 students were trained in 18 schools and during the 1960s, 40,000 to 50,000 students were trained annually (Lachenmaier, 1973, p.55). The largest number of students came from farm schools (see 4.2.1), where a one-week course on mechanization was mandatory. Others were normal driving students and rural agricultural technicians (AID, 1960; Lohde, 1965). The courses consisted of 70 to 90% applied, "hands-on" training (AID, 1960, p.52). Each course had 5 to 10 students (AID, 1960; p.52). Teachers were trained during a period of twelve months with regard to contents and pedagogical techniques and they continuously received additional training on new machines offered by manufactures (AID, 1960). DEULA-schools financed running costs such as wages with charging tuition fees only (AID, 1960). The construction of new buildings was often supported by the government, and 80% of the machines in use were sponsored by the German machinery manufacturers (AID, 1960). Until today, DEULA has remained a major provider of mechanization training in Germany. In recent years, DEULA-schools are financed by mix of sources consisting of public funding, fees and increasingly also funds from the agro-industry.

4.3.3. Specific training of technicians

During the first phase of mechanization, in the 1920s, there was no comprehensive network of well-equipped workshops with qualified personnel. Rural blacksmiths struggled with relatively

[12] Driving licenses were mandatory by law since 1909 but this regulation seemed not to be enforced in practice.

simple repairs, such as reworking plough blades and they were not qualified to do machinery repairs (Uekötter, 2010). In 1926, the German Farmers Union demanded special education for mechanics—a call that went unheard by the public administration. Realizing the competitive advantage of a strong after-sale service, agricultural machinery companies started to train technicians themselves (Uekötter, 2010).

Hanomag had a network of technicians provided with toolboxes and small cars to fix breakdowns in rural areas (Uekötter, 2010). Yet, agricultural mechanics became an official and certified craft only in 1941. Farmers, dealers, blacksmiths, and fitters organized themselves in a guild which was allowed to organize the training of agricultural mechanics. In 1956, there were 2,141 "masters" of agricultural mechanics. These were already professional mechanics, who were then allowed to train apprentices as well. Additional lectures were provided by vocational schools, which also ensured the quality of apprentice training by organizing the examinations. In the 1960s, around 3,000 apprentices finished this dual vocational training yearly, which became a prerequisite to start a certified professional craft (Agrartechnik, 2001, p.3; Herrmann, 1985).

While private companies trained mechanics, they showed little interest in offering operators' training on topics that were not brand-specific. As mentioned above, the Heinrich Lanz AG had imported English and American tractors after 1859 and developed its own machines from 1887 onwards. From 1930 until 1932, this company trained 3,000 operators and farm managers through 50 courses (Derlitzki and Nauck, 1933 as cited in Uekötter, 2010, p.293). Other companies also trained operators and farm managers at a large scale, e.g., the Toro-Motorpflug AG and the Hansa Lyod-Werke, but these efforts were mostly brief and at the point of sale (Wendler, 1994). Besides, these efforts, manufacturers and dealers supported skill development indirectly, e.g., by sponsoring the tractors of the DEULA-schools, which also provided some training for technicians and by supporting ploughing competitions (AID, 1960; Kemmer, 1983).

4.3.4. Extension

Germany was the first country worldwide to widely implement the idea of extension services during the second half of the late 19th century (Chang, 2009). Itinerant extension officers were hired to move from village to village by farmer's organizations, the winter schools (and its successors, the farm schools) and agricultural ministries and chambers (Achilles, 1993; Hage, 1965; Lehmann, 2005)[13]. In the 1910s, the extension system was still patchy and the quality was limited (Uekötter, 2010).

During the 1920s, mechanization was only slowly incorporated into the extension system. In 1921, the RATL demanded more engaged agricultural engineers, but still in 1932, only ten of the 25 agricultural chambers in Prussia had mechanization advisory centers (*Maschinenberatungsstellen*), and some thought about closing theirs to cut costs (Schlabach,

[13] Agricultural chambers, which originated from farmers' organizations (*Zentralvereine*), were established from the late 19th century onwards, mainly in the North of Germany. These chambers conducted, e.g., applied research, provided extension services and supported farm schools. They were financially supported by the state and the provinces (Achilles, 1993). In Southern federal states, these tasks were fulfilled directly by the agricultural administration.

1932; Quäsching, 1933). Furthermore, these centers played marginal roles within the agricultural chambers and were mostly based on provisions from manufacturers (Dencker, 1928; Quäsching, 1933). This limited public support is surprising because where these centers were established, the demand for their services exceeded their capacities. Between its establishment in 1929 and 1933, the staff of the office set up in Brandenburg organized various exhibitions, held 2,800 consultations, delivered 160 lectures, published 60 leaflets, checked 150 invoices and repairs, and offered 25 courses on mechanization (Quäsching, 1933, p.47). Recognizing the limited skills of the extension officers, the DLG trained 4,600 of them across Germany until the interim closure of the organization in 1934 (Lachenmaier, 1985).

In the 1950s the extension system was less patchy. In 1955, one extension agent was responsible to serve 273 farmers (Hage, 1965, p.497). Yet, the official extension system was still largely inadequate when it came to mechanization, both with regard to quantity and quality of the services provided (AID, 1960; Uekötter, 2010; Seidl, 2006). Uekötter (2010) argues that there were few areas, where "the agricultural extension system was so highly beaten (…)" (p.23). However, there were expectations. Albers (1999, p.51) showed that some agricultural chambers such as the one in Westfalen-Lippe played an important role in promoting agricultural mechanization. From 1948 until 1959, the chamber organized 300 field days showing machinery attracting 50,000 visitors. The chamber also trained more than 21,000 students on mechanization (using two itinerant schools and cooperating with the DEULA). Beside the official extension system, farmers also used self-help extension groups (*Beratungsringe*) and private extension services to access information related to mechanization.

4.3.5. Media

Since the mid-18th century, agricultural magazines mushroomed throughout Germany (Hermann, 1992). Gradually, these mostly weekly and monthly magazines moved from addressing bureaucrats, scientists and estate owners to the mainstream of farmers (Klauder, 1956). This was possible because the literacy rate reached 90% around 1900, even though it was slightly lower among smallholder farmers (Schenda, 1970). Publications still had to be simple, illustrative and amusing as few farmers understood complicated graphs and calculations due to the limited quality of rural schools (Uekötter, 2010, Wittmann, 1973). In the early 1920s, there were 550 agricultural magazines, but few addressed agricultural mechanization (Klauder, 1956, p.64). There were, however, exceptions. The DLG published leaflets that were easy to understand as well as handbooks on mechanization to be used by agricultural schools, extension offices and farmers (Klauder, 1956; Lachenmaier, 1985). The RKTL distributed handbooks on the use, handling, and maintenance of tractors. It also published information including practical advices, machinery tests, cost-benefit-calculations and trends in mechanization through its easy-to-understand leaflets (Schriften) (Gose and Weddig, 1942).

From 1921 until 1944, the German Industrial Association published the magazine Technology in Agriculture (*Technik in der Landwirtschaft),* an important information hub for agricultural engineers and technicians (Lachenmaier, 1985). The magazine had a section where experts of the *DEULAkraft* (see 4.2.2) answered questions of readers. With the rise of the Nazi regime, the number of agricultural magazines declined to 300, which sold 4.5 million copies – but out of the 300 magazines, only 6 covered mechanization. For comparison, there were 18 that dealt with beekeeping (Klauder, 1956, p.66).

After World War II, mechanization rapidly received increasing attention in agricultural magazines. General agricultural magazines, which were subscribed by 6 out of 10 farmers, were essential information channels for farmers and extension officers and the magazines increasingly covered mechanization topics. (Preuschen, 1954; Uekötter, 2010). Moreover, in 1952, 13 out of 318 magazines focused entirely on mechanization, which sold 84,000 copies (Klauder, 1956, p.67). From 1950 onwards, the Bavarian Agricultural Publishing Company (*Bayerische Landwirtschaftsverlag),* founded by the Bavarian Farmers' Union, published the magazine "The Tractor" (*Der Traktor,* today called DLZ Agricultural Magazine - *dlz agrarmagazin*) with reports on machinery tests and drive reviews and it has provided practical advices on repairs and maintenance. The magazine sold 24,000 copies in 1954 (Zeitschriften-Almanach, 1954). In 1972, the Agricultural Publishing Company Münster-Hiltrup (*Landwirtschaftsverlag Münster-Hiltrup)* founded the monthly magazine *top agrar,* which has provided monthly information about a wide range of topics in farm management. Machinery has received considerable attention in this magazine, which has aimed to help farmers' decision-making. In 1976, it sold 25,000 copies and in 1983 76,000 copies (Landwirtschaftsverlag, 1983, p.82). Today, 110,000 copies are sold and 76% of all farmers with more than 100 hectares read the magazine (LV, 2016). The biggest magazine focusing on mechanization is "profi – the magazine for professional agricultural technology" (profi - *Das Magazin für professionelle Agrartechnik*), which was founded 1989. Profi also tests machinery and had 72,000 subscribers in 2016 (LV, 2016b).

Books were crucial as well. The following examples give an overview on the types of books that have supported the development of the skill base for agricultural mechanization. In 1954, the Bavarian Agricultural Publishing Company (*Bayerische Landwirtschaftsverlag)* published the book "Our Max – A Guideline for the Correct Use of Farm Tractors" (*Unser Max – Eine Anleitung für richtigen Schleppereinsatz, Preuschen, 1954).* The book is a combination of an agricultural novel and a handbook: The storyline centers around intra-generational conflicts and social aspects of mechanization. Interwoven into this story are illustrations on how to buy, handle, maintain, and fix tractors. The book also depicts the importance of special radio programs for farmers *(Landfunk)* during mechanization. In 1959, a private publisher (*Wasserturm-Verlag)* published a book with economic and technical advice for farmers, technicians, and scientists on how to buy tractors *(Schlepperkauf mit Rechenstift).* In 1971, the DLG and the *Bayerische Landwirtschaftsverlag* published a handbook with 900 pictures on maintenance and repairs. The oil-company Shell published a book on the importance of maintenance, e.g., of greasing (*Landmaschinenpflege nach Maß).*

4.3.6. Exhibitions and award of medals

Similar to the United States, Germany farmers could visit a wide range of agricultural exhibitions. Some of them covered all aspects of agriculture, others focused on machinery only. In 1839/1840, the Association for the Exhibition of a Collection of Agricultural Machinery and Implements (*Verein für die Ausstellung einer Sammlung landwirtschaftlicher Maschinen und Instrumente)* organized the first agricultural machinery exhibition on continental Europe (Seidl, 2006).

The first agricultural exhibitions which received a larger audience were the ones by the DLG. In 1887, the DLG organised its first itinerant exhibition in Frankfurt, which was comparable with the Smithfield Show in the United Kingdom. The five-day exhibition had a strong focus on machines and attracted 50,000 visitors (Haushöfer, 1960). With 438,000 visitors in Hamburg in 1910, the number of visitors reached its peak (DLG, 2018b). Compared to previous exhibitions, the DLG exhibitions were more science-oriented and less entertainment-based (Haushofer, 1963; DLG, 2018a). Technical innovations were evaluated by experts according to rigorous criteria and awarded with medals (DLG, 2018a). Also, farmers had the chance to inform themselves about different types of machinery at extension centres (AID, 1960). The first DLG exhibition after the Second World War, held in Frankfurt in 1950, attracted 400,000 visitors. The 1951 DLG exhibition in Hamburg was attended by even 817,000 visitors (DLG, 2018b).

Since 1985, the machinery section of these exhibitions has taken place as a separate show, the *Agritechnica*, which is today the world’s largest exhibition on agricultural machinery. The first *Agritechnica* in Frankfurt attracted 542 exhibitors and 125,000 visitors; the latest in Hannover, 2017, attracted 458,000 people (DLG, 2018b). Each exhibitor can submit innovations to the *Agritechnica* neutral commission of experts, which awards outstanding developments with medals. The jury consists of scientists, extension specialists and farmers which are appointed by the board of DLG. Initially, innovations were classified into “new and considerable”, “new and promising” and “DLG-accepted”. Since 1997, the jury awards gold and silver medals. The medals are used by manufacturers for advertising themselves as innovative manufacturer and are great honour for product designers.

4.3.7. Ploughing Competitions

Similar to the United States, the potential of ploughing competitions, which combine education with competitive spirits, was already discovered during the early 19th century (Kemmer, 1983). Since 1839, the above mentioned Association for the Exhibition of a Collection of Agricultural Machinery and Equipment organized ploughing competitions (Uekötter, 1839; Seidl, 2006). In 1950, based on the assumption that the youth lacked the skills and interest to plough properly, the KTBL initiated and revived the ploughing competition with tractors (Böhm, 2013; Böhm, n.d.; Kemmer, 1983). Since then, the agricultural chambers of the official extension system have been organizing ploughing competition, mostly as parts of youth programs (*Landjugendwettbewerbe*) (AID, 1960; Kemmer, 1983). Several thousand farmers participated at these competitions annually during the 1950s (AID, 1960). In 1967, the German ploughing association (*Deutscher Pflügerrat*) was founded, which has also organized German championships in ploughing (Böhm, n.d.).

4.3.8. Standardized Tractor Testing

In the 19th and early 20th century, there were hundreds of machinery producers in Germany. This led to a confusing bundle of qualities, types and manufacturers and the risk of fraud (Hermann, 1985; Schlange and Schöningen, 1931, Verband der Landmaschinen-Industrie, 1927). German farmers thus faced the same problems as their counterparts in the United States. In both countries the same types of institutions emerged to protect farmers from misguided investments: machinery tests. In the U.S., these were carried out by the University of Nebraska. In Germany, universities played a role as well but other actors were important, too.

From 1867 onwards, the state supported machinery test centers (*Prüfanstalten*), which were often attached to universities and agricultural chambers (Hermann, 1985). In 1908, there were 18 such stations, which were organised in an Association of Agricultural Machine Testing Institutes (*Verband landwirtschaftlicher Maschinenprüfanstalten*) (AID, 1960). The German Agricultural Society DLG coordinated (which was apparently a challenging task) and supported these centers. DLG also introduced certificates that were valid for five years (ADI, 1960; Hermann, 1985, Lachenmaier, 1985). Until 1934, these centers tested 5,400 different machines (e.g., tractors, sprayers, potato harvesters) with regard to technical performance, emission, safety, and drivability (Lachenmaier, 1985, p.24). The results were disseminated through the DLG Newsletter (*DLG-Mitteilungen).*

After the Second World War, the DLG continued machinery tests. Yet, the fast speed of mechanization between 1950 and 1953 initially went beyond the capacities of the DLG and other institutions. Between 1949 and 1954, only 20 to 60 machines were tested (Haushofer, 1960, p.226). In 1954, the DLG set up its first own testing centres, still in collaboration with universities and institutes and - against its early principles—with public support through the KTBL (Lachenmaier, 1985). In 1959, 231 machines were tested (Haushofer, 1960, p.226). Today the DLG does not receive financial public support for the machine testing any more.

5. Discussion

The past literature has focused on the economic and agro-ecological conditions and farm characteristics that are conducive to smallholder mechanization (see, e.g., Diao et al., 2014; Hayami and Ruttan, 1971; Houssou et al., 2018). This study has focused on two rather neglected but equally important factors: technological change—the evolution of machinery (see chapter 3) and institutional change—the evolution of the institutional landscape to support the adoption of this machinery (see chapter 4). The study has focused on these two aspects since mechanization is neither technologically static nor does it happen in an institutional vacuum. For example, in the two case study countries, the United States and Germany, the design of tractors has changed continuously, and institutions evolved to support mechanization in both countries. This has been the case because agricultural mechanization depends on an enabling environment providing various key functions such as knowledge and skills development (see chapter 2). The functions can be promoted through different activities such as vocational training, extension, media, and ploughing competitions. Such an enabling environment has emerged both in the United Sates and the Germany during mechanization. However, while both countries witnessed the emergence of an institutional landscape delivering these functions, this landscape was created by different institutional actors in the United States and Germany. For example, standardized tractor testing, an important activity to ensure machinery quality, has been initiated through a private initiative and was then conducted by a university in the United States but was done by state supported centers and later by a farmers' organization in Germany (see section 4.2.8 and 4.3.8). With regard to knowledge and skills development, which also has had a large influence on the profitability of machinery (Houssou et al., 2013), public agencies played a larger role in Germany than in the United States, where private initiatives were more prominent (see sections 4.2.2. and 4.3.2.). In general, in Germany we found more evidence of orchestrated public sector involvement.

The results indicate that while certain institutional support functions are needed for successful mechanization, no blueprint exists to answer all of the questions about who is the best candidate to provide them. Is it the public, private sector or a third sector? Under what conditions are activities provided by private actors? In addition, under which conditions should the public sector play a larger role? Different factors may determine the answer to these questions. One big difference between the United States and Germany during early mechanization was the fact that the U.S. was a young country with a rapidly expanding land base, which was thus constantly short on labor. At the same time, the United Sates faced a high demand for cereals from Europe during these frontier decades. Both created a strong demand for mechanization. At the same time, public administrative structures struggled to follow the fast moving frontier. Combined, these factors may explain while the United States has seen much more private sector engagement to provide the enabling environment for mechanization. Widely held political opinions regarding the role of the state vis-à-vis the role of the private sector may also have played a role. While the idea of a welfare state with far-reaching responsibilities had become well established in Germany at the turn of the 20th century, more emphasis on private initiatives was placed and a more limited role of the state was stressed in the U.S.

In line with these considerations, one could observe, as shown in this paper, that in Germany the public and third sector had played a much larger role in promoting mechanization than in the U.S. This was the case already before the World War II, when most institutions to promote mechanization were established. The push for mechanization was certainly weaker than in the U.S., because farm area was not expanded, while the population still increased. Hence, labor was not in short supply. Not surprisingly, mechanization unfolded only with a slow pace prior to World War II. The situation was different after World War II, when economic development and rising wages created a high demand for mechanization. At this time, many of the institutions to support mechanization that were established before the World War II were revived and expanded. Interestingly, some of them, such as the standardized tractor testing, changed hands, in this case from the public to the third sector in Germany (the German Agricultural Society DLG).

To sum up, this comparative historical analysis indicates that institutional support is key for mechanization. However, the study suggests that different types of governance structures (public, private and third sector) can provide this support. This confirms Chang (2009, p.511), who argued that “institutional forms of successfully delivering critical needs of the agricultural sector have varied enormously across time and space.” What is key, however, is that these needs or functions are indeed delivered, be it the public, private and third sector. This indicates that each of today’s “mechanizing” countries has to develop its own mechanization policies tailored to its institutions, farmers, and machinery companies. The historical evidence from the United States and Germany suggests that in countries where the state has limited administrative power, more private and third sector involvement may be needed than in countries with strong administrative capacity and a political situation that favours government involvement in support of private sector activity.

The study suggests that, while each country needs to make its own decisions, the design of new policies does not need to happen in a historical vacuum. As argued by Chang (2009) it is possible to “import” policies and institutional innovations from abroad. Today’s mechanizing countries can derive insights from the past experiences of the United States and Germany. As shown in the paper, Germany copied many technologies and some policies from the United States, but still, both countries also developed their own unique technologies and policies. One also needs to take into account that the potential “mechanization policy toolbox” is much larger than the one used by these two countries. It may involve today’s newest technologies such as ICT-based solutions for some of the functions outlined in Table 1, such as provision of information and skills development.

6. Conclusions

Agricultural mechanization depends on an enabling environment that fulfils supporting functions such as knowledge and skills development and quality assurance. In both the United States and Germany institutional solutions emerged to fulfil these key functions. However, the activities used to provide these functions differed between the two countries, and many activities were provided by different institutional channels (private, public and third). In some cases, the type of institutional channel changed over time. In Germany, we find more evidence of an orchestrated public-sector support to promote mechanization but private and third-party actors, such as farmer’s organizations, also played a large role. In the United States, private and third-party initiatives were crucial, and many of them were later supported by the government. For today’s mechanizing countries, the findings suggest that different types of governance structures (public, private, and third sector) can be combined to fulfil the needed functions for mechanization. There is no one-size-fits-all solution. Instead, government agencies, private actors, farmer organizations as well as development partners can all contribute to fulfil these functions. However, dedication is key, as mechanization is unlikely to take place if these functions are not fulfilled.

7. References

Anonymous. “Schools with Agricultural Mechanics Programs.” 2018. Retrieved from https://learn.org/articles/Schools_with_Agricultural_Mechanics_Programs_FAQs.html (18/05/2018)

Ashburner, J.E. and Kienzle, J. (eds.) (2011). Investment in agricultural mechanization in Africa: Conclusions and recommendations of a Round Table Meeting of Experts. FAO, Agricultural and Food Engineering Technical Report No. 8. Rome.

Achilles, W. (1993). Deutsche Agrargeschichte im Zeitalter der Reformen und der Industrialisierung. Ulmer. Stuttgart.

AID (1960). Die Landtechnik in der Bundesrepublik. Land- und Hauswirtschaftlicher Auswertungs- und Informationsdienst e.V. (AID). Bad Godesberg.

Aereboe, F. (1928). Agrarpolitik – Ein Lehrbuch. Paul Parey. Berlin.

Aikins, S. (2012). A survey of agricultural tractor operators’ background at Ejura, Ghana. Global Journal of Biology, Agriculture and Health Sciences, 1(1), 1–6.

Aikins, S., and Haruna, K. (2012). Tractor Owners and Operators’ Perception about Tractor Breakdown causes at Tamale, Ghana. International Journal of Engineering Research and Technology, 1(8), 1–9.

Albers, H. (1999). Die stille Revolution auf dem Lande. Landwirtschaft und

Landwirtschaftskammern in Westfalen-Lippe 1899-1999. Landwirtschaftsverlag. Münster-Hiltrup.
Benin, S. (2015). Impact of Ghana's agricultural mechanization services center program. Agricultural Economics, 46(S1), 103-117.
BGBI (2002). Sozialgesetzbuch (SGB) Sechstes Buch (VI) - Gesetzliche Rentenversicherung - (Artikel 1 des Gesetzes v. 18. Dezember 1989, BGBl. I S. 2261, 1990 I S. 1337). Anlage 1 Durchschnittsentgelt in Euro/DM/RM.
BMEL (1964). Übersicht über die Entwicklung der Zahl der Landwirtschaftschulen und deren Schüler. Bonn.
Boserup, E. (1965). The Conditions of Agricultural Growth: The Economics of Agrarian Change under Population Pressure. George Allen and Unwin LTD. London.
Biehler, J. H. (1959). Geschichte der landwirtschaftlichen Berufsschule. Zeitung für Agrargeschichte und Agrarsoziologie 7.
Binswanger, H. P., Deininger, K., and Feder, G. (1995). Power, distortions, revolt and reform in agricultural land relations. Handbook of Development Economics, 3, 2659-2772.
Böhm, M. (n.d.). Entstehung des Deutschen Pflügerrat e.V. Retrieved from www.pfluegerrat.de/wir-über-uns/wir-über-uns (09/04/2018).
Böhm, M. (2013). Sächsische Pflügermeisterschaften. Damals und heute. Sächsischer Landesbauernverband e.V.
Brodell, A. P. and R.D. Jennings (1944). Work Performed and Feed Utilized by Horses and Mules. U.S. Bureau of Agricultural Economics, Farm Management No. 44. Washington, DC.
Bymolt, R. and Zaal, F. (2015). Moving to Mechanisation. Mechanisation in maize farming systems in Kenya, Tanzania and Ethiopia. Royal Tropical Institute. Amsterdam.
"California Polytechnic State University." Wikipedia. Retrieved from https://en.wikipedia.org/wiki/California_Polytechnic_State_University (18/05/2018)
Chang, H. J. (2009). Rethinking public policy in agriculture: lessons from history, distant and recent. The Journal of Peasant Studies, 36(3), 477-515.
Christensen, A-W. (1965). Die Landwirtschaftliche Berufsschule, Abt. Landwirtschaft. In Hudde, W. and Schmiel, M. (Eds.) (1965). Handbuch des Landwirtschaftlichen Bildungswesens. BLV. München, Basel, Wien, 262-295.
Cochrane, W.W. (1979). The Development of American Agriculture: A Historical Analysis. The University of Minnesota Press. Minneapolis, MN.
Colbert, T. B. (2000). Iowa farmers and mechanical corn pickers, 1900-1952. Agricultural History, 74(2), 530-544.
College of Agriculture and Life Sciences, Iowa State University. "CALS History." (2016). Retrieved from https://www.cals.iastate.edu/about/history (18/05/2018)
Daum, T., and Birner, R. (2017). The neglected governance challenges of agricultural mechanisation in Africa–insights from Ghana. Food Security, 9(5), 959-979.
Dencker, C. (1928). Maschinenberatung. Technik in der Landwirtschaft 9, 87-90.
Dencker, C. (1950). Mechanisierung der amerikanischen und der deutschen Landwirtschaft. Paul Parey. Berlin.
Diao, X., Silver, J., and Takeshima, H. (2016). Agricultural mechanization and agricultural transformation (Vol. 1527). IFPRI Discussion Paper 01527. International Food Policy Research Institute, Washington, DC.
Diao, X., Cossar, F., Houssou, N., & Kolavalli, S. (2014). Mechanization in Ghana: Emerging demand, and the search for alternative supply models. Food Policy, 48, 168-181.
DLG (2018a). Die Maschinenschauen und technischer Fortschritt auf den DLG-Ausstellungen. Retrieved from http://www.dlg.org/maschinenschauen.html (09/04/2018).
DLG (2018b). DLG-Ausstellungen seit 1887. Retrieved from www.dlg.org/ausstellungen_chronik.html (09/04/2018).

DLG (1971). Landmaschinenreparatur: Pflege und Instandsetzung. Eine Anleitung zur Selbsthilfe für den Landwirt mit 810 Abbildungen. BLV / DLG / Landwirtschaftsverlag. München.

DEULA Rheinland (2008). 50 Jahre. Supplement Landwirtschaftliche Zeitung Rheinland 45.

Evenson, R. E. (2001). Economic impacts of agricultural research and extension. In Bruce L. Gardner and Gordon C. Rausser (Eds.) (2001). Handbook of Agricultural Economics, 1. Elsevier. New York, 573-628.

Exner, P (2000). Die Modernisierung von Zukunftsvorstellungen: Die Unterrichtspläne an Landwirtschaftsschulen des 20. Jahrhunderts als Spiegelbilder der industriellen Revolution im Agrarsektor. Zeitschrift für Agrargeschichte und Agrarsoziologie, 48 (2000) 1, 51-75

Feder, G., Just, R. E., and Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A Survey. Economic Development and Cultural Change, 33(2), 255-298.

Fuglie, K., and Rada, N. (2013). Resources, Policies, and Agricultural Productivity in Sub-Saharan Africa. ERR-145, U.S. Department of Agriculture, Economic Research Service.

Franz, G. (Eds.) (1969). Die Geschichte Landtechnik im XX. Jahrhundert. DLG Verlag. Frankfurt/Main.

FAO (2015). Agricultural mechanisation strategy (AMS). Rural Infrastruce and Agro-Industries Division. Retrieved from www.fao.org/ag/ags/agricultural-mechanisation/agricultural-mechanisation-strategy-ams/en/ (09/04/2018).

Gisselquist, D., and Jean-Marie, G. (2000). An argument for deregulating the transfer of agricultural technologies to developing countries. The World Bank Economic Review, 14(1), 111-127.

Gose, H. and Wedding, K. (1942). Der Ackerschlepper und sein Gerät: Einsatz, Wirkungsweise, Bedienung und Pflege: Ein Handbuch der Deulakraft, Berlin-Wartenberg für Besitzer und Fahrer von Ackerschleppern. Reichskuratorium für Technik in der Landwirtschaft. Berlin.

Griliches, Z. (1960). The Demand for a Durable Input: Farm Tractors in the United States, 1921-57. In A.C. Harberger, (Ed.). The Demand for Durable Goods. The University of Chicago Press. Chicago, 181-210.

Hage, K. (1965). Die Beratung in der Landwirtschaft. In Hudde, W. and Schmiel, M. (Eds.) (1965). Handbuch des Landwirtschaftlichen Bildungswesens. BLV. München, Basel, Wien, 488-499.

Haushofer, H. (1963). Die deutsche Landwirtschaft im technischen Zeitalter. Verlag Eugen Ulmer. Stuttgart.

Hayami, Y., and Ruttan, V. W. (1971). Agricultural development: an international perspective. The Johns Hopkins Press. Baltimore, London.

Hirlinger, J. (2011). Mein Traum: Eine ungewöhnliche (Bulldog-)Geschichte in 4 Teilen. Der Schlepperfreund. Eberdingen.

Herrmann, K. (2000).Traktoren in Deutschland. Firmen und Fabrikate von 1907 bis heute. DLG-Verlag. Frankfurt.

Herrmann, K. (1985). Pflügen, Säen, Ernten. Landarbeit und Landtechnik in der Geschichte. Rowohlt. Reineck.

Houmy, K., Clarke, L., Ashburner, J., and Kienzle, J. (2013). Agricultural Mechanisation in Sub-Saharan Africa : Guidelines for preparing a strategy. Integrated Crop Management, 22. Plant Production and Protection Division. FAO. Rome.

Horowitz, J., Ebel, R., & Ueda, K. (2010). “No-till" Farming is a Growing Practice (No. 96636). United States Department of Agriculture, Economic Research Service .Washington, DC.

Houssou, N., Johnson, M., Kolavalli, S., & Asante-Addo, C. (2018). Changes in Ghanaian farming systems: stagnation or a quiet transformation? Agriculture and Human Values, 35(1), 41-66.

Houssou, N., Diao, X., Cossar, F., Kolavalli, S., Jimah, K., Aboagye, P. (2013). Agricultural Mechanization in Ghana: Is Specialization in Agricultural Mechanization a Viable Business Model? American Journal of Agricultural Economics 95(5): 1237-1244.

Hudde, W. (1965). Die Geschichte des landwirtschaftlichen Schulwesens. In Hudde, W. and Schmiel, M. (Eds.) (1965). Handbuch des Landwirtschaftlichen Bildungswesens. BLV. München, Basel, Wien, 96-131.

Huffman, W.E. (2014). Agricultural Labor: Demand for Labor. In Neal Van Alfen (Ed.) Encyclopedia of Agriculture and food Systems. Vo. 1, Elsevier, San Diego, 105-122.

Huffman, W. E., & Evenson, R. E. (2008). Science for agriculture: A long-term perspective. John Wiley & Sons. Hoboken, New Jersey.

Huffman, W.E. (2001). Human Capital: Education and Agriculture. In Bruce L. Gardner and Gordon C. Rausser (Eds.) Handbook of Agricultural Economics 1. In Bruce L. Gardner and Gordon C. Rausser (Eds.) (2001). Handbook of Agricultural Economics, 1, 207-261. Elsevier. New York, 333-381.

Hulme, D., and Mosley, P. (1996). Finance against poverty (Vol. 2). Psychology Press, London.

Klauder G. (1956). Entwicklung des landwirtschaftlichen Zeitschriftenwesens, Zeitung für Agrargeschichte und Agrarsoziologie 3/4, 60-69.

Kaiser, H. (1994). Dampfpflüge und Dampfpflüger im 19. Jahrhundert. In Fok, O., Wendler, U. and Wiese, R. (Eds.) (1994). Vom Klepper zum Schlepper. Zur Entwicklung der Antriebskräfte in der Landwirtschaft. Freilichtmuseum am Kiekeberg. Ehestorf.

Klein, E. (1973). Geschichte der deutschen Landwirtschaft im Industriezeitalter. Steiner Verlag. Wiesbaden.

Landwirtschaftsverlag (1983). Ein Verlag stellt sich vor. Landwirtschaftsverlag. Münster-Hiltrup.

Lachenmaier, F. (1973). 50 Jahre KTBL – 50 Jahre Fortschritt in der Agrartechnik. Kuratorium für Technik und Bauwesen. Darmstadt.

Lachenmaier, F., (1985). 100 Jahre Deutsche Landwirtschafts-Gesellschaft. DLG-Verlag. Ein Rückblick in Wort und Bild. Frankfurt am Main.

Lohde, H.-H. (1965). Die deutschen Landmaschinenschulen – DEULA. In Hudde, W. and Schmiel, M. (Eds.) (1965). Handbuch des Landwirtschaftlichen Bildungswesens. BLV. München, Basel, Wien.

Lehmann, I. (2005). Wissen und Wissensvermittlung im ökologischen Landbau in Baden-Württemberg in Geschichte und Gegenwart. Margraf. Weikersheim.

Lettingwell, R. (1991). The American Farm Tractor. Motor Books International. Osceola, WI.

LV (2016a). Landwirtschaftsverlag GmbH. Top Agrar - Medien-Daten 2016. Retrieved from www.lv.de/fileadmin/landwirtschaftsverlag/images/landwirtschaftsverlag/PDFs/Mediadaten/top_agrar_Mediadaten_2016.pdf (09/04/2018).

LV (2016b). Landwirtschaftsverlag GmbH. Top Profi - Medien-Daten 2016. Retrieved from www.lv.de/fileadmin/landwirtschaftsverlag/images/landwirtschaftsverlag/PDFs/Mediadaten/profi_Mediadaten_2016.pdf (09/04/2018).

Manuelli, R. E., & Seshadri, A. (2014). Frictionless technology diffusion: The case of tractors. American Economic Review, 104(4), 1368-91.

Merson, J.F. (1940). Can You Drive a Tractor? The Agricultural Education Magazine, July 1940.

Olmstead, A.L. and P.W. Rhode. (2008). Creating Abundance: Biological Innovation and American Agricultural Development. Cambridge University Press, New York.

Olmstead, A. L., & Rhode, P. W. (2001). Reshaping the landscape: the impact and diffusion of the tractor in American agriculture, 1910–1960. The Journal of Economic History,

61(3), 663-698.
Otsuka, K., and Place, F. (2013). Evolutionary Changes in Land Tenure and Agricultural Intensification in Sub-Saharan Africa. GRIPS Discussion Paper (13-22). GRIPS, Tokyo.
Peterson, C.L. "Technology and Power in Agriculture." In P. McNulty and P.M Grace (Eds). Agricultural Mechanization and Automation I, EOLSS Publications 2009.
Pollom, L.B. (1930). Farm Mechanics: Preparation of Teaches for Farm Mechanics. The Agricultural Education Magazine 12 (Nov. 1930), 92-93.
Pfebe, E. (2015). Zimbabwe's Tractor-Gate: $100m Government Loan Abused. Retrieved from www.changezimbabwe.com/index.php/news-mainmenu-2/1-latest/5382-zimbabwes-tractor-gate-100m-government-loan-abused (09/04/2018).
Quäsching, E. (1933). Maschinenberatung in der Praxis. Die Technik der Landwirtschaft, 14(2), 46-47.
Rahm, M. R., & Huffman, W. E. (1984). The adoption of reduced tillage: the role of human capital and other variables. American Journal of Agricultural Economics, 66(4), 405-413.
Renius, K. T. (1994). Zur Entwicklung des Traktors von 1945 bis in die 80er Jahre. In Fok, O., Wendler, U. and Wiese, R. (Eds.) (1994). Vom Klepper zum Schlepper. Zur Entwicklung der Antriebskräfte in der Landwirtschaft. Freilichtmuseum am Kiekeberg. Ehestorf, 263-276.
Schenda, R. (1970). Volk ohne Buch (Vol. 5). Deutscher Taschenbuch Verlag. München.
Schmiel, M. (1965). Die Landwirtschaftsschule, Abt. Landbau. In Hudde, W. and Schmiel, M. (Eds.) (1965). Handbuch des Landwirtschaftlichen Bildungswesens. BLV. München, Basel, Wien, 264-295.
Scoones, I. (2013). Tractors, power and development. Mechanising Zimbabwean agriculture. Retrieved from https://zimbabweland.wordpress.com/2013/03/04/tractors-power-and-development/ (09/04/2018).
Schlabach, W. (1932). Beratung und Unterweisung im landwirtschaftlichen Maschinenwesen. Berichte über Landwirtschaft 50. Berlin.
Schlange-Schöningen, H. (1930). Landwirtschaft von heute. Unternehmergeist und zeitgemäßer Betrieb. Paul Parey. Berlin.
Schlie, R. (1935). Gewicht-Leistung-Lebensdauer der landwirtschaftlichen Maschinen. Die Technik in der Landwirtschaft, 16(3), 59.
Schlögl, A. (1950). Schulen der Landwirtschaft. München.
Seel, N. M., and Hanke, U. (2014). Erziehungswissenschaft: Lehrbuch für Bachelor-, Master- und Lehramtsstudierende. Springer. Berlin Heidelberg
Senayah, J. K., Issaka, R. N., Abrefa, N. K., Asamoah, E., and Badu, J. (2012). Report on soil physical and chemical properties for crop production in the three Northern Regions of Ghana. Soil Research Institute. Kumasi.
Seidl, A. (2006). Deutsche Agrargeschichte. DLG-Verlag. Frankfurt.
Singh, S. (2013). Deere Lures Africa's First-Time Buyers of Tractors. BloombergBusiness. September 12, 2013.
Strauch, R. (1903). Didaktik und Methodik des Unterrichts an landwirtschaftlichen Schulen. Hugo Voigt. Leipzig.
Statistisches Reichsamt (1934). Statistisches Jahrbuch für das Deutsche Reich. Verlag der Reimer Hobbig G.m.b.H. Berlin.
Spector, D. (1983). Agriculture on the Prairies, 1870-1940. National Historic Parks and Sites Branch, Parks Canada.
Sunding, D., and Zilberman, D. (2001). The agricultural innovation process: research and technology adoption in a changing agricultural sector. In Bruce L. Gardner and Gordon C. Rausser (Eds.) (2001). Handbook of Agricultural Economics, 1. Elsevier. New York,

207-261.
Takeshima, H., Nin-Pratt, A., and Diao, X. (2013). Mechanization and agricultural technology evolution, agricultural intensification in sub-Saharan Africa: Typology of agricultural mechanization in Nigeria. American Journal of Agricultural Economics, 95(5), 1230-1236.
Takeshima, H., Edeh, H. O., Lawal, A. O., and Isiaka, M. A. (2015). Characteristics of Private-Sector Tractor Service Provisions: Insights from Nigeria. The Developing Economies, 53(3), 188-217.
Thebis, R. (1926). Traktoren und Raupenschlepper. Ausführliche leichtverständliche Beschreibung und Bedienungsanleitung der neuzeitlichen Zug- und Arbeitsmaschinen für deren Besitzer und Führer. Bernhard Friedrich Voigt. Leipzig.
The Tractor Guys. "Antique Tractor Trivia and Then Some". Time Line Encyclopedia of Our Antique Farm Tractor's in America: 1804-1959. Retrieved from http://domania.us/gts-today/TTG-Time-Line-Early-Farm-Tractor-Trivia.html (18/05/2018).
Tornow, W. (1955). Die Entwicklungslinien der landwirtschaftlichen Forschung in Deutschland. Landwirtschaftsverlag. Hiltrup.
Uekötter, F. (2012). Die Wahrheit ist auf dem Feld: eine Wissensgeschichte der deutschen Landwirtschaft. Vandenhoeck and Ruprecht. Göttingen.
Verband der Landmaschinen-Industrie (1927). Die Standorte und Erzeugnisse der deutschen Landmaschinen-Industrie. Berlin.
Wendler, U. (1994). Motortragpflüge, Schlepper und Motormäher – Die deutsche Schlepperentwicklung bis 1945. In Fok, O., Wendler, U. and Wiese, R. (Eds.) (1994). Vom Klepper zum Schlepper. Zur Entwicklung der Antriebskräfte in der Landwirtschaft. Freilichtmuseum am Kiekeberg. Ehestorf, 239-263.
Wik, R.M. (1983). Nebraska Tractor Shows, 1913-1919, and the Beginning of Power Farming. Nebraska History, 64, 193-208.
Wilson, C.A. (2014). A Manly Art: Plowing, Plowing Matches, and Rural Masculinity in Ontario, 1800-1930. The Canadian Historical Review, 95, 157-186.
White, W.J. (2000). An Unsung Hero: The Farm Tractors' Contribution to Twentieth-Century United States Economic Growth. PhD Dissertation. Ohio State University.
Wittmann, R. (1990). Der lesende Landmann: zur Rezeption aufklärerischer Bemühungen durch die bäuerliche Bevölkerung im 18. Jahrhundert. In Berindei, D. et. al. (Eds). (1973), Der Bauer Mittel- und Osteuropas im sozio-ökonomischen Wandel des 18. und 19. Jahrhunderts. Böhlau Verlag. Köln, 142-196.
World Bank (2017). Worldwide Governance Indicators. Retrieved from http://info.worldbank.org/governance/wgi/ (18/05/2018).
Zeitschriften-Almanach (1954). Zeitschriften-Almanach 1954-1955. Frankonia. Rehau.