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Shenggen Fan
Vernon W. Ruttan

ECONOMIC DEVELOPMENT CENTER
Department of Economics, Minneapolis
Department of Agricultural and Applied Economics, St. Paul

UNIVERSITY OF MINNESOTA

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Abstract

Induced Technical Change in Centrally Planned Economies

It has generally been assumed that the inferences of the induced technical change model with respect to the direction of technical change could not be expected to hold for the centrally planned economies. In this paper we test three hypotheses generated from the induced technical change hypotheses against the experience of centrally planned economies: (a) if land becomes increasingly scarce new technology will be biased in a land-saving direction; (b) if labor becomes increasingly scarce new technology will be biased in a labor-saving direction; and (c) changes in the land-labor ratio have been induced by changes in relative factor endowments. The results suggest a bias toward mechanical and against biological technology regardless of factor endowments. This is consistent with the well known ideological or policy bias in a number of centrally planned economies toward a capital intensive development strategy.

INDUCED TECHNICAL CHANGE IN CENTRALLY PLANNED ECONOMIES

by

Shenggen Fan and Vernon W. Ruttan*

The importance of technical change as a central element in modern economic growth has been accepted as almost self-evident since at least the middle of the nineteenth century. But it was not until the 1950s that economists began to develop the methodology to measure the contribution of technical change to economic growth (Schmooker 1952; Ruttan 1956; Solow 1957).

The primary focus of the early studies on technical change was simply to measure the contribution of technical change, relative to conventional inputs, to growth in output. Major effort was devoted to attempts to partition growth in output per unit of total input among conventional factors of production and a set of non-conventional factors including advances in knowledge and improvements in the quality of physical and human capital.[1] Technical change was viewed as a response to the economic opportunities resulting from advances in scientific and technical knowledge that were, themselves, exogenous to the economic system.

***Shenggen Fan is Research Associate, International Service for National Agricultural Research (ISNAR), The Hague, Netherlands. Vernon W. Ruttan is Regents Professor, Department of Agricultural and Applied Economics and Department of Economics, University of Minnesota.** **The authors are indebted to Karen Brooks, Justin Yifu Lin, and C. Bonte-Friedheim for comments on an earlier draft of this paper.**

In the mid-1960s, however, increasingly serious efforts were being made to explore the influence of economic forces on the rate and direction of technical change.
Models in which the rate of technical change was induced by growth in demand were employed by Zvi Griliches (1957) in studies of technical change in agriculture and by Jacob Schmookler (1966) to explore differential rates of technical change among industries.

Efforts to interpret the direction (or bias) of technical change in economic terms drew its inspiration from Sir John Hicks famous assertion that changes or differences in the relative prices of factors of production could be expected to influence the direction of invention or innovation (Hicks, 1932: 124-25). In response to criticism of the Hicks perspective by W.E.G. Salter (1960: 43-44) alternative "factor price induced" models of technical change were proposed by Charles Kennedy (1964) and Syed Ahmed (1966). The Ahmed model, which was built directly on Hicks' micro-economic foundations, has been more productive in generating empirical research than the Kennedy "growth theory" approach.[2]

The initial tests of the induced technical change model in agriculture by Hayami and Ruttan (1970; 1971: 111-135) demonstrated that differences and changes in relative factor prices offered a powerful explanation for differences in the direction of technical change in Japan and the United States during the period 1880-1960. In Japan advances in biological technology facilitated the substitution of chemical inputs (such as fertilizer) for land. In the United States advances in mechanical technology facilitated the substitution of mechanical technology (such as mechanized motive power) for labor.

Subsequent research by Binswanger (1974), Binswanger and Ruttan (1978), Hayami and Ruttan (1985) and a number of colleagues have contributed to the development of a more rigorous methodology for testing the induced technical change hypothesis. By the late 1980s the model had been tested against the experience of a large number of developed market economies (Thirtle and Ruttan, 1987: 49-73; Hayami and Ruttan, 1985: 163-205). In a review of the literature on agricultural development C. Peter Timmer used the induced technical change model as the dominant paradigm for the interpretation of the role of technical change in agricultural development (Timmer, 1989).

Relevance to Centrally Planned Economies

It has generally been assumed that the inferences of the induced technical change model with respect to the direction of technical change could not be expected to hold for the centrally planned economies. In the developed and developing market economies reasonably well-functioning factor and product markets have been regarded as essential for interpreting changes or differences in relative resource endowments - such as land-fertilizer, labor-horsepower, and land-labor ratios - to economic agents such as research institutions and farm operators. The presence of bias in relative factor prices could be expected to distort inducements to invent and adopt land-saving biological technology or labor-saving mechanical technology. Such biases have been shown to distort not only technology choices but also technology development (de Janvry, 1973).

In the centrally planned economies land markets are usually absent and labor and capital markets are severely distorted. It might be argued that if central planning is a perfect substitute for the market the factor saving character of technical change would be similar in a centrally planned economy as in a market economy with similar resource endowments. But there is now ample evidence that in the absence of markets planners and agents have few guides to efficient resource allocation either in research or production.

Wilken has argued, however, that in partially liberalized centrally planned economies, such as Poland and Hungary, a combination of decentralized decision making and market incentives are capable of driving the agricultural sector along a path of technical change similar to that implied by the induced technical change model (Wilkin, 1987). Justin Yifu Lin (1990) has made an important theoretical contribution by demonstrating that both the "demand induced" and "factor induced" models can be expected to hold even in economies where market exchanges of the primary factors, land and labor, are prohibited and product markets are constrained as long as producers can exercise choices with respect to factor input ratios and product mix. Lin's argument is that as a primary factor becomes increasingly scarce (or abundant) the marginal product of the factor will rise (decline) as farmers will search for technology that save the increasingly scarce factor and use the increasingly abundant factor. Lin then proceeds to demonstrate that the allocation of research resources in China's agricultural research institutions has been responsive to differences in resource endowments and market demand among provinces.

In Figure 1 we illustrate the process of induced technical change. P_1 represents the meta-production function (or envelope of regional production functions) at time 1. P_2 represents the innovation possibility curve. Curves a, b and c represent the neoclassical production functions available to producers at each point in time or at each location.[3] At time 1, for a region with factor ratio R_1, the optimal choice of technology is at point A. Assume that, as a result of population growth the factor ratio shifts from R_1 to R_2 between time 1 and time 2. However, as a result of the technical change, the optimal choice of technology is C rather than B at time 2. The shift from A to C can be visualized as two discrete steps. The change from A to B results from technical change that permits factor substitution but no gain in efficiency. The move from B to C results in a gain in efficiency associated with technical change. When the new regional production function becomes available the farmer's choice of technology and factor inputs will be at point C.

We can illustrate this process using China and USSR as examples. Since 1949, the Chinese government has put great effort into encouraging the invention of new biological technology to relieve the constraint of land on agricultural production. In 1956, Chinese scientists initiated a breeding program that led to the development of high-yielding dwarf indica varieties of rice. These varieties had high yield potential, were responsive to fertilizer, and were relatively resistant to lodging and disease (Hsu, 1982). With adequate fertilizer and water, the farmers produced yields of 5-6 metric tons per hectare, comparable to those of the IR-8 dwarf rice developed at the International Rice Research Institute in the Philippines. The Chinese varieties, however, had a shorter growing period of 110-115 days, making it possible to expand the double cropping of rice in the South and Southeast and therefore releasing the constraint of limited land input on production. By 1977, these varieties were grown in more than 80% of China's total rice land. The breeding of high yielding varieties of wheat and other crops began in the 1960s. Although the results were not as significant as those for rice, the introduction and diffusion of new wheat varieties have contributed greatly to wheat production in the North (Fan, 1990; 1991).

The resource endowments in the U.S.S.R. are very different from those in China. Land is abundant and labor is relatively scarce. As the country industrialized, labor migrated from rural to urban areas making labor an even more important constraint on agricultural production. Tractors were introduced in the 1920s and 1930s. Foreign agricultural equipment was purchased and used as models for redesign and production in the USSR (Dalrymple, 1964). Equipment with power-take-off was developed to integrate the power and operating units that give the tractor driver control over the attached equipment. Trailer operators were no longer required for most types of agricultural work because the tractor drivers could plough, cultivate, or sow using one-axle, two axles, or multiple hitches of a vertical or horizontal type. Increasingly powerful tractors were developed and imported in order to reduce labor requirements. The numbers of tractors increased from 1.122 million units to 2.798 million units and average power per tractor increased from 42.7 to 80.9 horsepower from 1960 to 1985 (Medvedev, 1987).

These factor ratios, when interpreted by the induced technical change model, suggest that technical changes in agriculture in China and the USSR were consistent with the changes in the land-labor and other factor ratio changes even though, in both countries, institutional constraints limited the productivity growth that might have been expected from an increasingly modernized agricultural system.

Testing the Induced Technical Change Hypothesis against the History of Centrally Planned Economies

In this section we present a "plausibility test" of the "factor induced" technical change hypothesis against the history of factor productivity growth differences in the centrally planned economies for the period 1950-1980.[4] We chose Bulgaria, Czechoslovakia, East Germany, Hungary, Poland, Romania, Yugoslavia, the Soviet Union, and China as our sample to represent the centrally planned economies. We have several reasons for testing the technical change hypothesis in socialist countries against the experience of the nine countries. (1) China and the USSR represent extremes in terms of resource endowments. China has little land and much labor. The USSR has a great deal of land but relatively scarce labor. (2) The other countries fall somewhere between China and the USSR in terms of relative resource endowments. (3) There has been a slowdown of agricultural productivity growth and the increased imports of food and feed by the East European centrally planned countries in recent years. (4) The recent successful institutional innovations in China which involve a return to household production have improved both production and productivity growth.

Among the socialist countries, Romania, Yugoslavia and China have experienced the most rapid rates of growth. Poland and Czechoslovakia have experienced the slowest rates of growth. Other countries fall between the above two groups. Except for China, all centrally planned countries have experienced an increase in their land-labor ratios (Table 1). The land-labor ratio has deteriorated since 1950 in China because of the rapid population growth and slow growth in demand for labor in the non-agricultural sectors. In the land-scarce countries land productivity growth is generally faster than labor productivity growth. In labor-scarce countries, labor productivity growth is generally faster than land productivity growth. Figure 2 is consistent with our earlier observation that China has experienced land-saving technologies and the Soviet Union, East Germany, Czechoslovakia and Hungary experienced relatively labor-saving technology. Romania, Yugoslavia and Poland appear to have experienced relatively neutral technology growth paths.

The empirical "plausibility" tests of the induced technical change model for the centrally planned economies presented below are based on three hypotheses generated from the model. The first two are "single factor ratio" tests. The third is a "two factor ratio" test.

In Table 2 we present a test of the hypothesis that if land becomes increasingly scarce new technology will be biased in a land-saving direction. To test this hypothesis we regress the fertilizer-land ratio against the five year time lagged labor-land ratio. To be consistent with the hypothesis the labor-land coefficient must be positive. (The machinery-land ratio and time trend are also included without specifying expected signs). The signs of the coefficients are consistent with the hypothesis for only two countries - China and the USSR. Therefore, for most of the centrally planned economies the test was inconsistent with the hypothesis that biological technology has been induced by changes in the labor-land ratio.

In Table 3 we present a test of the hypothesis that if labor becomes increasingly scarce new technology will be biased in a labor-saving direction. To test this hypothesis we regress the machinery-labor ratio against the five year time lagged land-labor ratio. To be consistent with the hypothesis the coefficient of the land-labor ratio must be positive. (The fertilizer-labor ratio and time trend are also included without specifying expected signs).

The signs of the coefficients of the land-labor ratio are consistent with the hypothesis except in Bulgaria, Poland, Romania and China. Thus the test is consistent with the experience of the countries which are the least labor intensive. For the centrally planned economies as a group, however, it would be imprudent to claim much more than that the single factor test is not inconsistent with the hypothesis that mechanical technology has been induced by changes in the land-labor ratio.

In Table 4 we present a test of the hypothesis that changes in the land-labor ratio itself has been induced by changes in relative factor endowments. To test this hypothesis we regress the land-labor ratio against both the five year time lagged fertilizer-land and machinery-labor ratios. To be consistent with the hypothesis the fertilizer-land coefficient must be negative and the machinery-labor coefficient ratio must be positive. The signs of the fertilizer-land coefficients are consistent with the hypothesis only for China. The signs of the machinery-labor coefficients are consistent with the hypothesis for five of the nine countries. And the coefficients are significant at conventional levels except for the Soviet Union and Bulgaria.

It is of interest that there is a bias toward mechanical and against biological technical change regardless of factor endowments. This is consistent with the well known ideological or policy bias in a number of centrally planned economies toward a capital intensive development strategy.

Implications

It has been wildly recognized that the absence of effective product markets has acted as a severe constraint on the rate of technical change and on the rate of growth in agricultural production in a number of centrally planned economies. The analysis presented in this paper suggests that the absence of effective markets has also resulted in a less efficient path or direction of technical change than might have been expected given the differences and changes in factor endowments. More efficient factor markets, particularly the markets for capital and operating inputs might have induced a path of technical change that exhibited greater consistency with the direction implied by the induced technical change model. The conclusion should, of course, be tempered by the fact that the absence of factor price data, resulting from missing or inadequate factor markets, made it difficult to develop a fully rigorous test of the induced technical change hypothesis against the experience of the centrally planned economies.

The liberalization that has been underway in China, Poland and Hungary for over a decade and is now underway in a number of other centrally planned economies will provide, in the near future, a chance to conduct more rigorous tests of the induced innovation hypothesis. In China liberalization resulted in unprecedented rates of growth in productivity and output between 1980-1986 (Fan, 1989). As liberalization in other countries continues it will be possible to test the implications of the induced technical change hypothesis on the rate and direction of technical change in the formerly centrally planned economies more rigorously.

Figure 1. Technical Change Induced by Factor Ratio Change

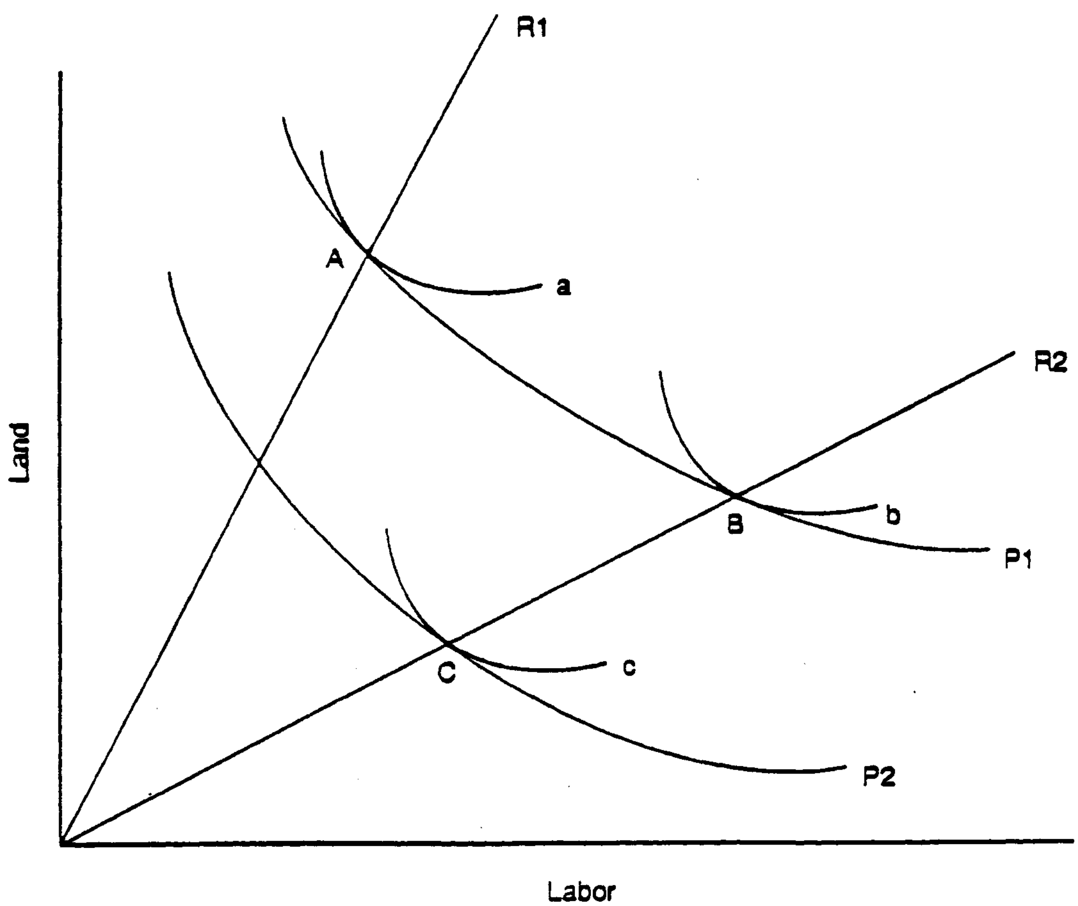
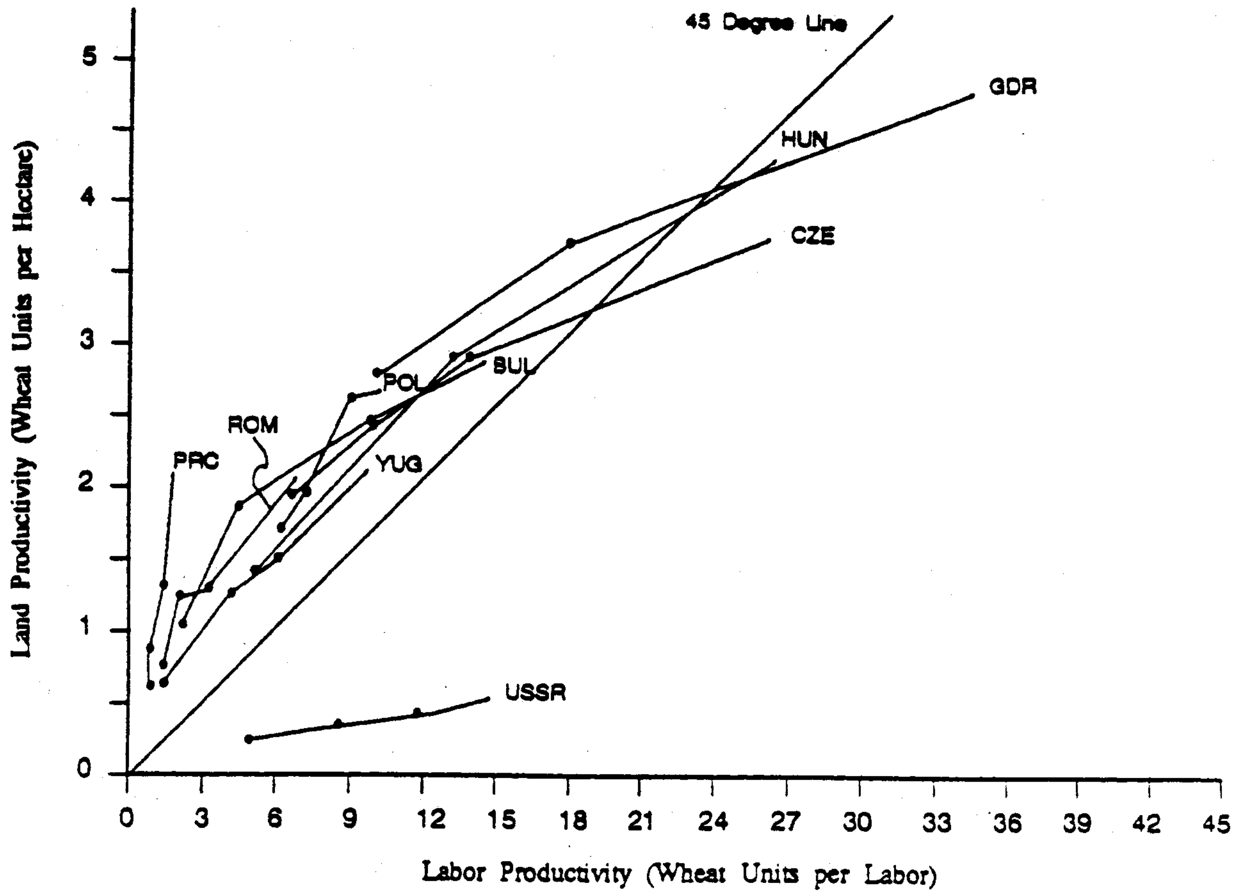


Figure 2. Comparison of Productivity Trends (1950, 1960, 1970, 1980)



Source: Lung-Fai Wong, 1986. Agricultural Productivity in the Socialist Countries. Boulder: Westview Press.

Table 1: *Agricultural Output, Partial Productivity, and Resource Endowments (1950-1980)*

	Year	BUL	CZE	GDR	HUN	POL	ROM	YUG	USSR	PRC
Agricultural	1950	100	100	100	100	100	100	100	100	100
Output Index[a]	1960	161	114	145	133	123	172	200	137	122
	1970	216	134	149	159	154	197	242	204	211
	1980	253	175	194	244	152	347	332	226	324
Labor	1950	2.43	7.16	11.36	5.27	6.08	1.67	1.71	5.51	1.31
Productivity	1960	4.69	10.69	19.85	7.99	7.65	2.64	3.96	8.00	1.46
(Wheat Units	1970	9.97	16.81	26.32	14.91	9.76	3.21	5.75	13.06	2.07
Per Labor)[b]	1980	16.46	27.12	37.19	27.44	11.61	6.28	9.65	15.14	2.39
Land	1950	1.18	1.97	2.86	1.50	1.61	.73	.68	.27	.65
Productivity	1960	1.92	2.35	3.79	2.07	1.99	1.23	1.27	.38	.88
(Wheat Units	1970	2.42	2.79	4.00	2.56	2.60	1.34	1.56	.57	1.47
Per Labor)[c]	1980	2.76	3.77	4.94	4.08	2.64	2.41	2.20	.63	2.20
Land/Labor	1950	2.06	3.64	4.40	3.50	3.77	2.31	2.50	20.40	1.98
Ratio	1960	2.45	4.55	5.24	3.86	3.84	2.15	3.12	21.01	1.66
(Hectares Per	1970	4.11	6.02	6.58	5.83	3.75	2.35	3.67	22.95	1.41
Labor)	1980	5.96	7.19	7.53	6.72	4.40	2.61	4.56	24.00	1.09

Source: The data used for this study is compiled by Lung-Fai Wong (1986).

[a]Output is measured as metric tons of the wheat units.
[b]Labor is defined as economically active population including all working farmers, their wives working in agriculture, helping members, and hired labor, measured in full-time man years.
[c]Land is defined as the total area of arable land, permanent crop land, permanent pasture and meadows, measured in hectares.

Table 2: *Regression of Fertilizer-Land Ratio on Labor-Land and Machinery-Land Ratios*

Country	Coefficients of labor/land	Coefficients of machinery/land	Coefficients of trend	R^2	Standard Error of Estimate	Durbin-Watson Statistics
Bulgaria	-.759 (-3.99)[a]	-.107 (-.497)	.551 (2.45)[a]	.987	.006	1.472
Czech.	-2.836 (-3.03)[a]	-.517 (-.76)	.606 (1.26)	.942	.157	.872
E. Germany	-3.519 (-3.32)[a]	-2.115 (-2.04)[b]	.527 (3.47)[a]	.918	.151	.929
Hungary	-.580 (-.18)	.543 (.54)	-.241 (-.321)	.900	.180	.461
Poland	-4.353 (-7.21)[a]	1.257 (20.70)[a]	-.107 (-2.21)[a]	.944	.064	1.076
Romania	-2.290 (-2.39)[a]	.411 (7.33)[a]	-.335 (-3.132)[a]	.975	.078	1.640
Yugos.	-7.839 (-6.67)[a]	-.675 (-.24)	.694 (.249)	.907	.315	.786
USSR	15.129* (5.09)[a]	.948 (6.69)[a]	.138 (7.66)[a]	.947	.084	1.592
China	5.859* (6.93)[a]	-.277 (-1.63)[c]	1.149 (7.18)[a]	.994	.0923	1.711

[a]The regression model is: $\log(F/A)_t = a + b\log(L/A)_{\bar{t}} + c\log(M/A)_{\bar{t}} + d\log(T)$. A is agricultural land (hectares); F is fertilizer input (Kg.); M is machinery input (horsepower); and T is time trend. The subscript t denotes the observation at t, and $\bar{t}$ denotes the average of five years proceeding the year t, i.e., the average from t-1 to t-5. The data are time series from 1950 to 1980.
[b]The two stage least squares (2SLS) technique is employed for the estimation and labor is used as an instrument variable for machinery/land ratio. The Prais-Winsten method is also used to avoid the autocorrelation in the disturbance term.
[c]The numbers in parentheses are T test values. a indicates significance at 5% level; b indicates significance at 10% level; and c indicates significance at 20% level.
[d]*denotes sign is consistent with hypothesis.

Table 3: *Regression of Machinery-Labor Ratio on Land-Labor and Fertilizer-Labor Ratios*

Country	Coefficients of			R^2	Standard Error of Estimate	Durbin-Watson Statistics
	horsepower/labor	fertilizer/labor	trend			
Bulgaria	-4.818 (-.635)	3.343 (.812)	-.745 (-.36)	.958	.254	1.833
Czech.	.362* (.101)	.282 (.212)	.605 (.914)	.982	.111	1.435
E. Germany	1.330* (.555)	-.371 (-.295)	.252 (.731)	.793	.127	1.285
Hungary	4.043* (.972)	-.444 (-.209)	.970 (.803)	.988	.144	.982
Poland	-5.207 (-3.803)[a]	.863 (9.574)[a]	-.001 (-.021)	.987	.081	1.683
Romania	-6.280 (-2.383)[a]	2.020 (3.422)[a]	.694 (1.97)[b]	.992	.137	2.081
Yugos.	4.731* (2.340)[a]	-.307 (-1.604)[c]	.597 (7.25)[a]	.988	.080	1.669
USSR	.285* (.046)	2.649 (3.178)[a]	-.261 (-1.75)[b]	.992	.085	1.809
China	-20.781 (-2.547)[a]	-7.468 (-2.105)[a]	10.162 (2.27)[a]	.954	1.185	.542

[a]The regression model is: $\log(M/L)_t = a + b\log(A/L)_{\bar{t}} + c\log(F/L)_{\bar{t}} + d\log(T)$. A is agricultural land (hectares); F is fertilizer input (Kg.); M is machinery input (horsepower); and T is time trend. The subscript t denotes the observation at t, and $\bar{t}$ denotes the average of five years proceeding the year t, i.e., the average from t-1 to t-5. The data are time series from 1950 to 1980.

[b]The two stage least squares (2SLS) technique is employed for the estimation and labor is used as an instrument variable for fertilizer/labor ratio. The Prais-Winsten method is also used to avoid the autocorrelation in the disturbance term.

[c]The numbers in parentheses are T test values. a indicates significance at 5% level; b indicates significance at 10% level; and c indicates significance at 20% level..

[d]*denotes sign is consistent with hypothesis.

Table 4: *Regression of Land-Labor Ratio on Fertilizer-Land and Machinery-Labor Ratios*

Country	Coefficients of fertilizer/land	machinery/labor	trend	R^2	Standard Error of Estimate	Durbin-Watson Statistics
Bulgaria	.948 (6.163)[a]	.058* (.696)	-.462 (-9.51)[a]	.990	.034	1.534
Czech.	.129 (1.109)	.262* (2.490)[a]	-.173 (-4.27)[a]	.976	.031	2.096
E. Germany	.216 (1.091)	-.387 (-5.314)[a]	-.102 (-1.81)[b]	.981	.027	1.339
Hungary	.066 (.180)	.206* (2.219)[a]	-.154 (-1.04)	.979	.034	1.828
Poland	.328 (8.712)[a]	-.351 (-7.119)[a]	-.003 (-.32)	.866	.016	1.705
Romania	.596 (10.777)[a]	-.160 (-7.800)[a]	-.022 (-1.251)	.638	.032	1.514
Yugos.	.064 (28.364)[a]	.459* (25.815)[a]	-.451 (-24.94)[a]	.945	.029	1.243
USSR	.0205 (.151)	.0346* (.924)	.003 (.126)	.945	.0109	1.408
China	-.235* (-13.266)[a]	-.117 (-6.977)[a]	.416 (22.92)[a]	.977	.034	1.296

[a]The regression model is: $\log(A/L)_t = a + b\log(F/A)_{\bar{t}} + c\log(M/L)_{\bar{t}} + d\log(T)$. A is agricultural land (hectares); F is fertilizer input (Kg.); M is machinery input (horsepower); and T is time trend. The subscript t denotes the observation at t, and $\bar{t}$ denotes the average of five years proceeding the year t, i.e., the average from t-1 to t-5. The data are time series from 1950 to 1980.

[b]The two stage least squares (2SLS) technique is employed for the estimation and labor and land are used as instrument variables for fertilizer/land and machinery/labor ratios respectively. The Prais-Winsten method is also used to avoid the autocorrelation in the disturbance term.

[c]The numbers in parentheses are T test values. a indicates significance at 5% level; b indicates significance at 10% level; and c indicates significance at 20% level.

[d]*denotes sign is consistent with hypothesis.

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ENDNOTES

[1]See particularly the set of reprints assembled by the Brookings Institution containing a series of exchanges on productivity by Dale W. Jorgenson, Zvi Griliches and Edward Dennison (1972).

[2]The Kennedy "growth theory" and the Ahmed "micro-economic" interpretations of the induced innovation perspective led to an extended theoretical debate. See the review of the debate in Thirtle and Ruttan (1987), pp. 22-48.

[3]For a more complete discussion of the concept of the meta-production function, Hayami and Ruttan, 1985: 133-137; Thirtle and Ruttan, 1987: 24-34.

[4]The data used as a basis for the list are drawn from Wong (1986) and Fan (1989). We term the test a "plausibility test" because we are forced to substitute factor use ratios for the factor ratios that were used as in price dependent variables in the more rigorous tests employed by Binswanger and Ruttan (1978: 215-242) and Hayami and Ruttan (1985: 187-205).

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