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Agricultural Mechanization

A Comparative Historical Perspective

Hans P. Binswanger

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Abstract

This paper provides a detailed comparative historical review of the patterns of agricultural mechanization by operation, emphasizing the similarities and differences in the patterns of adoption across developed and developing countries. The first section re-emphasizes the major conclusion of the induced innovation literature that the growth contribution of mechanization depends on the factor endowments of the economy in terms of land and labor, and on non-agricultural labor demand. Mechanization contributes most to growth where land is abundant and labor is scarce.

The second section shows the remarkable similarity in the early mechanization experiences of the developed and developing countries. New mechanical power sources were first used on power intensive operations such as processing, pumping, transport and tillage, while mechanization of control intensive operations came much later and usually in association with high wages. This specialization of new power sources leads, in the early stages of adoption, to the coexistence of the new and the old power source. Such coexistence was commonly observed in the developed world, with the new power source being used only on operations where it had a high comparative advantage. The control intensive operations were shifted to mechanical power sources only after massive wage rate rises, and such shifts should not be expected in the developing world in the absence of rising wages.

The rate of adoption of new mechanical techniques has been very rapid where the pay-offs to the adoption have been high. This close association between pay-offs and the rate of adoption has been documented for Europe and America and is observed in the developing countries today.

An investigation of the process of agricultural machinery innovation shows that the source of invention has been similar in the developed and developing world. Public sector and corporate research has contributed little to machinery invention which has generally been the domain of small manufacturers. Corporations, however, have been significant in later stages of product development and engineering optimization.

CONDENSE

La présente étude compare en détail les schémas de mécanisation des diverses opérations agricoles et met l'accent sur les similitudes et les différences constatées entre pays développés et pays en développement. La première section confirme la principale conclusion des études antérieures sur l'innovation induite, à savoir que la contribution de la mécanisation à la croissance dépend de l'abondance relative des facteurs terre et travail et de la demande de main-d'oeuvre des secteurs non agricoles. Cette contribution est d'autant plus forte que les terres sont abondantes et la main-d'oeuvre rare.

Comme le montre la deuxième section, on observe une très grande similitude dans la façon dont la mécanisation a commencé à se développer dans les deux groupes de pays. Les nouvelles sources d'énergie ont d'abord été utilisées pour les opérations exigeant beaucoup de force, comme la transformation, le pompage, le transport et la préparation des sols, tandis que les opérations exigeant beaucoup de jugement ont été mécanisées bien plus tard et habituellement lorsque les salaires étaient élevés. Du fait de cette sélectivité, on constate qu'aux premiers stades de la mécanisation, les agriculteurs utilisent à la fois les nouvelles et les anciennes sources d'énergie. Il en a généralement été ainsi dans les pays développés où la nouvelle source d'énergie n'a d'abord été utilisée que pour les opérations pour lesquelles elle était beaucoup plus avantageuse. Les opérations exigeant beaucoup de jugement n'ont été mécanisées qu'après de fortes augmentations des taux de salaire; aussi ne peut-on s'attendre que le même phénomène se produise dans les pays en développement en l'absence de hausses des salaires.

C'est lorsque la mécanisation était le plus rentable qu'elle a été adoptée le plus vite. L'existence d'un lien étroit entre la rentabilité de la mécanisation et son rythme d'adoption a été établie pour l'Europe et l'Amérique et on constate qu'il en est de même aujourd'hui dans les pays en développement.

L'étude fait en outre ressortir la similitude des sources d'innovation dans les pays développés et en développement. Les recherches du secteur public et des grandes sociétés ont peu contribué à l'invention de nouvelle machines, qui a été essentiellement le fait des petits fabricants. Les grandes sociétés ont toutefois joué un rôle important aux stades ultérieurs, en contribuant à l'amélioration et à l'optimisation des nouveaux matériels.

Extracto

En este documento se presenta un estudio comparativo histórico detallado de los modelos de mecanización agrícola desglosados por tipo de operación, señalando las similitudes y diferencias en las pautas de adopción por los países desarrollados y en desarrollo. En la primera sección se insiste de nuevo en la conclusión principal de los estudios existentes sobre el proceso conocido como "innovación inducida", a saber, que la contribución de la mecanización al crecimiento depende de la dotación de factores de una economía, en términos de tierra y mano de obra, y de la demanda de trabajo en actividades no agrícolas. Donde la mecanización contribuye más al crecimiento es allí donde la tierra es abundante y la mano de obra escasa.

En la segunda sección se muestra la notable similitud existente entre los países desarrollados y en desarrollo en cuanto a las experiencias iniciales de la mecanización. Las nuevas fuentes de energía mecánica se utilizaron primero en operaciones que requieren un alto coeficiente de energía, tales como elaboración, bombeo, transporte y labranza, mientras que la mecanización de las operaciones que precisan gran control humano se produjo mucho después y normalmente asociada a salarios elevados. Esta especialización de las nuevas fuentes de energía hace que en las etapas iniciales de su adopción coexistan con las fuentes de energía antiguas. Tal coexistencia pudo observarse comúnmente en el mundo desarrollado, donde la nueva fuente de energía se reservaba solamente para su uso en operaciones en las que tenía una gran ventaja comparativa. Las fuentes de energía mecánica comenzaron a utilizarse en las operaciones que requerían gran control humano sólo tras fuertes aumentos de las tasas salariales, y no cabe esperar que tal cambio ocurra en el mundo en desarrollo en ausencia de salarios en aumento.

El ritmo de adopción de las nuevas técnicas mecánicas ha sido muy rápido allí donde las recompensas de la adopción han sido grandes. Esta estrecha relación entre recompensas y ritmo de adopción está documentada en lo que se refiere a Europa y América del Norte, y se puede observar hoy día en los países en desarrollo.

Un examen del proceso de innovación de la maquinaria agrícola muestra que el origen de las invenciones ha sido similar en los países desarrollados y en desarrollo. Las investigaciones del sector público y de las grandes empresas han contribuido poco a los inventos de maquinaria, que por lo general han sido la esfera de actividad de los pequeños fabricantes. No obstante, las grandes empresas han sido importantes en las etapas posteriores de desarrollo de los productos y de optimación técnica.

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AGRICULTURAL MECHANIZATION: A COMPARATIVE HISTORICAL PERSPECTIVE

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1. Introduction

The world inventory of agricultural machines contains an astonishingly wide array of options for performing each of the major agricultural operations, from purely manual techniques to nearly automatic ones. The advance of mechanization in developing countries has often been limited and, therefore, many of the options are still in use today. In certain parts of Africa, in Java and in many hilly regions of the world, tillage is still performed with hand tools even though animal tillage has been common in other parts of the world for thousands of years. While draft animals have completely disappeared in the U.S., Europe and Japan, they have come to be widely accepted in Senegal only in the past two or three decades. Even in countries where mechanization is beginning to make strong in-roads, the use of power tillers and tractors is restricted to tillage and a few other operations.

Given this wide array of options, developing countries that have not yet resorted to a high degree of agricultural mechanization face many questions, such as:

1. How large is the contribution which mechanization can make to their growth?

2. What is the most efficient pattern of additional mechanization over the next 10 to 20 years, and what kind of pattern should be expected in the long run?

3. Should government resources be used to support agricultural mechanization, and if so, at what stage: machinery development, testing, production? or via subsidies and/or trade policy?

4. What are the harmful side effects, if any, on agricultural workers and small farmers?

5. Should government influence the choice of techniques directly, by regulating imports, restricting numbers of brands sold, or even by banning certain machines?

Not many general answers can be given to these questions. In section one we shall show that the growth contribution of mechanization, its efficient pattern, and its side effects or consequences depend in crucial ways on the factor endowments of an economy in terms of land and labor, on non-agricultural labor demand, on the level and speed of capital accumulation, and on energy costs.

In section two we will explore similarities and differences in the historical patterns of agricultural mechanization in the world. The similarities and differences will be related to similarities and differences in the macro-economic conditions which prevailed over time in the different countries, and to the state of basic engineering knowledge.

Section three discusses the determinants of the rate of adoption of mechanical techniques. Again, profitability and rising wages will play a major role. Section four discusses the process of mechanical invention, innovation and adaptation, and the resulting consequences for the structure of the agricultural machinery industry.

Section five provides a brief discussion of the questions posed in this introduction while section six discusses the relevance to China of some of the issues discussed in this paper. The paper contains no summary or conclusions; instead a set of generalizations is presented in the text.

Most recent discussions of mechanization concentrate on power sources: shifts from human to animal, to water or wind, to steam and eventually to internal combustion engines or electric motors. These shifts in power sources are clearly the most dramatic aspects of a long drawn-out process. Some discussions of mechanization have gone so far as to confine the definition of mechanization to the application of internal combustion engines and electric motors. This definition does not suit our purposes, however, because it tends to hide important historical and contemporary

regularities. We shall, instead, use a much broader definition of mechanization which includes all replacement of human muscle power by machines and implements. Much of the discussion in section two will focus on how different operations (land preparation, harvesting, etc.) were or are performed with different power sources such as animals, stationary engines or fully mobile machines.

We will not, in this paper, spend much time on the transition from hand hoe agriculture to animal-drawn plows. With the exception of Africa, this transition has largely occured before the present century. Moreover, this transition cannot be easily analyzed within the framework of traditional choice of techniques problems. As Boserup (1965) has shown, the move from hand hoe to the plow is best studied in the context of the evolution of farming systems. We close this introduction with a brief discussion of this evolution. More detailed research on this issue in Africa is currently underway.

The transition from hand hoe to animal-drawn plows is closely correlated with the intensity of the farming system, where farming intensity is defined as the frequency with which a plot of land is cultivated. Boserup (1965) has shown that the intensification of the farming system (i.e., the movement from shifting to permanent cultivation) is closely associated with population densities. The use of the plow is not feasible in forest and bush fallow systems because of the high density of stumps in the ground and the ease with which land can be prepared by hand under bush and tree cover. The subsistence nature of the cultivation system makes it unprofitable to make the high levels of investments in destumping and soil fertility maintenance required for continuous cultivation. As increasing population densities lead to a reduction in fallow periods, the fallow land becomes grassy and therefore very hard

to prepare by hand, the use of the animal drawn plows becomes necessary and feasible at this stage. A switch to the plow during grass fallow results in a substantial reduction in the amount of labor input required for land preparation. The net benefits of switching from the hoe to the plow are conditional on soil types and topography, being lower for sandy soils and for hilly terrain. Where markets exist for the agricultural products the transition to the plow takes place relatively faster due to the area expansion benefit of animal traction.

2. Economy-wide Factors and Agricultural Mechanization

The pattern and speed of adoption of existing designs of machines is influenced heavily by economy-wide factor scarcities and other macro-economic variables. Moreover, research has amply documented that the initial invention of machines and other agricultural technologies is in part governed by the same factors. The responsiveness of invention and innovation to economy-wide factors has come to be known as the process of Induced Innovation (Hayami and Ruttan, 1973, Binswanger and Ruttan 1978).

Generalization (1): The rate and the pattern of invention and adoption of agricultural machinery are governed to a substantial degree by an economy's land and labor endowments, by the non-agricultural demand for labor, and by conditions of demand for final agricultural products.

The history of agricultural growth and of mechanization in the developed world illustrates this generalization. Table 1 summarizes the agricultural growth record of six developed countries between 1880 and 1970. The countries are ordered roughly according to their land/labor ratios, with Japan representing a case of extreme land scarcity and the U.S. one of extreme land abundance. Figure 1 brings together in a single illustration the long-term trends in the three ratios between land and output (on the vertical axis), between labor and output (on the horizontal axis) and between land and labor (where the diagonal lines represent different land-labor ratios). Growth of output is represented by an inwards shift of the points towards the lower left corner. The following general points emerge from Table 1 and Figure 1.

In 1880 factor endowments differed widely among these countries, with Japan having only 0.65 ha of land per male worker and the U.S. having 25.4 ha, i.e. about forty times as much. Continental European countries fell in between, with land in the United Kingdom about twice as abundant as on the continent. These differences in endowments are reflected in massive differences in factor prices. In Japan a worker had to work nearly 2,000 days to buy a hectare of land, while his U.S. counterpart could buy land after working roughly one tenth of that time.

Over the course of the 90 years, land/labor ratios increased in all countries. These increases were modest in Japan and the European countries. In Denmark land/labor ratios even declined up to 1930, and rose rapidly thereafter. Furthermore, the increases in land/labor ratios in these countries accelerated after 1950. These increases do not reflect increases in arable land but rapid declines in agricultural labor forces in response to massive shifts of the labor force into the industrial-urban sector. In the U.S., on the other hand, the land-labor ratio grew rapidly throughout the period, both via area expansion and later via reductions in the agricultural labor force. In the U.S. this process accelerated after 1920. Differences in land/labor ratios between the U.S. and the other countries increased over the period.

With the exception of the U.K., all countries achieved an agricultural growth rate of roughly 1.6% per year. The countries with less favorable resource endowments have thus been able to achieve growth rates in total output (and in output per worker) which are comparable to the rate achieved in the U.S. Limitations on land has apparently <u>not been a critical constraint on growth of agricultural output</u>.

Japan and the continental European countries have been able to achieve these high growth rates because yields (output per ha of arable land) have grown at about 1.5%, <u>or roughly twice as fast as in the U.S.</u>

Figure 1 shows that Japan and the U.S. have relied on entirely different technological paths to achieve agricultural output growth. Careful historical and econometric enquires by Binswanger and Ruttan (1978) and Hayami (1975) substantiate this conclusion. The agricultural mechanization pattern discussed in detail in section 2 further confirms this view. Since long before the period covered by the data Japan has emphasized biological, yield-raising technology, much of it supported by heavy irrigation investments. This emphasis has continued with systematic investment in agricultural research initiated during the Meiji restoration after 1868. Mechanization played a minor role until the 1950s (Table 13). Note also that the emphasis on biological technology was supported by conscious government choice: in the late 19th century Japan tried imported U.S. machinery and found it not useful. It then hired biologists from Germany from the school of Liebig to assist in developing its biological research program; this program was successful.

The United States, on the other hand, emphasized mechanical technology even before 1880 and this tendency has been reinforced ever since (Tables 4 and 5). While publicly funded biological research was initiated in the 1870s, it led to substantial yield increases only from about 1930, well after the major land frontiers had been closed and a high level of mechanization had been achieved. Thus we see that successful agricultural growth in the different developed countries has capitalized on abundant factors of production: land and mechanization in the U.S.; labor, land improvements and biological technology in Japan. The continental European countries also emphasized biological technology before emphasis shifted to mechanical technology.1/

Generalization (2): Mechanization leads to direct yield increases only in exceptional cases such as the application of seeds, pesticides or

fertilizers.2/ Thus, higher levels of mechanization usually substitute for labor, or--where they are already in use--for animals.

Generalization 2 corresponds to the substitution view of agricultural mechanization (Binswanger 1978). It is in direct contrast to the net contributor view, which assumes that higher levels of mechanization, and in particular tractors, directly lead to yield increases or other output gains, regardless of the economic environment in which they are introduced. Such a view usually stems from a confusion of the direct effects of mechanization with the indirect productivity effects arising from the factor savings made possible.3/

Under the substitution view, the profitability of mechanization, and its contribution to economic growth depends on the opportunities available to workers (and sometimes draft animals) released from their tasks. It thus works via the indirect effects of released labor. Hence the third generalization follows:

Generalization (3): Mechanization is most profitable and contributes most to growth where land is abundant, where labor is scarce relative to land and/or where labor is being rapidly absorbed into the non-agricultural sector.

Several major cases are illustrated in Figure 2, which is also designed to show the varied employment effects of mechanization. In case (1) unused land is available and mechanization leads to output growth, and the more so, the higher the elasticity of final demand.4/ The best example is 19th century U.S. agriculture. In the second half of the 19th century, an impressive horse-based mechanization led to massive agricultural growth in the U.S. because land was rapidly opened up and export markets in Europe provided a highly elastic demand for final agricultural products. The faster horse replaced the slower oxen which was not suitable for the machinery

invented. Total farmland more than doubled in the 50 year span of 1870 to 1920 for which we have data. Average farm size, on the other hand, stayed roughly constant. Thus total farm employment must have nearly doubled as well. Existing agricultural labor, far from being displaced, was redeployed within agriculture, and large numbers of immigrants were accommodated as well.

It is important to realize that the elastic final demand provided by export markets played a crucial role. Without these export possibilities, areas planted, employment and agricultural output would have expanded by less and mechanization would probably have proceeded at a slower pace. (If final demand was very inelastic, mechanization could possibly lead to a reduction in agricultural employment even if extra land were available.)

It is also well known that the horse-based mechanization of U.S. agriculture up to 1920 did not result in increases in yield. Massive yield increases in U.S. agriculture were a much later development (see Table 6) and were linked to fertilizers and biological innovations.

Mechanization can also be induced by labor scarcity arising out of nonagricultural labor demand (Case 2 in Figure 2). Production costs rise because wage rates rise rapidly. Therefore, other things being equal, output will fall (or grow more slowly), depending on the elasticity of final demand. Although mechanization is usually not capable of preventing production costs from rising altogether, it can help reduce the rate of increase in production costs. This case is again best illustrated by the U.S. from 1940 onwards. Tractors, combines and a broad spectrum of sophisticated machines expanded at unprecedented rates (Tables 3 and 5). While labor input per acre or per animal had declined at a fairly slow pace between 1915 and 1939, the pace of labor input reductions became dramatic after 1940 (Table 6). Agricultural employment fell substantially both in absolute and relative

terms. Labor was redeployed in the non-agricultural sectors of the economy rather than in agriculture itself. The number of workers per farm stayed very stable. Therefore farm sizes grew at an extremely rapid pace from an average of 167 acres in 1950 to 401 acres in 1978. Europe went through equally dramatic changes after 1955.

The discussion of these two U.S. time periods shows that labor effects of mechanization must be evaluated in the context of the alternative available to the economy and to the workers. Consider the Indian Punjab as an opposite example: the green revolution initiated in the mid nineteen-sixties led to sharply increased demand for labor, which caused a substantial rise of real wages around 1968 (Gupta and Shangari, 1979). This in turn led to increased seasonal and permanent migration, primarily from Eastern India.5/ But it also led to the adoption of tractors and threshers. The combined effect of these developments was a decline in real wages after 1972/73 to bring them more in line with the stagnant real agricultural wages in the rest of the economy.

Had the process of mechanization in the Punjab been embedded in a rapidly growing economy of the country as a whole, there would have been little cause for concern. Under the existing conditions, however, a slower rate of mechanization and a larger volume of migration could have solved the labor problem in the Punjab at a lower capital cost, and the extra employment would have led to a wider sharing of the benefits of the green revolution with workers in poorer regions.

Mechanization can also be a powerful engine of agricultural growth when it makes a new method or crop profitable which previously was not profitable (Figure 2, Case 3). The best example is pump irrigation. While it is always possible to lift water with animal or human power, it may often not be profitable to do so even at extremely low wages. The pump, which is still a potential substitute for human or animal power, therefore enables an expansion in production, the magnitude of which

will be determined by the elasticity of final demand. Since the extra output requires additional labor, agricultural employment expands more or less in step with the output expansion. Numerous studies in contemporary Asia document such patterns.

2.1 Capital scarcity and energy costs

Poor societies have lower accumulated capital stocks than rich ones and the cost of capital (in terms of labor) is higher. High capital costs retard mechanization in several ways. First they reduce the increases in costs of production and reduce the profitability of all forms of agricultural investment. It is important to realize that this affects all forms of agricultural investment, including those for land improvements, irrigation, animals, building and current inputs. A second effect of high capital costs (relative to labor) may be a reallocation of whatever investment takes place away from mechanical inputs towards other forms of investment. This reallocation will be stronger the more expensive and long-lived the mechanical inputs are and the easier it is to produce other forms of capital (such as land improvements) by hand. A third effect, discussed in detail in section two, is that higher capital costs lead to a highly selective pattern of mechanization in favor of power intensive operations. Finally, higher capital costs influence the design of machines toward simpler and less durable designs. Repair costs are relatively low and more frequent repair substitutes for durability.

Generalization (4): High capital costs (relative to labor) retard mechanization, and lead to selective emphasis on power intensive operations. Machinery design adjusts to high capital costs by lack of convenience features, simplicity and reduced durability.

Energy is only one of the cost components of machines. Capital and maintenance costs often are equally large or larger. Since the profitability of machines, i.e. their comparative advantage, is tied closely to labor costs, high energy costs are likely to retard mechanization much more in environments where labor cost is low than where it is high.

2.2 Farm size

Average farm size in an economy is to a large extent a reflection of the scarcity of land to labor, and thus need not be an important additional consideration in the cross country analysis of mechanization. Most of the mechanization originated in North America where farms were traditionally larger than elsewhere. However, as we have seen before, mechanization was associated with average farm size growth only after 1940. At that time it undoubtedly became the key facilitator of post 1940 farm size growth, not only in the U.S. but also in Western Europe. Rather than emphasizing the causal link we emphasize the facilitating role:

Generalization (5): Mechanization (e.g., growth of large, corporate farms in the U.S. and disappearance of small family farms) is the key facilitator of farm size growth.

Within any given country, relative access to mechanization by different farm size classes is often a more important issue than the impact of average farm size. Historical data and contemporary experience are unanimous on the following generalization.

Generalization (6): Large farms adopt new forms of mechanization considerably faster than small farms.

There are two reasons for this: one, it is now well understood that in any given economy the opportunity cost of capital relative to that of labor differs among

different farm size groups. Two, it is high on small farms which own few assets with collateral value but have abundant family labor, and it is lower on large ownership holdings which have much better access to owned or borrowed capital but which have to depend on hired labor.6/

An added reason for earlier adoption is that certain (but not all) machine processes are subject to genuine economies of scale: it is technically more efficient to design a large rather than a small machine. Historically these engineering limitations have been quite important because machines were initially developed in labor-scarce countries with large farm sizes. Machines invented in countries with more abundant labor (and therefore smaller farm sizes) were first developed for the largest farms within those countries because it was on those farms that relative costs of capital to labor were the lowest.7/ The market for machines expanded to smaller farm sizes only when labor costs rose or capital became more abundant. The engineering history therefore is frequently one where engineering solutions were embodied into smaller and smaller machines.8/

Engineers have thus greatly expanded the scale options in almost all machines. Japan, in particular, has developed a vast array of machines for small farms and plots. Thus, while the engineering limitations on size were undoubtedly important historically, they are less important today.

For certain operations the impact of economies of scale on the use pattern (rather than the ownership pattern) of machines across farm size is further mitigated by the ease of establishing rental markets. Two factors contribute to rental markets: first, the technically optimal farm size required for machine ownership must exceed the sizes of numerous small farms. Second, it is easier to establish rental markets for those operations which are not time-bound, and which do not necessarily occur at roughly the same time (i.e. are not synchronic).9/ Threshing and milling are examples of such operations.

It is thus no accident that, as discussed in section two, rental markets for threshing machines have been well established in 19th century U.S., Europe and are now common all over Asia (Gardezi et al., and Walker and Kshirsagar). Threshing can be stretched over long periods and economies of scale have traditionally been important. Milling of rice for home consumption is similar: the mill owner "rents" his machine to his customer. Rental markets for land preparation, via animals or tractors, have been common in colonial U.S. when plows were still scarce, or in Europe. Such rental markets are now common in Asia wherever tractors or power tillers have penetrated. Within small regions rental markets for time-bound and synchronic operations are harder to establish because of sharp conflicts about timing among potential users. The time-bound operations include, in particular, the seeding of crops and the harvesting of most grain crops and hay.

Table 17 contains some data for tractor rentals in South Asia and confirms the observations just made. Census data for the Philippines may illustrate the importance of rental markets in perhaps the most striking manner (Table 15). These data show that most farmers own their animals, carts, plows and harrows. However, harvesting and threshing equipments, tractors, and motor vehicles are used on about five to seven times as many farms as those who own them, i.e. rental markets are extremely well developed. Sprayers occupy an intermediate position with about 0.7 renters per owner of each equipment.

Generalization (7): Farm sizes play a much less important role in determining optimal machine sizes for operations where rental markets are fairly easy to establish.

2.3 Subsidies

A fourth macro-economic factor favoring mechanization is explicit or implicit subsidies in the form of credit, special tax and tariff treatments and/or on energy (Case 4, Figure 2). Subsidies may speed up mechanization. But as we have seen direct yield effects of mechanization are small. Any effect of subsidies on agricultural output, therefore, must be an indirect one which arises from the cost reduction made possible by mechanization. But when mechanization is not spontaneously driven by some form of labor scarcity, the production cost impacts are not very large and, therefore, indirect output effects of subsidies cannot be large.

On the other hand, reductions in labor use can be substantial. But what will the labor so released do? Since the redeployment is initiated by a reduction in agricultural labor demand, the alternative employment opportunities faced by the released workers must be inferior to the ones they lost whether they be within the agricultural sector or outside of it. Some of the workers may remain unemployed or withdraw from the labor force. Unlike in Cases 1 and 2, the redeployment of labor is not a productivity benefit, but a loss. Appeal to the potential relief of drudgery is quite inappropriate in this case.10/

The major point of section one is that the growth benefits from mechanization, and its consequences for employment and farm size, are only partly determined by the nature of the machine itself. The same machine can have drastically different consequences depending on the macro-economic environment into which it is introduced. In particular the consequences are extremely sensitive to the factor endowments of the economy in terms of land and labor and to the conditions of final demand for agricultural output.

3. Patterns of Mechanization

The most dramatic aspect of mechanization clearly is the shift from one source of power to another. In ancient China replacement of human labor by cattle for transport and tillage was initiated more than 3200 years ago. Between the second and fourth century A.D. fairly widespread use of water is reported from China for rice pounding, grinding and water lifting (Liu Xianzhou). Water power was widely used for milling purposes in Europe during the middle ages, during which the use of wind power is reported from China and Europe as well. The 19th century saw a widespread displacement of oxen by horses which, in Europe and North America, provided power for an impressive array of mechanical devices from about 1850 to as late as 1965. Steam engines on the other hand, were widely used only for about 50 years between 1870 and 1920. They were rapidly displaced by internal combustion engines and electric motors from 1900 onwards. Tractors came into widespread use in North America after about 1920, but co-existed with horses for roughly 25 to 30 years. Except for Great Britain, where tractors began to be adopted in the 1930s, tractorization of European and Japanese agriculture was delayed up to about 1955, after which it occurred with an explosive speed (Table 21).

Emphasis on shifts in power sources, and especially on tractors obscures the selectivity of the mechanization process in terms of operations. This leads to widespread misunderstandings about which operations are the most likely candidates for mechanization in developing countries. In what follows I therefore discuss patterns of mechanization in terms of operations, with only selected attention to power sources. Most of this discussion will be based on machinery stock data. Such data are far from ideal since they gloss over much detail, but no other data can give nearly as comprehensive a picture over long periods of time.11/

Data on use patterns of animals and tractors by operation has to come from detailed surveys. Such surveys are very scarce in the developed world, but fortunately more abundant in South and Southeast Asia.

Operations can be usefully grouped in terms of the relative intensity with which they require power (or energy) relative to the control functions of the human mind (or judgement). We will show below that, regardless of the stage of mechanization, new power sources are always first used for power-intensive operations. Furthermore it appears that mechanization of the power-intensive operation is less dependent on the price of labor than the mechanization of control-intensive ones, i.e. it often pays to move to a higher stage of mechanization in power intensive operations even at low wages when mechanization of control-intensive operations is not profitable. The rest of this section provides support for the following generalization:

Generalization (8): When new power sources become available, they are initially used only for selected operations where they have high comparative advantage. Power-intensive operations are shifted most rapidly to new power sources. Control-intensive operations are shifted to more highly mechanized techniques when wages are high and/or rapidly rising.

3.1. Power intensive processing and pumping

Milling, threshing, chopping, sugarcane crushing, pumping of water, etc. are extremely power-intensive but appear to require little control input. Moreover, both stationary and mobile power sources can be used for them. Among the stationary power sources water was first used for milling, pounding and grinding in the first century B.C. in China and its use for these purposes was fairly widespread between the second and fourth centuries A.D. Water powered milling was also invented in France in the

fourth century A.D. It was only in the 12th century that it had been adopted in all corners of Europe. Wind power has historically been used almost exclusively for milling and lifting of limited amounts of water. Mills and threshers were the most common users of steam power in the late 19th and early 20th century in both Europe and the U.S.

Mechanical threshing based on human power, but especially on horses, became widespread in the U.S. and Britain as early as 1830, and by 1850 virtually all grain in the U.S. was threshed by large mechanical threshers which shifted from farm to farm during the winter months. Rental markets were very well developed. Already by 1852 the number of threshing machines in France had reached nearly one-third of its peak 1929 level (Table 10). Introduction of threshers in Germany may have been somewhat slower (Table 11). Except for some animal-drawn primary tillage, stationary machines for power-intensive operations preceded all other forms of mechanization in Japan (see Table 13).12/

In South Asia, animals have long driven Persian wheels, sugarcane crushers and oil crushers. Animals used in these operations are increasingly being replaced by diesel and electric engines (Table 16). In India, in 1972, the number of stationary engines for power intensive operations was about 20 times the number of tractors. And in China (Table 20) the number of threshers alone exceeded the combined number of tractors and power tillers even in 1980. In all of Asia mechanical rice milling for large trade quantities was already introduced in the late 19th century, usually based on steam and later on internal combustion engines. Smaller rice mills have swept across Asia since the 1950s and it is hard to find villages where hand pounding of rice is still done. Thus mechanical milling is even more widespread than threshing. But where the green revolution has raised wages and increased harvested volumes, small threshers were rapidly adopted once efficient designs were available (Indian Punjab, Philippines, and Central Thailand). The new threshers are now also penetrating into other South Asian regions (Walker and

Kshirsagar, 1981). As in earlier U.S. and European mechanization, neither mills nor threshers are usually owned by the individual farmers who use them.

Generalization (9): The mechanization of power-intensive processing and pumping operations always precedes the mechanization of harvesting and crop husbandry operations, and can be profitable at low wages.

3.2. Land preparation

Unlike the power-intensive operations, land preparation requires mobile power sources such as animals, tractors or power tillers (hand tractors). Of all land preparation operations, primary tillage (the breaking of the soils, often combined with the turning of the top layer), is the most power-intensive operation. In the move from hand labor to animals, and later in the move to steam and to tractors, primary tillage is usually the first land preparation operation to use the new power source. Investment into animal-drawn harrows occurs later and is usually much lower than into plows. Iron harrows are documented for China around 500 A.D., at least 1,000 years after iron plows. The widespread use of modern steel harrows in the U.S. was delayed until after the 1880s, roughly 50 years later than the massive shift to cast iron and steel plows. When tractors were introduced they began to be universally used for primary tillage while animals continue to be used for other soil preparation operations. (For U.S. examples, see Table 8 and Figure 3.) In the initial stages of animal cultivation or of tractorization the scarce new power source is used where its comparative advantage is highest, i.e. it is spread thinly over a wide area for primary tillage.

Generalization (10): Primary tillage is one of the first operations to be mechanized when a new mobile power source becomes available. Secondary tillage operations often continues to be performed by the old power source for a considerable period of time.

3.3. Transport

This power-intensive operation is also quickly shifted to new mobile power sources when they become available. Carrying loads is the earliest use of domesticated work animals, even preceeding tillage. Shifts to animal-drawn sleds or carts follow, especially where marketed quantities become larger. The cart and the plow are the basic farmer-owned implements of early animal drawn mechanization, as the data from the Philippines, India and Senegal clearly show for contemporary animal-based systems (Tables 15, 16 and 19).

When mechanical power becomes available it is quickly used for farm-to-market transport. Early tractors had no tires and in the 1920s were rarely used for farm-to-market transport in the U.S. or Great Britain. Instead mechanizing farmers typically bought both tractors and trucks at about the same time (Tables 3, 8, 12, and utilization data in Figure 3). For on-farm transport U.S. farmers continued to use horses well into the 1940s. A similar pattern of simultaneous growth of tractors and trucks is apparent in Mexico after 1960 (Table 18). In Asia, where farm sizes rarely support the purchase of a truck, farm-to-market transport is increasingly done by hired trucks or tractors. Rubber tires have given tractors a high comparative advantage in on-farm transport. The data from South Asia in Table 17 reveals that--unlike in the case of early U.S. mechanization--transport is one of the major operations performed by tractors.

Generalization (11): Transport, along with primary tillage, is one of the first uses of new mobile power sources. Where distances are long, trucks, rather than tractors are used for farm-to-market transport.

3.4. Harvesting operations

If not mechanized harvesting is very labor-intensive. However, the different crops vary widely in the types of labor required, i.e. in their power-and control-intensity. Harvesting of root crops is probably the most power-intensive one, while still requiring a fair level of control input. Most grains occupy an intermediate position. Harvesting of cotton, fruits and vegetabes require intensive control input. Harvesting of apples is an extreme case of control-intensity. The threat of damage to apples is so large that the harvesting of apples for eating purposes has not been successfully mechanized.13/ In many of the control-intensive harvesting operations the threat of yield loss from higher levels of mechanization is the principal problem to be overcome by engineers.

During the 19th century attempts to develop harvesting machinery were widespread in Europe and the United States (van Bath, USDA 1940). Early adoption of such machines, however, was largely confined to the United States and Canada where the reapers for small grains became widely adopted after 1850 and especially during and after the U.S. Civil War of the 1860s. Grass mowers for the dairy regions followed shortly afterwards. In France and Germany it was not until 1890 or 1900 that these machines made a substantial impact, fully 40 years after widespread U.S. adoption (Tables 10 and 11). This time lag, as many other lags, cannot be explained by lack of engineering knowledge in Europe. After all, at that time the same countries were using mechanical threshers for virtually all their crops and seed drills had already been widely adopted. Labor was more abundant, farms were smaller, and the harvesting machines were not profitable.

The United States moved from reapers to wheat binders starting in the 1870s and to corn binders in the 1880s. These developments coincided, or even preceded, the development of modern harrowing technology: spring tooth harrows and disk

harrows. European adoption of reaper-binders was delayed until the first decade of the 20th century (Bogart). In Japan reaper-binders had a perceptible impact only after 1967, virtually a hundred years later than in the U.S. and a good thirty years after Japan started mechanizing pumping, threshing, and winnowing in earnest (Table 13). Again, technological ineptitude in Japan cannot possibly have been the cause for such an enormous lag.

Practical development of horse-drawn harvesting combines started in California in the 1860s. By the 1880s combines drawn by 24 to 30 or 40 horses reaped between ten to fifteen hectare a day in California. In the 1890s combines drawn by stream tractors had a capacity of up to 20 hectares of wheat a day (van Bath, Yearbook of Agriculture, 1960), but combines did not spread outside of extremely labor-scarce California until 1914. They did not appear in Great Britain until 1928, nor in most of continental Europe until 1935, and not in Japan until about 1970.

At each level of mechanization machines for harvesting maize tended to lag a few years behind those for small grains. Hay harvesting equipment, horse rakes and tedders became important during the U.S. Civil War of the 1860s and remained important until the Second World War (Table 7). In France in 1892, hay-raking machines had not reached ten percent of their 1955 peak number. Data are not available for Germany. Hay loaders became widely used in the U.S. after 1880 but did not spread in continental Europe until after World War II, only to be quickly replaced by hay balers and other more sophisticated hay harvesting machines (Table 10).

Most of the animal-drawn harvesting machines derived their power from the traction of the horse.14/ When tractors became available adaptation of the horse drawn harvesting machines to tractor use was straightforward, since similar machines could simply be pulled by tractors. Nevertheless, as Table 7 and Figure 3 show, it

took considerable time before horses lost their comparative advantage even in the harvesting operations.

Harvesting machines for other crops were later developments. Horse-drawn potato diggers and spinners were used in the U.S. and Europe in the inter-war period but little data has yet been assembled on their adoption patterns. Many other harvesting tasks vary in their power input but require intensive control input, often in order not to damage the crops, e.g. tobacco, cotton, sugarbeets, sugarcane, vegetables and fruits. Even in the U.S. machines for these tasks became popular only well after the Second World War (Table 5).

Generalization (12): Mechanization of harvesting operations is directly dependent on the levels of labor costs and rarely profitable in low wage countries. The higher the control intensity of the operation, the higher must labor costs be in order to warrant adoption of a machine to perform it.

3.5. Crop husbandry

Weeding and interculture of crops, fields, and orchard cleaning are control-intensive operations. Hand weeding is thus practiced in animal systems long after the introduction of the plow and cart. It is still required within rows until rising wages make herbicides profitable.15/ Inter-culture with animals becomes feasible only when line seeding is practiced. Interculture also tends to be performed by animals long after tractors are used for tillage and for stationary machines (Tables 7 and 8, Figure 3).

Generalization (13): Crop husbandry operations are shifted to new power sources only after tillage, transport, threshing and seeding have been shifted.

3.6. Seeding and planting

These are among the few agricultural operations where animal and tractor-drawn machines appear to be capable of greater precision than hand methods. Mechanical means thus may lead to modest direct yield effects. Line sowing is more precise than hand spreading, making inter-row cultivation with hand tools, animals, or tractors easier and saving on seed. Mechanical seed and fertilizer placement may thus be attractive in land-scarce, intensive cultivation systems. Indeed the first seed drills were developed in China and Mesopotamia in the third millenium B.C. (van Bath). The Mesopotamian drill required three workers, one to drive the oxen, one to put grain in the hopper, and a third to hold the drill steady. It was apparently only possible to profitably use this instrument in the fertile soils of Mesopotamia where high yields could be achieved and labor was abundant. The drill soon fell into oblivion.

Design of improved seed drills for small grains was attempted in Europe from the 16th to the 19th centuries. Seed drills with mechanical dribbling devices came to be commonly used in the U.S. in the 1860s and 1870s. In continental Europe their use started only slightly later and became widespread in the late 19th century. Maize drills and cotton seeders became widespread about a decade later.

The use of seed drills similar to the Mesopotamian drill has been growing rapidly in India since 1966 (Table 16). In Senegal, where animal traction is primarily a post World War II development, the seed drills have become one of the most popular implements (Table 19). Improved seed drills with mechanical dribbling of seeds are becoming popular in South Asia and are one of the more successful machines in Mexico (Table 18). In all these cases it is not saving of labor but probably the improvement in yields, the saving of seed, and the ease of interculture which leads to their success. For most developed and developing countries for which

data are available, the spread of seed drills is closely paralleled by the spread of inter-row cultivators or, at an earlier stage, simple animal-drawn hoes or blade harrows for interculture.

Generalization (14): In labor-abundant environments seeding of grains tend to be mechanized before grain harvesting, but the order is usually reversed in labor-scarce environments.

3.7. Fertilizer and pesticide placement

While fertilizer can be placed by hand, precision dispensing leads to higher yields for the same amount of fertilizer. Thus, animal-drawn machines for fertilizer placement developed along with increased use of fertilizer. Since in the inter-war period fertilizer was more intensively used in Europe, fertilizer distributors were widely used (Table 10). Large cart-mounted barrels for spreading liquid cow manure were also widely used as well as elaborate pumping systems for the same purpose. The practice of using liquid manure was virtually unknown in land-abundant North America.

Application of pesticides in liquid form cannot be performed without at least a hand pump. And for pesticides in dust form, mechanized dusters achieve higher precision and save on pesticide. Development of sprayers, therefore, went hand-in-hand with the development of pesticides. In France, for example, spraying carts were widely used for wine cultivation in 1929. But in Japan hand-carried power sprayers became popular for rice and other crops only with the development of a much broader array of pesticides after World War II (Table 13). Such power sprayers are now widely used all over Asia, often on a hire-contract basis.

Generalization (15): The use of hand and power sprayers is driven by the availability and use of pesticides and is widespread even at

very low wages. Higher wages, however, lead to the use of larger sprayers which may be animal or tractor drawn.

3.8. Interpretation of the patterns

The selective use of new power sources, and in particular of the tractor, for the power-intensive operations just discussed has often been viewed as a sign of inefficiency. Given that a farmer has to make a huge investment in a tractor, why not use it for all operations? The U.S. studies carried out in the 1920s and 1930s, however, are quite clear in showing there is nothing inefficient in a selective use of tractors for power intensive operations. Given that wages were still low by post-World War I standards, it was more efficient on large farms to maintain a tractor and a truck along with some horses. The horse took care of virtually all operations where power was not the overridingly crucial input. Each power source specialized in those operations where it had the greatest comparative advantage. As Figure 3 and Table 8 clearly show, tractors were thus mainly used for tillage and as power sources for stationary machines such as threshers, saws, silo fillers and choppers (pulley work). The same pattern of tractor use was common in Europe prior to about 1960, and is now common in South Asia, Southeast Asia and in China (Table 17). The only differences are that direct power takeoff has replaced the belt and pulley and that the modern tractors are more frequently used for transport than their early counterparts. While modern tractors are more efficient than pre-war ones, wages in Asia are much lower than in the pre-war U.S.A. We should therefore anticipate the continued use of animals in these environments, along with tractors, until wages rise to a level where the high cost of drivers renders the animals inefficient.

4. The Speed of Adoption

There is no question that during the 20th century and especially since World War II, the length of adoption cycles has shortened. In Japan, for example, each of the machines listed in Table 13 experienced massive spurts in mechanization: from 1939 to 1955, i.e., in roughly 15 years motors, threshers and hullers increased five to ten-fold. Power tillers grew from less than 100,000 to more than 3 million between 1955 and 1975. Binders, combines and rice transplanter spread even more rapidly in the 1970s.

Such spurts are not unique to Japan. Continental Europe experienced many similar spurts in the period from 1955 to 1970 (Tables 9, 10, 21). In Taiwan, China after 1968 it took only about a decade to completely shift primary tillage to power tillers. Central Thailand, starting from the late 1960s, has completely shifted to tractor tillage with locally designed power tillers and small four-wheel tractors in about 15 years. Also, the adoption of small paddy mills in Southeast Asia was very rapid.

We should not, however, think that such spurts are only a phenomenon of the 20th century. In the U.S. once satisfactory designs were available threshers spread within a 20-year period from 1830 to 1850 (USDA, 1940). Thresher adoption seems to have been very rapid in Europe as well.

Historical statistics which focus on power sources at a national level rather than on operations at a regional level tend to obscure the rapid speed of adoption. Growth of tractors in the U.S. was spread over a 50-year period, with occasional spurts. However, once tractors became available, primary tillage was shifted to tractors in a much shorter period of time. Further growth of tractors, then, was a process of shifting additional operations from horses to tractors. Today

few farms in the Indian Punjab plow land with animals, thresh wheat by hand, or use Persian wheels. This is only about 15 years after tractors, threshers and pumpsets became an important factor. The aggregate Indian data of Table 16 hide these facts because animals continue to be used for other operations even in the Punjab and because many other regions have not yet shifted massively to tractor plowing or mechanical threshing.

In the case of threshers, adoption cycles appear to have always been fairly fast. Once locally adapted designs are available the cost advantage seems to be overwhelming. For other machines the explosive growth patterns of the post war period must be understood as responses to rates of growth in agricultural wages which were unprecedented by any historical standards. We conclude this section with two generalizations.

Generalization (16): Where cost advantages are large or change rapidly, individual operations are mechanized in very short periods of time. Within smaller regions, adoption periods are often of the order of 10 to 15 years.

This speed of adoption implies directly:

Generalization (17): In private enterprise economies, supply-bottlenecks in production, distribution, and servicing of machines are rarely a major cause for slow adoption of new machines.

5. The Process of Mechanical Invention

The previous sections imply the following:

Generalization (18): Neither power sources nor the basic engineering solutions for particular operations are very sensitive to agroclimatic and soil variations. However, the power sources must be embodied in specific machines and the basic engineering solutions adapted to different environments. Both agroclimatic factors (soils, terrain, rainfall regimes) and economic factors (land, labor, capital endowments, farm sizes, and materials available) require an amount of adaptive innovation which has been vastly underestimated.

The extent of adaptive innovation required is best illustrated by United States patent statistics which Robert Evenson has put together on a regional basis. I cannot do better than to reproduce his tables, as well as his discussion.

"In fact, it would appear that the patent system was working quite effectively in stimulating invention in mechanical and chemical technology fields relevent to agriculture. Thousands of patents had been granted to private inventors in agricultural research. Further, the inventive base was broad. Patents were granted to inventors in all states with varied backgrounds (including a number of illiterate inventors). Tables 23, 24, 25 provide a summary of patent data in three major mechanical invention fields, plows and cultivators and planters and seed drills, which provide some insight into this invention.

"The data show the numbers of patents granted by decade by the state of origin of the inventor. They also show (in parenthesis) the number of these inventions which were assigned to a corporate entity at the time of the patent grant. This is a good proxy for corporate invention.

"The reader will note two phenomena in all three tables. The first is the steady growth in assignment, reflecting the development of the farm machinery industry. The second is the regional pattern of invention. As settlement proceeded westward we observe tillage inventions emerging from a region roughly 50 years or so after settlement of the region. We also observe patenting, particularly assigned patenting, tending to be located where the farm equipment firms were located. In the period prior to 1880 or so, a large number of small firms producing tillage equipment were in business. Danhoff (1967) reports that 800 distinct models of plows were advertised for sale in the northern U.S. in 1880. Many of these small firms or shops started their businesses around a particular invention.

"During the 1880s and 1890s the industry consolidated rapidly. The large firms (McCormick, Derring, John Deere, Case, Allis Chalmers, Minneapolis Moline, etc.) in the industry were located in the Midwest. These firms often purchased the assets, including patents, of small firms as they expanded.

"The second phenomena revealed in the tables is that those regions with the earliest inventions are the first to exhibit declines in patenting activity. By the late 1800s the New England and Middle Atlantic states appear to have lost their initial comparative advantage in inventions.

"A stylized story of an invention product cycle in a narrowly defined technology field can be characterized as follows:

1. During an initial period (sometimes lasting for three or more decades) invention is sporadic. Most of this invention is produced by individual inventors who, by reason of specialized experience, believe that they can solve the problems of the field.

2. A point is reached where the pieces begin to fit together around one or more (often more), technology "cores." Further development and commercialization

is now undertaken and major investments in inventive activity, pilot production, etc., are made.

3. Each technology core now provides strong disclosure effects which enable other inventors to make inventions and improvements.

4. With an active core process underway, the scope is opened up for adaptive or derivative invention. In agriculture the settlement of new regions opened up tremendous scope for modifications of plows, planters, etc., to new soil, climate and economic conditions.

5. Industrial organization and markets now come to be critical to further development. There is a tendency for one or at most two cores to become dominant commercially. This has two effects. First, it eliminates invention incentives associated with inferior cores. Second, it causes the elimination of firms based on inferior cores and is a force leading to consolidation.

6. The cycle may then reach a new equilibrium with a slow rate of further invention and high industrial concentration. Most of the highly original, high-risk invention is left to wildcat inventors, with the industry concentrating on refinements of the going core and process inventions.

"By the early 1900s many technology fields in agriculture had reached stage 6. The agricultural machinery (and agricultural chemical) industries were concentrated with several large firms dominating production. Yet every new agricultural implement to be commercialized since 1900 has been invented and commercialized by independent wildcat inventors (and in a few cases by the public sector)."

Investigation of agricultural machinery innovation has been much less systematic in other developed countries and in the developing world. Nevertheless, even selected case studies, field observations and discussions with engineers and

machinery manfacturers reveal very similar trends. The emergence of a diversified machinery industry out of small shops is well known for the Indian Punjab. For the Thai power tiller industry, it has been well documented in Wattanutchariya. Innovations in the Philippines has been described by Mikkelsen.

Generalization (19): In the early phases of mechanization invention, sub-invention and adaptation are almost exclusively done by small manufacturers or workshops in close association with the farmers. On a world-wide basis, public sector research has contributed little to machinery development, but more to education. The contribution of large corporations increases over time but continues to be most important in the area of engineering optimization.

The reasons for these patterns are threefold. First, in sharp contrast to biological innovation, where public funding is crucial private machinery producers can capture the gains from their innovation effort via the sale of machines. The protection of the innovator's rights is stronger the more developed the patent system is and the better it is enforced. (For a full discussion of alternative patent systems see Evenson.) Second, the location-specificity of many of the adaptive solutions give farmers, blacksmith repair shops, or small firms an important advantage over public research institutes or large corporations. They are constantly exposed to the particular local problems to be solved. Third, mechanical innovation, unlike biological or chemical ones, do not usually depend on university-acquired skills of chemistry, genetics or statistics. Mechanically minded individuals with little formal education are thus not at a disadvantage. It is when optimization of design of complex or self-propelled machines is involved that metallurgical and mathematical knowledge become more important and it is at this stage that engineering staffs of corporations are more effective.

The widely dispersed process of innovation and adaptation and the comparative advantages of larger firms in design optimization, sales, finance and production lead to the pattern of industrial structure which Evenson discussed for the U.S., but which has been characteristic wherever mechanization proceeded rapidly.16/

Generalization (20): At the beginning of a mechanical spurt many small firms enter with alternative designs. The most successful ones either grow to larger size or are bought up by larger firms while small producers disappear or revert to machinery service.

Evenson also shows evidence for the following:

Generalization (21): Inventive activity on a particular operation often precedes initial widespread machinery use by decades. However, it reaches a peak during the initial adoption cycle when derivative invention, refinements and adaptation to slightly different environments is required.

The most impressive lags between inventive activity and adoption of machines occur when inventive activity is directed towards mechanizing operations for which there is as yet little demand. In early 19th century Europe inventive activity on seed drills and harvesting may have been one of the best examples of frustrated innovative activity. But examples from developing countries abound, especially in the machinery parks of publicly funded agricultural engineering programs.

6. Policy Implications for Developing Nations

The world inventory of machine processes and basic engineering solutions is large. Developing nations are thus not normally confronted with solving basic engineering problems for any of the operations they will want to mechanize in the future, but with fostering a healthy climate for the reinvention, adaptation, design modification and straightforward copying of existing solutions. By the very nature of agriculture, this process must be a decentralized one, carried out separately for different nations or agroclimatic regions.

The following conclusion emerges from sections one and two on the question of introduction: the growth contribution of mechanization varies widely according to the economic environment into which it is introduced. In general it would be low or negative in countries without a land frontier and with high agricultural population densities such as Bangladesh, most of India or China. Given the high proportion of the work force still primarily engaged in agriculture in these countries, even very rapid non-agricultural growth will not lead to rapid wage rate rises. Labor scarcity arising from non-agricultural growth cannot therefore be expected to emerge as a driving force for broad mechanization in the near future.

The labor demand situation is quite different in middle income countries of South America such as Brazil. An open land frontier and rapid non-agricultural growth lead to a demand for labor which has to be met out of a proportionally much smaller labor pool than in the poor Asian countries.17/

Not only does the growth contribution of mechanization in general vary, but the growth contribution of mechanizing different operations varies widely across economic environments. It is, therefore, not easy in any given situation to know which operations to mechanize next. Farmers tend to be the best judges; outside

analysts often simply know too little about the farming system, or worse, they may attempt to solve perceived problems with solutions with which they are familiar in their home environment. The patterns of mechanization discussed in section two may be helpful in anticipating future developments somewhat better.

The historical record is quite clear on government intervention. Mechanization in the developed countries did not depend on direct government intervention in machinery development, production, technology choice or finance. The most successful experiences in the developing world, such as the mechanization of milling, pumping or harvest processing did not depend on such special intervention either. Once economic conditions have led to effective machinery demand, private firms have responded rapidly in the developed world. Responses to fewer and more selected opportunities have been equally rapid in developing countries as diverse as Thailand, India, Taiwan (China) or Mexico.

In the developed world specific government policy towards mechanization 18/ has been confined to the following: (1) patent laws for the enforcement of innovator's rights and encouragement of disclosure effects, (2) testing of machinery, support of standardization measures and information dissemination, and (3) support of agricultural engineering education and some university-based research. These are clearly appropriate interventions.19/

Where governments have intervened more drastically they have either had little success, as in the numerous publicly funded research efforts, or they have made wrong and/or controversial choices.20/ Pakistan not only subsidized large scale tractors but also prohibited imports of all but a few selected brands.21/ Trade policies not only restricted imports of an array of smaller machines and implements, but made it almost impossible to import small engines and parts which could have been used by small innovating firms to design locally adapted machines. The contrast

between Pakistan and Thailand could hardly be sharper. The laissez-faire policy in Thailand has resulted in the development of indigenous power tillers and small tractors, the availability of broader mechanization options, and few adverse social consequences.

Mechanization would undoubtedly have been profitable on its own in Brazil. However, Brazilian policy has done much more to accelerate mechanization by subsidizing loans for machine purchases. Interest rates were often lower than inflation thus reducing real borrowing costs below zero. Furthermore, ample evidence exists that credit subsidies, especially for tractors and other large scale machines, are largely captured by large farms and Latifundia. These large farms gain a cost advantage over the small ones and expand at their expense. This process has, for example, been documented for Pakistan in two studies spanning a 15-year time span (McInerney and Donaldson, Lockwood)22/ and for Brazil (Sanders). Furthermore, the subsidies often favor the well endowed regions where savings capacities are larger and farms can more easily take advantage of the subsidies. Sanders shows that in Brazil machinery credit subsidies have increased imbalances between Sao Paolo Province and the poor northeast. In China subsidized or zero credit and subsidized energy have undoubtedly benefitted the more prosperous regions over the poorer ones where investment in machines is still very limited. This evidence and the discussion of section 1.5 lead to the following:

Generalization (22): Subsidies to mechanization tend to have low output effects and adverse employment effects. They also tend to favor larger farms over smaller ones and relatively rich regions over poorer ones.

It is important to note in contrast that, where mechanization has occurred spontaneously in response to vigorous labor demand, equity issues have

usually been unimportant. Released workers were redeployed in areas where they were more productive and received higher wages, and the remaining workers ended up farming larger areas.23/

There are a few cases, however, where governments may be faced with severe distributional dilemmas even where mechanization occurs spontaneously: harvest combines appear to be modestly profitable in the Indian Punjab. Their introduction would displace a large number of migrant workers from poverty stricken regions (Laxminarayan et. al.). In the absence of rapid employment growth elsewhere the Indian government may have sufficient cause to ban the machines. Mechanical rice milling has been controversial in Indonesia (Turner, Collier). It is now penetrating into Bangladesh, reducing labor demand for women who--because of social customs--have already very few employment options. On efficiency grounds the introduction of the machines is clearly warranted, but the equity issue poses a severe dilemma for policy.

7. Implications for China

Whether we are concerned with a capitalist or a socialist economy does not alter the analysis of the potential growth contribution of mechanization. In socialist economies payoffs depend just as much on the opportunity costs of labor, land and capital as in a capitalist one. As an inspection of Table 20 reveals that despite massive attempts to influence mechanization by various policies and programs over the past thirty years, mechanization patterns in China are surprisingly similar to those of other labor abundant developing countries: limited tractorization, use of tractors for tillage and transport, substantial mechanization of power intensive harvest processing and pumping.

Given the similarity in payoff structure to various forms of mechanization, all remarks about the payoffs to mechanizing different operations thus apply as much to China as elsewhere. To the extent that historical patterns clarify the structure of the payoffs they should be as useful to planners in China as elsewhere. Since China is a labor-abundant and a land-scarce economy the policy implications do not differ much from those for similarly endowed economies.

Equity issues, however, may differ to some extent in China. In principle, when a brigade or production team invests in a machine, all members save the work and share in the returns from agricultural production. It should therefore be feasible to mitigate potential negative distributional impacts within the commune. Decisions concerning mechanization can therefore be based primarily on payoff or profitability criteria. The complimentarity between animal and mechanical power in Chinese agricultures found by Ramaswamy (1981), could be explained in this context.

Interregional equity issues are a more complicated matter, however. As long as migration is restricted, labor cannot be redeployed from slow growing regions towards rapidly growing ones. The rapidly growing regions may therefore experience

increased labor demand and find it necessary and profitable to mechanize. The alternative of migration to solve the regional labor scarcities may, however, be a better one than mechanization. Migrants from poorer regions could participate in the growth benefits of the richer ones and scarce capital could be used for alternative investments rather than machines.24/

FOOTNOTES

1/ Induced innovation processes can also be documented in the developing world. Mechanization in central Thailand, one of the most successful cases, appears to have been clearly induced by increasing scarcity of labor. The Thai case has been discussed in detail in World Bank, 1982.

2/ For evidence that tractors have no direct yield effect in South Asia see Binswanger, 1978.

3/ Generalization (2) is often obscured: We may compare different techniques for doing a certain operation across different farming systems in which yields differ widely. For example, hoe cultivation may be observed in an extensively farmed area of Africa where yields are low, while yields in an intensively farmed tractorized region of India may be much higher. The yield differences may partly be caused by differences in other inputs such as fertilizers or improved seeds. But they could also be caused by better soil tillage in the Indian environment. This does not, however, mean that the Indian level of tillage could not be achieved by hand. Examples from Java show that hand cultivation can be as thorough as ox or tractor cultivation. Instead the lower tillage intensity in Africa is a secondary effect which may simply reflect the abundance of land: in order to maximize labor productivity, the available labor is thinly spread over a large area of land.

In order to reject generalization one, an investigator has to show that a given operation, at a given level of quality or intensity, has not, or cannot, be performed by different techniques. The world inventory of technique is very large indeed, and few cases exist where over the course of history the same operation has not been performed equally well by different techniques and/or by different power sources.

Generalization 1 is also obscured in the shift from animals to other sources of power such as tractor or stationary engines. In this case, since the number of animal drivers is usually reduced, higher levels of mechanization substitute both for labor and animals.

4/ Final demand is said to be elastic or inelastic according to whether an increase in quantity supplied leads to a small drop (elastic) or a large drop (inelastic) in the price received.

5/ For a discussion and estimates of temporary migration for harvest work see Laxminarayan et.al.

6/ For a thorough discussion of this issue, see Binswanger and Rosenzweig. That discussion distinguishes carefully between the effects of operational holding size and ownership holding size on costs of capital and labor. Here we assume that the two are closely related.

7/ For careful investigation of the impact of scale on machinery adoption in 19th century U.S. and Britain, see David.

8/ This is so despite the fact that the growth of tractor sizes and harvesting machines in the U.S. may often attract more attention. The U.S. growth in machine sizes, however, occurred in response to rapid farm size growth and the widening of operations performed by tractors, and, as we have seen, was an indirect response to the unprecedented wage rate rises of the past 40 years.

9/ The development of contract hire systems for combines in the U.S. is an interesting example of how problems of synchronic timing can be overcome. Even many large midwestern farmers nowadays rent the services of combines rather than owning them. The contractors achieve higher machinery utilization rates by migrating annually following the harvest from the Texas-Oklahoma area up to northern states where harvesting takes place months later.

10/ There is no question that mechanization relieves drudgery, and such relief of drudgery is an important side benefit when mechanization occurs in response to labor scarcity. However, when subsidies lead to mechanization those who loose their work can only find inferior work options, which may involve more drudgery, or they may become unemployed.

11/ Detailed census-type machine inventories are available only for a few countries and that too for recent periods only. Where census type data is not available, machinery sales data can be used as a substitute to some extent. Where even sales data are not available, judgements on relative importance of different machines must be based on scattered reports. Such reports often emphasize the first dates of appearance of a machine on a few large farms and thus may exaggerate the prevalence of new machines. Furthermore, innovation may precede widespread use by decades. Reports which emphasize innovation are therefore not reliable in terms of timing of adoption.

Comparing machine numbers across countries can also be hazardous. Different countries have used widely different sizes and types of machinery. Stationary Japanese rice threshers tend to be small machines while their U.S. counterparts were very large, moving from farm to farm for custom hire work. The data presented in the tables is therefore most useful for judging relative importance of different machines within a given country at a particular time.

12/ The data shown in Table 13 concentrate on power driven machines. Improved pedal threshers, and hand powered, animal powered, or stream powered mortars and mills had appeared between 1880 and 1920.

13/ The highest level of mechanization consists of self-propelled harvesting platforms. Several workers stand on these platforms, pick the apples and place them on slow moving conveyor belts which deposit the apples gently into a crate.

14/ Oxen could not successfully be used because sufficient power could only be generated at the higher speeds of horses. The demise of the oxen in U.S. and European agriculture is largely the result of this inability to use them with harvesting machines.

15/ Wages are so low in South Asia that, except for tea plantations, it is still cheaper to handweed than use herbicides (Binswanger and Shetty, 1977).

16/ Switzerland, for example, had at least five producers of tractors in 1950. None of them survives to date.

17/ For a thorough discussion of this issue see Herdt.

18/ We do not include here general policies which have side effects on mechanization such as agricultural price policy. Such policies affect all agricultural investments, not just mechanization.

19/ Unlike the case of agricultural research it is difficult to make a case on welfare economic grounds for additional intervention than the ones just listed.

20/ A good case in the developed world is the invention of the tomato harvester in California. For a recent summary of the controversy see de Janvy et.al.

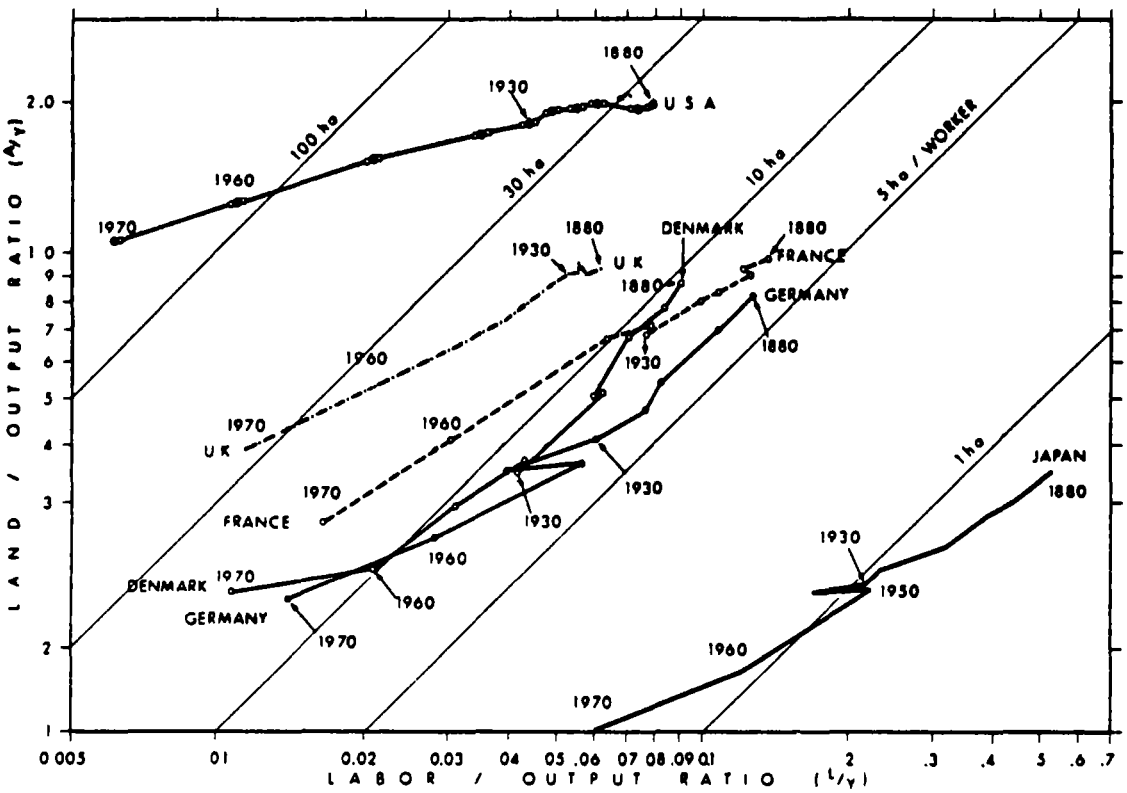
21/ These brand choices had usually been made under donor pressure rather than as conscious economic choices. Brands from different countries were added whenever the respective governments donated or helped finance tractors. Several were later dropped when aid flows stopped (Lockwood, 1981).

22/ In Pakistan farm size growth was extremely rapid and was accomplished by a combination of tenant eviction, purchases, additional renting of land and a modest amount of reclamation.

23/ It must be recognized, however, that wages might often have been rising faster in the absence of mechanization.

24/ Current Chinese policy emphasizes "sideline activities," i.e. the redistribution of industrial and tertiary activity to rural areas to overcome interregional income distribution problems. While such decentralization is certainly desirable and necessary, many regions face locational and agroclimatological disadvantages which put severe limitations on how much can be achieved.

Figure 1: INPUT-OUTPUT RATIOS FOR SIX COUNTRIES 1880-1970
(In logs; Diagonals are land-labor ratios).

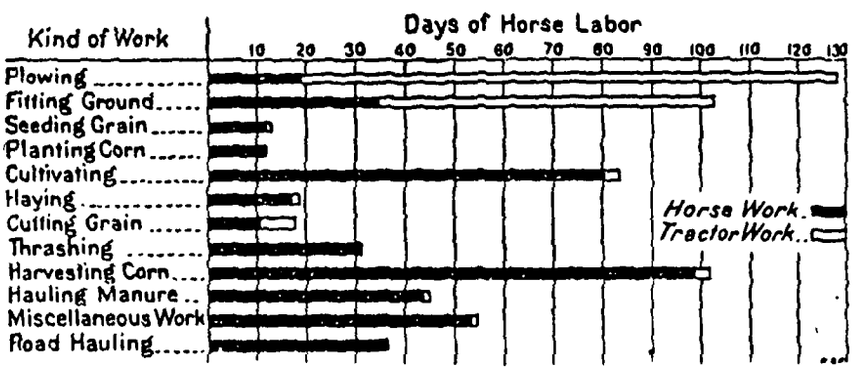


Source: Binswanger, H.P. and V.W. Ruttan (1978) p. 55.

Figure 2: DIRECT AND INDIRECT EFFECTS OF AGRICULTURAL MECHANIZATION

Forces leading to mechanization	Immediate consequence of mechanization	Indirect effect on agricultural output	Indirect effect on agricultural employment	Examples
(1) Land available	Labor used on larger areas, production costs drop	Expands, the more so the more elastic final demand	Expands if demand elastic; stagnates or falls if demand inelastic	19th century U.S.
(2) Rising wages (in response to nonagricultural labor demand)	Production costs rise less than in absence of mechanization	Falls (or grows slower) but by less than in absence of mechanization	Falls	U.S. after 1940 Japan, Europe after 1955
(3) Unmechanized technique unprofitable	A new method of production becomes profitable	Expands, the more so the more elastic final demand	Expands, the more so the more elastic final demand	Pumping in contemporary Asia
(4) Subsidies on capital and/or energy	Production costs may drop modestly or stay constant	Small expansion at best	Falls, sometimes sharply	Contemporary Baizil, Pakistan, China, etc.

Figure 3: PROPORTION OF DIFFERENT KINDS OF WORK DONE WITH HORSES AND TRACTORS IN U.S. IN EARLY STAGES OF MECHANIZATION



Source: Reynoldson, L.A. and H.R. Tolley (1923) p. 4.

Table 1: AGRICULTURAL GROWTH AND FACTOR ENDOWMENTS IN DEVELOPED COUNTRIES

		Japan	Germany	Denmark	France	United Kingdom	United States
Agricultural output Index	1880	100	100	100	100	100	100
	1970	428	412	459	334	236	403
	Growth Rate	(1.63)	(1.59)	(1.71)	(1.35)	(0.96)	(1.56)
Agricultural output per male worker (in wheat units)	1880	1.89	7.9	10.6	7.4	16.2	13.0
	1970	15.77	65.4	94.4	59.9	87.6	157.4
	Growth Rate	(2.39)	(2.37)	(2.46)	(2.35)	(1.89)	(2.81)
Agricultural output per ha of arable land, in wheat units	1880	2.86	1.25	1.19	1.06	1.10	0.513
	1970	10.03	5.40	5.27	3.70	2.61	.981
	Growth Rate	(1.40)	(1.64)	(1.67)	(1.40)	(0.96)	(0.72)
Agricultural land per male worker, in ha	1880	.659	6.34	8.91	6.96	14.7	25.4
	1970	1.573	12.20	17.92	16.19	33.5	160.5
	Growth Rate	(0.97)	(0.73)	(0.78)	(0.94)	(0.92)	(2.07)
Days of labor to buy one ha of arable land	1880	1874	967	382	780	995	181
	1970	1315	244	177	212	203	108

Source: Binswanger, H.P. and Ruttan, V.W., (1978) Tables 3-1 and 3-2.

Table 2: THE GROWTH OF AGRICULTURAL LAND, LABOR AND FARM SIZE IN THE U.S.

Year	Number of farms	Area under farms	Average Farm size	Total Farm Employment	Total Labor Force	Agr. Empl. as percent of labor force
	'000	mill. acres	acres	million	million	
1870	2660	408	153			
1880	4009	536	134			
1890	4565	623	137			
1900	5737	839	146			
1910	6406	879	137	13.6	38.2	35.6
1920	6518	956	147	13.4	41.6	32.2
1930	6546	987	151	12.5	48.8	25.6
1940	6350	1061	167	11.0	53.0	20.8
1950	5648	1202	213	9.9	59.6	16.6
1960	3956	1178	298	7.1	69.9	10.2
1960 a/	3963	1176	297			
1970	2949	1102	374	4.5	82.1	5.5
1975	2767	1081	391	4.3	94.8	4.5
1978	2672	1072	401	3.9	102.5	3.8

a/ After 1960, number of farms and area under farms is based upon 1969 definitions.

Source: Number of farms, Area under farms: 1870-1960, USDA, A Century of Agriculture in Charts and Tables, 1960-1978, U.S. Dept. of Commerce, Statistical Abstract of U.S. 1980.

Farm Employment, Labor Force: 1910-1970: U.S. Bureau of Census, Historical Statistics of U.S. from Colonial Times to 1970. 1975-1978: U.S. Dept. Commerce, Statistical Abstract of U.S. 1981.

Table 3: SOURCES OF FARM POWER IN UNITED STATES
in thousands

Year	No. of Farms	Workstock above 2 years			Windmills	Steam Engines	Gas Engines	Tractors (exclusive of Steam and Garden)		Trucks
		Oxen	Mules	Horses				Number	Horse Power in millions	
1870	2660	1319	1125	7145						
1880	4009	994	1813	10357	200	24				
1890	4565	1117	2252	15266	400	40				
1900	5737	960	2753	15506	600	70	200			
1910	6406	640	3787	17430	900	72	600	10	0.5	0
1920	6518	370	4652	17221	1000	70	1000	246	5	139
1930	6546		17612 f/		1000	25	1131	920	22	900
1940	6350		13029					1567	62 b/	1047
1945	5967		11116					2354	88 c/	1490
1950	5648		7415					3394	93	2207
1955	4654		4101					4345	126	2675
1959	4105									
1960	3963 d/		2883					4685	153	2826
1965	3356		~					4787	176	3030
1970	2949							4619	203	2984
1975	2767							4469	222	3032
1979	2672 e/							4350 a/	243	3045

a/ Tractors over 40 h.p. only.

b/ Average horsepower for 1930-34 multiplied by number of tractors in 1930.

c/ Average horsepower for 1940-44 multiplied by number of tractors in 1940.

d/ After 1960 corresponds to 1969 definition

e/ Figure corresponds to 1978.

f/ From 1930 onwards refers to total workstock on farm.

~ discontinued.

Blanks indicate non availability.

Sources: 1. Number of Farms: upto 1959, USDA, Century of Agriculture in Charts and Tables.
1960-1979: U.S. Dept. of Commerce Statistical Abstract of United States, 1980.

2. Oxen, Mules, Horses, Windmills, Gas Engines and Steam engines (1850-1930) Hurst, W.M. and Church, L.M. - Power and Machinery in Agriculture, (1933) Table 8, p. 12.
1930-1979: U.S. Dept. of Commerce, Historical Statistics of U.S. from Colonial Times to 1970, (1975).

3. Tractors, Horsepower, Trucks: 1970-1930, Hurst, W.M. and Church, L.M. (1933) Table 8, p. 12.
1940-1959. U.S. Dept. of Agriculture, Changes in Farm Production and Efficiency, 1964 and 1973.
1960-1979: U.S. Dept. of Commerce, Statistical Abstract of the United States 1980.

Table 4: PRODUCTION/OR SALES OF HORSE DRAWN AND TRACTOR DRAWN MACHINES IN U.S.
in thousands

Year 1/	No. of Farms	Plows (m.b. + disc) Horse	Plows (m.b. + disc) Tractor	Harrows (all types)	Cultivators	Seed Drills Horse	Seed Drills Tractor	Corn Surface Planters Only Hand & Horse	Self Rake Reapers	Grain Binders	Threshers Horse (Small)	Threshers Steam (Large)	Combines	Hay Making Mowers	Hay Making Horse Rakes	Hay Making Loaders	Hay Making Stackers
1870	2660	865		9	89			22	60		23				81		
1880	4009	1326		128	318			69	35		10				96	9	
1890	4565	1249		269	445			132	9		11				115	3	
1899	5737 a/	1075		478	505			208	36		1.3	3.6			216	7	
1899 2/		973		478	296	92		208	36	233	1.3	3.7		399	216	7	12
1909	6406 b/	1358		701	435	68		219	58	179	2.2	8.0	0.5	359	266	35	17
1920	6518	714	145	604	579	107	3	132	2	100	16.5	4.2	2.7	173	118	32	10
1929	6512	324	117	540	398	36	16	93		65	9.6	1.3	19.6	115	91	26	6
1938	6527	137	124	351	214		28	57		31	2.7	3.6	41.5	76	54	19	1

a/ Figure corresponds to 1900.

b/ Figure corresponds to 1910.

1/ Figures for years previous to 1920 represent numbers manufactured. The earliest sales figure available are for 1920.

2/ Data comes from a different source for the second half of table.

Blank spaces indicate non availability.

Source: For the first half of the table 1870-1899: U.S. Census.

For the second half 1899-1938: McKibben, F.G., Hopkins, I.A. and Austin Griffin R., Changes in farm Power and Equipment Field Implements (1939).

Table 5: PATTERN OF MODERN LABOR SAVING MACHINES IN UNITED STATES
in thousands

Year	Number of Farms	Combines 1/	Corn Pickers and Picker Shellers	Pick-up Balers	Field Forage Harv.	Farms with Milking machines
1910	6406	1				12
1920	6518	4	10			55
1930	6546	61	50			100
1940	6350	190	110	25 b/		175
1945	5967	375	168	42	20	365
1950	5648	714	456	196	81	636
1955	4654	980	688	448	202	712
1960	3963 a/	1040	795	680	290	666
1965	3356	910	690	751	316	500
1970	2949	790	635	708	304	
1975	2767	524	615	667	255	
1978	2672	538	602	610	272	

a/ From 1960 onwards is based upon 1969 definition.

b/ Figure corresponds to 1942.

1/ From 1975 onwards self-propelled combines only

Blanks indicate non availability.

Sources: Number of farms see Table 3.
All others: 1910-1965: USDA, Changes in Farm Production and Efficiency, 1964 and 1973.
1970-1978: USDA, Agricultural Statistics, 1979.

Table 6: PRODUCTIVITY INDICATORS
SELECTED CROPS: LABOR-HOURS PER UNIT OF PRODUCTION AND RELATED FACTORS, UNITED STATES, INDICATED PERIODS, 1915-78 1/

Crop and item	1915-19	1925-29	1935-39	1945-49	1955-59	1965-69	1974-78 2/
Corn for grain:							
Hours per acre	34.2	30.3	28.1	19.2	9.9	5.8	3.7
Yield-bushels	25.9	26.3	26.1	36.1	48.7	78.5	87.8
Sorghum grain:							
Hours per acre		17.5	13.1	8.8	5.9	4.2	3.9
Yield-bushels		16.8	12.8	17.8	29.2	52.9	50.8
Wheat:							
Hours per acre	13.6	10.5	8.8	5.7	3.8	2.9	2.9
Yield-bushels	13.9	14.1	13.2	16.9	22.3	27.5	30.0
Hay:							
Hours per acre	13.0	12.0	11.3	8.4	6.0	3.8	3.5
Yield-ton	1.25	1.22	1.24	1.35	1.61	1.97	2.15
Potatoes:							
Hours per acre	73.8	73.1	69.7	68.5	53.1	45.1	38.3
Yield-cwt	56.9	68.4	70.3	117.8	178.1	212.8	257.0
Sugarbeets:							
Hours per acre	125	109	98	85	51	33	26
Yield-ton	9.6	10.9	11.6	13.6	17.4	17.5	19.7
Cotton:							
Hours per acre	105	96	90	83	66	30	10
Yield-pounds	168	171	226	273	428	484	462
Tobacco:							
Hours per acre 3/	353	370	415	460	475	427	250
Yield-pounds	803	772	886	1,176	1,541	1,960	2,049
Soybeans:							
Hours per acre	19.9	15.9	11.8	8.0	5.2	4.8	3.7
Yield-bushels	13.9	12.6	18.5	19.6	22.7	25.8	27.8

1/ Labor-hours per acre harvested, including preharvest work on area abandoned, grazed, and turned under.
2/ Preliminary.
3/ Per acre planted and harvested.

Source: Economics, Statistics and Cooperatives Service-Economics.

LIVESTOCK: LABOR-HOURS PER UNIT OF PRODUCTION AND RELATED FACTORS, UNITED STATES, INDICATED PERIODS, 1915-78

Kind of livestock and item	1915-19	1925-29	1935-39	1945-49	1955-59	1965-69	1974-78
Milk cows:							
Hours per cow	141	145	148	129	109	78	48
Milk per cow (pounds)	3,790	4,437	4,401	4,992	6,307	8,820	10,783
Cattle other than milk cows:							
Hours per cwt. of beef produced 2/ 3/	4.5	4.3	4.2	4.0	3.2	2.1	1.4
Hogs:							
Hours per cwt. produced 3/	3.6	3.3	3.2	3.0	2.4	1.4	.6
Chicken (laying flocks and eggs):							
Hours per 100 layers		218	221	240	175	97	61
Rate of lay		117	129	161	200	219	234
Chicken (farm raised):							
Hours per 100 birds	33	32	30	29	23	14	12
Hours per cwt produced 3/	9.4	9.4	9.0	7.7	6.7	3.7	3.0
Chicken (broilers):							
Hours per 100 birds			25	16	4	2	.6
Hours per cwt produced 3/			8.5	5.1	1.3	.5	.2
Turkeys:							
Hours per cwt produced 3/	31.1	28.5	23.7	13.1	4.4	1.3	.6

1/ Preliminary

2/ Production includes beef produced as a byproduct of the milk-cow enterprise.

3/ Live-weight production.

Source: Economics, Statistics and Cooperatives Service-Economics.

Table 7: MACHINERY IN USE DURING EARLY STAGES OF UNITED STATES TRACTOR MECHANIZATION:

A. Sample Farms in Eastern Dairy Region in Numbers

Year	M.B.		disk plows + disk harrows		Rollers		Grain drills		Row Crop cult. + weeders		Row and Grain Binders		Grain Combines		Mowers	
	H	T	H	T	H	T	H	T	H	T	H	T	H	T	H	T
1909	128	0	80	0	88	0	84	0	126	0	90	0	0	0	124	0
1919	274	21	167	19	180	2	189	0	275	0	201	7	0	0	272	0
1929	372	111	222	82	275	11	306	0	421	5	303	53	0	0	420	4
1936	361	148	218	117	278	18	317	0	434	7	293	68	0	0	429	9
									B. Sample Farms in Northern Grain Region in Numbers							
1909	105	0	76	0	3	0	111	0	68	0	111	0	11	0	79	0
1919	276	45	252	27	27	2	322	13	209	3	342	5	36	19	256	0
1929	270	166	223	171	38	11	331	155	267	48	387	49	70	125	361	4
1936	154	251	140	279	30	24	217	276	217	120	278	118	33	203	345	11
									C. All United States in Thousands							
1945	7240	1616	1318	1608			1221	421	6764a/	1171a/	1401	423		375	2424	395

a/ Row crop cultivators only.
Blanks indicate non availability.
H Horse drawn.
T Tractor drawn

Source: A and B - Computed from various tables in Mc Kibben, Eugene G., Hopkins, J.A. and Griffin, R., Austin (1939). The data relates to NRP Farm Survey of 4,300 farmers in 1936.
C - Commonwealth Economic Committee, Report No. 36, Table 54.

Table 8: TRACTOR UTILIZATION DURING EARLY U.S.MECHANIZATION IN AVERAGE HOURS/FARM

Year	Region	Land preparation Planting Cultivation	Threshing	Other belt work	Heading and Binding Grain	Combine Grain	Other Work	Total	Of which Total Custom work
1926	New York (50 General farms)	279.6	58.2	60.6	16.7		8.2	423.3	75.6
1926	New York (42 Dairy farms with cash crops)	181.9	5.1	62.7			32.3	282	39.1
1933	Northern Great Plains	304	22		20	48	10	404	7
1933	Pacific Northwest	444	1		1	139		585	25

Source: Computed from: for 1926; Gilbert, C.W. (1926), pp. 37-38.
for 1933; Washburn, R.S. and R.S. Kiefer (1936), pp. 14-16.

Table 9: SOURCES OF FARM POWER IN FRANCE
in thousands

Year	Animals on Farm				Water Wheels	Wind Mills	Steam Engines	Internal Comb. Engines	Electric motors	Tractors
	Horses	Mules	Work Oxen	Work Cows						
1852	2866	375					1.5			
1862	2914	331					3			
1872+										
1882	2838	251	1519		13	9	9			
1892	2795	218	1387		12	6	12			
1900+	2903	205								
1910+	3198	193								
1920+										
1929	2986	143	965		9	3	22	151	159	27
1937	2263	111								30
1941	1744	102	1038	1894 a/						36
1946	1823	96						262	432	60
1950	1865	91						343	534	137
1955	1755	82						373	685	305
1960	1411	67						384	922	680
1965	731	41	118							996
1970	382	32	40							1230
1977	182	15	9							1413

a/ From year 1942.

1/ After 1937 horses on farms older than 3 years only

\+ To be collected.

Blank spaces indicate non availability.

Source: Ministire de L Agriculture, Statistique Agricole (Retrospectifs 1930-1957), Paris, 1959.
Statistique Agricole Annuelle,
Annuaire Statistique Agricole de La France,
Statistique Agricole de La France.
Various issues of each.

Table 10: MACHINERY PATTERNS IN FRANCE
in thousands

Year	Plows		Cream Separators	Threshers	Root Cutters	Hay and Straw Presses	Pick up & Trucks	Sowing Machines	Fertilizer Distributors	Sprayers of Traction	Reaper/ Binders	Mowers	Motor Mowers	Combines	Hay Balers	Potato Diggers	Sugar Beet Diggers	Horse		Milking Machines
	Improved	Country																Rakes	Tedders	
1852		2578		60																
1862	794	2412		101	28			11			9	9							6	
1872 +																				
1882		3267		211				29				19							27	
1892		3669		234				52			23	39							51	
1900+																				
1929	1190 a/		666	204		10	74	322	119	142	420	1389				60	13	739	354	4
1937				152		9					341			0.3						
1941				141		9					481	1279		0.3				733	448	
1946	1325		626	206	1007	12		385	151	85	501	1373 b/				67	10	740		
1950	1385		686	218	1099	17		410	165	104	529	1470 b/		5		77	11	785		46 e/
1955	1427		696	215	1152	26		447	221	122	560	1547 b/		18	17	90	12	839		80
1960			672	191	1152	33		514	321	153	534		97	50	51	91	15 d/			124
1965				122						223	361		104	102	169	100	20			186
1970										304	133		105	133	292	92	25			283
1977										406			84	148 c/	445					392

a/ double sided plows only after 1929

b/ includes motor driven

c/ only self-propelled combines

d/ includes only diggers upto 1960 and only complete harvesters from 1965 onwards.

e/ Figure corresponds to 1951

f/ Reaper binders only after 1937.

\+ Data to be collected

Blank spaces indicate non availability

Source: Same as Table 9.

Table 11: SELECTED MACHINES ON GERMAN FARMS IN THE LATE 19TH AND EARLY 20TH CENTURY
in thousands

Year	Steam Plows	Steam Threshing Machines	Other Threshers	Sowing and Planting	Reaping Machines
1882	1	76	298	64	20
1895	2	259	597	170	35
1907	3	489	947	290	301

Source: Bogart, Ernest L. Economic History of Europe, (1942), p. 282.

Table 12: PATTERN OF FARM MECHANIZATION IN GREAT BRITAIN
in thousands

	Number of operational holdings	Horses for agri. use incl. breeding	Stat. Petrol and oil engines	Electric motors	Tractors	Trucks	Seed drills (corn)	Reaper Binders	Combines	Potato Spinners	Complete Potato Harvestors	Sugar Beet Harvestors	Milking Machinery Installations
1900	541 a/	1078											
1910	510	1137											
1920	494	927											
1930	481 a/	803											
1939	436	649		~	55		92	125	0	31			
1942	447	585	154		102	48	94	132	1	37			30
1946	437	519	179	54	180	58	99	149	4	59	0	0	48
1950	448	347	227	94	295	90	100	150	11	74	1	1	79
1956	437	124	224	184 a/	426	90	98	137	32	78 a/	1	5 a/	108 a/
1960/61	399	54	192	290	416	77	95 a/	144	54	71 a/	3	11 a/	121 a/
1965/66	367	21	146	350 a/	428 a/	114 a/	73 a/	60 b/	65	56	7	15	
1969/71	262	14	108	385	478	92	68		64	42	11	15	135
1976/77	232	5	149	~	480	102	48		56	35	12	10	131

a/ These data points are linearly intrapolated using nearest figures available within one or two years.

b/ The data for England and Wales is from 1965.

c/ The data for Scotland is from 1967

~ discontinued

Blanks indicate non availability.

Source: Upto 1966: Ministry of Agriculture, Fisheries and Food
A Century of Agricultural Statistics, Great Britain 1866-1966.
After 1966: Ministry of Agriculture, Fisheries and Food,
Agricultural Statistics of United Kingdom.
Agricultural Statistics England and Wales.
Agricultural Statistics Scotland.
various issues of each.

Table 13: PATTERN OF AGRICULTURAL MECHANIZATION IN JAPAN
in thousands

	No. of Farms	Draft and Beef Cattle	Horses	Motors	Pumps	Threshers	Rice Hullers	Power Sprayers Dusters	Cultivators	Power Tillers	Riding Tractors	Binders	Combines	Rice Transplanters
1880	5500	1152	1626											
1900	5502	1204	1542											
1910	5518	1259	1564											
1920	5564	1256	1468	2	2	0.5	0.6							
1931	5632	1361	1477	92	28	56	77	0.2						
1939	5492	1767	1168	293	83	211	132	5	3	3				
1945	5670	1827	1049	424	87	364	177	7	8	7				
1951	6145	~	1112	1295	92	1080	460	20	29	16				
1955	6027		888	2140	122	2060	700	87	82	82				
1960	5966		618	2799	288	2651	878	305	791	514				
1966	5665 a/		396 b/	3108 a/		3172	1008 a/	1126		2725	39	146 a/		
1971	5342 a/							2400		3201	267	582	84	46
1976	4835 a/							2898		3183	721	1498	428	1046
1979	4742							2618		3168	1096	1704	747	1601

a/ Figure corresponds to nearest adjacent year.

b/ Figure corresponds to 1963.

~ Continued as beef cattle.

Blanks indicate non availability.

Source: Okawa, K. et. al (1966).
Farm Machinery Statistic (1981).

Table 14: PATTERN OF FARM MECHANIZATION IN PHILIPPINES
in thousands

Year	Work animals (carabaos on farms)	Tractors	Plows	Harrows	Harv/Thresh	Sugarcane crushers	Manila Hemp Strippers	Power producing machines	Carts	Sleds	Motor vehicles	Sprayers	Incubators
1939	2526	.2	1357	912	.6		19		181	578			
1948	1965	1	1272	918			8		164	634			
1960	2828	8	1913	1315	7	2	6		452		10	49	6
1970	2731	11	1170	887	14	16 a/		5	262		14	79	

a/ Includes sheller's and shredders

Blanks indicate non-availability of data.

Source: National Census and Statistics Office, Philippines census of agriculture, various issues.

Table 15: OWNERSHIP AND USE OF FARM EQUIPMENT IN PHILIPPINES IN 1971

	Number of Farm Machines Owned by Farm Operator (in thousands)		Number of Farms using Machines		Ratio of renters to owners
	Number of farms reporting	Number of Machines owned	Owned fully or partly	Rented or provided by landlord	
Total number of farms in Philippines	2355				
Plows	1170	1511	1366	129	0.09
Harrows	887	1069	1031	94	0.09
Tractors	11	16	12	78	6.50
Stripping machines, Crushers, Shellers	16	19	18	85	4.72
Harvesters and Threshers	14	26	16	132	8.25
Power producing machine	5	7	6	3	2.00
Carts and wheel barrows	262	292	306	46	0.15
Motor vehicles	14	19	15	69	4.60
Sprayers	79	90	89	61	0.69

Source: National Census and Statistics Office, Philippines Census of Agriculture 1971.

Table 16: PATTERN OF FARM MECHANIZATION IN INDIA
in thousands

Year	Draft Animals	Persian wheel	Oil Pumps	Electric Pumps	Power Tillers	Tractors	Plows: Bullock: Wooden	Plows: Bullock: Iron	Plows: Tractor: m.b. + disc	Other tillage implements harrows, cultivators etc.: Bullock	Other tillage implements harrows, cultivators etc.: Tractor
1945	59333		12	9		5	27306	487			
1951	67383		83	26		9	31796	931			
1956	70690		123	47		21	36142	1376			
1961	77986	600	230	160		31	38372	2298			
1966	78517	680	471	415	17	54	39880	3521		2724	
1972	80137	638	1558	1618		148	39294	5359	57	17119	111

Year	Sugarcane Crushers: Power	Sugarcane Crushers: Bullock	Oil Extractors: Above 5 seer	Oil Extractors: less than 5 seer	Shellers: Indigenous	Shellers: Modern (Power)	Threshers: Indigenous	Threshers: Modern (Power)	Chaff Cutter: Rotary	Chaff Cutter: Power	Transport: Bullock Carts	Transport: Tractor Trailers	Seed drill/Planter: Bullock	Seed drill/Planter: Tractor	Sprayer/Duster
1945	9	481									8483				
1951	21	505	243	20							9862				
1956	23	545	66	212							10968				
1961	33	590	78	172							12072				
1966	45	650	74	159			249		4729		12695		1135		211
1972	87	678	40	76	175	16		207		161	12960	55	4047	34	413

a/ Figure corresponds to 1974.

Blanks indicate non availability.

Source: Directorate of Economics and Statistics, Agricultural Situation in India, June 1976, p. 141.
Central Statistical Organization, Statistical Abstract of India 1975, pp. 57-61.

Table 17: TRACTOR UTILIZATION IN SOUTH ASIA

Author Area	Range or average size of farm (ha)	Total hours used (1)	Uses by owners as percent of (1): Tillage (2)	Irrigation (3)	Treshing (4)	Sowing (5)	Transport (6)	Total agri. uses (7)	Non-agri. uses (8)	Hired out (9)
Government of Punjab (India)	7-10	682	35.9	19.9	11.6	1.5	3.4	72.7	19.8	7.5
	10-20	792	45.6	18.7	9.2	3.5	5.8	80.6	17.7	1.7
	> 20	1008	49.7	8.3	11.8	3.6	5.1	79.5	18.8	1.8
Kahlon, Punjab (India)	I 10.6	655						70.4	26.9	0.0
	II 9.5	707						90.9	9.0	0.1
	III 10.9	279						87.9	12.1	0.0
	IV 8.5	360						89.5	9.4	1.1
	V 15.5	550						63.4	33.5	3.1
Sharma, Haryana	6-10	(278)	68.6	0.0	12.0	1.0	6.2	87.8		12.2
	10-14	(407)	70.1	1.0	11.3	0.7	10.1	93.1		6.9
	14-20	(575)	68.5	6.9	7.9	0.5	9.8	93.4		6.6
	>720	(870)	73.7	3.9	11.5	1.5	8.0	98.6		1.4
McInerney & Donaldson, Punjab (Pakistan)	0-24	1019								23.6
	24-49	1273								24.7
	49-73	1325								8.9
	> 73	1523								0.4
Motilal, Delhi	0-6	375								9.1
	6-10	672								5.2
	> 10	1243								0.7
Desai & Gopinath, Gujarat — Dascroi, Anand	TO 9.6	655	28.6	0.0	2.7	0.0	18.6	49.8	5.8	44.3
Dascroi, Anand	TO 7.1	882	15.1	0.0	0.5	0.1	15.7	31.4	9.5	59.1
Dholka	TO 35.3	861	25.7	0.0	5.9	3.8	20.7	56.1	6.9	37.0
Dascroi, Anand	TH 4.6	(55)	76.0		12.7		11.3	100		n.appl.
	TH 3.4	(57)	59.7	0.0	40.3	0.0	0.0	100		n. appl
Sapre, Maharashtra	41.5	544	(51.6)	(25.2)	n.av.	n.av.	(17.1)	n.av.	n.av.	34.0
Narayana Chittoor, Andhra Pradesh	11.0	475	21.9	10.5	2.9	0.0	12.6	47.9	29.3	22.7

Source: Binswanger, H.P. (1978) p. 48-49.

Table 18: PATTERN OF FARM MECHANIZATION IN MEXICO
in thousands

Year	Number of holdings	Work animals	Engines (fixed & movbl)	Electric motors	Tractors	Plows		Harrows and Cultivators	Threshers (Fixed)	Shellers		Forage Choppers	Carts	Trucks	Seed drills	Mowers/ Reapers	Hay Balers	Combines
						Indigenous	Iron			Engine	Hand							
1930	858				4	904			4 a/				106	4	24	8		
1940	1234		9		5	925	720	102	2 a/	2	4	2	131	6	27	5	2	
1950	1383	3920	14		23	1135	1128	240	3 a/	3	5	3	175	18	60	8	3	
1960	1365	3476	18		55	1100	1286	308	5	5	9	6	211	40	93	10	5	4
1970	1020	4150	47	28	91	916	1301	387	3	13	18	6	161	104	122	12	12	7

a/ May include some combines

Blanks indicate non availability.

Source: Direccion General de Estadistica,
Censos Agricola Ganadero Y Ejidal, decennial.

Table 19: PATTERN OF FARM MECHANIZATION IN SENEGAL
in thousands

Year	Animals			Tractors	Plows	Hoes	Harvestors Threshers	Carts			Sowing machines	Groundnut lifters
	Horses	Asses	Work Oxen					Horse	Oxen	Ass		
1950					.1	.8			.3		11	
1955					.6	2			3		31	
1959	98	78	1 a/	.2	2	4	.1	1 a/	6	0	46	0
1965	160	147	1		7	36	.1	18	5	.3	94	6
1970	200	185	2	.5	8	102	.3	23	5	6	120	18
1975	210	196	8	.4	39	219	.1	38	14	14	189	42

a/ Figure corresponds to 1960.

Blanks indicate non availability.

Source: Tractors and Harvester/Threshers: FAO Production Yearbook, various issues.
Work Oxen: 1959-1965: World Bank, Senegal (1974).
Others: upto 1955, Marie-Saite, Y (1963).
1959 onwards: Ministere du Plan et de L industrie, Situation Economique du Senegal, various issues.

Table 20: PATTERNS OF MECHANIZATION IN THE PEOPLE'S REPUBLIC OF CHINA

	Four wheel Tractors (1)	Garden tractors (2)	Threshers (3)	Combines (4)	Farm trucks (5)
1957				2	4
1962	55			6	8
1965	73	4	110	7	11
1970	125	78	455	8	16
1975	345	599	1553	13	40
1979	667	1671	2328	23	97
1981	790	2030			

1980:	Tractor trailers	560
	Wheelbarrows with rubber tires	36000
1979:	Oxen	52411
	Cows used for draft	558
	Water buffaloes	18377
	Horses	11145
	Donkeys	7473
	Mules	4023
	Camels	604
Total draft animals (including young stock)		94591

Source: Agricultural Yearbook of 1980 and China Academy of Agricultural Engineering.

Table 21: GROWTH OF TRACTORS IN SELECTED COUNTRIES
(in thousands)

Year	Japan 2 wheel	Japan 4 wheel	Germany	Denmark	France	U.K. (G.B. + N. Ireland)	U.S.	Spain	Yugoslavia	Korea-Rep 2 wheel	Korea-Rep 4 wheel	India	Mexico	Philippines
1910							10							
1920						10	246							
1930					27	30	920						4	
1938/39	3		30	4	36	55	1545	3					5	.2
1945/47	8		69	4	77	244	2613	5				5		1
1950	16		140	17	137	325	3394	10	6			9	23	
1955	82		462	58	305	436	4345	25	10			21		
1960	514		857	111	680	456	4688	39	36	1		31	55	8
1965/66	2725	39	1164	161	996	482	4787	148	45	11		54		
1970	3201	267	1371	175	1230	514	4619	260	80	44	0	148	91	11
1975/76	3183	721	1425	185	1363	541	4469	379	226	60	1	228	102	
1979	3168	1096	1456	190	1430	508	4350	492	385			310	114	

Source: Japan; see Table 13

Germany, Denmark, Spain and Yugoslavia: 1939-1960; OECD, Development of Farm Motorization and Consumption and Prices of Motor Fuels in Member Countries, Paris, June 1962.
1965-1979; FAO, Production Yearbook, various issues.

France: see Table 9
U.K.: see Table 12
U.S.: see Table 3
Korea: FAO Production Yearbook, various issues. Garden Tractors are treated as 2 wheel tractors.
India: 1945-1970; see Table 16
1975-1979: FAO, Production Yearbook, various issues.
Mexico: 1930-1970; see Table 18
1975-1979; FAO Production Yearbook, various issues.
Philippines: see Table 14

Table 22

PATENTING IN PLANTERS AND DRILLS PATENT CLASS: SUB-CLASS, 111; 1 to 89

Time Period	New England	Middle Atlantic	Eastern Corn Belt	Western Corn Belt	Lake States	Appala-chia	South	Plains States	Mountain States	Pacific States	Foreign	Canad-ian
Pre-1830												
1830-39		5				6	1					
1840-49	14	31	7									
1850-59	20	103	98	66	25	9	3	8			1	1
1860-69	10	181 (1)	282	408	69 (3)	17	19	9		2 (1)		
1870-79	21 (1)	126 (3)	247 (15)	467 (19)	81 (10)	107	70	43	1	9 (1)	3	4
1880-89	31 (1)	101 (10)	263 (42)	631 (82)	102 (19)	125 (4)	160	207 (15)	14 (2)	27	7	7
1890-99	10 (1)	99 (8)	216 (58)	339 (69)	102 (12)	110 (13)	155 (1)	211 (26)	8	13	10	13 (3)
1900-09	4	46 (9)	149 (44)	393 (94)	131 (30)	94 (9)	135 (1)	149 (9)	15 (3)	15 (1)	18 (1)	12 (2)
1910-19	3	43 (7)	99 (28)	312 (75)	90 (29)	63 (6)	82 (4)	133 (7)	22	28 (6)	14 (1)	14 (1)
1920-29	4	14 (2)	37 (11)	81 (35)	23 (5)	28 (3)	18	43 (2)	9 (1)	17	13	6
1930-39	6	29 (9)	66 (29)	126 (57)	51 (23)	32 (10)	11	59 (11)	15 (2)	26 (5)	25 (2)	13 (6)

Table 23

CULTIVATORS, PATENT CLASS: SUB-CLASS, 172: 329-381

Time Period	New England	Middle Atlantic	Eastern Corn Belt	Western Corn Belt	Lake States	Appala-chia	South	Plains States	Mountain States	Pacific States	Foreign	Canad-ian
Pre-1830												
1830-39	4	2			1							
1840-49	4	9	1	1	1	1	1					
1850-59	7	10	8	10	2	3	14	1				
1860-69	26	67	120 (3)	376 (4)	38	21	28	11		1		
1870-79	17 (1)	66 (2)	119 (4)	255 (9)	51 (2)	39	56	29 (2)	1	7		2
1880-89	27	66 (2)	133 (21)	223 (50)	48 (3)	48 (2)	53	36 (1)	2	20 (1)	1	2
1890-99	11 (1)	48 (9)	67 (12)	138 (47)	43 (12)	37 (1)	63	70 (2)	7	5	4	2
1900-09	10	35 (2)	51 (12)	104 (27)	52 (8)	38 (1)	62	91 (3)	5	22 (2)	6	2
1910-19	6	29 (1)	43 (17)	88 (35)	23 (4)	35 (4)	76 (4)	52	7	22 (1)	14 (1)	3
1920-29	11 (3)	16 (3)	23 (11)	43 (20)	14 (3)	17 (2)	32	47 (1)	12	27	17	5 (1)
1930-39	6	15	5	6 (3)	12 (1)	10	20	14 (4)	7	17	8	1

Source: Evenson, 1982

Table 24

PLOWS, PATENT CLASS: SUB-CLASS, 172: 133-203

Time Period	New England	Middle Atlantic	Eastern Corn Belt	Western Corn Belt	Lake States	Appala-chia	South	Plains States	Mountain States	Pacific States	Foreign	Canad-ian
Pre-1830	7	61	7			11	5					
1830-39	9	60	15	1	1	18	3		1			
1840-49	7	45	20	7	2	11	5					
1850-59	11	65	30	32	8	30	46	2		1		
1860-69	43	177	153	294	51	68	76	10		62	8	3
1870-79	36	96 (1)	121	123	44 (3)	90	74	30		46	3	4
1880-89	20	58 (3)	80	94 (4)	39 (1)	37 (2)	58	85	4	13	2	3
1890-99	14 (1)	36 (8)	31 (2)	67 (8)	18	17	53	80 (1)	4	21 (1)	8	3
1900-09	5 (1)	26 (3)	38 (5)	74 (7)	24 (3)	22 (1)	71 (3)	84 (2)	15	33	11	4
1910-19	5	17 (3)	30 (7)	55 (16)	21 (2)	27 (2)	51 (1)	74	26 (1)	33 (3)	7	10
1920-29	2	5 (1)	21 (7)	34 (6)	20	22	29 (2)	47 (3)	22	26 (2)	8 (1)	5
1930-39	1	7 (5)	9 (4)	23 (10)	12 (3)	4	17	25	16	11 (1)	2	5 (1)

Source: Evenson, 1982

Appendix

GLOSSARY OF MACHINE NAMES

Abaca stripping machines:
Strips fiber from stem of Manila-hemp plant.

Choppers:
Hand, animal, or engine-powered stationary machines to chop green forage, beets or other crops into smaller pieces.

Combines:
Self-propelled machines which do reaping and threshing of grain crops in one single operation.

Cream separators:
Hand or engine-driven machines which separate cream from rest of milk using centrifugal action.

Cultivators, row crop cultivators:
Animal or tractor-drawn machines to cut weeds and loosen soil between rows.

Harrows:
Implements to further break up soil after plowing. Animal or tractor-drawn. Made of wood until 19th century. Spring-tooth and disk harrows are late 19th century inventions based on steel.

Liquid manure barrels:
Animal or tractor-pulled carts with large barrels for transporting and spreading liquid manure.

Liquid manure pumps:
Pumping systems to spread liquid manure on pastures and other fields. Piping systems sometimes permanently installed underground.

Maize shellers:
Hand, animal, or engine-powered stationary machines to separate maize from maize cob.

Mowers:
Machines similar to reapers but for mowing grass. Horse-drawn, tractor-mounted or self-propelled on a small two wheel tractor.

Persian wheels:
Animal-driven machines which lift water from wells using a suspended chain of buckets. Made of wood and clay pots or of iron and steel.

Pickup balers:
Tractor-drawn or self-propelled machines to make hay or straw bales.

Potato harvester:
Tractor-drawn or self-propelled. Does all harvesting operations, i.e., in addition to separating soil and potatoes they pick them up. Several attendants are usually required to ride on the machine to sort stones and soil clods from potatoes and to put potatoes in bags.

Potato spinners:
Horse or tractor-drawn. Machines which lift potatoes and soil up and spread them over an area two or three meters wide, thus separating potatoes from soil for easy pickup.

Pulley:
Power take-off point on early tractors for stationary machines using belts.

Reapers:
Machines for cutting grain and laying it into a well-formed swath. Horse-drawn or tractor-drawn.

Reaper-binders:
Machines which cut grains and bind them into bundles at the same time.

Rice hullers:
Another name for rice mills.

Rollers:
Animal or tractor-drawn implements to press soil, usually after seeding.

Sprayers and dusters:
Machines to spread pesticides and herbicides.

Sugarcane crushers:
Animal or engine-powered machines to press sugar juice out of sugarcane.

Steam plows:
Cart-mounted steam engine, sometimes self-propelled, which pulled large plows with several shares across the fields using a cable system. Popular only on large estates in England, Prussia and Egypt.

Tedders:
Horse or tractor-drawn implements to spread out swaths of grass and hay (or turn hay upside down) for drying.

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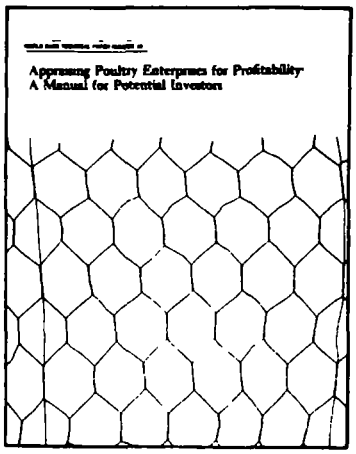

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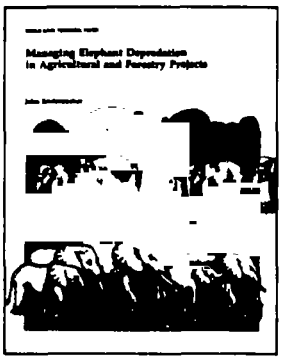

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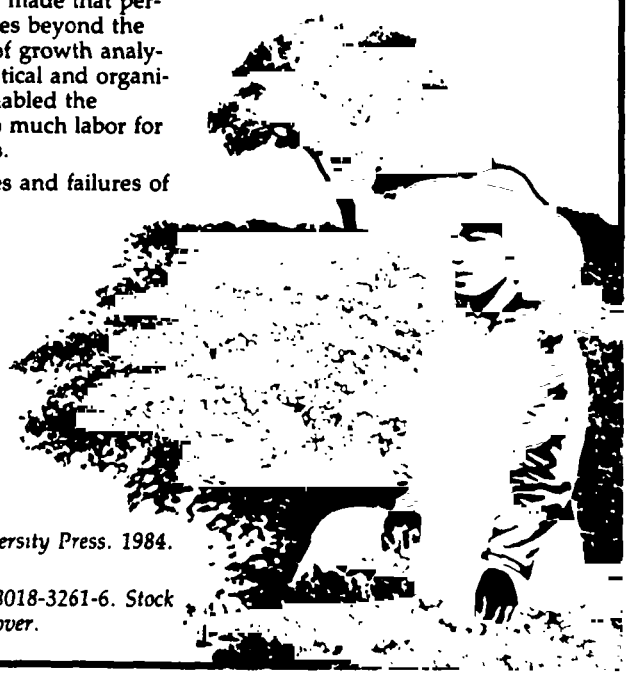

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