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Economic growth: Lessons from two centuries of American agriculture

by

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Overview

The growth process spans over time, and studying it requires the analysis of time series data. The time-series variability in the determinants of growth, however, is often insufficient for sorting out the impact of the various effects. More variability in these variables exists between countries, and for this reason some of the empirical growth analysis is based on cross-country data. Each of these two possibilities has its advantages and limitations, and it is therefore natural to utilize both sources to compare the experience of a particular country with that of other countries.

The US is of a particular interest for a variety of reasons. From the vantage of economic development, and of historical perspective, it has made the transformation from an agricultural based economy to nonagricultural economy in relatively short time. "The first census of the United States found that 95 percent of the population was rural, and it was not until 1830 that the urban population exceeded 10 percent of the total." (Johnson 1997, p.3). With US agriculture accounting currently for about 2 percent of the labor force, the US accounts for about 14 percent of world agricultural production, it has been a major player in international agricultural markets, it has had elaborate agricultural programs, and has maintained high level of productivity in agriculture and in the economy. In addition, it had been written on extensively, and above all, it has data covering a the complete period of the transformation, which is essential for the task.

To capture the picture of the main forces at work, we can organize the discussion of the experience of US agriculture around four periods: 1800-1840, 1840-1900, 1900-1940, and 1940 to date. For some purposes these periods can be subdivided, where 1880, 1920, and 1980 serve as useful reference years. The nineteenth century was a decade of high growth rate in the economy and in agriculture; the growth rate of agricultural output exceeded that of the twentieth century, but was lower than that of nonagriculture. Initially, the growth in agriculture was largely resource based, where land, capital, and labor grew at similar rates, but around the middle

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[1] I would like to thank Bruce Gardner and Alan Olmstead for comments on an earlier draft.

of the century growth rate of labor began to lag behind. The gradual mechanization in agriculture increased average labor productivity, and served as the main source of productivity growth. This pattern continued into the twentieth century, but with a changing pace. Labor growth continued to decline and early in the century the total agricultural labor started to decline. From the late 1930s, the implementation of biological and chemical intensive practices, or techniques, was intensified and yields started to increase substantially.

When we talk about agriculture as a sector we implicitly deal with a dual, or a two-sector, economy. For some reasons, one gets the impression that discussions of the dual economy are associated mainly with countries where agriculture, or the rural sector, is still dominating. Such an association is unjustified because if the model is geared to deal with sectors of unequal relative size, its pertinence should not depend on which sector is dominating. The power of the model is rooted in the decisions made on the margins, and those determine the trade between the sectors in resources and in products. It is the exchange and the behavior of the product and factor markets which are crucial for the development process. Those, naturally, change across countries and over time, and it is this variability that makes the analysis interesting and useful. What varies across samples is the economic environment which consists of all the elements that determine the economic decisions. To extend this line of thinking, the same applies to the implementation of technology. To sum up, the study of development covers the dynamics of resource allocation and technical change, and these elements play a center role in this paper. The paper is based largely on discussions and evidence reported in the literature that help us to identify and interpret the processes associated with agricultural growth, along the lines spelled out in Mundlak (2000).

To place the US development in global perspective, we are restricted with data availability, and there is a tradeoff between the number of countries and the period of analysis. Our discussion relies on the database used by Mundlak, Larson, Crego, and Butzer in the references that appear below, and this consists of mostly data for the years 1967-1992. The comparison is, therefore, related to the more active period of US agriculture in terms of land productivity. This period is most pertinent for near future development of world agriculture. To facilitate the comparison, we mark the US in the presentation of the country distributions.

For the experience of the US agriculture in the whole stretch of the twentieth century, we rely on the recent book by Bruce Gardner (Gardner, 2002). The evidence on the experience in the nineteenth century is more eclectic. Because the data for that century is sparse and of lower quality, we deal separately with the two centuries.

We begin with an overview the developments and a summary of the evidence used in the discussion. It should come as no surprise that technical change has been the main force that moved agriculture, in the US and elsewhere. In spite of its importance, there is no consensus on its nature and impact. We therefore devote much of the paper to gain an insight into the role played by technology. The growth in productivity is discussed within the framework of heterogeneous technology. This framework links productivity changes to resource flow. Available data and studies make it possible to discuss the problems encountered in inferring on the form of technical change from production data. Specifically, it leads us to question the validity of the familiar paradigm of induced innovation, and its relevance to the explanation of agricultural development.

The paper is bifocal in its coverage, and in addition to the general issues related to dynamic aspects of resource allocation, productivity, and growth, it covers the dynamic aspects of agricultural growth and their implications. The general picture, common to the US and to trends in world agriculture, is that over the last century world agricultural production grew faster than demand. As a result, real world prices of agricultural products declined roughly by a factor of 2. The output growth was triggered largely by new technology, which in part was labor saving. This, together with the development of nonagriculture, resulted in off-farm occupational migration of labor. The decline in food prices improved consumers' welfare, and the labor mobility to nonagriculture contributed to overall economic development. The off-farm migration was a major factor in the alleviation of rural poverty. The pace of change varied considerably across countries, and it is for this reason that the country experience is of interest. The paper is concluded with a summary of the welfare implications of the agricultural growth, and with some general methodological comments.

Production

Output*:* An index of US real agricultural output was 24 in 1900, 36 in 1940, and 94 in 1990.[2] The implied average growth rates are 1 percent for the period 1900-1940, and 1.94 percent for the period 1940 to 1990.[3] The change in the pace of growth in US agriculture started around 1940. To bring in the global experience, we turn to Figure 1, which presents two distributions of growth rates of agricultural output, based on a Fischer output index, of 130 countries for the period 1967-1992.[4] The uniform distribution assigns equal weight to each country, and its median is 1.9

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[2]Based on Gardner Figure 8.1.

[3] Throughout, the term 'rate of change' or 'growth rate' imply the annual compounded average rate of change.

[4] The number of countries was dictated by the available information, and it is therefore not the same in all the figures presented in this paper. In addition to differences among sources in time coverage, variables may differ also in their definitions even though they may carry the same names. An important difference is the way the variables are converted from nominal to real terms. For instance, in the country study, output and prices are measured by Fischer index, which is not the case in the variables presented by Gardner. The purpose of this note is to indicate a source for differences, and not to judge the quality of the series.

percent. In the weighted distribution countries are weighted by their value output, and the median of this distribution is 2.25. The US value for this period is 1.4 percent, which is very similar to the value implied by Gardner (Figure 8.1) Thus, in this period, the growth rate in the US was lower than the median, and in fact 70 percent of the countries realized higher rates than that of the US in that period.

The lower growth rate in the US may reflect demand conditions. Figure 2 presents the distribution of per capita growth rates for the period 1967-92 for 130 countries. The median of the uniform distribution is nearly zero. The median of the weighted distribution, however, is 0.7 percent, and 81 percent of world production was produced in countries with positive growth rates in per capita production. The difference between the two distributions indicates that the bigger producers realized higher growth rates. The rate in the U.S. is 0.4 percent, which is more than the growth in per capita demand.

The faster growth in supply in th US was directed in part to markets abroad, and in part caused a decline in prices. The index of real prices received by US farmers (1992=100), was 192 in 1900, 150 in 1940, and 75 in 2000 (Gardner 2002, Figure 5.1). The implied rates of change are –0.6 percent for the period 1900-1940, –1.4 percent for the period 1940-90, and –1.5 percent for the period 1967-92. As to the global picture, Figure 3 presents the distribution of the rates of change of the real agricultural prices, derived from Fischer index, for 112 countries for the period 1967-92. The median of the uniform distribution is –0.45 and that of the weighted distribution is -0.6. Interestingly, 71 percent of world production was produced in countries where the real agricultural price was declining. In this series the rate for the US is –2.1. Thus, in that period the US experienced a stronger price decline than most other countries.

<u>Land</u>: The US land in farms, in million acres, was 300 in 1850, 839 in 1900, 1061 in 1940, 1159 in 1950 which was nearly the peak year, and 930 in 1990 (Tostlebe 1957, Table 6, and Gardner Figure 1.1). This implies average growth rates of 2.06 percent between 1850 and 1900, 0.59 percent between 1900 and 1940, and –0.44 percent between 1940 and 1990. Land expansion had been a major force in the nineteenth century, and was still an important factor of growth in the first half of the twentieth century; this role was, however, reversed in the second half. In spite of these changes, the cropland was fairly stable, and stood around 300 million acres throughout the whole century (Gardner 2002 Figure 3.2). It showed a growth rate of 0.2 percent during 1900-1940, and little change thereafter, so that the level in 1990 was similar to that in 1940.

The world experience is summarized in terms of agricultural area in accordance with the FAO classification, which includes arable and permanent cropland and permanent pastures, and is different from the US definition of farm land. The median growth rate of 131 countries during

1967-1992 was 0.4 percent, and the average growth rate for the world was 0.58 percent. Thus, unlike in the US, land has still played a role in the growth of world agriculture.

Labor: The US agricultural labor force was approximately 11 millions in 1900, it reached a peak of 11.6 millions in 1910, or thereabout, and declined to nearly 3 millions in 1990.[5] The rate of decline was about 0.42 percent for the period 1900-1940, and 2.14 percent for the period 1940-1990. The median growth rate of the uniform distribution of 148 countries for the period 1950-1990 is 0.56 percent. It thus appears that the US has been ahead of most countries in the decline of the agricultural labor force.

Fertilizers: The US use of fertilizers, in million tons, was approximately 3.5 in 1900, 6.2 in 1910, 10 in 1940, and around 50 in 1990 (Gardner 2002, Figure 2.6a). The implied average growth rates are 2.7 percent for the period 1900-1940, and 3.3 for the period 1940-1990. The changes in fertilizers use reflect changes in cultivated area and in the intensity of application. The difference in growth rates of fertilizers and those of farmland gives the growth rates in intensity: 2 and 3.6 percent for the pre and post 1940 periods respectively. A similar growth pattern took place in the use of pesticides. Gardner attributes the growth in fertilizers use to changes in crops and the decline in real fertilizers prices. These two factors were pervasive, and so was the increase in fertilizers use. For a comparison, the average growth rate for a sample of 37 countries for the period 1970-90 was 3.04 percent (Mundlak, Larson, and Butzer 1999, Table 2).

Capital: The value of reproducible capital, in billions of 1910-1914 prices, increased from 12.3 in 1900 to 17.9 in 1920, and then declined to 15.4 in 1940.[6] A turn about came shortly thereafter, leading to a level of 19.2 in 1950. The rate of growth for the period 1900-1940 is 0.55 percent, very close to the rate of growth of land, indicating a stable capital-land ratio in that period.

In the subsequent period investment was positive from 1943 until 1980, but turned negative thereafter, (Gardner 2002, Figure 8.3) The capital stock, based on this investment series, declined between 1930 and mid 1940s, and rose from there on reaching a peak in 1980, (Op. cit,

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[5] Data up to 1950 come from Tostlebe (1957, table 4), for later years we use figures based on census data reported by Barkley (1990) for the period 1940-85. The extension to 1990 is based on growth rates derived from Gardner (Figures 8.1 and 8.2). Mundlak, Larson, and Crego (1998) use ILO data, which differ somewhat from the census data for the US.

[6] Reproducible capital in agriculture is total agricultural capital less land value; based on Tostlebe (1957, Table 9).

Figure 8.4).[7] The rate of growth for the period 1940-1990 is 2.17 percent.

Turning to the global picture, the median growth rate for the stock of fixed capital in agriculture in the period 1967-92 is 2.1 percent (Mundlak 2000, Table 10.3). The US value in this series is 0.23 percent, reflecting the decline from 1980. This value is consistent with Gardner (Op. cit, Figure 8.4) which shows the same level for the capital stock in 1992 and 1967. It thus appears that in that period the capital stock in US agriculture grew far less than in other countries.[8]

The US figures do not reveal the dramatic change, which was taking place in US agriculture, in the composition of the capital stock from around 1920, with the draft power changing from animals to tractors. The decline in draft animals, measured in billion 1910-1914 dollars, from 2.86 in 1920 to 1.64 in 1940, accounts for a large part of the decline in capital in that period. The number of tractors was practically zero in 1910, and rose to about 4.8 million in 1965. About one half of this growth took place between 1920 and 1945 (Op. cit, Figure 2.2). Setting the level in 1920 at 0.35 million and in 1945 at 2.3 million, yields a growth rate of 7.8 percent. Later on the growth rate declined; it was 3.7 percent between 1945 and 1965, the peak year for the number of tractors. It is possible that the increase in the number of tractors was valued less than the displaced draft animals. This would be an indication of the technical change bestowed on agriculture.

Aside from the change in technology, the variability in investment was influenced by the changes in the terms of trade of agriculture. Demand expansion during World War I brought the real prices received by farmers to a level of 317 in 1917, about 58 percent above their level in 1900.[9] This generated a boom in land prices, but this boom did not last long, and prices soon began to deteriorate, declining from 1917 to 1940 by a factor of 2 , and then again by the same factor between 1973 and 2000, (Op. cit, Figure 5.1). This fall in prices was followed by a fall in farm income and liquidity, and a collapse in the price of farm land. Figure 4 presents the land prices in the US, Canada, Japan, and South Africa for a long time period (Mundlak, Larson, and Crego, 1998). The top panel shows the price of land deflated by the agricultural GDP deflator, as such, the price is expressed in terms of the agricultural product, say cereals. The lower panel

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[7] The interpolation of the BEA series reported in Gardner (2002, Figure 8.4) in 1982-1984 dollars series is: 44 in 1940, 188 in 1980, and 128 in 1990. The rate of growth of the stock was 3.4 percent in the period 1943-1980. After that the stock declined at a rate of 3.7 percent.

[8] The series of fixed capital may not be identical with that of reproducible capital, but the rates of growth are likely to be sufficiently close for our needs.

[9] “Between the outset of the war and 1920, the price of corn nearly doubled. ... The peak came in 1920. Within two years, corn prices had dropped more than 50 percent. (Clarke 1994, pp.106, 107).

presents the land price deflated by the consumer price index, and as such it is expressed in terms of the consumption good. We discuss the differences between the two panels when we discuss the welfare consequences at the end of the paper. The two panels show a somewhat different pattern, but in both cases we see the decline in land prices from the post World War I period to the 1940s. This drop in product and land prices caused a financial crisis, and that was not conducive for investment. This is reflected in the investment figures.

Partial productivity measures

Table 1 presents the growth rates of the average productivities. The growth rate of the average land productivity in the U.S. was 0.41 and 2.38 percent for the periods 1900-40, and 1940-1990 respectively. The crop output per acre shows no trend during 1910 to 1939, implying no growth in yield in the first period. The trend line from 1935 on shows a growth rate of 2.1 percent, but this was not all due to rise in yields; there was an expansion in double cropping, which changed from 3.1 million acres in 1969 to 12.5 in 1982, mainly due to soybeans, (Gardner 2002, Figure 2.5).

The growth rate of the average labor productivity in the US was 1.42 and 4.08 percent in the two periods respectively. The difference between the growth rates of the labor and land productivity reflects the decline in the labor-land ratio, at the rate of 1.01 and 1.7 percent in the two periods respectively. This reflects the impact of the mechanization of agriculture, which was gaining steam with time.

Turning to the global picture, Figure 5 presents the weighted distributions of the growth rates of the two partial productivity measures for 87 countries for the period 1960-1992. The medians are 2.6 percent and 1.84 percent for the average labor productivity and land productivity respectively. The corresponding rates for the US in this sample are 2.96 percent and 1.46 percent respectively. Thus this series indicates that the US performance was above the median of the labor productivity rate and below that of the of the land productivity rate. The faster rise of the labor productivity in the US reflects the faster decline of the agricultural labor force discussed below. The slower rise of the land productivity in the US reflects the lower growth rate in output.

In contrast to the rise in the average productivity of labor and land in the US, the average productivity of fertilizers declined considerably throughout. The rate of change of this measure was –1.66 and –1.33 for the two periods respectively. This highlights the fact that fertilizers consumption grew faster than output. To interpret this result we should note that with constant technology, the decline in the average productivity of fertilizers in response to an increase in the intensity of application is consistent with a concave production function. With constant technology, a growth in the fertilizers-output ratio can be caused by a decline in the real fertilizers price, or in its shadow price if initially the supply was limited. Indeed, there was a dramatic decline in the real price of fertilizers. Binswanger (1978, Table 7-1) presents an index of the price of fertilizers relative to the price of the aggregate input for the period 1912-1968. From these data it appears that this price ratio declined at the average annual rate of 1.9 percent and 5.1 percent in the periods 1912-1940, and 1940-1968 respectively. The concavity of the function does not, however, explain the fast growth in the fertilizers-output ratio over a very long time period. This can only be accounted for by a fertilizers-intensive change of the implemented technology, as explained below.

The growth rate of the average capital productivity was 0.45 and -0.23 for the two periods respectively. The negative value of the second period indicates capital deepening in this period. Following the discussion on fertilizers, the negative value reflects capital intensive technical change and possibly declining real prices of capital.

Total factor productivity

The changes in the average productivity are sometimes taken as indicators of the changes in technology, and even of innovations. In order to see the limitation of this indicator, we digress on some basics. Consider the production function:

$$Y = F(T_K K, T_L L), \tag{1}$$

Label $V_K = T_K K$ and $V_L = T_L L$; as such, they represent land and labor measured in terms of efficiency units, respectively. T_K and T_L are the augmenting functions; in general they are considered as functions of time, but more profoundly they should be considered as functions of variables representing the economic environment. F(.) is a constant returns to scale, and twice differentiable function in V_K and V_L. Let β be the production elasticity of labor, differentiate and rearrange the terms to obtain:

$$\begin{aligned} &\frac{d\ln(Y/K)}{dt} = b\,\frac{d\ln(L/K)}{dt} + \frac{d\ln \mathrm{T}}{dt} \\ &where \quad \frac{d\ln \mathrm{T}}{dt} = b\,\frac{d\ln \mathrm{T}_L}{dt} + (1-b)\frac{d\ln \mathrm{T}_K}{dt} \end{aligned} \tag{2}$$

Under constant production elasticities, the rate of change of the average productivity of land is the sum of two effects: factor intensity and technical change. As a matter of definition, this formulation does not support the assertion that “In agriculture it appears consistent with technical conditions of production to consider growth in land area per worker and output per hectare as somewhat independent, at least over a certain range.” (Hayami and Ruttan, 1985, p.171)[10]. Furthermore, the technical change component is a weighted average of the rates of change of the two factor-augmenting components, and it does not identify their individual contribution. Specifically, a rise in the average land productivity is not a sufficient statistics for concluding that the technical change is land augmenting. By implication, narratives based on that assumption are misleading. To explain changes in average productivity, we have to explain not only the changes in technology but also the changes in factors intensity. In fact, much of the work on productivity deals with the decomposition of the output growth to its factor and technology components. The two components are not, however, independent as the above citation indicates. Also, to anticipate the discussion below, the above quotation is inconsistent with the hypothesis that the technical change is induced by factor ratios, which is the essence of the induced innovation hypothesis. We return to this topic in the discussion of heterogeneous technology.

The calculation of changes in the total factor productivity is essentially an estimate of the aggregate technology component in equation (2), and therefore does not provide information on the values of the factor augmenting functions individually. The identification of the augmenting functions is of interest, but requires a different approach, as discussed below.

By inspection of the rates of inputs growth in Table 1, it is clear that the calculation of the change in the aggregate factor, referred to as total factor (TF), is sensitive to the weights assigned to the various inputs in the aggregation. There are two basic practices in the choice of weights, constant weights and varying weights. In practice, weights derived from empirical production functions are mostly constant for the whole sample, whereas varying weights are mostly factor shares, or based on factor shares. The factor shares can be thought of as proxies for the production elasticities.

There are various estimates of the growth of the TFP in the US. Their differences reflect differences in period coverage, definition of inputs, quality adjustments, and in the choice of weights. We dwell shortly on the choice of weights. For illustration, we take as a point of reference the estimates suggested by Gardner for the TFP growth rate: 0.4 percent in 1910-1939, and 2.0 percent in 1940-1996 (Op. cit pp. 45-6). These are incidentally very similar to the growth rate of the average land productivity (Table 1). We have no definitive weights to suggest, but it is instructive to examine what weights would reproduce these numbers. Table 2 presents results

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[10] This statement is attributed to Griliches (1968).

using two alternative sets of arbitrary weights that do the task. Note that a single set will not work well for the two periods in question. Of course, the weights are not unique, but at the same time there is little scope for big deviations. If we had to provide the inspiration for these values, beside the claim that they perform the task, we would start with land. The cropsharing arrangements provide the landlord one half of the crop, so a value of 0.5 for the share of land is a good starting point. This number should be adjusted downward for a two reasons. First, under cropsharing the landlord has responsibilities some of which are capital inputs. Second, cropsharing arrangement does not cover livestock which constitutes a major component of output. We thus settle on 0.3. The distribution of weights between land and capital does not affect the results in the first period because they both grew at similar rates. We choose 0.25 for the two periods, even though the growth rates of land and capital diverged in the second period. Fertilizers in our case represents other chemicals, primarily insecticides, and perhaps other purchased inputs. We try 0.1 and 0.15. The logic for 0.1 is that it seems to be a reasonable value for the share of output used for chemicals. However, observing the fast growth of fertilizers use from the early years when the level was very low, it seems that the production elasticity of fertilizers was initially high, reflecting a relatively high shadow price. In the earlier years, also the real fertilizers price was relatively high. The low level of application may indicate that the shadow price was even higher than the market price. A postulated scenario, subject to empirical verification, is that two changes took place with time, the price declined and the assumed gap between the shadow price and market price was narrowed, or perhaps disappeared. The chosen weight for fertilizers is consistent with the evidence on the share of expenditures on manufacturing inputs in total production (Gardner 2002, Fig 3.5).[11] The growth of this share was faster in the first half of the century, from 5 to 12 percent. Thereafter, the share fluctuated between 12 to 16 percent. Some empirical studies show larger values for the elasticity of fertilizers, but this is attributed to statistical bias, (Mundlak 2001). The weights for labor are 0.3 and 0.35. These might seem low, compared to other studies. Our choice reflects an assumption that labor force data exaggerate the labor input in agriculture. This seems to be a common problem in developing economies. Referring to Table 2, we see that the weights w1 result in TFP growth of 0.41 in the period 1900-1940, and the weights w2 result in growth rate of 1.95 in 1940-1990. The difference between the two groups of weights is in the shares of labor and fertilizers.

The weights may not appear 'reasonable' to the reader, but this seems to be the cost of getting a sensible approximation to the reported estimates of the TFP. Gardner alludes to weights

[11] The group is an aggregate of "[e]xpenidtures on tools, fuels, machinery, fertilizers, pesticides, and other purchased inputs." (Op. cit p. 62)

derived from empirical production functions, but his estimates of the TFP are based on Ball et al (1997), which use varying weights, similar in concept to factor shares.

Two important messages come out of this discussion. The substantive one is related to the strong productivity growth in the second period, compared to the first one. This result reflects the assigned weights and the changes in the inputs that occurred in the two periods. Land expanded in the first period, and declined in the second period; The strongest rate of input decline is in labor in the second period. This suggests that the new technology was labor saving and capital using. If we were to increase the share of TF in the second period, it would be necessary to attribute larger weights to fertilizers and capital and to decrease the weights of labor and land, which does not seem attractive.

The other message is related to the change in weights. This can be expressed by extending the differential in (2) to allow for a change in the elasticity:

$$\frac{d\ln(Y/K)}{dt} = b\frac{d\ln(L/K)}{dt} + \frac{d\ln \mathrm{T}}{dt} + \ln(L/K)\frac{db}{dt}$$

$$where\;\; \frac{d\ln \mathrm{T}}{dt} = b\frac{d\ln \mathrm{T}_L}{dt} + (1-b)\frac{d\ln \mathrm{T}_K}{dt}$$

This expression generalizes to more than two factors. In this spirit, our foregoing discussion of the decline in the average productivity of fertilizers is consistent with the decline in the production elasticity of fertilizers. The reason for the time changes in the parameters of the production function is discussed in the next section within the framework of heterogenous technology.

Heterogeneous technology

The reader who is accustomed to the notion that there is a unique production function may be suspicious of the practice of changing the weights in order to obtain desirable results. The problem with such a view is that the basic presumption of a unique production function is wrong. To explain this assertion, and to broaden the discussion below, we expand the framework to account for the fact that the technology is heterogeneous in the sense that at any time there is more than one technique that can be used in production. In a world of heterogenous technology, there are two pertinent concepts of technology, available technology and implemented technology. The available technology represents the state of knowledge, whereas the implemented technology is that part of the available technology that is actually implemented. By definition, the empirical work on productivity deals only with the implemented technology, because this is where the data are generated. What is not observed is not measured.

To review briefly the essence of this framework, we note that at any point in time, producers chose the implemented techniques given the economic environment. This makes the choice of the implemented technology an economic problem. The choice is made jointly with the decisions on the composition and level of outputs and inputs (Mundlak 1988, 2000 chapters 6, 13). This is the *jointness* property. As Simon Kuznets (1957 p. xi) observed: “The point to be stressed-and it is simply illustrated in Dr. Tostlebe’s discussion-is that physical capital assumes meaning only within a given technological and institutional framework, and it follows that in a progressive economy such as ours, this meaning changes all the time. Thus, while there is a continuous demand for capital replacement and addition, the magnitude needed are a function of an ever changing and ever increasing stock of knowledge.”

We refer to the determinants of the choice as state variables. They consist of the available technology, constraints, incentives, and institutional factors. The state variables change over time and also across countries, and consequently the coefficients of the empirical production function, the levels of inputs and outputs change accordingly. For this reason, strictly speaking, the aggregate production function cannot be identified. Empirical aggregate production functions are approximations to a hypothetical function that is locally invariant to changes in the state variables. The quality of this approximation increases with the errors in the first order conditions for optimization.[12]

In terms of our discussion, this implies that the weights used in order to decompose the output growth to its components have to change, and in fact in the above exercise we have not changed them enough. This would have stood out if we were calculating the TFP for shorter periods. It should be noted that measures of TFP based on index numbers with changing weights are quite common, and, as indicated above, the measure used by Gardner is a refinement of the results reported by Ball et al (1997) obtained using changing weights.[13]

The *jointness* property is the source for the correlation between inputs and technology shocks. Technological, as well as other, shocks generally affect positively the intensive and extensive margins, a subject we discuss below. The change in the extensive margin induces an expansion of cultivated area. The change in the intensive margin calls for an increase in inputs associated with the new technology. For instance “Our regression analysis indicated that farm

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[12]This framework should narrow down the scope of the assertion that theories of growth “[f]ocus more on the consequences of growth than on causes. They incorporate investment and technological change, but do not analyze the adoption of technology.”(Gardner 2002, p.255).

[13]Without getting too technical, the weights in Ball et al are chosen so as to approximate a quadratic production function. Thus, the procedure assumes the existence of such a function. Nevertheless, the use of changing weights is an improvement.

scale and the tractor adoption were co-determined. Large scale induced greater adoption and greater adoption, larger scale. Given this result it is inappropriate to treat farm scale as an exogenous variable." (Olmstead and Rhode 2001 p. 693).

There is a great variability among firms in scale of operation, which indicates that the technology is not the sole factor in the determination of the farm size. The scale of operation reflects the implemented technology, and as such it is also influenced by idiosyncratic factors such as managerial ability, financial constraints, discount rate, and expectations. These attributes determine the differential response to the changing technological and market situation. This explains the concentration of large farms in acreage, and in output (Gardner Table 3.4). In addition, there is the impact of attrition in family farms where the family continuity in operation is not always secured. In this case, the incentive to expand by farmers who do not see the continuity is rather weak.

The correlation between inputs and technological shocks emerging from the *jointness* property, is the source for the biased estimates of the empirical production function. The bias has been investigated in the context of panel data, where measures to overcome it are simpler to develop. Panels often consist of aggregate economies such as counties, regions, states, or countries. The variability that exists between the units, say countries, is thought to provide information for reliable estimates of the function. This is the underlying assumption in several of the empirical studies reviewed by Gardner (Chapter 8). But since the various units operate under different sets of state variables, their implemented production functions are not the same. This argument is illustrated in a study of the agricultural production functions using data of 37 countries for the period 1970-90, (Mundlak, Larson, and Butzer, 1999). The study reports estimates of the three canonical regressions of panel data, based on variations between time, between countries, and within country and time. The results of the three regressions are very different, which is inconsistent with the notion of a homogneous technolgy. This is not the place to review the study in detail. We only mention that the median growth rate of agricultural GDP in the sample was 3.82 percent, and the decomposition, using the median rates of inputs change, results in about equal contribution of the TF and TFP growth.

To sum up, because the decomposition of output growth to that of TF and TFP is endogenous in the system, the growth accounting exercise is bound to yield different results under different environments. Is then the decomposition useful? Yes, very much so, because it tells us how the economic environment affects the growth process. Specifically, it is shown that when changes in the available technology increase the demand for inputs the supply of which is constrained, most of the technical change will be absorbed by a rise of the shadow price of the restricted inputs, this will increase the share of TF and reduce the share of the TFP. This is illustrated by the experience of Asian countries, (Mundlak, Larson, and Butzer, 2002). With this insight, it is tempted to suggest that the US experience from about 1940 has represented a regime with smoother flow of resources between agriculture and nonagriculture, or in the language of Gardner, a more integrated markets.

Resource flow

The discussion of productivity brings us to the subject of resource flow. Changes in the state variables such as the available technology and incentives change the demand for the various inputs. The response to such changes depends on the supply of the inputs when more are needed, as in the case of capital, or alternative employment when less are needed, as in the case of labor. Both, the demand and the supply may depend on constraints that affect the timing of the adjustment. Consequently, a gap is generated between the instantaneous shadow and market prices of the inputs. Under the assumption that inputs move from employments of low returns to employments of high returns, which we name The Economic Law of Gravity (ELG), the gap will be narrowed with time. The pace of the adjustment depends on the magnitude of the gap. The problem is of particular interest when the decision is subject to setup or adjustment costs and as such is not reversible without a loss. The behavior of forward looking producers calls for considering the future consequences of their decisions, taking into account the uncertainty involved in such an evaluation. The gap may be interpreted as an indication that the economy is in disequilibrium. This is the case with the assertion - made by Schultz (1947), adopted by Griliches (1963), and by Gardner - that US agriculture has been in disequilibrium over a very long period. This assertion focuses on static equilibrium, but as such it is not very revealing in our attempt to understand the behavior of the economy.[14] It is important to realize that we deal here with dynamic behavior and the relevant concept is that of dynamic equilibrium. Making this switch, we find ourselves in a search for the determinants of such equilibrium and of the pace of the resource movements in line with the ELG. This is well illustrated in the case of changes in the agricultural labor force.

<u>Labor</u>

As we have seen, the agricultural labor force declined considerably during the century as labor moved from agriculture to nonagriculture. Some of the workers, even though worked in the

[14] "The main focus of this paper is upon factor disequilibria that are causing widespread economic inefficiency in the American economy and affecting adversely especially farming in the United States." (Schultz 1947, fn 5, p.646). The supporting evidence consists of large disparity in average labor productivity within agriculture, between agriculture and other sectors, and inequality of value marginal productivity of labor and capital with the alternative returns.

nonagricultural sector continued to live on the farms. For this reason, we name this change of occupation as occupational migration. The reason for this migration is the decline in the demand for labor in agriculture, and the increase in the demand for labor in nonagriculture. From the micro point of view, the potential migrant chooses between the anticipated stream of income in the various occupations. It is postulated that the larger is the gap between the income in nonagriculture and agriculture, the more workers will migrate. This postulate provides the conceptual framework for empirical migration studies using country time-series data and cross-country data. The driving variable in such studies is the intersectoral income differential, where income is proxied by the average labor productivity. Barkley (1990) studied the off-farm labor migration in the US. The dependent variable is the migration rate, measured as the ratio of migration to the agricultural force. The elasticity of the migration rate with respect to the intersectoral income differential obtained from regressions covering the period 1940-85 is 4.5 for total labor and 3.34 for farm operators. This result is consistent with other country studies, as well as cross-country studies, (Larson and Mundlak 1997, and Mundlak 2000 Chapter 9).

The average annual US off-farm migration rate in the period 1940-1985 was 2.3 percent.[15] This is somewhat higher than the average rates for a large number of countries, which are closer to 2 percent (Larson and Mundlak 1997). This difference, however, is not sufficiently large to account for the fact that the agricultural labor force declined relatively fast in the US whereas in other countries, the pace was slower, or was even in the other direction, though weak. The reason is that the change in the labor force is determined by two variables, the migration rate and the natural growth rate of the labor force. Formally, let m be the migration rate, n the population (or labor force) growth rate, than the change of the agricultural labor force between t-1 and t is given by: $L_t - L_{t-1} = L_{t-1}(n - m)$. Thus, when n is smaller than m, the labor force declines. This is the US experience. In other countries, primarily developing countries, the natural growth rate is still slightly higher than the migration rate and therefore the agricultural labor force rises, although its share in the total labor force declines. Does the decline of the agricultural labor from 11 million in the beginning of the century to 3 million at the end of the century indicates that throughout the century agriculture was in disequilibrium? The answer is no. During the century, the state variables, and specifically the available technology, changed in agriculture and in non agriculture, causing changes in the demand and supply of labor in agriculture. In each period the individuals made their choice given the prospects available to them. People differ in many respects pertinent to such a decision (such as age, gender, education, health, family composition, ability, attitude toward risk) and so some chose to move while others

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[15] This is the average of the series reported in Barkley (1990, Table 1)

chose to stay.

Capital

With all the reservations about the capital data, we turn to Table 3 which shows the growth rates in the ratios related to capital. The ratios of capital to output, and capital to land declined in the first period, but increased in the second one. This is consistent with the hypothesis that capital was relatively scarce in the first period, and that the big progress in the second period was associated with capital deepening. We have discussed above the financial crisis following the events of WWI. Alluding to the debts accumulated following the events of WWI, Clarke writes that "[s]uch debts had precluded many individuals from making cash outlays for new equipment. ... Critics found that creditors set maturities for all types of loans too short to suit many farmers. " (p.248). There were geographical differences in the response to the financial situation; "But what was striking about this geographic variance was that the lag in tractor's adoption varied systematically with farmers' financial problems: their margin of cash between receipts and outlays, the variability of corn yields, the relative burden of debts, the proportion of indebted farmers, and the relative deposit holdings of commercial banks." (Op. cit p. 248)

This is supported by the information embedded in Gardner (Op. cit Figure 3.7) which indicates that during 1900-1940 interest payments as a share output fluctuated between 6 to 16 percent, as compared to the range of 2 to 6 percent in the period of fast growth of 1940 to 1973. The share rose again from 1973 to 1982 and reached 16 percent, before trending back to 6 percent in 1994.

More evidence - US agriculture in the nineteenth century

We now extend the discussion to review some of the US experience in the nineteenth century. The information for this period, particularly for the first half of the century, is more sparse, and of inferior quality compared to that for the twentieth century. This judgement is made explicit in some of the sources we depend on in our discussion. The information, nevertheless, serves the discussions on the developments in the nineteenth century, and we follow this practice with the same qualifications.

To provide perspective we summarize in Table 4 information related to the economy, in addition to that for agriculture. The nineteenth century was a period of strong growth, in agriculture and more so in the economy. As shown, the growth rate of GNP was roughly 4 percent, and this exceeded the rates observed for agriculture. Much of the growth is attributed to growth in inputs, and less to productivity. For the economy, the growth of TFP accounted for only 15 and 18 percent of output growth in the two subperiods.

The growth rate of agricultural output in the nineteenth century was high relative to that of the twentieth century. Much of this growth came from the expansion to new land. At the beginning of the century, land, capital, and labor grew (or assumed so) at similar rates, but as the century wore on the growth rate of labor started to lag behind that of land, leading to a rise in the land-labor ratio.[16] The decline in the growth rate of labor relative to that of output, land and capital continued throughout the century and accelerated in the twentieth century. The changes in agricultural labor are reflected in the rates of labor migration out of agriculture. The migration rate picked steam as time wore on.

Unlike average labor productivity, average land productivity did not change much.[17] Capital grew faster than labor, and more so in the economy than in agriculture. Still the growth rate of capital in agriculture was high. The major part of the agricultural capital was in land improvement, but that changed with time. "The structural changes in the composition of capital influenced the means by which the capital stock was assembled. In the antebellum years, almost half of the depreciable capital stock (constant prices) consisted of agricultural land improvements, many of them created by family labor, or labor attached to plantation on which they were

[16] See the note to Table 4, and also Rasmussen pp. 573-4.

[17] "Land productivity, measured by yield per acre, changed relatively little for most crops during the nineteenth century, in large part because land, particularly in the western states, was not the resource on which most farmers needed most to economize. Indeed, initial yields following land clearing were often higher than those realized later as soil nutrients depleted by repeated cropping were not replaced. ... The great improvement in yields lay almost a century into the future when chemical fertilizers, hybrid seeds, irrigation, and various scientific developments came into widespread use." (Atack, Bateman, and Parker 2000, p. 259-60)

constructed, or by other local sources of labor. These work were typically carried out in the off season, ... Little external finance were required to carry them out. But the structural changes of modernization brought to the fore industries, forms of capital, and organizational scales of operation that enhanced the roles of markets and of external finance in the provision of capital." (Gallman 1986, p. 200). The percentage share of farm improvement in agricultural capital (total capital), was: 61 (38) in 1840, 58 (22) in 1880, and 54 (12) in 1900, (Op. cit Table 4.2).

The need for capital required some choices to be made: "Farming became increasingly expensive in late nineteenth century. The real price of land was rising throughout the period until World War I. Moreover, mechanization, a growing imperative for successful farmer, further strained the financial resources of farmers. For many, tenancy was the only way to farm, but others chose to borrow." (Attack, Bateman, and Parker, p. 274). "Mortgages typically lasted three years or less and might be renewed, though renewal terms were never certain. The long-term, amortized mortgages so familiar today did not begin to appear until the 1920s." (Ibid).

Additional evidence is provided in Table 5, which presents growth rates of factor intensity and average productivity for three leading crops, calculated from data in Rasmussen (Table 1). The data show a continuous rise in the land-labor ratio for all the three crops, at a faster rate than that observed for total agriculture. Labor was diverted to the extensive margin, and there was little growth in the output-land ratio, which marks the intensive margin. This is mirrored in the rise of the output-labor ratio.

Historians mark two revolutions in American agriculture due to technical change: First, the change from manpower to animal power centered around the Civil War. The second is the change from animal to mechanical power, and the adoption of chemistry to agricultural production. It centered around World-War II. The latter period was covered in the foregoing discussion and we concentrate here on the nineteenth century. There is a debate on whether these were revolution or evolution, because the transition, as important as it was, evolved gradually. Regardless of the definition, the important developments that were taking place at the time, illustrate the existence of time lag between changes in the available technology and its complete implementation, and the uneven implementation between regions.[18] The uneven implementation of the available

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[18]"Ross suggested that transitions in agriculture had been "delayed, halting, hesitant, as well as uneven between regions and even, at times, adjoining farms. The same year, Clarence H. Danhof showed that even as simple a device as the revolving horse rake had slow acceptance among farmers." (Rasmussen 1962, pp. 578-9).
"Although agriculture was expanding onto the more fertile midwestern soils during the 1820s and 1830s, these years do not seem to have been ones of marked practices, or techniques, whereas in the Civil War years and immediately thereafter, mechanization was proceeding rapidly and there were more organized and systematic efforts to diffuse knowledge about best-practice farm methods." (Atack, Bateman, and Parker, p. 258).
A review of the debate and the result of data revisions is given by Weiss (1993). Weiss concludes that "The Civil

technology is an economic decision, reflecting the pertinent economic environment. Indeed, Rasmussen argues that the rate of adoption of machinery and other technological advances benefitted from the sharp rise in demand in the Civil War and World-War II (Rasmussen 1962, pp. 578-9).

In the case of the first American agricultural revolution, "It is important to note that every stage in the growing of grain was amenable to the use of horse-drawn machines by 1860. ,..., A backlog of technology, particularly in the form of horse drawn machinery, was available by 1860. The Civil War provided the incentive and the opportunity for its adoption, especially in the Midwest. The rate of investment in farm machinery and the implements increased rapidly from 1850 to 1880, and then declined." (Op cit, pp. 580-81). The *jointenss* property is embedded in the following statements: "The results of the confluence of technological advances, manpower shortages, better prices, and greater demand may be seen, at least in part in Table 1." (Op cit, p. 582). "The effect of the first American agricultural revolution and the fact that it was a revolution rather than an evolution are shown by J. W. Kendrick. In his net output, input, and productivity ratios for agriculture." (Op cit, pp. 583-4). The implied growth rates of Kendrick's index of average labor productivity are 1.67 and 0.67 percent for the periods 1869-1879 and 1879-1889 respectively. "From 1880 to 1940, increases in productivity, ..., flatten out, indicating that the first American agricultural revolution was at an end." (Ibid).

There is no unanimous agreement on the foregoing description of causality. Olmstead (1976) attributes the mechanization to a decline in the real prices of harvesting equipment which was triggered by increasing competition in the industry. This caused nominal prices to remain constant, while other prices, and specifically wages rose. Thus, the pace of the implementation is related to changes in the price environment. Christensen argues that the availability of cheap power and high labor cost were the incentives to mechanization. The emphasis here is a comparison with England, and not the timing of the implementation in the US. (Christensen 1981, p. 326). As such, this is a cross-country comparison of fundamentals, rather than of time series variability.

To sum up, the distinction between revolution and evolution is guided by the rates of change in the actual output, rather than by the changes in the available technology. As such, it reflects the pace of the implementation of the changes in the available technology, which was determined by the economic environment.

War, or at least the decade of the 1860s, may have marked a turning point in productivity, as has been suggested by many earlier writers." (P. 339)

Factor augmentation

The evidence in Tables 4 and 5 ties up the output growth with the factor supply and the available technology. But this is only part of the story, the rest involves the technical change. The declining labor-land ratio is commonly attributed to mechanization, or to labor-augmenting technical change. This, however, does not exclude land augmenting changes. In a series of papers, Olmstead and Rhode (1993, 2000, 2002) document relentless efforts in the nineteenth century of land augmenting activities, such as the development of new varieties, pest control etc. Accepting the existence of such activities, the question is what can we say about the relative strength of the changes in the factor augmenting functions. Recall that we cannot answer this question by tracing the changes in the average productivity and in factor ratios alone. We turn therefore to explore the relationship between the marginal rate of substitution and the factor ratio. In this we utilize data on the price ratio of land to wages. During the mid 1880s land prices appreciated at fairly high rates in response to market returns. "Despite vocal protests to the contrary, American farmers were not doing badly. They averaged return of 6 to 10 percent on current production, a usually realized capital gain of 3 to 7 percent." (Atack, Bateman, and Parker 2000, p. 277). This was reflected in the price ratio of land to labor. "Data are scarce before the midcentury mark, but standard historical accounts suggest that between 1790 and 1850 the number of days of farm labor required to purchase an acre of agricultural land increased two - to threefold (Christensen 1981; Lindert 1988a, 1988b)." (Olmstead and Rhode, 1993, pp. 104-5). We will use the information in Christensen (Op. cit Table 1) showing that the price of 1 acre of land increased from 1.1 labor weeks in 1790 to 2.9 labor weeks in 1850. The implied average growth rate of the land-labor price ratio for 1790-1850 is 1.3 percent. The price ratio stood at 33.8 in 1850, and at 64.7 in 1880, and 63.8 in 1900 (Olmstead and Rhode 1993, Table 1). This translates to an average growth rate of 2.19 percent between 1850 and 1880, and practically no growth between 1880 and 1900. In view of the reservation on the accuracy of the data for the nineteenth century, we note that the procedure we are about to follow is applied later on to other data, and that the results are consistent.

In what follows we deal with a world of two factors, labor and land, which are the most pertinent to our discussion. As in reality there are more inputs, our analysis assumes that the production function is separable in the sense that the marginal rate of substitution of labor and land is unaffected by the level of the other inputs. This is assumed to be a reasonable first order approximation, and in fact embedded in most of the empirical analyses. A more general analysis is presented in the appendix. Turning to equation (1), K stands for land, the average labor productivity of physical labor is $y=T_L f(\tau k)$, where $\tau = T_K/T_L$ is a measure of the technical change bias. The function f(.) is defined in terms of the efficiency units, it is concave and maintains: f(0)

= 0, $f'(0) = \infty$, $f(\infty) = \infty$, $f'(\infty) = 0$. When the wage-rent ratio, ω (ω^e), is equal to the ratio of the marginal productivity of labor to land in physical (efficiency) units, we can write[19]

$$\tau\, \omega(k) = \omega^e(\tau k) \tag{3}$$

Label the elasticity of the function $\omega^e(\tau k)$ as $1/\sigma$, and refer to σ as the elasticity of substitution, and note the restriction, $\sigma>0$. Write the differential of (3), and rearrange terms to obtain[20]

$$(1-\sigma)d\ln\tau = \sigma d\ln\omega - d\ln k \tag{4}$$

To apply this result empirically using average growth rates, we seek a function that is consistent with the evidence, and maintains the properties of a production function as specified above. For this, we approximate the differentials in (4) and (2) with average growth rates, using the notation *dln x/dt = gx*. We assume that the changes in the factor price ratios reflect with sufficient precision the changes in the marginal rate of substitution, and that the average growth rate of the rent on land is equal to that of the price of land.[21] Note that we apply the assumptions to averages over a long period, and as such they are not as strict as if they were applied to annual variations. We can then use the rates of change of the labor-land price ratio given above as the rates of change of ω.

We note that for positive growth of the land-labor ratio (which is the case for the values in Table 4), and negative growth of wage-rent ratio, the right hand side of equation (4) is negative. To isolate $g\tau$ we need the value of σ, but we have only one equation to solve for the two unknowns, σ and $g\tau$.[22] We can, however, tell the direction of the technical change bias for

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[19] An expository discussion (3) is given in Mundlak (2000, Chapter 5). The empirical testing of the bias in the technical change is discussed by Binswanger (1978).

[20] Alternatively, we can express (14) in terms of factor shares. The ratio of the factor shares of labor to that of land is $\theta \equiv \omega/k$, hence $d \ln \theta \equiv d\ln \omega - d\ln k$. Substitue in (4), and rearrange to obtain: $(1-\sigma)\, d\ln \tau = d\ln \theta - (1-\sigma)\, d\ln \omega$.

[21] According to Christensen the rental rate in terms of labor grew at an average rate of 1.8 percent between 1790 and 1850, which is more than the growth rate of the land-price-wage ratio. In this sense, our calculation is conservative.

[22] The identification problem is discussed in (Diamond, McFadden, and Rodriguez, 1978). Binswanger (1978) tries to overcome the identification problem by following a two stage procedure. Using data for US agriculture, he estimates first the price effect (σ in equation 4 above) from pooled state data, and second the estimated price effect is used in aggregate time-series data to estimate the bias in the technical change. This is based on the assumption that the identification problem is suppressed in the cross-section. There is however no reason that this

reasonable values of σ. Specifically, when the right hand side of (4) is negative, values of $\sigma<1$, are sufficient for $g\tau<0$, meaning that in this case the technical change bias was labor augmenting. This conclusion does not require that σ be constant throughout the period, the result applies as long as σ is smaller than one. The combination of $\sigma<1$, and labor augmenting technical change yields a decline in the ratio of the factor shares of labor to that of land, as can also be seen from the footnote 20, meaning that the technical change was labor saving. This is consistent with the common wisdom.

We also apply this procedure in Table 6 to the twentieth century data. Our data on land prices begin in 1910, and this determines the starting year. The jump in the average land productivity which began around 1940 has made it of interest to examine if that has affected the results, and for this reason we examine also the period 1940-50. The wage-rent ratio declined in 1950-90, thus the sign of the right hand side of equation (4) is negative, the same as in the nineteenth century. For the other periods in the table the sign of the right hand side of (4) is ambiguous in that both, gk and $g\omega$, are positive. Here we have two possibilities. The first is when $gk > g\omega > 0$. By inspection of equation (4), and given $\sigma<1$, we conclude that $0 > g\tau$. The second case is where $g\omega > gk > 0$. In this case we derive an upper bound for σ for which $g\tau$ is negative, and refer to it as the critical value. The results are reported in the last line of Table 6. Thus, the values of σ which are consistent with labor augmenting bias are bounded from above by 0.79 for the period of 1910-1940, 0.94 for the period 1940-1950, and 1 otherwise. The period 1910-1940 is an interesting period because it was the prelude to the jump in the land augmenting technical change. It has the lowest critical value but still to have land augmentation bias, it would require σ to exceed 0.79, which is unlikely. Also notethat in the subsequent periods when the big jump in yields was occurring, the bias was still labor augmenting.

We can now go further one step and obtain orders of magnitude for the growth rates of the augmenting functions. We do it for the values in the nineteenth century, concentrating on the role of land and labor and ignoring the role of capital. For this we need the growth rates of TFP, gT.[23]

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is indeed the case. In addition, there is the question of the invariance of the production function to the sample. Binswanger realizes difficulties by observing that "Of course, we will never find a cross section where all units are on exactly the same production function." (Op. cit p. 232). This lack of robustness in the estimates is an outcome of the fact that in a world of heterogenous technology, the production function estimates depend on the state variables that determine the choice of the implemented technology. For discussion of the subject, see (Mundlak 2001).

[23]Attack, Batman, and Parker (2000, Table 6.1) provide estimates of TFP for total agriculture, which are said to be based on Weiss. Weiss (1993, Table 4), presents these very same figures as growth rates for output per worker of farm gross product ("broad definition"). we thus suspect that these values are actually growth rates of average labor productivity, rather then of TFP, and therefore do not use them here.

In our derivation of the TFP we use equation (2), and assume equal weights to labor and land, $\beta=0.5$. For the individual crops we have only one version, based on our calculation.

We use the definition $g\tau = gT_K - gT_L$ to estimate the bias for two possible values of σ, 0.2 and 0.5, and the growth rates in Table 4. The results are presented in Table 7. In most cases, the growth rate of the labor augmenting component is sizable, whereas that of the land augmenting is either negative, or positive but weak. The difference in the growth rates of the two augmenting functions broadens for $\sigma=0.5$.

It is hard to believe that there was a deterioration of the land augmenting function, particularly in light of the various efforts made to improve the biological practices, as documented by Olmstead and Rhode (1993, 2000, 2002) . If this is the case, how can we explain the results? A convincing explanation given by Olmstead and Rhode (2002) is that the new lands brought under cultivation were either of lower quality, or needed changes in varieties or other practices to maintain the observed yield level.[24] Under this claim, the average yield should have declined, and if it did not, this is an outcome of the land-augmenting technical change. They make some calculations to quantify the effect of the variability in quality. The question is whether the allowance for heterogeneous land quality is sufficient to elevate the growth rate of the land augmenting function to that of the labor augmenting function. To answer this, we take a different tack and explore the issue without resorting to the average yield, and the answer is negative.

Land of heterogeneous quality

In what follows we outline the model with heterogeneous land, and state pertinent results. The discussion is based on Mundlak (2000 pp. 157-161). We change the notations slightly, labeling the available amount of quality q land as A(q), where q is assumed to be a continuous variable that takes on nonnegative values; the higher is the value of q, the better is the land. The cultivated land is all the land of quality $q \geq z$, where z is the marginal quality, characterized by zero rent, to be determined by the model: $A = \int_z^\infty A(q)dq$. To simplify the discussion, we assume that there are only two inputs, land and labor, L(q) is the amount of labor allocated to quality q land, and x(q) is the ratio of labor to land adjusted for quality, $x(q) = L(q)/qA(q)$.[25] Total agricultural

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[24] Also, “The westward drift dragged down the average quality of American farm land faster than the 0.29 percent annual quality of improvements on fixed sites.” (Lindert 1988, p. 51). See also Cochrane (1993, Chapter 5).

[25] Thus, compared to the foregoing discussion, A replaces K, $x=1/k$, and $\alpha=1/\tau$.

labor is $L = \int_z^\infty x(q) q A(q) dq$.

To allow the marginal rate of factor substitution to depend on land quality, the production function is expressed in terms of land measured in quality units, *qA(q)*. The production function is linear homogeneous:

$$Y(q) = F[T_A qA(q), T_L L(q)] = T\alpha qA(q) f[ax(q)] \tag{5}$$

where $\alpha = T_L/T_A$ is the bias in the technical change, T_A is the land augmenting technical change, and serves here as the neutral component, and hereon will be denoted by T. The bias is labor (land) augmenting when α is larger (smaller) than 1. The output per unit of quality q land is $Y(q)/A(q) = Tqf(ax)$, and total output is

$$Y = \int_z^\infty Y(q) dq = T \int_z^\infty q f[a x(q)] A(q) dq$$

The quantities *A*, *L*, and *Y* are functions of *z* and *x(q)*; these in turn are determined by the state variables which vary with the specification of the model. Let *w* be the wage rate of physical labor, *p* be the product price, and *c* be the unit cost of using land, independent of its quality. The rent on quality *q* land is $R(q) = pTqf[\alpha x(q)] - c - wqx(q)$. Differentiate R(q) with respect to q to obtain $R'(q) = [R(q)+c]/q > 0$. The neutral component of technical change and the product price play a similar role in the equation, so we combine them conveniently, $H \equiv pT$. The optimization problem is

$$\max_{x(q),z} L(x(q),z) = \int_z^\infty \{Hqf[\alpha x(q)] - wqx(q) - c\} A(q) dq \tag{6}$$

The first order conditions are:

$$\alpha f'[\alpha x(q)] = w/H \tag{7}$$

$$Hzf[\alpha x(z)] = [wzx(z) + c] \tag{8}$$

The elasticity of labor demand is $\epsilon = \ln x / \partial \ln w/H$, note that $\epsilon < 0$. Following the general framework in the appendix, we differentiate (7), and rearrange terms to obtain:

$$d \ln x(q) = -(\epsilon + 1) d \ln \alpha + \epsilon d \ln(w / H) \qquad (9)$$

Hence $\partial \ln x(q) / \partial \ln \alpha < 0 \quad iff \quad 0 > \epsilon > -1.$

The differentiation of (8) yields:

$$d \ln z = \frac{zwx(z)}{c} [d \ln \frac{w}{H} - d \ln \alpha] + d \ln \frac{c}{H} \qquad (10)$$

Hence $\partial \ln z / \partial \ln \alpha < 0$.

The impact of technical change and prices on the two margins is summarized in Table 8.

An increase in α increases the rent on land of all qualities, and thereby marginal land is brought under cultivation. As labor becomes more productive, there is an expansion of the *supply* of efficiency-labor at the rate dln α, which presses down the wage rate and thus increases the quantity demanded. The extent of the response to the wage decline depends on ϵ. When the demand is inelastic, the increase in the quantity demanded of efficiency labor is insufficient to match the increase in its supply and the labor-land ratio declines. The outcome is summarized as follows:

<u>Proposition</u> When agriculture is a price taker, labor-augmenting technical change increases the rent on land of all qualities, thus reduces the marginal quality land and increases the cultivated area. The labor-land ratio declines when the elasticity of labor demand is smaller than one.

The changes covered by the proposition are consistent with the evidence for US agriculture in the nineteenth century. Land, land-labor ratio, the rent and the rent-wage ratio all increased. These changes are inconsistent with the other possibilities of technical change. Land-augmenting technical change acts in the opposite direction, and thus increases the labor-land ratio and this is inconsistent with the data, and thus ruled out as the typical case. Neutral technical, like the product price, have a positive effect on the intensive margin and are therefore ruled out as the typical case. Aside of this, real product prices trended down as a result of the technical change, and thus the impact of the technical change was offset in part by the price decline.

This analysis yields the same qualitative result of labor augmenting bias obtained above under the assumption of homogeneous land. This, however, does not rule out land augmenting, or neutral changes, it just says that the labor augmenting change was dominating.

In this discussion, we have concentrated on the impact of technical change, and neglected the impact of the cost involved in the operation of land, *c,* and the nature of the labor supply. The cost can have various interpretations, depending on the context. In the case of expansion to new territories, it would represent the cost of reaching the site and of bringing the land under cultivation. In that case, the model could be extended to multi period optimization. As reviewed above, there was a considerable investment in infrastructure of the land augmenting nature, and also in investment in land clearing and improvements. The cost term could also include tax or subsidy, as well as the payments for set aside land under government programs of supply control. The cost could also be made a function of q. As to labor supply, we assumed it to be perfectly elastic at the ongoing wages, but this could be modified to upward sloping market supply. All these are interesting possibilities, but they are unlikely to modify our qualitative conclusion and therefore are not pursued here.

Innovations

What can we learn about innovations from the changes in the factor productivity? The answer is not much, and definitely less than some studies suggest. The experience of US agriculture is part of the paradigm of the development of American and Japanese agriculture told by Hayami and Ruttan in which the hypothesis of induced innovation plays a center role. The hypothesis views innovations "[a]s a process of easing the constraints on production imposed by inelastic supplies of land and labor." (Hayami and Ruttan, 1985 p.4). This is translated into price signals: "The Hicks theory of induced innovation implies that a rise in the price of one factor relative to that of other factors induces a sequence of technical changes that reduces the use of that factor relative to the use of other factor inputs."(Op. Cit. p.85). This is not meant to be just another theory, it aspires to replace "The process by which technical change is generated has traditionally been treated as exogenous to the economic system - as a product of autonomous advances in scientific and technical knowledge."(Op. Cit p.84). It should be pointed out right at the outset that the theory is concerned with the bias in technical change and thereby excludes the neutral component. By this token alone it is rather narrow in scope.

To relate the hypotheses to our discussion of the implemented technology we write the augmenting functions as functions of the state variables: $T_j(s)$, $j=K, L$, and s stands for a vector of state variables. The hypothesis sets s=K/L as an indicator of the resource constraints, or alternatively, under the translation to price ratio, s=ω. This is the essence of the following statement: "In the United States the long-term decline in the prices of land and machinery relative to wages ... could be expected to encourage the substitution of land and power for labor. ... In Japan the supply of land was inelastic and the price of land rose relative to wages. It was not therefore, plausible to substitute land and power for labor. Instead the new opportunities arising from continuous declines in the price of fertilizers relative to the price of land were exploited through advances in biological technology." (Hayami and Ruttan 1971, pp 123-4).

Limitations of the paradigm of the induced innovation as applied to US agriculture are discussed by Olmstead and Rhode (1993). In addition to questioning some stylized facts, they dispel the story on basically two grounds. First the hypothesis that the abundance of land relative to labor in the US would result in an increase of the wage-land-price ratio, is inconsistent with the evidence. As has already been indicated above, during the period of the big land expansion in the nineteenth century the price of land increased substantially relative to wages. This rise is expected and is consistent with the analysis of the previous section; labor-augmenting technical change increases the rent on land of all qualities, and larger rent should translate into higher land price. Thus, land price responded to technical change and not the opposite, and the expected causality is consistent with the evidence and not with the hypothesis. Second, Olmstead and Rhode document various research efforts in land-augmenting activities in the nineteenth century. We return to this subject below.

Our conclusion of labor-augmenting bias is in the US is in line with the Hayami Ruttan paradigm. On the other hand, the decline in the wage-land-price during the period of land expansion is not but, nevertheless, it is supportive to the finding of labor augmenting bias. This is, however, only part of the story, the other part is Japan. To complete the story, we repeat the calculations to include Japan. To avoid data disputes, we use the Hayami and Ruttan data, as reported in Ruttan et al (1978, Tables 3-1, and 3-2). The results are presented in Table 9.

For a background, we present the growth rate of output, where we see a difference between the two countries in the first period (1880-1930); it was 1.62 percent in Japan and only 1.03 in the US. This difference disappears in the second period. Turning to factor growth, Japan, considered as the land scarce country, or where "the supply of land was inelastic", had a handsome average growth rate of land of 0.47 percent in the first period, and the wage-land-price ratio declined in this period. These changes are consistent with the US paradigm, and this is the period where Japan is claimed to have followed a different innovation path. The land growth came to a halt in Japan in the second period. There is also a great deal of similarity between the two countries in the change of the agricultural labor in the first period. The trend is also similar in the second period, but the decline was stronger in the US. The fast decline in the US is related to the off-farm migration, discussed above, and has to do more with the development of nonagriculture than with the induced innovation hypothesis. The wage-land-price ratio declined in Japan in 1880-1930, similar to the evidence for the US in Table 4, and thus the right hand side of equation (4) is negative, and for $\sigma<1$ the technical change is labor augmenting. For the other cases in Table 9 we compute the critical σ, as we did in Table 6. The result is 1 in the US in both periods, and in Japan in the first period, and 0.7 for Japan in the second period. Yeung and Roe (1978) estimate a CES production function, with a variety of modifications aiming to capture the induced innovation effect, using data for Japan 1880-1940, reach a similar conclusion. This leads us to conclude that the bias in the technical change was labor augmenting in both countries. Incidentally, the highest estimate of the elasticity of substitution that Yeung and Roe report for Japan is 0.26. Recall, labor augmenting technical change and $\sigma<1$ implies labor saving technical change. Thus, whatever merits the Hayami Ruttan paradigm might have, it is not supported by their own data.

Beside the message on the direction of the technical change, there is an implication concerning the approach to the empirical verification of the hypothesis. The fundamental weakness is in that the judgement on the nature of the intended innovations is based on the observed changes in factor productivity and not on the innovation process itself. To sharpen the discussion, we should distinguish between two production processes, the first, labeled generically as research, produces changes in the available technology and the second is the production, which uses technology and inputs to produce the final product. The connection between the research effort and the realization in terms of measured productivity gains is not immediate: First, there is the subject of identifying and measuring the research effort, which should deal directly with the resources devoted to research. This direct approach can also help in judging what has induced the research, and what have been the objectives and the time profile of the expected results. Specifically, it may also shed light on the extent to which the research builds on “autonomous advances in scientific and technical knowledge.” If we take the term “induced innovation” nominally, this is the only stage which is pertinent to the hypothesis and the rhetoric of the induced innovation. Second, there is the subject of the research productivity, which relates the effort to outcome. Good intentions, in research like in other matters, do not always lead to the desired results. In research, the gap is related to the fundamental fact that there is no production function for knowledge. Presumably, the innovation opportunity frontier should guide resources to their more productive use. The problem is that such a frontier, purely speaking, is nonexistent, (Mundlak 2000, p.362), and judgement has to be passed on less solid ground. Not independently, there is a question of the timing of the realization, sometimes the results are obtained with long lags. For instance, Olmstead and Rhode (2002) argue that the green revolution has its roots in the research efforts made in the nineteenth century. Work on hybrid corn started at the beginning of the twentieth century, but it was not put to work until the 1930s, (Griliches, 1957). These illustrate research activity with the objective of land augmentation, but the outcome was a late bloomer.

Finally, there is the question of implementation. Not everything that is known is immediately implemented. After all, the inventors and users are two different groups, each is motivated by different criteria, sets of incentives, and constraints. This is illustrated by the claim made by Rasmussen with respect to the implementation of new technology in response to the changes in the economic environment following the Civil War and World-War II. The technology was already there, and it was a change in the economic environment that triggered the implementation. Similarly, Gavin Wright (1986), and Peterson and Kislev (1986) relate the adoption of cotton pickers to the economic environment. In fact, Hayami and Ruttan state that in Japan, "The tractor was not adopted extensively until World War II."(Op. Cit, p.171). This is a statement about implementation and not about innovation.

We finally come back to the second point of Olmstead and Rhode who document various research efforts of land-augmenting activities in the nineteenth century. For instance, "[t]he nineteenth and early twentieth century witnessed a stream of "biological" innovations that rivaled the importance of mechanical changes on agricultural productivity growth. These new biological technologies addressed two distinct classes of problems. First, there was a relentless campaign to discover and develop new wheat varieties and cultural methods to allow the wheat frontier to expand into the Northern Prairies, the Great Plains, and the Pacific Coast states."(Olmstead and Rhode 2002). The second effort aimed at pest control. This is a direct report on research effort, not blurred by the productivity of the research and by the degree of the implementation of the available technology.

To sum up the argument, there was no lack of trying to get land-augmenting technical change. Simply, the outcome was less dramatic than in the case of labor augmentation, because the mechanical innovations were so much more effective. This edge, most likely, reflects possibilities generated by the overall technological developments in the economy, largely exogenous to agriculture. The most dramatic changes in technology originated in the manufacturing sector, and it would hard to assume that profit on the production of the new machines was overlooked by their developers and producers. To this we can add that narrowing down the research objective to labor saving innovations would fail to explain the growing successful agricultural research in the US and the world over in spite of the continuous decline in real agricultural prices. This effort, both public and private, can only be justified by expectations that the research will pay off, regardless of the direction of the augmentation, and that the innovations will be implemented.

On the methodological aspect, we should recognize that the empirical analysis triggered by the hypothesis of induced innovation in agriculture has mostly dealt with the implementation of technologies rather than with innovations. Failing to realize it leads to some obscure consequences. Specifically, the *jointness* property of the implemented technology makes explicit the relationship between the technology and the inputs and thus precludes statements that factor ratios are independent of the technical change.

Implementation and incentives

Technical change has moved agricultural output in the US, as elsewhere. The foregoing discussion has emphasized that the available technology is only one determinant of the implemented technology. The other determinants include incentives and constraints. Often, the spread of technology is viewed as a process of diffusion.[26] This term is somewhat misleading in that it creates an aura of a passive process, whereas in reality entrepreneurs are active in their decisions on the implementation of the available technology. If we were to obtain the production function in (1) as the maintained hypothesis, then all the state variables, and specifically the available technology, would appear as arguments of the augmenting functions, as well as in the production function itself.

The evaluation of productivity changes within the framework of the implemented technology is discussed in (Mundlak, 1988, 2000, 2001). Empirically, as productivity generally increases with time, trended variables turn out to be “good” explanatory variables, whereas non trended variables seem to perform poorly. The first group includes measures of human capital, research, and infrastructure, whereas the second group includes incentives. In what follows we review some evidence and fundamental difficulties encountered in capturing the impact of incentives in empirical analysis. The role of the incentives in the determination of productivity changes is most difficult to identify empirically, and for good reasons. To clarify what is behind this difficulty, we have to ask ourselves why should the introduction of more profitable techniques depend on prices. If the new technique is more productive, it is likely to be profitable even under a price decline. This is, after all, the big picture with respect to technical change in agriculture in the last century, which has taken place under declining price environment. In fact, the causality is from technical change to prices.

To a large extent, the scope for the positive role of prices in the implementation of new techniques is related to the *jointness* property of the implemented technology. This is the case when the implementation of the new techniques requires new investment. In part this due to embodied technical change (Solow, 1959). The foregoing discussion has shown the importance of mechanization in the development of agriculture. To benefit from the productivity of the tractor

[26] For instance “I study productivity in terms of the diffusion of technology...” (Clarke, p. 13)

someone must acquire the tractor. The investment responds favorably to higher product price, lower factor price, and lower risk over its life time.[27]

The embodied technical change constitutes a sufficient, but not a necessary, condition for the *jointness* property. The green revolution in Asia, where new productive varieties of rice and wheat were introduced, provides an example of jointness generated by disembodied technical change. These varieties have reached their potential under irrigation and heavy doses of fertilizers. The progress of their implementation was therefore paced by the mobilization of resources for expanding the irrigated area and fertilizers production, (McGuirk and Mundlak, 1991, Mundlak, Larson, and Butzer, 2002). But resources move with incentives, and this is where the prices and risk come in. Once the investment has been made, and the necessary infrastructure put in place, it is usable for future improvement, such as new varieties. At that stage the shift to the new varieties will not depend on prices to the extent it did when the initial investment had to be made. Consequently, in the case of disembodied technical change, we can observe a ratchet effect; investment made for the implementation of a new technology is likely to accommodate future technical changes. When this feature is ignored in empirical analysis, the impact of prices is distorted.

There are various claims on the relevance of prices to the implementation of new technology. Griliches's (1957) relates the trend in the adoption of hybrid corn to market forces. Cochrane and Ryan (1976, p.373) attribute the surge in productivity to the price and income support programs, which provided both stability and desirable income level. Clarke (1994) argues convincingly on the role of capital and liquidity constraints in the mechanization of US agriculture in the post World War I period.[28]

Reservations with respect to the importance of prices come from more structural empirical analysis (Huffman and Evenson 1993, Gonipath and Roe 1997). Such analysis follows a recursive procedure where first a production function is estimated, second the function is used to generate the TFP series, which in turn is analyzed to find its determinants. This procedure conceals the contribution of the technology, as well as the other state variables, to the variability of the inputs,

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[27] Tractor prices deflated by the GDP deflator start at a level of 100 in 1910, declined sharply to roughly 30 in 1920, and remained there more or less with small variability until 1960. Quality adjustment would probably show further declinde from 1920. Interestingly, the price of horses had a similar pattern until 1942 and then realized a sharper decline to a level of the 20s. (Olmstead and Rhode, 2001)

[28] For instance, referring to the role of the financial constraints on purchases of tractors: "But what was striking about this geographic variance was that the lag in tractor's adoption varied systematically with farmers' financial problems: their margin of cash between receipts and outlays, the variability of corn yields, the relative burden of debts, the proportion of indebted farmers, and the relative deposit holdings of commercial banks." (Op. cit p. 248)

and distorts the results, and thereby does not provide the true estimates of the TFP and the variables associated with it. The reason is that the orthogonal decomposition of output changes to inputs and productivity distorts the contribution of the technical change. This follows from the *jointness* property of the implemented technology, which asserts that the two components are not orthogonal. This is similar in concept to the effect of ignoring fixed effects in the estimation of production functions from panel data. In terms of the econometric analysis, the parameters of the production function, and the inputs are both functions of the state variables, including prices, constrains and technology. This recognition is important in that it provides a conceptual framework for the evaluation of the evidence, and also in guiding us to alternative approaches to the estimation. In essence, the state variables should be included in the empirical production functions in the same way as the inputs. As many of the variables are trended, this would lead to multicollineairty. This problem, however, is an expression of the implementation process and not of the framework. This is not the place to discuss techniques to overcome the multicollinearity problem.

Welfare consequences

Consumers enjoyed a substantial decline in the price of the agricultural product and thus benefitted greatly from the growth in agricultural productivity. Another positive outcome of the agricultural growth has been the supply of labor to the nonagricultural sector, which facilitated the growth of nonagriculture. This is true for the US as well as for most countries.

It remains to consider how the growth affected farmers. This is not a trivial question because it requires to define who is a farmer for this purpose. Over the twentieth century the number of workers in US agriculture was sized down to almost one fourth, and the number of farms declined to one third. Obviously, the farmers who moved out of agriculture decided that the opportunities in nonagriculture exceeded those in agriculture. The evidence indicates that they were not wrong. The proportion of income from nonagricultural activities in the income of farm households has reached one half. This suggests that as far as income foregone by moving out of agriculture, the average migrant has benefitted. This is the only way to explain the sizable migration from agriculture. If we contemplate what would have been the income in agriculture in the absence of such migration, we cannot avoid the conclusion that the off-farm migration had a major role in the alleviation of rural poverty (Mundlak 1999).

And what about those who remained in farming? There are two specific factors that absorb the rent of the sector: land for the sector as a whole, and the returns to entrepreneurship or management of farm operators. Figure 4 presents the land prices in the US, Canada, Japan, and

South Africa for a long time period (Mundlak, Larson, and Crego, 1998). The top panel shows the real prices obtained by deflating the nominal land prices by the agricultural GDP deflator. As such, this price is expressed in terms of the agricultural product, say cereals. The level of this land price in 1993 was about three times higher than that in 1910. In fact, it was about four times higher around 1980, but has declined thereafter. This development reflects the fact that because of technical change, land is more valuable in terms of the agricultural product. The pattern is common to the other countries shown in the figure, indicating that the technical change was pervasive. The price pattern, however, is very different in the lower panel where land prices are deflated by the consumer price index. In this case, the graph presents the price in terms of the consumer goods. For the US the index of the consumption-based land price in 1993 stood at a level of 0.833 as compared to a level of 0.727 in 1910, an increase of 15 percent over a period of 83 years. By this measure, there was little difference in the welfare of land owners (or their families) who kept the land for most of the whole century. This is an indication that the benefits of the technical change have been distributed to the economy at large and have not been retained in agriculture. Here again, the pattern is the same for the other countries in question, indicating that the main shocks affecting agriculture, and leading to the decline in the real agriculture price, were pervasive..

Land prices, like agricultural prices, have undergone cyclical variations. At its peak in 1980, the consumption-based US land price was twice as high as in 1910, or four times as high as its trough value in 1942. This highlights the sensitivity of this measure of agricultural welfare to changes in the economic environment. Another view of the same phenomena is obtained from a comparison of the index of agricultural output and the agricultural GDP made by Gardner (2002, Figure 8.1). The output index measures changes in output in terms of agricultural prices, and thus it is the analogue of the upper panel of Figure 4. The second measure is GDP in 1992 dollars obtained by applying the overall GDP deflator to the nominal agricultural GDP. Because the GDP deflator is close to the CPI, this measure is the analogue of the lower panel of Figure 4. In 1910 the value of the real agricultural GDP was 74 billion of 1992 dollars, and this was also the value in 1996 (it was even lower in 1993). For comparison, the output index increased from 26 in 1910 to 86 in 1996, more than a threefold rise. It should be noted that the two measures differ not only by the deflator but also in the coverage of the components included in each. This difference in coverage is, however, of secondary importance to that of the deflator. To sum up, the difference is dramatic.

The big changes in agriculture where the labor force shrank drastically, the number of farms declined, the lack of long term trend in the consumption-based land price, has had its impact on the income of those stayed in agriculture. "USDA's detailed economic surveys of individual farms in the 1980s and 1990s indicate that about 40 percent of U.S. operate at a loss in any given year." (Gardner 2002, p.269). The survival in the sector underlines the importance of the idiosyncratic qualities for success.

Conclusions

The development of US agriculture in the last two centuries had some of the more important ingredients discussed in the growth literature. Starting from a resource based growth generated by the inflow of labor and capital from abroad, followed by the introduction of mechanization leading to the reduction labor demand, and later on by the biological and chemical based growth. Thus, land in farms grew by a factor of 4 between 1850 and 1950, the peak year for land in farming. Agricultural labor was initially increasing together with the land expansion, but this came to an end. Between 1900 and 1990 agricultural labor shrank nearly by a factor of 4. Thus, the output growth in the twentieth century cannot be attributed to labor. During the period of fast land expansion, land played a major role in output growth, but this has changed from around 1940, when chemical, biological, and capital inputs were gaining importance. Growth based on land expansion is not a future option for most countries, but it has had its legacy in some thinking about the pattern of development. Future growth will be based on technical change, and growth in the inputs needed to its implementation.

For this reason, we have concentrated on the role played by technical change. The US long experience, like that of other countries, is consistent with the fact that the implementation of new technologies depends on the economic environment. Because the available technology in agriculture is largely a public domain, the variability in its implementation depends on the incentives and constraints, and those vary over time and across countries. This is reflected in the country distribution of the productivity measures. The decomposition of output growth to that of TF and TFP is endogenous in the system, and the growth accounting exercise, therefore, is bound to yield different results under different environments. Is then the decomposition useful? Yes, very much so, because it tells us how the economic environment affects the growth process. Specifically, when changes in the available technology increase the demand for inputs the supply of which is constrained, most of the technical change will be absorbed by a rise of the shadow price of the restricted inputs, and this will increase the share of TF and reduce the share of the TFP. This is illustrated by the experience of Asian countries, (Mundlak, Larson, and Butzer, 2002). With this insight, it is tempted to suggest that the US experience has benefited from a relative smooth flow of resources between agriculture and nonagriculture. Such a flow is essential for reaping the opportunities created by changes in the available technology.

There is a considerable literature documenting the extensive research and development serving agriculture, and its positive impact. Has there been enough research, or too much? Direct evaluation of returns to research suggest that the returns to research have been high (Evenson 2001). The relation between research and productivity, however, is not direct, and its impact is not immediate. First, there is a time lag between the beginning of research, its intensity, and the realization of positive results leading to a change of the available technology. Second, having reached positive results, their implementation often requires resources. The mobility of such resources requires a supportive economic environment. Thus the changes in productivity reflect, in addition to changes in the available technology, also the prevailing economic environment. For this reason, inference from actual productivity changes on the research effort and its direction is likely to yield distorted results. This, for instance, applies to the view that Japan, with relatively low land-labor ratio, has pursued land augmenting innovations, unlike the US where the innovations were labor augmenting. We have shown that in both countries the technical change had labor augmenting bias, and was labor saving. The reason that in both countries the bias is in the same direction is that mechanization has been so productive that it has had a dominant effect on the productivity changes everywhere. This does not, however, rule out other forms of technical change, and those were important and pervasive.

Another lesson is drawn from the changes in the average labor productivity. Here the rate in the US exceeds somewhat the median of the country distribution. This is due to the changes in output and in labor. The agricultural labor force in the US declined relatively fast, reflecting the rate of off-farm migration, and also the relatively low growth rate of the rural labor force. The rate of the off-farm migration has been affected favorably by the growth of the nonagricultural sector. It is expected that when such development will take place in other countries, agricultural labor will decline, following the US trail. This view asserts that the increase in the average labor productivity reflects not only the labor demand in agriculture, but also the labor demand in nonagriculture. This poses another hurdle in inferring from changes in the labor productivity on the nature of the intended research effort.

Because the implementation of changing available technology requires changes in resource allocation in the economy, the ease of such changes is an important factor in the observed productivity changes. This is a general statement that covers the physical and institutional infrastructure for flow of information and resource mobility, and lack of monopolistic bottlenecks along the road. It is suggested that the markets' performance in the US have been relatively conducive to the needed resource flow.

Appendix

I. Decomposition of inputs' response to price and augmentation effects.

The production function is $y \equiv f(v_1, ..., v_J)$, where f(.) is linear homogeneous in v. The FOC for optimal allocation, conditional on y: $f_j = p_j$, where p_j is the price of a unit of v_j, normalized by the output price. Differentiate the FOC

$$\begin{bmatrix} f_{11} & . & f_{1J} \\ . & . & . \\ f_{J1} & . & f_{JJ} \end{bmatrix} \begin{bmatrix} dv_1 \\ . \\ dv_J \end{bmatrix} = \begin{bmatrix} df_1 \\ . \\ df_J \end{bmatrix}$$

Express the differentials in terms of logs,:

$$\begin{bmatrix} f_{11} & . & f_{1J} \\ . & . & . \\ f_{J1} & . & f_{JJ} \end{bmatrix} \begin{bmatrix} v_1 & 0 & 0 \\ 0 & v_j & 0 \\ 0 & 0 & v_J \end{bmatrix} \begin{bmatrix} d \ln v_1 \\ d \ln v_j \\ d \ln v_J \end{bmatrix} = \begin{bmatrix} f_1 & 0 & 0 \\ 0 & f_j & 0 \\ 0 & 0 & f_J \end{bmatrix} \begin{bmatrix} d \ln f_1 \\ . \\ d \ln f_J \end{bmatrix}$$

Write the above as $[f_{ij}]$ [D(v)] [dln v] = $[D(f_j)]$ $[\text{dln } f_j]$, or $[D(f_j]^{-1}$ $[f_{ij}]$ [D(v)] [dln v] = $[\text{dln } f_j]$.

Decompose v to inputs in physical terms and the augmenting functions, $v_j = T_j x j$, and similarly the prices, $p_j = w_j/T_j$, where w is the normalized price of the physical input. The corresponding vectors are : [dln v] = [dln x] + [dln T], and [dln f] = [dln w] - [dln T], Label $E^- = [D(f_j)]^{-1}$ $[f_{ij}]$ [D(v)], then

E^- (dln x + dln T) = [dln w - dln T], or

$(E^- + I)$ dln T = [dln w] - E^- [dln x]

E^- is a generalized inverse of the matrix of factor demand elasticities, conditional on y,

$e_{ij} = \partial \ln v_i / \partial \ln p_j = v_j f_{ij} / f_i$, and I is the identity matrix. The result generalizes (4), (Mundlak 1968, p. 231). The identification problem, stems from the fact that we observe only x and w, and without knowing E, we cannot calculate the changes in T. In the discussion, we have determined the direction of the bias by placing boundaries on the elasticity of substitution.

II Differentiation of the condition on the extensive margin (equation 8):

Initially assume that w and c are deflated by H, and note that dx(z) vanishes by the envelope theorem. We thus write equation (8) as:

$$f(ax) = wx(z) + c/z, \qquad or \quad f(.) \equiv f(ax) \text{, then}$$

$$f'(.)x(z)da = x(z)dw - cdz/z^2 + dc/z$$

Note that $f'(.) = w/a$ and rearrange

$$zwx(z)da/a = zwx(z)dw/w - cdz/z + dc$$

$$cdz/z = zwx(z)[dw/w - da/a] + dc$$

Hence $\P \ln z / \P \ln a < 0.$ In the text, we trace the impact of H explicitly.

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TABLES

Table 1 US agriculture: growth rates (percent)

	Variables		**Average productivity**	
	1900-40	1940-90	1900-40	1940-90
Output	1	1.94		
Land	0.59	-0.44	0.41	2.38
Fertilizers	2.66	3.27	-1.66	-1.33
Labor	-0.42	-2.14	1.42	4.08
Capital	0.55	2.17	0.45	-0.23

Source: Capital and labor for 1900-1940, based on Tostlebe (1957, Tables 4 and 9). The rest is based on Gardner (2002): Output Figure 8.1, land Figure 1.1, fertilizers Figure 2.6a, labor Figures 8.1 and 8.2, Capital 1940-1990 Figure 8.4.

Table 2 US agriculture: decomposition of output growth

	1900-1940		**1940-1990**	
	TF	TFP	TF	TFP
weights 1	0.59	0.41	0.26	1.68
weights 2	0.43	0.57	-0.01	1.95
	Weights			
	w1	w2		
Land	0.3	0.3		
Fertilizers	0.15	0.1		
Labor	0.3	0.35		
Capital	0.25	0.25		

Source: author’s calculations

Table 3 US agriculture: growth rates of factor intensity (percent)

	1900-1940	**1940-1990**
Capital-output	-0.45	0.23
Capital-labor	1.04	4.31
Capital-land	-0.04	2.61
Fertilizer-output	1.66	1.33
Fertilizer-land	2.07	3.71

Source: Based on Table 1

Table 4 Average growth rates (percent)

	1800-1840	1840-1880	1880-1900	1800-1840	1840-1900
		Agriculture			Economy
Output	2.98	2.59	1.82	3.92	4.1
Labor	2.78	1.9	1.18	3.09	2.72
Capital	2.98	2.59	1.74	3.98	4.96
Land	2.8	2.17	2.17	2.8	2.17
TFP				0.59	0.74
Output/labor	0.2	0.69	0.64	0.83	1.38
Land/labor	0.02	0.27	0.99		
Capital/labor	0.2	0.69	0.56	0.89	2.24
Capital/land	0.18	0.42	-0.43		
Labor -total	3.1	2.78	2.6		
Migration rate	0.32	0.88	1.42		
Wage/land price	-1.3[a]	-2.19[b]	0		

Notes:
The source for the data in the Economy columns is Gallman (2000, p.15).
In the Agriculture columns, the variable labor-total represents the total labor force in the economy (Margo, 2000); the other variables are for agriculture.
Output/labor ratio - Based on Weiss (1993), Table 4, where output is farm gross product, including farm improvements ('broad definition').
Labor - Based on Margo (2000) Tables 5.1 and 5.3.
Output - Computed from the growth rates of labor and of output-labor ratio.
Land - 1800-1840-1900 Gallman (2000), and Gardner, Figure 1.1. The growth rate of land of 2.17 is the average for the period 1840-1900.
Capital - For the period 1840-1880 Gallman (1986, Table 4.8) reports the ratio of capital to value added in constant prices. The ratio was 2.67 in 1840 and 2.73 in 1880. For lack of better information, we assume it to be constant, and thus approximate the growth rate of capital to be the same as that of output. In the same spirit, we apply the same assumption to the period 1800-1840. For later years, the source is Tostlebe (1957, Table 9) which provides capital values starting with 1870. (Kendrick p.355, and Table B-III, modifies Tostlebe's data, but the effect on the growth rates is negligible for our discussion). The growth rate in 1880-1900 comes out close to that of the output growth.

Note, however that the rate for 1870-1880 was 3.6. Thus, the average rate for 1870-1990 is 2.35, which is in the range of the values used.

Migration rate is the difference between the growth rate of total and of agricultural labor.

Wage-land price ratio 1790-185 Christensen (1981, Table 1). For 1850 on, Olmstead and Rhode (1993 Table 1).

[a] The number is for 1790-1850

[b] The number is for 1850-1880

Table 5 US agriculture: Growth rates, selected crops (percent)

	1800-1840	**1840-1880**	**1880-1900**
		Wheat	
Output/labor	1.17	1.06	1.69
Land/ labor	1.17	1.39	1.43
Output/land	0	-0.36	0.37
		Corn	
Output/labor	0.55	1.06	1
land/ Labor	0.55	1	0.95
Output/land		0.1	0
		Cotton	
Output/labor	0.78	0.9	0.35
land/ Labor	0.78	0.31	0.3
Output/land	0	0.64	0.05

Source for crops:

Based on Rasmussen, Table 1. The source for Rasmussen is M. R. Cooper, G. T. Barton, and A. P. Brodell, *Progress of Farm, Mechanization*, U. S. Agricultural Department, Misc. Pub., No. 630. Washington D. C.: Govt. Printing Office, 1947. Land: 1800-1840-1900 Gallman (2000).

Notes: The units are: Labor-land in terms of hours of labor per acre; output-land in terms of bushels of wheat and corn per acre, and pounds of cotton per acre; labor-output in terms of labor hours per 100 bushels of wheat and corn, and hours per bale of cotton.

The rate of growth of labor-output ratio should be the difference between the rates of growth of labor -land and output-land rates. The discrepancies are due to rounding errors.

The years are defined in the source as ‘about 1800', ‘about 1840', etc.

Table 6 US agriculture: Average growth rates of selected variables (percent)

	1910-40	1940-50	1950-90	1940-90
Real ag wages	-0.32	5.45	1.43	2.22
Real land price	-2.07	1.78	1.61	1.65
wages/land price	1.75	3.67	-0.18	0.57
Farm land	0.61	0.89	-0.59	-0.3
Ag labor	-0.77	-2.5	-2.03	-2.14
land/labor	1.38	3.39	1.44	1.84
Critical σ	0.79	0.94	1	1

Source: Agricultural wages, Gardner (2002, Figure 4.4a). The wages are deflated by the GDP deflator.
Real land prices Mundlak, Larson, and Crego (1997). The prices are deflated by the CPI.
Farm land , Gardner (Op. Cit)
Agricultural labor, 1900-1940 Tostlebe (1957, Table 4), 1940 on, Gardner Figures 8.1 and 8.2.
Critical σ - positive values of σ below the critical value are consistent with labor augmenting technical change.

Table 7 US agriculture: Decomposition of technical change (percent)

	1800-40	1840-80	1880-1900	1800-40	1840-80	1880-1900
	σ=0.2			σ=0.5		
			Total agriculture			
TFP	0.19	0.56	0.15	0.19	0.56	0.19
Labor AT	0.37	1	0.76	0.86	1.92	1.13
Land AT	0.015	0.11	-0.47	0.48	-0.81	-0.85
			Wheat			
TFP	0.58	0.4	1.08	0.58	0.4	1.08
Labor AT	1.48	1.54	1.99	2.4	2.9	2.51
Land AT	-0.31	-0.75	0.19	-1.2	-2.1	-0.34
			Corn			
TFP	0.27	0.6	0.47	0.27	0.6	0.47
Labor AT	0.78	1.5	1.07	1.47	2.7	1.42
Land AT	-0.23	-0.3	-0.12	-0.92	-1.5	-0.47
			Cotton			
TFP	0.39	0.79	0.2	0.39	0.79	0.2
Labor AT	1.04	1.26	0.39	1.82	2.2	0.5
Land AT	-0.26	0.32	0.01	-1.04	-0.61	-0.01

Notes: σ is the elasticity of substitution, T_L and T_K are the labor and land augmenting terms. The calculations of the TFP are based on the values in Table 4, equations (2) and (4), and on the assumption of equal weights for land and labor. Following the discussion, we use for the growth rates of the rent-wage ratio of 1.3 for the first period, 2.19 percent for the second period and 0 for the third period.

Table 8 Margins' response to the economic environment

	Intensive (x)	**Extensive (z)**
Labor augmenting bias (α)	negative for $\epsilon > -1$	negative
Neutral TC (T)	positive	negative
Product price (p)	positive	negative
wage rate (w)	negative	positive
land charge (c)	no effect	positive

Table 9 Critical value of the elasticity of substitution - US and Japan

Growth rates	**1880-1930**	**1930-1970**	**1880-1930**	**1930-1970**
	Japan		United States	
Output	1.62	1.64	1.03	1.72
Land	0.47	-0.08	0.87	0.28
Labor	-0.18	-1.48	-0.08	-3.27
Output/land	1.15	1.73	0.16	1.43
Output/labor	1.79	3.13	1.1	4.99
Land/labor	0.64	1.38	0.94	3.5
Wage/land price	-0.89	1.97	0.9	0.16
Critical σ	1	0.7	1	1

Source: Ruttan and Binswanger (1978, Tables 3-1 and 3-2). Except for the last raw, the entries are average annual growth rates in percent.

Critical σ - Positive values of σ below the critical value are consistent with labor augmenting technical change.

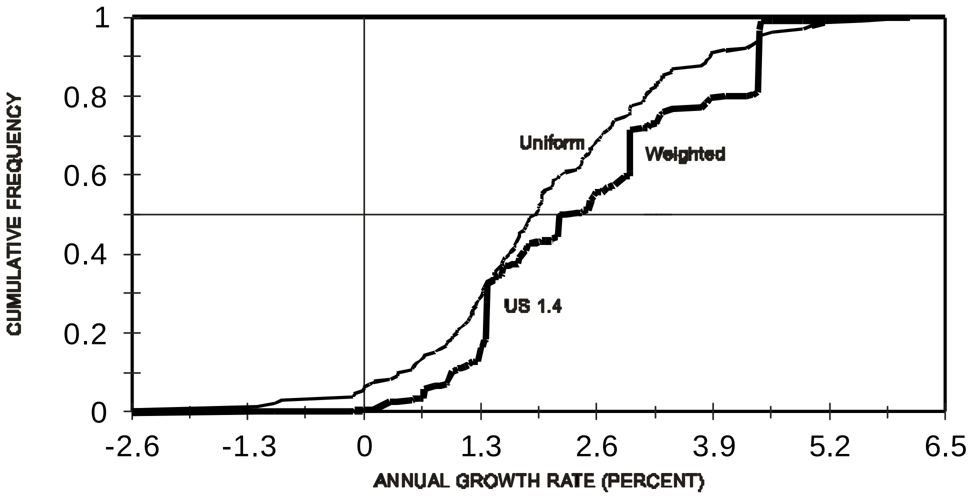


FIGURE 1 TOTAL AGRICULTURAL PRODUCTION
130 COUNTRIES (1967-1992)

Source: Mundlak, Larson, and Crego (1996)

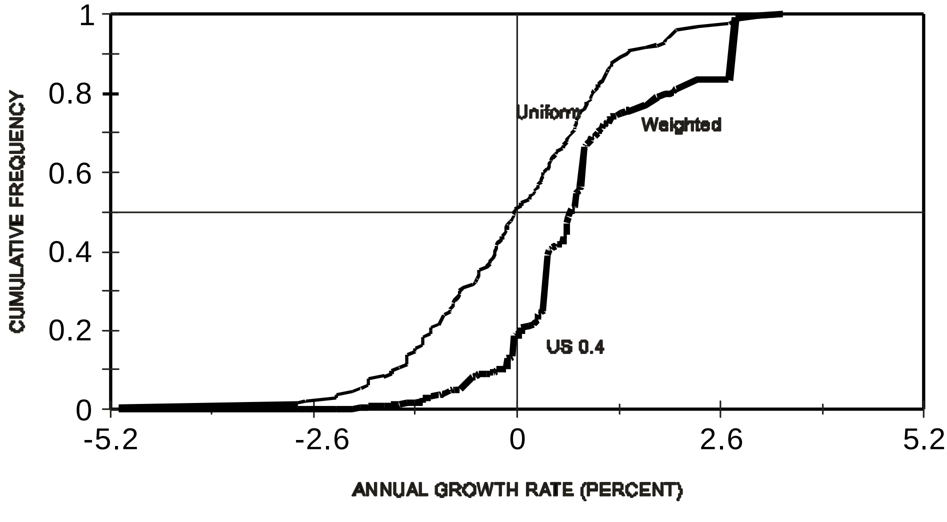


FIGURE 2 PER CAPITA AGRICULTURAL PRODUCTION
130 countries (1967-1992)

Source: Mundlak, Larson, and Crego (1996)

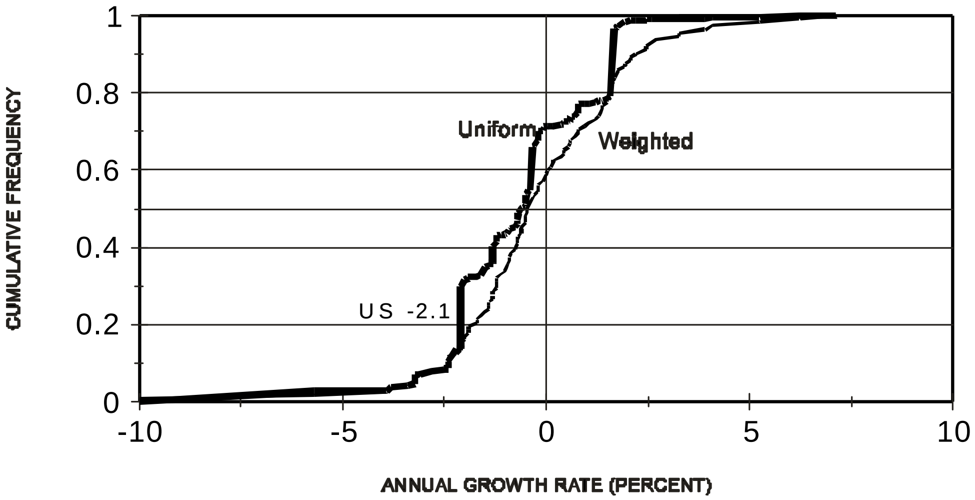


FIGURE 3 AGRICULTURAL PRICES
112 COUNTRIES (1967-1992)

Source: Mundlak, Larson, and Crego (1996)

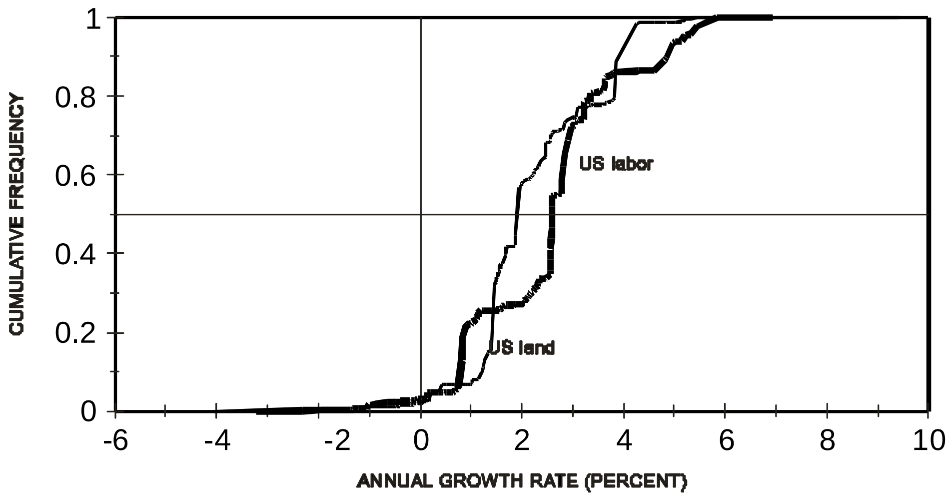
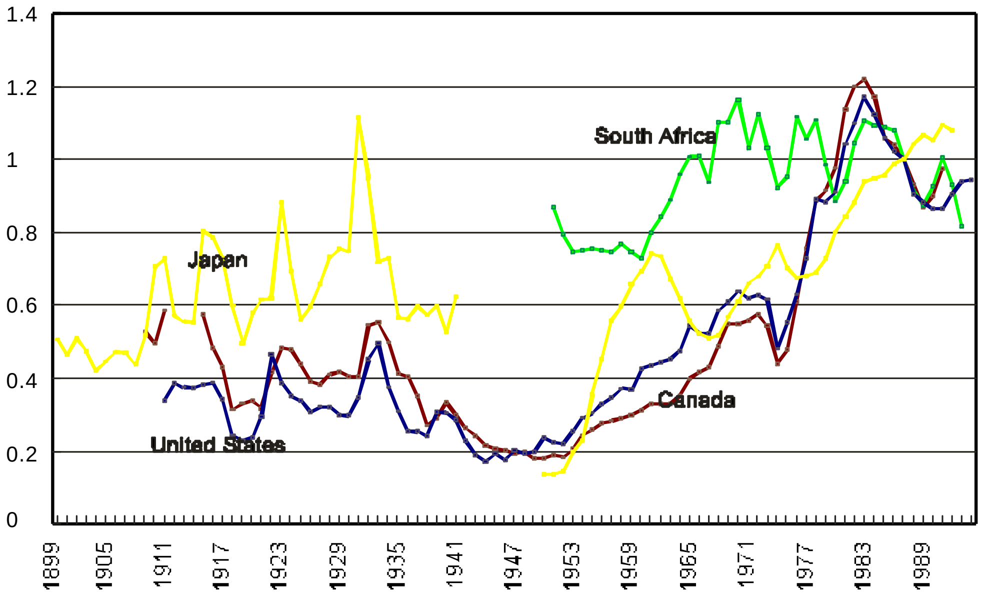


FIGURE 5 LABOR AND LAND PRODUCTIVITY
87 COUNTRIES (1960-1992)

Source: Mundlak, Larson, and Crego (1996)

OUTPUT UNITS



Source: Mundlak, Larson, and Crego (1998)

CONSUMPTION UNITS

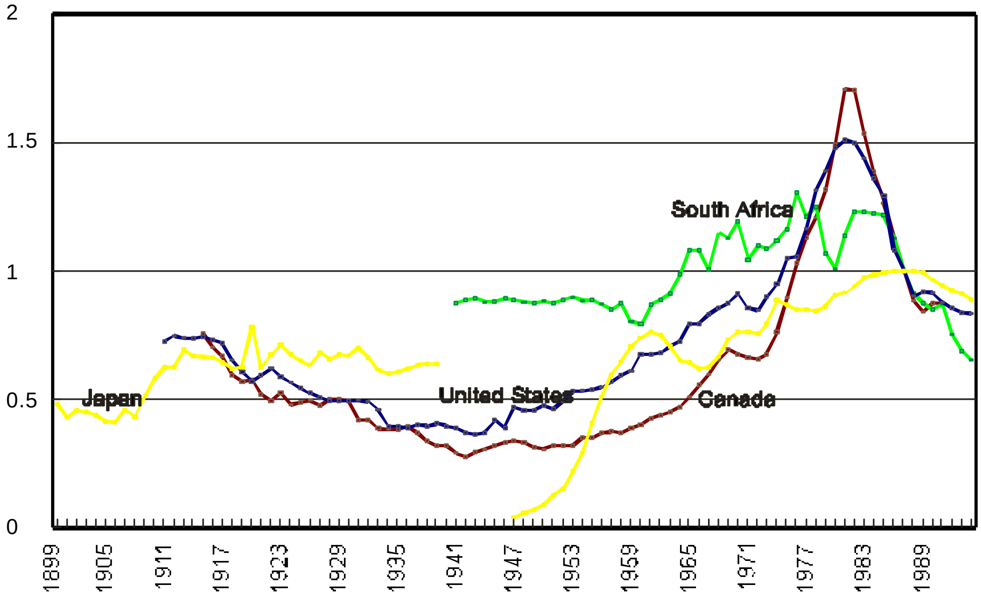


FIGURE 4 REAL LAND PRICE

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