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Expected Developments of the Power-Labor Ratio in Agriculture through Intercountry Comparison*

by

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1. Introduction

There are many studies in different countries which explore the prerequisites and effects of agricultural mechanization. Only a few recently published studies will be mentioned here.

To begin with specific trends of future technological development of agricultural mechanization have been studied by agricultural engineers (12,15). At the same time economists have built models or analysed data to forecast agriculture's future power requirements (2,4,10). Other economists with national time series or survey data related the higher power utilization by agricultural workers to rising prices of labor relative to farm machinery or tractor horsepower (8,13).

Our approach has much in common with these studies. The focus is on the amount of power (= energy) used in agriculture, because power is the common denominator of production and mechanical processes in agriculture in different countries. The hyopthesis developed and tested is that the amount of power per agricultural worker used or the power-labor ratio depends on the degree of economic development.

Throughout this study agricultural mechanization will be conceptualized as tractorization and electrification. Each respectively represent the increasing mobile and stationary power basis which expands mechanical technologies in agriculture. This concept of mechanization is suggested by the availability of relatively compatible data[1]. It has some shortcomings because we are excluding the power of animate sources and in self-propelled combines, trucks, airplanes, wind- or watermills used in agricultural production processes. But even if we could include such data they would only stress the higher power availability for agricultural workers in industrially advanced countries. Developing countries as well as highly industrialized countries have tractors and are consuming electricity in agriculture, but in different proportions. This is certainly not the case with airplanes, to mention the extreme case.

The restriction of our power concept to tractor horsepower and electric power per agricultural worker or differences in the power-labor ratio enbbles us to study simultaneously different degrees of economic development.

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1. Lack of space prohibits discussion of the quality of data. Sources and methods of calculation are fully indicated in Appendix II.

2. The Unassisted Man in Food Gathering Systems

Man's ability to provide himself with dietary energy depends in primitive food gathering systems mainly on the locationally determined photosynthetic efficiency. A rain forest area needs less work inputs to guarantee man's survival than a seasonal pulse climate with long winters and irregular growing and ripening conditions (9, pp. 107). The relationship between the productivity of food gathering and the photosynthetic efficiency or the natural power[1] in producing edible organic matter can be expressed, as follows

$$(1) \quad \frac{DEF}{FGT} = f\left(\frac{NP}{Area}\right)$$

where DEF/FGT represents dietary energy of food per time unit of labor spent on food gathering activities and NP/Area stands for natural power, in some specific area..

In a strictly food gathering system man is/an integrated part of the surrounding ecological system. His own share in the total power budget of a location is too low to alter the composition of the naturally grown variety of plants and animals.

3. The Two Power Revolutions and the Increased Food Production from Agricultural Land.

A better understanding of the laws of nature enabled man to tap and to shape gradually nature's power sources to his own needs. He became a cultivator of land. But for a long time man was restricted to his low physical performance, which has been estimated to be 2,500 annual working hours. This is equivalent to 150 Kilowatt-hours (kWh) per worker and year. The first power and technological revolution started, therefore, when man was able to harnass the energy of draft animals. A single draft animal which works 800 hours per year increased his power availability by 600 kWh, a team of horses by 1200 kWh (3, p. 7).

Technological breakthroughs permitted a transformation of fossil fuels into combustion engines, electricity, and new industrial inputs (chemicals and machinery) for agriculture. Even in agriculture man's access to power increased tremendously. Some data for Germany (West) illustrate this process. In 1969 each male agricultural worker used from inanimate sources 8,670 kWh. Of this figure 43.4% was consumed as electricity. In total a worker's power increased fifty-eightfold as compared to the food gathering man.

In the rain forest area the food gathered by the unassisted primitive man was 0.4 kcal/m^2/year. In a "fuel subsidized industrial agriculture" the food output grew to 1,000 kcal/m^2/year in grain farming areas (9). With more power inputs from different sources, the food output is in some parts of the world even higher. The power derived directly and indirectly[2] from fuel enables the

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1. Under natural power we understand the current solar radiation and the environmental energy (water flow, wind and tidal energy). A scholarly treatment and a more expanded formula representing natural power (NP) can be found in (5, pp. 5).

2. The reader should be aware that we are excluding from our analysis the power use in industry for agricultural purposes. The power requirements to produce, to transport to distribute agricultural inputs and agricultural products from the farm to the consumer surpasses the power used by agriculture proper many times. Therefore, to make power equation complete, we had to insert additionally in the equation expressions of energy use for agricultural and non-agricultural purposes in the industrial, distributional and household systems.

farmer to select and to grow appropriate varieties of plants and animals. Compared to the natural vegetation the different farming systems are increasing the dietary energy in the form of more organic matter per unit of land.

4. Model

Two power forms must be distinguished. Natural power is independent of man, the other power inputs are under the control of man. In such a system the difference in labor productivity between countries depends on the power available. This might be expressed in a general power equation for labor productivity in agriculture, as follows

$$(2) \quad \frac{Y}{AW} = f\left(\frac{NP}{AW}; \frac{HP}{AW}, \frac{AP}{AW}, \frac{THP}{AW}, \frac{EP}{AW}\right)$$

where Y stands for food production, AW for agricultural worker, NP for natural power, AP for animal power, HP for human power, THP for tractor horsepower, and EP for electric power. We are assuming the existence of a production function of CES-type in the agricultural sector. This yields the relationship

$$(3) \quad \frac{Y}{AW} = f\ (WAW)$$

where WAW is the wage of an agricultural worker. Comparative studies demonstrate that agricultural labor productivity and the price of agricultural labor show a high correlation between countries (7, p. 13). If we now invert equation (3) we get an equation where WAW is a function of the labor productivity in the agricultural sector.

We substitute this function into aquation (2) and get the relationship

$$(4) \quad WAW = f\left(\frac{NP}{AW}; \frac{HP}{AW}, \frac{AP}{AW}, \frac{THP}{AW}, \frac{EP}{AW}\right)$$

At this stage of our research we have not enough information for the variable s NP, HP, AP. Unfortunately, THP is observable only as stock variable and EP as consumption flow[1]. Therefore, each variable has to be estimated separately. Thus we arrive at

$$(5) \quad WAW = f\left(\frac{THP}{AW}\right) \quad \text{and}$$

$$(6) \quad WAW = f\left(\frac{EP}{AW}\right)$$

Also for WAW we do not have any data available. Therefore, we have to search for a plausible explanation in terms of a measurable variable. Assuming that the agricultural wage rate is approximately proportional to the general wage rate we have

$$(7) \quad WAW = w_0 \cdot w$$

where w is the general wage rate and w_0 a factor of proportionality which in most countries will be less than one.

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1. To transform the stock variable THP to a flow variable we would need data on tractor use measured by tractor fuel consumption. Only a few countries are publishing such data.

Now we know from many studies that it is not unreasonable that the production function of the whole economy is of the CES-type. If, as most studies in the theory of growth assume, the working population is a constant fraction of the whole population, the CES-production function implies the relationship w

(8) $w = f\ (GNP/C)$

where GNP/C stands for Gross National Product per Capita. Inserting this equation (8) in equation (7) and finally (7) into (5) and (6) yields our final regression equations. Thus we have to estimate

(9) $THP/AW = f\ (GNP/C + u_t)$ and

(10) $EP/AW = f\ (GNP/C + u_t)$;

where the random variable u_t collects all factors determining the dependent variable except GNP/C.

Casual observations show (15, pp99, 16, p.160) that prices, e.g. in Latin America, for tractors and farm machinery are very often double the corresponding prices in the United Kingdom or the USA. The same can be observed for electricity prices. High income countries have for several decades accumulated scientific and engineering know-how in producing farm machinery. Additionally, they are capturing scale effects in producing huge amounts of farm machinery. It can be expected that in developing countries the prices of farm machinery relative to labor declines as GNP/C increases. Mass production of farm machinery will reduce the absolute real price of farm machinery.

5. Statistical Test of Tractor Horsepower

Regressions of THP/AW on GNP/C are presented for different countries in Table 1, Appendix I. The variable GNP/C explained only 50.5% for 17 countries of Latin America the variation in THP/AW. Cuba and Uruguay (1, p,38) had more and Venezuela[1] much less THP/AW than would be expected from GNP/C (see Graph 1). Dropping those countries brings the explanatory power of GNP/C in regression (2) to 76%. In terms of statistical criteria the estimations for Europe and the USA. improved in regression (3). For regression (5) we obtained a good fit when China, India and Japan were added to American and European countries. 96% of the differences in THP/AW could be explained by GNP/C. Predictions of the quantities of THP/AW with respect to GNP/C can be calculated from regression (5)

$$\log THP/AW = -5.8558 + \log \underset{(0.078)}{2.1422}\ GNP/C.$$

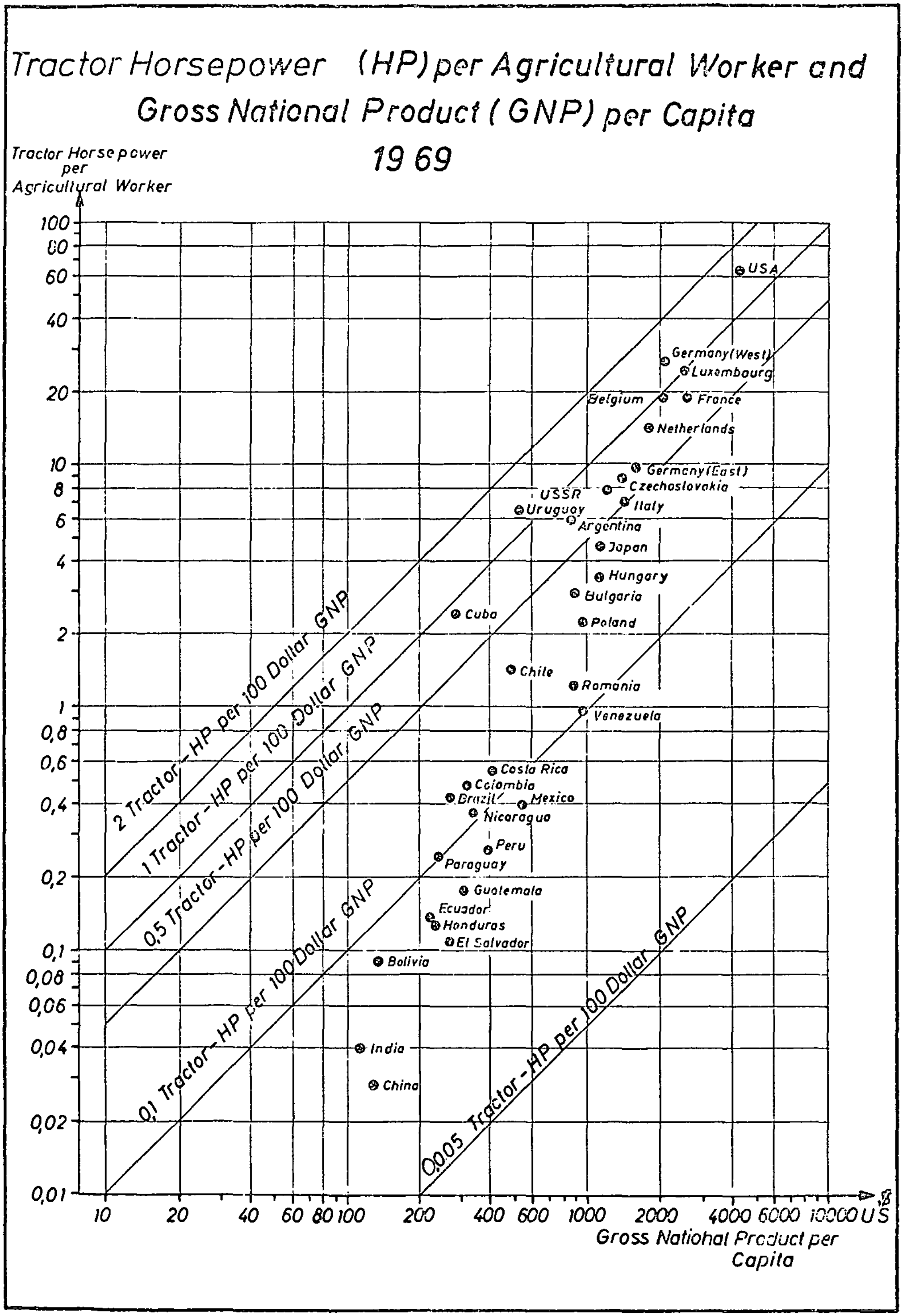
Parallel lines at an angle of 45^{o} in graph 1, each of which represents a constant amount of THP/AW per GNP/C (0.005, 0.1, 0.5, 1.2) help to quantify the different power levels. High income countries have normally 0.5 to 2 THP/AW per 100 Dollar/ GNP/C and low income countries are on the averege around the 0.1 THP-line.

- Graph 1 -

6 Policy implications

Forecasts of tractor power needs should be made on the basis of price retios and trade-offs between tractors and other power sources. If tractor production is determined to be desirable the size of the tractor producing firm should be considered. A modern four-wheel tractor plant needs a minimum output of 10,000 tractors per year (6, p.235).

(Note 1 appears at bottom of page 5)



Tractor Horsepower (HP) per Agricultural Worker and Gross National Product (GNP) per Capita
1969
Tractor Horsepower per Agricultural Worker
100
60
40
20
10
8
6
4
2
1
0,8
0,6
0,4
0,2
0,1
0,08
0,06
0,04
0,02
0,01
10
20
40
60
80
100
200
400
600
1000
2000
4000
6000
10000
US $
Gross National Product per Capita
2 Tractor-HP per 100 Dollar GNP
1 Tractor-HP per 100 Dollar GNP
0,5 Tractor-HP per 100 Dollar GNP
0,1 Tractor-HP per 100 Dollar GNP
0,005 Tractor-HP per 100 Dollar GNP
USA
Germany (West)
Luxembourg
Belgium
France
Netherlands
Germany (East)
Czechoslovakia
USSR
Uruguay
Italy
Argentina
Japan
Hungary
Bulgaria
Cuba
Poland
Chile
Romania
Venezuela
Costa Rica
Colombia
Brazil
Mexico
Nicaragua
Peru
Paraguay
Guatemala
Ecuador
Honduras
El Salvador
Bolivia
India
China

Plans to provide each worker with 5 (10) THP by a given minimum capacity of 10,000 tractors per year need at least 640,000 (320,000) agricultural workers under the assumption of a lifetime of 8 years and 40 HP per tractor. Many countries have a much smaller labor force. Foreign supply of tractors or the production of two-wheel tractors in such cases might be a more economic solution than the setting up of plants for the production of large tractors which produce more than a country can use.

There has been growing concern recently about the possible replacement and unemployment of workers by tractorization. It has been argued that countries could overstress the importance of promoting mechanization (1, p.12). Subsidies to tractor imports by applying special exchange rates would not reflect the real costs to the economy. Additionally, inflationary conditions reduced risks and costs of machinery, because credit is available for capital investments but not for labor. Private profits were assumed to be higher than social benefits if released workers could not find appropriate jobs.

To become a more efficient producer every agricultural worker doubtlessly needs more power. In the author's opinion the absolute increase in the utilization of tractor horsepower per agricultural worker will be less at lower levels of GNP/C than at higher levels. Conversely, the increase of tractor horsepower per agricultural worker in relative terms will be larger at lower levels of GNP/C compared to higher levels of GNP/C. This might be kept in mind if growth rates in tractor horsepower are compared between countries or farms.

There always will be some large farms in low-income countries which have different factor proportions when compared to the average farm. A recent study dealing with farming in Sri Lanka and India has convincingly shown that only large farms have the purchasing power to buy tractors (11, p.238). They had little effect on general employment. But for tractorization on a large scale the mass of farms must work under the condition of high prices of labor. Otherwise, the conditions are not favourable for rapid tractorization. Governments should, in any case, avoid long-lasting price distortions caused by designing and promoting a non-competitive tractor industry.

7 Statistical Test of Electricity Consumption

Studies dealing with agricultural mechanization sometimes neglect electricity as a power prerequisite for higher productivity in agriculture. This can bring some bias into the designing of an efficient mechanization policy. Studies in Indian agriculture demonstrated the labor-using effect of electrification in irrigated areas (11, p.327.) Multi-cropping became a more widespread practice and enlarged the resources available.

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1 (refer to page 4)

Further studies to explain the low THP/AW in Venezuela are needed. Discussing the paper, Professor Aziz, Kuala Lumpur, Malaysia proposed to consider deviations in tractor horsepower per agricultural worker additionally as a consequence of the type of land use and not only of differences of GNP/C. This seems to be a very useful distinction, because countries with a large proportion of plantations, pastures, and meadows doubtlessly need less work of tractors.

Farmers in high income countries derive their income mainly from livestock production. The rise in the price of labor induced the electrification on a large scale of such processes as lighting barns, drying grain and hay, preparing silage, feeding, milking, controlling climatic factors and removing manure.

Another important factor influencing electricity consumption is the average temperature in a country. Many European countries with short growing seasons have a high electricity consumption (EC) per agricultural worker when compared to Australia and New Zealand (see graph 2). They are forced to substitute the missing natural power of a permanent grazing season by high inputs of labor and electric power.

The previously described technique to show consumption levels with respect to income is used in graph 2. Broadly interpreted, with rising GNP/C there are increases in EC/AW. Data for EC could be gathered only for a few countries. It is, therefore, no surprise, that $\bar{R}^2$ in regressions (7) and (8) is relatively low.

Another reason for these weak results in our estimation might be that an economically based demand can only be satisfied by an electricity supply in each village. In India, e.g., only 10.6% of villages between 5,000 and 10,000 population with 32 millions of people were electrified (Appendix II, EPAFE, p119). Probably in other countries the situation will not be very different; electrification lags behind the economic needs of rural areas.

- Graph 2 -

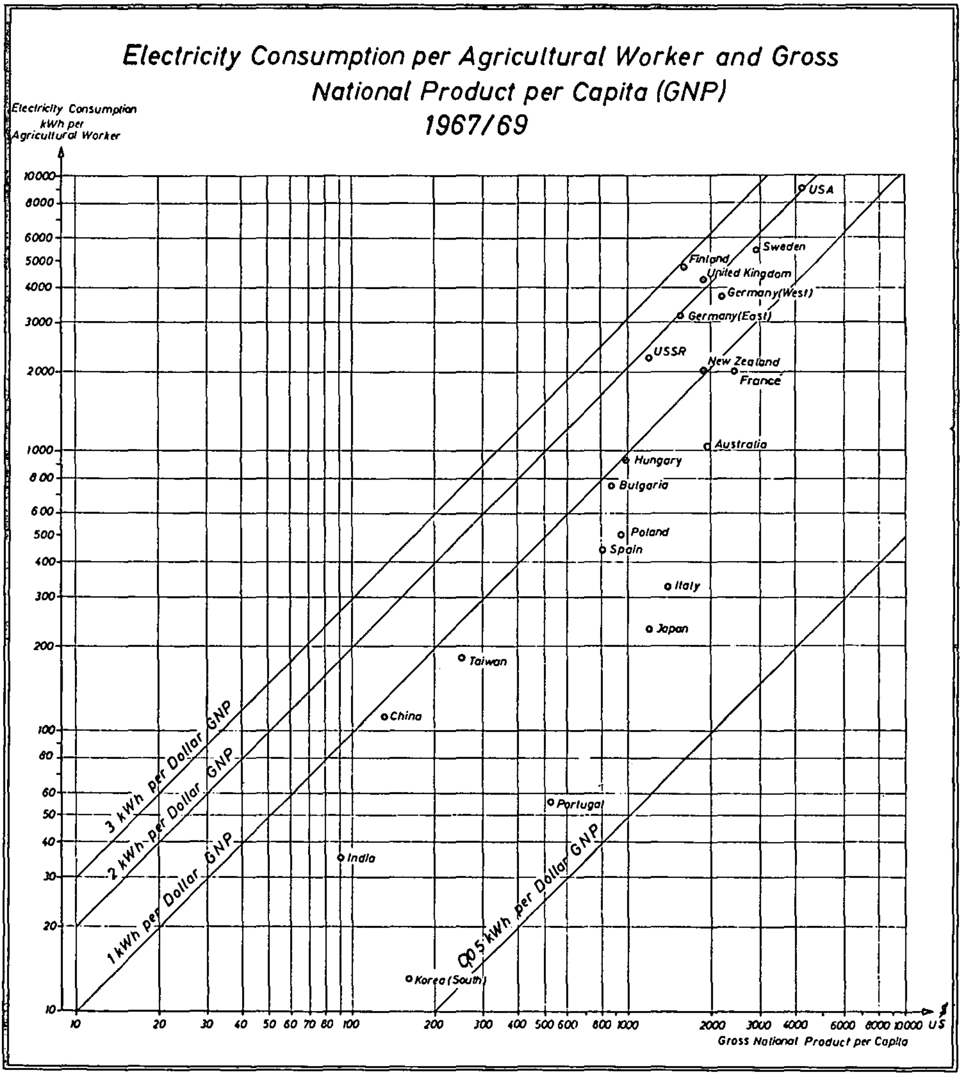
8 Mechanization in a Historical Perspective

The growth of agricultural mechanization for Germany is shown in table 2 for the period from 1925 to 1969. The use of tractors and electricity in 1925 was very low. Even in 1938 the level was not very different from those observed for China and India today. But Germany already hadin 1930 a relatively high per capita income. At that time it was around 740 US-dollars when measured in 1968 prices.

After World War II the process of mechanization accelerated. Interestingly, the growth rate of THP/AW was in the Fifties higher than for electricity. However, in the Sixties electrification took the lead when comparing growth rates. This was favoured by declining electricity prices. This process was accompanied by a fast growing industrial branch which sold electricity-using equipment to farms. There have been until now no economic studies known which make the attempt to identify the repercussions on industry and farms of this growth in electricity consumption.

9 Final remarks

The discussion in this paper was intended to shed some light on the change of the power-labor ratio through intercountry comparisons in the process of agricultural mechanization. The Gross National Product per Capita can be considered as a relatively reliable indicator to estimate the requirements of tractor horsepower per agricultural worker. Electricity consumption per agricultural worker probably depends upon many more factors (electricity distribution, irrigation possibilities, type of livestock production per agricultural worker, length of growing season, patterns of land use) than the price of labor measured as GNP/C. Further research is needed to identify more clearly the strength of these factors.


Electricity Consumption per Agricultural Worker and Gross National Product per Capita (GNP) 1967/69
Electricity Consumption kWh per Agricultural Worker
10000
8000
6000
5000
4000
3000
2000
1000
800
600
500
400
300
200
100
80
60
50
40
30
20
10
10
20
30
40
50
60
70
80
100
200
300
400
500
600
800
1000
2000
3000
4000
6000
8000
10000
US $
Gross National Product per Capita
3 kWh per Dollar GNP
2 kWh per Dollar GNP
1 kWh per Dollar GNP
0.5 kWh per Dollar GNP
USA
Sweden
Finland
United Kingdom
Germany (West)
Germany (East)
USSR
New Zealand
France
Australia
Hungary
Bulgaria
Poland
Spain
Italy
Japan
Taiwan
China
Portugal
India
Korea (South)

One result of this discussion might be the fact, that the quantity of mechanical technologies can be measured with the concept of tractorization and electrification, because power is the common denominator for using them. Strategies of agricultural mechanization are calling for an economic assessment on the price and productivity of current and future power sources.

The author hopes, finally, that despite the weaknesses of his presentation and deficiencies in data quality the contribution stimulates discussion and insight into the process of agricultural mechanization.

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Appendix 1
Table 1: Regressions of Power/Labor Ratio on Gross National Product per Capita (GNP/C) Regions and Selected Countries, 1969

Regression Number	Dependent Variable	Region/Country	Number of Countries or observations	Coefficient Of Explanatory Variable GNP/C	$\bar{R}^2$	$\bar{S}$	von Neumann Ratio	F	t
(1)	Tractor Horsepower per Agricultural Worker	Latin America (LA[a])	17	1.957 (0.500)	0.505	0.573	1.070**	15.325**	3.915**
(2)	Tractor Horsepower per Agricultural Worker	Latin America (LA_{wo}[b])	14	2.284 (0.367)	0.764	0.484	3.186**	38.76**	6.226**
(3)	Tractor Horsepower per Agricultural Worker	Europe[c], USA	14	2.227 (0.172)	0.933	0.463	1.884**	166.73**	12.913**
(4)	Tractor Horsepower per Agricultural Worker	Europe, LA_{wo}[b], USA	28	2.126 (0.091)	0.954	0.867	2.863**	542.66**	23.295**
(5)	Tractor Horsepower per Agricultural Worker	Asia[d], Europe[c], LA_{wo}[b], USA	31	2.142 (0.078)	0.963	0.933	2.811**	746.30**	27.318**
(6)	Tractor Horsepower per Agricultural Worker	Asia, Europe, LA[a], USA	34	1.771 (0.222)	0.665	0.898	1.160	63.412**	7.963**
(7)	Electricity (kWh) per Agricultural Worker	Selected Countries	21	1.358 (0.285)	0.544	0.844	3.082**	22.620**	4.756**
(8)	Electricity (kWh) per Agricultural Worker	Countries with more than 600 Dollars GNP per Capita	16	1.659 (0.450)	0.492	0.477	3.200**	13.574**	3.684**

a) LA= Latin America (Argentina, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Ecuador, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Paraguay, Peru, Uruguay, Venezuela). b) LA_{wo} = Latin America (without Cuba, Uruguay, Venezuela). c) Europe = Comecon-countries (Bulgaria, Czechoslovakia, Germany (East), Hungary, Poland, Romania, USSR) and Common Market-Countries (Belgium, France, Germany (West), Italy, Luxembourg, Netherlands). d) = Asia = China, India, Japan. Equations are linear in logarithms. Standard errors of the estimated coefficients are in parentheses. ** means for the von Neumann Ratio test there is no serial correlation at the 1% level and the F-value and the t-value is significant at the 1% level.

Source: Appendix II

Table 2 : Historical Growth Path of Agricultural Mechanization

Germany (West)

1925 to 1969

	Tractor Horsepower (THP)		Electricity Consumption (kWh)	
	per Agricultural Worker (AW)			
Period	THP/AW	%[a]	kWh/AW	%[a]
1925[b]	0.13		96	
1938[b]	0.29		208	
1925-1938		6.5		6.1
1951	1.52		325	
1959	7.78		795	
1951-1959		26.5		11.8
1960	10.60		1 042	
1969	27.86		3 653	
1960-1969		11.6		15.0

a) Annual compound rate. - b) Germany.

Source: Statistisches Jahrbuch des Deutschen Reichs and Statistisches Jahrbuch für Ernährung, Landwirtschaft und Forsten. Various issues.