# INFRASTRUCTURE AND AGRICULTURAL PRODUCTION: CROSS-COUNTRY EVIDENCE AND IMPLICATIONS FOR CHINA

Fabrizio Felloni, Thomas Wahl, Philip Wandschneider, and John Gilbert[1]

TWP-2001-103

Please direct correspondence to:

Thomas I. Wahl
IMPACT Center
123 Hulbert Hall
Washington State University
PO Box 646214
Pullman, WA 99164-6214
Ph: (509) 335-5563
Fax: (509) 335-3958
e-mail: wahl@wsu.edu

[1] The authors are, respectively, Graduate Research Assistant, Department of Agricultural Economics, Washington State University; Director, IMPACT Center and Associate Professor, Department of Agricultural Economics, Washington State University; Associate Professor; Department of Agricultural Economics, Washington State University; and Assistant Professor, Department of Agricultural Economics, Utah State University.

**INFRASTRUCTURE AND AGRICULTURAL PRODUCTION: CROSS-COUNTRY EVIDENCE AND IMPLICATIONS FOR CHINA**

## ABSTRACT

This study uses cross-sectional data from 83 countries and 30 provinces in China to assess the effect of transportation infrastructure and electricity on agricultural production and productivity. Evidence from both datasets suggests that, in accordance with economic theory, the density of roads and the availability of electricity are significant predictors of production and productivity in agriculture.

These results are particularly interesting for China, where, in the past twenty years, the increase in Chinese agricultural output, specialization and mobility in rural areas has been impressive. Results of the analysis suggest that access to transportation infrastructure and electricity will be crucial in the modernization of Chinese agriculture.

**Keywords:** Chinese Agricultural Development, Transportation and Agriculture, Transportation and Development

# INFRASTRUCTURE AND AGRICULTURAL PRODUCTION: CROSS-COUNTRY EVIDENCE AND IMPLICATIONS FOR CHINA

## Introduction

The extraordinary importance of roads and transportation as a driving force behind economic development has been recognized in Western thought since at least the second half of the eighteenth century. Before Adam Smith, the French physiocratic school had brought attention to the importance of investment in public works ("*avances souveraines*") such as bridges, aqueducts, and roads, in the reduction of costs of transportation of commodities (in particular agricultural products), and the creation of national markets, allowing prices to signal and regulate relative scarcity or abundance of resources in different regions.

In the 20$^{th}$ century, beginning with the 50s, the expansion and improvement of transportation and infrastructure was regarded as a necessary pre-condition to the accumulation of capital and the rise in production and productivity in Third World countries (Rostow). Fromm classifies the contributions of transportation to economic development under four main aspects: transportation (i) provides better access to market of inputs and final products and promotes the access of remoter areas to monetized exchanges, (ii) shifts the production possibility frontier by reducing production costs, (iii) enhances a more efficient allocation of factors and, (iv) by sharing characteristics of both private and public consumption goods, transportation increases the mobility of individuals and provides positive externalities (e.g., better social services and access to education) to the economy.

These established judgements about transportation were slightly revised during the 1960s, based on critiques by, among others, Hirshmann and Fogel. The importance of infrastructure has never been seriously questioned. Even if transportation cannot be claimed as the (only) origin of sustained growth, it is, without doubt, one of its vital ingredients. Nevertheless, the observations of Hirshmann and Fogel are important in at least one respect: the relative scarcity of data has been a major constraint on empirical analysis of the relationship between the development of infrastructure and the growth of a specific sector or the whole economy. Hence there are comparatively few empirical studies in this important area.

In this study we extended and updated earlier studies conducted by Antle and Benziger, to test the impact of infrastructure on aggregate agricultural production and productivity. We used both international cross-country and Chinese datasets. The remainder of the paper is organized as follows: we first describe a cross-country analysis of the effect of infrastructure on agricultural output and productivity. We then apply similar techniques to Chinese provincial data. Our results indicate that transportation and energy are significant explanatory variables of the aggregate value of agricultural production, and of agricultural productivity in China. Concluding comments and policy implications of our results are contained in the final section.

## Cross Country Analysis

Recent attempts at statistically investigating the relationship between roads and national income are available in Querioz and Gautam, and Canning. The Querioz and Gautam study combines a cross-section analysis of data from 98 countries and a time series analysis on U.S. data from 1950 to 1988. Their results indicate that the density of roads (km of roads/capita) has a positive and significant effect on GNP, but the simple regression technique used implicitly assumes that other factors do not interact in the determination of income per capita. Canning's analysis highlights the complexity of the infrastructure/growth relationship. Non-transportation infrastructure increases one-to-one with population, but more than proportionately with GDP per capita. Transportation increases less than proportionately with population and increases with GDP per capita after a "middle income threshold" has been met.

Studies that directly analyze the link between agricultural (as opposed to total) output and infrastructure are scarce. Antle uses a production function approach with data from 66 countries, for the year 1965. The dependent variable is the value of the gross national agricultural production, while the explanatory variables are agricultural land area, active population in agriculture, consumption of chemical fertilizers and stock of live animals, secondary school enrollment ratio (as a proxy for human capital) and gross national output of transportation and communication industries per land unit (as a measure of infrastructure). With the exception of education, all of the variables are found to be significant.

Following Antle, we ran a regression based on data available for 83 countries for the year 1991 and adopted an econometric model based on a Cobb-Douglas production function:[1]

(1) $$\ln Y_j = a_0 + \sum_{i=1}^{k} b_i \ln X_{ij} + d_1 HINC_j + d_2 LINC_j + u_j,$$

where $Y_j$ is the value of the agricultural production (1,000,000 USD), the $X_{ij}$ are factors of production: active agricultural population (1,000 persons), agricultural land (1,000 ha), chemical fertilizers (1,000 tons), infrastructure (value in USD of gross output of the transportation and energy sectors divided by the total country land area), and adult literacy (as a proxy of human capital). Two control variables, $HINC_j$ and $LINC_j$ are included to account for the general productivity level in high and low income countries respectively;[2] $u_j$ is the error term under standard OLS assumptions. GNP data, the value of agricultural production and gross output in the transportation, communication, and energy sectors were collected from the *United Nations Statistical Yearbook*. Data on agricultural land, active agricultural population, chemical fertilizers and tractors were retrieved from the FAO online statistical database. Estimated rates of adult literacy were collected from the UNESCO online database.

Results of the analysis are displayed in Table 1. The estimated coefficients represent elasticities, t-ratios are presented in brackets. Five equations have been estimated, to represent the effects of the introduction of different regressors. Five variables have a positive and significant coefficient in all the equations: (i) the active agricultural population (estimates range from 0.431 to 0.683), (ii) the number of tractors (0.173 to 0.216), the dummies representing (iii) high and (iv) low income countries (0.902 to 1.127 and -0.677 to -0.914 respectively), and (v) the indicators of infrastructure, respectively energy, transportation and the sum of the two in equations 3, 4 and 5.

The significance of chemical fertilizer was reduced as we controlled for low-income countries: this suggests that disadvantages in factor endowment are embedded in this control variable, in addition to other institutional factors. The introduction of transportation in equations 4 and 5 clearly increased the significance of agricultural land, suggesting that the abundance of land becomes of crucial importance when a modern transportation sector is available to improve access to markets and factor allocation. Human capital, as measured by the adult literacy rate, took low and non significant coefficient values in all of the equations, probably because international differentials in know-how and relative abundance of skilled and semi-skilled labor are better represented by controlling for the category of country income.

On the whole, the model seems to provide a good explanatory framework, always explaining more than 84% of the variance in the dependent variable. There is, however, an important critique of this specification: the output of the transportation, communication and energy sectors per unit of land is an indicator of the flow of infrastructure resources and does not directly measure the stock of the available infrastructure. Thus, our analysis provides stylized facts about the production of goods and services in the sector of transportation (corresponding to operating, maintenance and current investment expenditure), but is silent on the effect of the quantity and quality of capital accumulated over the years.

Another perspective from which we can consider the effects of infrastructure on the agricultural sector is productivity. The methodology adopted is the same as above and the model specification has an analogous functional form with respect to equation (1), with the exception that the dependent variables in the two new regressions are defined respectively as:

$$AVPL = \frac{\text{Value of Agricultural Production (USD)}}{\text{Agricultural Land (1,000 ha)}}$$

and,

$$AVW = \frac{\text{Value of Agricultural Production (USD)}}{\text{Active Population in Agriculture (1,000 persons)}}$$

In addition to land, labor, tractors, adult literacy and control variables for the income level, regressors now include irrigated land, density of roads per agricultural land, production of electricity per capita and the population density per total country area.[3]

Recalling the previous discussion, transportation and electrical infrastructure can be expected to positively affect agriculture in several ways. First, electricity and transportation may enter the production function directly as intermediate inputs. Second, they connect distant production and consumption areas: this is crucial for perishable goods. Third, road density can positively impact the availability of agricultural inputs, such as fertilizer, as well as the availability of technology. Roads and electricity become essential when agricultural activities become more specialized and when the presence of processing plants of raw products close to the production area is economically advantageous.

Tables 2 and 3 report the results of the econometric analysis conducted on AVPL and AVW respectively (again, given the Cobb-Douglas specification, coefficients represent estimated elasticities). A cross-country analysis implies the comparison between different agro-climatic settings that are likely to affect the factor productivity. Nonetheless, the analysis indicates that the application of inputs, the availability of infrastructure and differences in technology may significantly affect productivity in diverse agricultural economies.

As far as land productivity is concerned (Table 2), the regression output shows that the estimated elasticity for fertilizer application per unit of land (equation 2) is positive (0.116), the ratio of agriculturally active population to agricultural land also has a positive and significant coefficient (approximately 0.4). The infrastructural indicators, measured by km of highways per agricultural land and production of electricity per capita, have positive and significant elasticities (0.253 and 0.283 in equations 1 and 2 for roads and 0.128 in equation 2 for electricity). The density of highways, per unit of cultivated area, represents a measure of the communication infrastructure available to agricultural areas, promoting specialization and the diffusion of high-value crops, in response to changes in relative prices. In our sample, the density of roads per agricultural land for countries in the highest quartile of land productivity is 4.3 times higher than in countries in the lowest quartile.

The availability of electricity, measured by the production of electricity per capita, can be interpreted as an indicator of international differences in the mechanization of agriculture. Electricity provides an agricultural input in the form of power for machinery (e.g., water pumps or milking machines). At the same time, a high ratio of electricity production per capita may be an indicator of the relative industrialization of a country. This seems in accordance with Schultz's thesis of the urban industrial impact: factors and product markets are expected to be more efficient in areas of rapid industrial development than in areas where the economy has not made a transition to industrialization.

Countries have been divided into high, middle and low income groups (following the 1991 World Bank classification scheme) and two intercept shifters have been introduced in the regression model. They provide control variables for the overall level of productivity of the economy. The estimated coefficient is negative and significant for low-income countries and positive and nearly significant for high-income countries. This finding corroborates the argument of the urban industrial impact model: countries with a low GNP per capita are less likely to have experienced industrial growth. In addition, belonging to the category of low-income countries may also imply disadvantages in other institutional factors, such as security of property rights, efficiency of the public sector and higher investments in research and development.

Another control variable is represented by the density of the population per total country area. The estimated coefficient (0.13) is positive and significant: this result seems consistent with Boserups's perspective of agricultural intensification (and higher productivity of land) as a response to higher population pressure.

Tractors per unit of agricultural land and percentage of adult literacy are not found to be significant: in the former case, the simple number of tractors may not faithfully represent the level of technology and the power available for agriculture. In the latter, literacy may not adequately mirror the importance of human capital or, perhaps, differences in skills and availability of technical knowledge may be already embedded in the classification of countries by income level. The percentage of irrigated land over the total agricultural land provides an almost significant explanatory variable.

The analysis of labor productivity (Table 3) confirms the importance of density of roads even if global econometric results are different with respect to land productivity. Fertilizers and tractors per unit of land, when considered separately, are not significant, however, by multiplying the two variables, we obtained a significant regressor (Fertilizer x Tractors, with an estimated coefficient equal to 0.022 and 0.018 in equations 1 and 2 respectively). This suggest that, perhaps, at this level of analysis, the interaction of tractors and fertilizers may be more important than the separate impact of the two factors.

The coefficient of the low-income control variable is still positive and significant, the same result holds for the density of roads per unit of agricultural land and the ratio of agricultural land per worker. In addition, the mean quantity of irrigated land per agricultural worker is also found to be significant in both equations in Table 3.

The availability of electricity per capita, though having a positive estimated coefficient, is not significant. Perhaps the total production of electricity does not allow for an exhaustive representation of the electrical energy available for agricultural activities, or the agricultural land per agricultural worker may have a stronger impact on labor productivity than electricity, as in extensive cattle-rearing areas.

The density of population per total country area has a positive and significant coefficient: this is not consistent with Boserup's model, which predicts an increase in land productivity and ambiguous effects (or perhaps decrease) on labor productivity, in response to increased population pressure. However, Boserup's theoretical framework focused on pre-industrial societies and did not allow for diffusion technology capable of increasing both land and labor productivity.

## Implications for China

Benziger has investigated the impact of access to infrastructure and urban markets on the factor proportions and on the specialization and productivity of agriculture in Hebei Province. His study is based on Schultz's hypothesis of industrial-urban centers and on Myrdal's concept of cumulative causation. The industrial-urban perspective has already been discussed; according to Myrdal, advantages, in terms of income and productivity of factors, accumulated by first-mover regions in the development process, tend to persist, rather than being dissipated through the mobility of factors. Benziger shows that road density, and distance to the nearest cities positively affect the proportion of fertilizers per unit of land, machinery power per worker, as well as productivity of labor and land.

Over the last two decades, China has experienced a sustained increase in the gross value of its agricultural output. From 1978 to 1996, the value of agricultural output has increased by 250 percent at constant prices. Over the same period, consumption of chemical fertilizers has increased by 333 percent, power of agricultural machinery by 228 percent, and consumption of electricity in rural areas by 562 percent. The growth of infrastructure has been somewhat slower: the total length of public roads has increased by 33 percent. However, since the population has increased by 27 percent, the length of public roads per capita has increased by 5 percent. Despite the considerable public expenditure targeted towards infrastructure development, the state of transportation in China is still considered to be lagging behind, by international standards.

Important geographical disparities characterize the spatial concentration of transportation infrastructure in China, which is strongly biased in favor of the Northeastern regions of the country, an historical heritage of unequal development. The Chinese government and multilateral international organizations are now directing an increasing level of investment to the development of transportation infrastructure.

To assess the effect of roads and electrical energy on the value of agricultural production per province we use cross sectional data for the 30 provinces of China, available for 1991, 1993 and 1996. [4] The specification of the model follows the functional form of (1) with slight modifications:

$$\ln Y_j = a_0 + \sum_{i=1}^{k} b_i \ln X_{ij} + d_0 IRRj + d_1 D93_j + d_2 D96_j + d_3 NCO_j + d_4 SCO_j + d_5 NCT_j + d_6 MWE_j + d_7 FWE_j + u_j . \qquad (2)$$

The main explanatory variables ( $X_{ij}$ ) are: agricultural land area (thousands of hectares), active population in agriculture (1,000 persons), power of agricultural machinery (10,000 kw), consumption of chemical fertilizers (thousands of metric tons), availability of electricity in rural areas (10,000 kw), number of draught animals, and the density of roads per capita and per unit of agricultural land. $IRR_j$ represents the proportion of irrigated land to total agricultural land and it is expressed as a percentage rather than a logarithm. Two variables, D93 and D96, have been introduced for the years 1993 and 1996, in order to control for possible trend effects. Moreover, following Wei and Ma, China has been divided into six regions: North Coastal, South Coastal, Mid-Western, Far-Western Central, North Central and Central Provinces, the first five represented by control variables (NCO, SCO, MWE, FWE, NCT).[5] Data for the 30 Chinese provinces and municipalities have been collected from the Statistical Yearbook of China, with a total of 90 observations.

The results are presented in Table 4. In all the equations, the high adjusted $R^2$ indicates a good fit of the model. In equations 1 and 3 geographical factors have been excluded; here power of machinery, fertilizers and km of roads per unit of agricultural land are the only significant explanatory variables for the value of agricultural production. As we control for geographical differences, more explanatory variables, such as the agricultural labor force and the electrical energy available in rural areas become significant and their coefficients take a positive value.

Data from China reflect the prevalence of different activities (cropping, cattle rearing, forestry etc.) and the disparities in the availability of technology and other institutional elements (such as the quality of research and the efficiency of extension services) in different provinces. It should not be surprising that, when adding the geographical variables, the fit of the equations improves and more regressors become significant.

A partially unexpected result of controlling for geographical factors is the negative (and significant) coefficient taken by the power of machinery. It could be argued that machinery such as tractors are often used for transportation purposes and do not represent a good measure of technological input in agriculture. In addition to that, there might be an important substitution effect between factors and higher levels of land productivity might be attained through a higher application of fertilizers per unit of land or by using animal power, rather than through a more intensive use of machinery. An example could be paddy cultivation, often carried out with animal power on irrigated land.

We have used density of roads per agricultural areas as an indicator of transportation infrastructure, since it has provided encouraging results in our previous cross-country analysis. Following Querioz and Gautam, we have also used density per population size. In Table 4, density per agricultural areas provides significant coefficients, reinforcing, at the provincial level, the conclusions that the analysis of cross-country data suggested. In other words, better access to input and output markets, as well as diffusion of technical knowledge (Hayami and Ruttan) may positively affect production, through an improvement of productivity. Density per population size does not yield a significant coefficient. However, it should be noted that high density of roads per population may identify those areas where mobility of rural population out of agricultural production is encouraged. The loss of labor force may partly offset the benefits of improved access to markets and availability of inputs, when labor is not substituted with capital or agricultural production does not shift to activities with lower ratio of labor to capital. Due to these partially contradictory effects, the analysis of cross-regional data on gross value of agricultural output perhaps does not offer the best representation of the role of infrastructure for agricultural development.

As in the cross-country case, we also analyzed the average values of agricultural productivity of land (AVPL) and labor (AVW) for each of the Chinese regions and municipalities in 1991, 1993 and 1996 (Tables 5 and 6). The selected explanatory variables combine (i) agricultural inputs, (ii) infrastructure indicators (roads and energy, the latter also representing a direct input), (iii) regional intercept shifters and (iv) two indicator variables for 1993 and 1996. A few common patterns emerge from the statistical output: fertilizers per agricultural worker and density of roads (both per unit of agricultural land and population) always have a positive and significant estimated elasticity. The introduction of the geographical control variables produces interesting variations in the results: the coefficient for agricultural machinery always becomes negative, the level of significance of electricity increases, and the number of draught animals becomes significant. As we have already remarked, in many areas, comparatively higher levels of land and labor productivity are attained through the use of traditional techniques (e.g., the use of animal power) and a more intensive fertilizers application. The latter conclusion is corroborated by the significance of the coefficient for large animals in equations 2 and 4 of Table 6. The distribution of agricultural land in small plots and the scarcity of larger estates may be an important element discouraging the adoption of agricultural machinery, in addition to the relative scarcity of higher technology.

Thus the geographical element seems of paramount importance in explaining the variation of the indicators of productivity. Agro-climatic conditions, persistent backwardness, and the predominance of different agricultural activities in each of the macro-areas have to be incorporated in the control variable in order to avoid biases in the estimation.

The results also display a remarkable stability and show that roads and electricity have a positive impact on productivity. Per capita availability of electricity probably provides a better explanatory variable than the simple per capita production of electricity that we used in cross-country analysis. Electricity in rural areas represents an input for agriculture but can also be interpreted as an indicator of rural industrialization and dissemination of technology in agricultural areas. In addition to that, rural industry can also stimulate higher demand for agricultural products and particularly demand for raw higher-value crops to be processed.

Density of roads per agricultural areas is significant as in the previous analysis. In addition, density of roads per population also becomes a significant predictor of labor productivity. If a high road per population ratio identifies areas with higher loss of agricultural labor force, this is an obvious result. Assuming that labor loss does not induce a major reduction of agricultural production, labor productivity may increase. However, this does not rule out the traditional explanation of better availability of transportation services and integration of markets.

## Conclusion

Our analysis provides empirical evidence on the importance of infrastructure for agriculture. Cross country analysis of data from 83 countries shows that the gross product in the transportation and energy sectors, as well as in the two sectors combined, is a significant explanatory variable of the aggregate value of agricultural production. However, these results should be carefully interpreted, since the analysis focuses on annual expenditure and does not consider the stock of physical infrastructure. Cross-country data and indicators of physical infrastructure have been included in an econometric analysis of productivity of land and labor. Roads and electricity have been found to be significant predictors of land productivity.

Cross-sectional data for Chinese provinces have also been used to test explanatory models for the value of agricultural production and land and labor productivity. In the analysis of gross agricultural output, density of roads per agricultural area has a positive and significant coefficient, while the elasticity for electricity consumption in rural areas is positive and nearly significant. In the analysis of productivity of land and labor, the density of roads per agricultural land as well as of roads per capita has a positive and significant coefficient. The consumption of electricity per agricultural worker appears to be a positive and significant explanatory variable of the productivity of labor. The density of roads implies advantages in access to information, to markets for inputs as well as factors of production and technology. These are crucial elements in the transition from staple crops to higher-value agricultural production. Energy is a key factor in agricultural production, when processing or intensification (intensive livestock rearing) of production is required. Thus, the results presented in this paper suggest that the availability of roads and electricity represents a key factor in the modernization of Chinese agriculture.

## Notes

[1] Argentina, Australia, Austria, Bahrain, Bangladesh, Belgium Luxembourg Belize, Benin, Bhutan, Bolivia, Brazil, Burkina Faso, Cameroon, Canada, Central African Republic, Colombia, Costa Rica, Cyprus, Denmark, Egypt, El Salvador, Ethiopia, Finland, France, Gambia, Germany, Ghana, Greece, Honduras, Hungary, India, Indonesia, Iran, Iraq, Israel, Italy, Jamaica, Japan, Jordan, Kenya, South Korea, Lesotho, Liberia, Libya, Malawi, Mali, Mexico, Morocco, Myanmar, Nepal, Netherlands, New Zealand, Niger, Nigeria, Norway, Pakistan, Panama, Paraguay, Peru, Philippines, Portugal, Rwanda, Saudi Arabia, Seychelles, Somalia, South Africa, Spain, Sri Lanka, Sweden, Switzerland, Syria, Tanzania, Thailand, Tunisia, Turkey, Uganda, United Kingdom, Uruguay, USA, Venezuela, Yemen, Zambia, Zimbabwe.

[2] We have followed the 1991 World Bank classification scheme.

[3] In the cross country-analysis of productivity, the sample has been augmented with the following countries: Algeria, Burundi, Cambodia, China, Cuba, Czechoslovakia, Ecuador, Guatemala, Guinea, Haiti, Lebanon, Madagascar, Mauritania, Mongolia, Nicaragua, Poland, Romania, Senegal, Togo, USSR. El Salvador, Ethiopia, Gambia, Niger, Portugal, Seychelles, Somalia have been dropped, owing to lack of relevant data on irrigation and physical infrastructure.

[4] Values have been deflated, using the general purchase price index of farm products.

[5] North Coastal: Beijing, Tianjn, Hebei, Liaoning, Shanghai, Jiangsu, Zhejiang, Shandong; South Coastal: Fujian, Guangdong, Guanxi, Hainan; North Central: Inner Mongolia, Jilin, Heilongjiang; Central: Shanxi, Anhui, Jiangxi, Henan, Hubei, Hunan; Western: Sichuan, Guizhou, Yunnan, Shaanxi, Nigxia; Far Western: Tibet, Gansu, Qinghai, Xinjiang.

## References


Aldcroft, D.J. and M.J.Freeman (eds.) (1983) *Transport in the Industrial Revolution*, Manchester University Press, Manchester.

Antle, J.M. (1983) "Infrastructure and Aggregate Agricultural Productivity: International Evidence," *Economic Development and Cultural Change* 31(2): 609-620.

Benziger, V. (1996) "Urban Access and Rural Productivity Growth in Post-Mao China," *Economic Development and Cultural Change* 44(2): 539-570.

Boserup, E. (1965) *The Conditions of Economic Growth*, Aldine, Chicago.

Canning, D. (1998) *A Database of World Infrastructure Stocks, 1950-1995*, World Bank, Washington DC.

Fromm, G. (1965) *Transport Investment and Economic Development*, Brooking Institute , Washington DC.

Hayami, V. and V.W.Ruttan (1971) *Agricultural Development: An International Perspective*, The Johns Hopkins University Press, Baltimore.

Hirschmann, A.O (1958) *The Strategy of Economic Development*, Yale University Press, New Haven.

Lyons, T.P. (1997) "Intraprovincial Disparities in Post-Mao China: A Multidimensional Analysis of Fujian Province," *Journal of Developing Areas,* 32(1): 1-28.

Myrdal, G. (1957) *Economic Theory and Under-Developed Regions*, Duckworth, London.

Oi, J.C. (1999) *Rural China Takes Off*, University of California Press, Berkeley.

Owen, W. (1987) *Transportation and World Development*, The Johns Hopkins University Press, Baltimore.

Querioz, C. and S.Gautam (1992) "Road Infrastructure and Economic Development. Some Diagnostic Indicators," World Bank, Policy Research Working Paper WPS 921.

United Nations (1995) *The United Nations Statistical Yearbook*, New York.

Rostow, W.W. (1960) *The Stages of Economic Growth, A Non-Communist Manifesto* Cambridge University Press, Cambridge, UK.

Shultz, T.W. (1953) *The Economic Organization of Agriculture*, McGraw-Hill, New York.

Wei, Y. (1999) "Regional Inequality in China," *Human Geography* 23(1): 49-59.

Wei, Y. and L.J.C. Ma (1996) "Changing Patterns of Spatial Inequality in China, 1952-1990," *Third World Planning Review* 18(2): 177-191.

World Bank (1991) *World Development Report*, IBRD, Washington D.C.

World Bank (1993) *World Tables*, IBRD - Johns Hopkins University, Baltimore.

**Table 1: Value of Agricultural Production - Cross-Country Data.**

| Independent Variables | Equation 1 | Equation 2 | Equation 3 | Equation 4 | Equation 5 |
|---|---|---|---|---|---|
| **Log of Intercept** | 4.761<br>(6.385)*** | 4.851<br>(6.852)*** | 4.902<br>(7.087)*** | 4.498<br>(6.631)*** | 4.438<br>(6.468)*** |
| **Active Agricultural Population** | 0.431<br>(5.459)*** | 0.581<br>(6.499)*** | 0.645<br>(6.997)*** | 0.688<br>(7.558)*** | 0.683<br>(7.476)*** |
| **Agricultural Land** | 0.024<br>(0.361) | 0.000<br>(0.012) | 0.154<br>(1.632) | 0.260<br>(2.554)** | 0.248<br>(2.438)** |
| **Chemical Fertilizers** | 0.180<br>(2.167)** | 0.102<br>(1.234) | 0.076<br>(0.930) | 0.042<br>(0.527) | 0.049<br>(0.609) |
| **Tractors** | 0.216<br>(2.863)*** | 0.206<br>(2.867)*** | 0.175<br>(2.448)** | 0.175<br>(2.550)** | 0.173<br>(2.512)** |
| **Adult Literacy** | 0.005<br>(0.958) | -0.000<br>(-0.108) | -0.003<br>(-0.519) | -0.003<br>(-0.664) | -0.003<br>(0.288) |
| **High-Income Country** | 0.903<br>(3.517)*** | 1.127<br>(4.432)*** | 0.988<br>(3.856)*** | 0.908<br>(3.630)*** | 0.902<br>(3.571)*** |
| **Low-Income Country** | | -0.914<br>(-3.074)*** | -0.747<br>(-2.487)** | -0.692<br>(-2.389)** | -0.677<br>(-2.310)** |
| **Transportation and Energy** | | | | | 0.264<br>(3.024)*** |
| **Transportation** | | | | 0.274<br>(3.158)*** | |
| **Energy** | | | 0.162<br>(2.161)** | | |
| **Adjusted $R^2$** | 0.841 | 0.857 | 0.864 | 0.872 | 0.871 |
| **Observations** | 83 | 83 | 83 | 83 | 83 |
| **Chi-square statistic for Breusch-Pagan Test** | 7.505<br>(6 DF) | 8.646<br>(7 DF) | 6.601<br>(8 DF) | 6.778<br>(8 DF) | 6.073<br>(8 DF) |

* Significant at 10%

** Significant at 5%

*** Significant at 1%

Results from runs test and Jarque-Bera Asymptotic LM test are compatible with the assumption of normality for residuals.

**Table 2: Land Productivity - Cross Country Data.**

| Independent Variables | Equation 1 | Equation 2 |
|---|---|---|
| **Log Intercept** | 5.508<br>(10.01)*** | 5.591<br>(11.62)*** |
| **Fertilizers / Land** | 0.093<br>(1.201) | 0.116<br>(1.875)* |
| **Tractors / Land** | 0.022<br>(0.308) | |
| **Workers / Land** | 0.414<br>(3.785)*** | 0.382<br>(3.722)*** |
| **Irrigated Land (%)** | 0.009<br>(1.535) | 0.009<br>(1.575) |
| **Roads[1] / Agriland** | 0.253<br>(2.570)** | 0.283<br>(3.104)*** |
| **Electricity per Capita** | 0.11<br>(1.434) | 0.128<br>(1.718)* |
| **High-Income Countries** | 0.458<br>(1.658) | 0.406<br>(1.514) |
| **Low-Income Countries** | -0.443<br>(-1.787)* | -0.473<br>(-1.942)* |
| **Adult Literacy** | 0.004<br>(0.790) | |
| **Population / Country Area** | 0.243<br>(2.419)** | 0.258<br>(2.612)** |
| **Adjusted $R^2$** | 0.797 | 0.800 |
| **Obs.** | 98 | 98 |
| **Chi-Square Statistic for Breusch-Pagan Test** | 7.896<br>(10 DF) | 7.071<br>(8 DF) |

* Significant at 10%

** Significant at 5%

*** Significant at 1%

Results from runs test and Jarque-Bera Asymptotic LM test are compatible with the assumption of normality for residuals.

**Table 3: Labor Productivity - Cross Country Data.**

| Independent Variables | Equation 1 | Equation 2 |
|---|---|---|
| **Log Intercept** | 6.290<br>(10.62)*** | 6.498<br>(12.08)*** |
| **Fertilizers / Workers** | 0.068<br>(0.865) | |
| **Tract / Worker** | -0.060<br>(-0.736) | |
| **Fertilizer x Tractors** | 0.022<br>(1.930)* | 0.018<br>(2.033)** |
| **Land / Worker** | 0.349<br>(3.077)*** | 0.350<br>(3.275)*** |
| **Irrigated Land / Worker** | 0.136<br>(2.361)** | 0.151<br>(2.867)*** |
| **Roads[1] / Agriland** | 0.235<br>(2.397)** | 0.235<br>(2.435)** |
| **Electricity per Capita** | 0.052<br>(0.674) | 0.064<br>(0.841) |
| **High-Income Countries** | 0.230<br>(0.764) | 0.287<br>(0.998) |
| **Low-Income Countries** | -0.489<br>(-1.986)** | -0.473<br>(-1.978)* |
| **Adult Literacy** | 0.005<br>(1.086) | 0.005<br>(1.059) |
| **Population / Country Area** | 0.217<br>(2.252)** | 0.232<br>(2.546)** |
| **Adjusted $R^2$** | 0.836 | 0.838 |
| **Obs.** | 98 | 98 |
| **Chi-Square Statistic for Breusch-Pagan Test** | 5.667<br>(11DF) | 6.433<br>(9 DF) |

* Significant at 10%

** Significant at 5%

*** Significant at 1%

Results from runs test and Jarque-Bera Asymptotic LM test are compatible with the assumption of normality for residuals.

**Table 4: Value of Agricultural Production - Chinese Data.**

| Independent Variables | Equation 1 | Equation 2 | Equation 3 | Equation 4 |
|---|---|---|---|---|
| **Log Intercept** | 0.010<br>(0.014) | -1.211<br>(-1.819)* | 1.610<br>(3.180)*** | 0.339<br>(0.573) |
| **Land** | 0.065<br>(0.577) | 0.513<br>(3.439)*** | -0.226<br>(-2.495)** | 0.199<br>(1.405) |
| **Irrigated Land (%)** | 0.004<br>(2.397)** | 0.007<br>(3.844)*** | 0.003<br>(2.015)** | 0.007<br>(3.385)*** |
| **Agricultural Workers** | 0.030<br>(0.521) | 0.139<br>(2.165)** | 0.102<br>(1.773)* | 0.221<br>(3.267)*** |
| **Power of Machinery** | 0.122<br>(1.717)* | -0.286<br>(-3.195)*** | 0.120<br>(1.759)* | -0.274<br>(-2.785)*** |
| **Fertilizers** | 0.665<br>(7.121)*** | 0.419<br>(4.127)*** | 0.741<br>(8.144)** | 0.497<br>(4.462)*** |
| **Rural Electricity** | 0.037<br>(0.680) | 0.069<br>(2.217)** | 0.048<br>(0.878) | 0.083<br>(2.248)** |
| **Draught Animals** | 0.005<br>(0.103) | 0.064<br>(1.382) | 0.059<br>(1.117) | 0.117<br>(2.362)* |
| **Roads / Agricultural Land** | 0.274<br>(4.162)*** | 0.282<br>(4.244)*** | | |
| **Roads / Population** | | | 0.089<br>(1.566) | 0.104<br>(1.416) |
| **Year 1993** | 0.040<br>(0.554) | 0.164<br>(2.263)** | 0.101<br>(1.363) | 0.230<br>(2.955)*** |
| **Year 1996** | 0.018<br>(0.207) | 0.239<br>(2.618)** | 0.074<br>(0.845) | 0.296<br>(2.984)** |
| **North Coastal** | | 0.379<br>(4.517)*** | | 0.380<br>(4.118)*** |
| **South Coastal** | | 0.284<br>(3.179)*** | | 0.325<br>(3.255)*** |
| **North Central** | | -0.085<br>(-0.664) | | -0.018<br>(-0.125) |
| **Western** | | -0.240<br>(-2.585)** | | -0.214<br>(-2.081)** |
| **Far-Western** | | -0.416<br>(-3.229)*** | | -0.380<br>(-2.594)** |
| **Adjusted $R^2$** | 0.945 | 0.967 | 0.938 | 0.958 |
| **Observations** | 90 | 90 | 90 | 90 |
| **Chi-square statistic For Breusch-Pagan Test** | 35.238<br>(9 DF)*** | 21.904<br>(15 DF) | 34.187<br>(10 DF)*** | 21.602<br>(15 DF) |

* significant at 10%

** significant at 5%

*** significant at 1%

White's correction has been applied to the estimates of the residuals' variance for significant values in B-P test.

Results from runs test and Jarque-Bera Asymptotic LM test are compatible with the assumption of normality for residuals.

**Table 5: Land Productivity - Chinese Data.**

| Independent Variables | Equation 1 | Equation 2 | Equation 3 | Equation 4 |
|---|---|---|---|---|
| **Log Intercept** | -3.009<br>(-4.230)*** | -4.038<br>(-6.050)*** | -2.613<br>(-2.416)** | -3.957<br>(-4.108)*** |
| **Active Pop. in Agr. / Ag. Land** | -0.037<br>(-0.650) | 0.090<br>(2.132)** | 0.116<br>(1.442) | 0.231<br>(4.000)*** |
| **Power of Machinery / Ag. Land** | -0.035<br>(-0.472) | -0.376<br>(-4.909)*** | 0.001<br>(0.011) | -0.353<br>(-3.423)*** |
| **Fertilizer Cons. / Ag. Land** | 0.366<br>(4.056)*** | 0.180<br>(2.149)** | 0.394<br>(2.922)** | 0.175<br>(1.913)* |
| **Irrigated Ag. Land (%)** | 0.008<br>(5.035)*** | 0.011<br>(7.354)*** | 0.011<br>(3.643)*** | 0.014<br>(6.773)*** |
| **Rural Electricity Cons. / Ag. Land** | 0.041<br>(0.717) | 0.057<br>(1.203) | 0.117<br>(2.630) | 0.123<br>(2.002)** |
| **Draught Animals / Ag. Land** | 0.070<br>(1.277) | 0.102<br>(2.083) | 0.159<br>(2.574)** | 0.191<br>(3.047)*** |
| **Roads / Agricultural Land** | 0.492<br>(7.953)*** | 0.466<br>(8.827)*** | | |
| **Roads / Population** | | | 0.544<br>(3.838)*** | 0.503<br>(4.427)*** |
| **Year 1993** | -0.005<br>(-0.027) | 0.136<br>(2.291)** | 0.096<br>(1.006) | 0.226<br>(3.163)*** |
| **Year 1996** | -0.026<br>(0.315) | 0.242<br>(3.314)*** | 0.095<br>(0.825) | 0.317<br>(3.427)*** |
| **North Coastal** | | 0.400<br>(5.925)*** | | 0.432<br>(4.800)*** |
| **South Coastal** | | 0.370<br>(4.495)*** | | 0.472<br>(4.662)*** |
| **North Central** | | 0.009<br>(0.068) | | 0.074<br>(0.472) |
| **Western** | | -0.146<br>(-2.307)** | | -0.063<br>(-0.721) |
| **Far-Western** | | -0.174<br>(-1.445) | | -0.087<br>(-0.510) |
| **Population / Total area** | 0.170<br>(3.915)*** | 0.167<br>(3.864)*** | 0.255<br>(2.810)*** | 0.267<br>(3.067)*** |
| **Adjusted $R^2$** | 0.887 | 0.928 | 0.843 | 0.887 |
| **Observations** | 90 | 90 | 90 | 90 |
| **Chi-square statistic For Breusch-Pagan Test** | 15.987<br>(10 DF) * | 17.155<br>(15 DF) | 16.247<br>(10 DF) ** | 16.724<br>(15DF) |

* significant at 10%

** significant at 5%

*** significant at 1%

White's correction has been applied to the estimates of the residuals' variance for significant values in B-P test.

Results from runs test and Jarque-Bera Asymptotic LM test are compatible with the assumption of normality for residuals.

**Table 6: Labor Productivity - Chinese Data.**

| Independent Variables | Equation 1 | Equation 2 | Equation 3 | Equation 4 |
|---|---|---|---|---|
| **Log Intercept** | -1.907<br>(-2.973)*** | -2.997<br>(-4.659)*** | -0.503<br>(-0.611) | -1.882<br>(-2.045)** |
| **Agricultural Land. /<br>Nr. Agriworker** | 0.210<br>(1.842)* | 0.137<br>(3.769)*** | -0.294<br>(-2.730)*** | 0.038<br>(-0.239) |
| **Irrigated Land /<br>Nr. Agriworkers** | 0.296<br>(3.618)*** | 0.416<br>(4.884)*** | 0.263<br>(2.360)** | 0.433<br>(3.750)*** |
| **Power of Machinery /<br>Nr. Agriworker** | 0.021<br>(0.279) | -0.365<br>(-4.591)*** | 0.162<br>(1.278) | -0.246<br>(-2.088)** |
| **Fertilizer Consumption /<br>Nr. Agriworker** | 0.434<br>(4.338)*** | 0.231<br>(2.359)** | 0.549<br>(4.860)*** | 0.298<br>(2.667)*** |
| **Rural Electricity Cons. /<br>Nr. Agriworker** | 0.049<br>(0.863) | 0.062<br>(1.310) | 0.109<br>(1.415) | 0.122<br>(1.953)* |
| **Draught Animals /<br>Nr. Agriworker** | 0.024<br>(0.438) | 0.039<br>(0.781) | 0.095<br>(1.596) | 0.106<br>(1.704)* |
| **Roads / Agricultural Land** | 0.476<br>(7.652)*** | 0.480<br>(8.987)*** | | |
| **Roads / Population** | | | 0.378<br>(3.012)*** | 0.391<br>(3.270)*** |
| **Year 1993** | 0.156<br>(2.072)** | 0.295<br>(4.668)*** | 0.247<br>(3.104)*** | 0.390<br>(5.077)*** |
| **Year 1996** | 0.726<br>(8.539)*** | 0.960<br>(12.53)*** | 0.782<br>(8.486)*** | 1.030<br>(10.35)*** |
| **North Coastal** | | 0.391<br>(5.347)*** | | 0.403<br>(4.048)*** |
| **South Coastal** | | 0.324<br>(4.073)*** | | 0.413<br>(3.947)*** |
| **North Central** | | -0.003<br>(-0.021) | | 0.021<br>(0.115) |
| **Western** | | -0.213<br>(-2.834)*** | | -0.157<br>(-1.600) |
| **Far-Western** | | -0.130<br>(-0.927) | | -0.083<br>(-0.418) |
| **Population / Total Area** | 0.125<br>(2.899)*** | 0.141<br>(2.855)*** | 0.119<br>(1.525) | 0.157<br>(1.622) |
| **Adjusted $R^2$** | 0.922 | 0.947 | 0.890 | 0.915 |
| **Observations** | 90 | 90 | 90 | 90 |
| **Chi-square statistic<br>For Breusch-Pagan Test** | 17.246<br>(10 DF)* | 17.663<br>(15 DF) | 18.653<br>(10 DF)** | 19.132<br>(15 DF) * |

* significant at 10%

** significant at 5%

*** significant at 1%

White's correction has been applied to the estimates of the residuals' variance for significant values in B-P test.

Results from runs test and Jarque-Bera Asymptotic LM test are compatible with the assumption of normality for residuals.