AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
<http://ageconsearch.umn.edu>
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

EPTD DISCUSSION PAPER NO. 84

**HOW PRODUCTIVE IS INFRASTRUCTURE?
NEW APPROACH AND EVIDENCE FROM RURAL INDIA**

Xiaobo Zhang and Shenggen Fan

Environment and Production Technology Division

International Food Policy Research Institute

2033 K Street, N.W.

Washington, D.C. 20006 U.S.A.

October 2001

EPTD Discussion Papers contain preliminary material and research results, and are circulated prior to a full peer review in order to stimulate discussion and critical comment. It is expected that most Discussion Papers will eventually be published in some other form, and that their content may also be revised.

EPTD DISCUSSION PAPER NO. 84

**HOW PRODUCTIVE IS INFRASTRUCTURE?
NEW APPROACH AND EVIDENCE FROM RURAL INDIA**

Xiaobo Zhang and Shenggen Fan

Environment and Production Technology Division

International Food Policy Research Institute

2033 K Street, N.W.

Washington, D.C. 20006 U.S.A.

October 2001

EPTD Discussion Papers contain preliminary material and research results, and are circulated prior to a full peer review in order to stimulate discussion and critical comment. It is expected that most Discussion Papers will eventually be published in some other form, and that their content may also be revised.

ABSTRACT

There have been competing arguments about the effect of public infrastructure on productivity in the literature. Level-based regressions generally show a much higher return to public capital than private capital, while difference-based regressions tend to find insignificant or even negative effects. To help reconcile this debate, this paper proposes that researchers should first test for causality in their data to check for length of lagged relationships and the existence of reverse causality, as a critical step before specifying a final model and estimating procedure on the relationship between the stock of capital and productivity growth. A newly developed system GMM method of estimation is proposed for this purpose. Second, a new method of estimating the relationship between the capital stock and productivity in level form is proposed that controls for possible endogeneity problems arising from reverse causation. These methods are illustrated using a unique set of pooled time-series, cross-section data for India. It is shown that infrastructure development in India is productive with an estimated impact lying between those obtained from level-based and difference-based estimates.

TABLE OF CONTENTS

1. Introduction.....	1
2. Causality Test In a Panel.....	3
3. Productivity Effect of Infrastructure Development	11
4. Conclusions	14
References	16

HOW PRODUCTIVE IS INFRASTRUCTURE? NEW APPROACH AND EVIDENCE FROM RURAL INDIA

Xiaobo Zhang and Shenggen Fan

1. INTRODUCTION

Many developing countries have invested heavily in rural areas. These investments have resulted in significant improvements in rural infrastructure, technology, and education with the result that agricultural production and productivity have grown much faster than population growth in many developing countries (Binswanger et al. 1989; Antle 1984). Rapid growth in agricultural productivity has also led to significant trickle down benefits for the rural poor (Fan, Hazell, and Thorat 2000).

Despite these successes, the relationship between the stock of public capital and productivity growth remains controversial from a macroeconomic perspective in the general literature (Gramlich 1994). This debate arises in large part from differences in the methodology used in assessing the impact of public capital. Using aggregate time-series or panel data measured in level rather than change or difference form, a number of studies have found a positive link between public capital (especially infrastructure) and productivity growth and have reported rates of return to public capital far exceeding those to private capital (Aschauer 1989; Munnell 1992). Critics have pointed out that there are a number of econometric problems with this approach because variables measured in level form have common trends and measurement errors. Moreover, these statistical problems may be compounded by endogeneity problems when there is reverse causation between productivity growth and levels of capital formation.

To avoid these econometric problems, other researchers have used some form of differencing method. In contrast to the high rates of return to public capital obtained in prior studies, these studies suggest an insignificant or negative relationship between the capital stock and productivity growth (Tatom 1993; Holtz-Eakin 1994; Evans and Karras 1994; Garcia-Mila et al. 1996). But these studies in turn are suspect because the use of difference methods can destroy any long-term relationship in the data, leaving only short term impact to be captured in the model (Hsiao 1986; Munnell 1992). Since there are often long lags between investment and productivity growth, then jettisoning these relationships *ex ante* is not justified.

In an attempt to help reconcile this debate, this paper proposes the following. First, researchers should test for causality in their data to check for length of lagged relationships and the existence of reverse causality, as a critical step before specifying a final model and estimating procedure on the relationship between the stock of capital and productivity growth. For this purpose we suggest using a newly developed system GMM method of estimation. Second, we propose a new method of estimating the relationship between the capital stock and productivity in level form that controls for possible endogeneity problems arising from reverse causation. We also illustrate the proposed methods using a unique set of pooled time-series, cross-section data for India¹.

The paper is structured as follows. In the next section, we outline our causality test strategy for a panel data set and undertake an empirical test of the relationship between infrastructure capital and productivity in rural India. In Section 3 we estimate the impact

¹ The literature on the puzzle of productivity and public capital has primarily focused on developed countries so far. Among those studies on developing countries, Canning (1999) has evaluated the returns to public capital in both lower-income and higher-income countries using cross-country data, while Binswanger et al. (1993) and Fan, Hazell, and Thorat (2000) have estimated the returns for a particular developing country.

of increases in the capital stock on productivity growth in India. Our conclusions comprise Section 4.

2. CAUSALITY TEST IN A PANEL

There are two reasons to conduct a causality test before estimating the productivity impact of infrastructure capital. First, such test may be necessary to ensure that there is a causal relationship between these two variables to avoid spurious regressions. Second, a test to determine the direction of the causal relationship is also important because if a reverse relationship exists, the ordinary least squares technique will yield inconsistent estimates of the parameters (Gramlich 1994; Jimenez 1995).

To date, most causality tests have used time-series data.² However, time-series data are rarely available for many years and it is difficult to control for measurement errors and omitted variable problems. To overcome these problems, we apply a newly developed system GMM technique for panel data to conduct the causality test. The system GMM method can help reduce the estimation bias often inherent in a panel data set when lagged dependent variables are used as regressors. Our study differs from previous studies on the panel causality tests developed by Holtz-Eakin et al. (1988) by including initial conditions as additional instruments to improve estimation accuracy.

To illustrate, assume that there are N cross-sectional units observed over T periods. Let i index the cross-sectional observations and t the time periods. Assume further the existence of an individual effect α_i for the i^{th} cross-sectional unit. The model is:

² Tatom (1993) has conducted a causality test for productivity and infrastructure capital using time-series data and finds a two-way impact. Holtz-Eakin and Schwartz (1995) found a one-way impact of infrastructure on productivity growth.

$$y_{it} = a_0 + \sum_{e=1}^m a_e y_{it-e} + \sum_{k=1}^n \mathbf{b}_k x_{it-k} + \mathbf{h}_i + u_{it} , \quad (1)$$

where $i=1, \dots, N$; $t=m+2, \dots, T$; the a 's and $\hat{a}$'s are parameters; and the lag lengths m and n are sufficient to ensure that u_{it} is a stochastic error. While it is not essential that m equals n , we follow typical practice by assuming that they are identical.³ The test of whether x causes y is simply a test of the joint hypothesis that $\mathbf{b}_1 = \mathbf{b}_2 = \dots = \mathbf{b}_n$ are all equal to zero. If this null hypothesis is accepted, then it means that x does not cause y . To account for the individual effects, the intercept is often allowed to vary with each unit in a panel analysis, which is represented as $\mathbf{h}_i$ in (1).

When the number of cross-sectional units (N) is much larger than the number of time periods (T), the nonstationarity problem commonly seen in time-series data can be attenuated (Holtz-Eakin et al. 1988).⁴ But in a dynamic panel model, including an individual effect together with a lagged dependent variable generates biased estimates for a standard LSDV (least squares dummy variable) estimator especially when N is much larger than T (Hsiao 1986). A common way to deal with this problem is to take the first difference as shown in (2) and exploit a different number of instruments in each time period using either an instrument variable estimator or a GMM estimator as an estimation method (Holtz-Eakin et al. 1988 and 1989; Arellano and Bond 1991).

³ Constraining the lag lengths to be equal simplifies the problem by reducing greatly the number of potential combinations of lag lengths for the right-hand side variables, and hence commensurately reducing the number of tests that have to be performed. A consequence of this strategy is that some variables may appear with more lags than are truly nonzero. Because these variables have zero coefficients, their presence does not affect the behavior of the system. Thus, the only cost to this strategy is some loss in efficiency.

⁴ When T is larger than N or T increases faster than N , the nonstationarity problem may cause estimation bias with standard methods. Unit root and cointegration tests are usually needed to identify the nonstationarity problem. For recent development in this area, please see papers collected in a special issue of *Oxford Bulletin of Economics and Statistics* (Vol. 61, November 1999) and a review by Baltagi and Kao (2000).

$$\Delta y_{it} = \sum_{e=1}^m a_e \Delta y_{it-e} + \sum_{e=1}^m b_e \Delta x_{it-e} + \Delta u_{it} , \quad (2)$$

For the first-difference equation (2), suitably lagged endogenous variables can be used as instruments. For example, if u_{it} are not serially correlated with each other, then for time $t = m+2$, $(y_{i1}, y_{i2}, \dots, y_{im})$ are uncorrelated with y_{im+2} and therefore can be used as valid instruments at time $m+2$. Similarly, the instruments for time period T are $(y_{i1}, y_{i2}, \dots, y_{i(T-2)})$. For the whole period, the instrument matrix for the differenced equation (2) is:

$$Z_i^D = \begin{pmatrix} y_{i1} & y_{i2} & \dots & y_{im} & 0 & 0 & \dots & 0 & \dots & 0 & 0 & \dots & 0 \\ 0 & 0 & \dots & 0 & y_{i1} & y_{i2} & \dots & y_{i(m+1)} & \dots & 0 & 0 & \dots & 0 \\ \cdot & \cdot & & \cdot & \cdot & \cdot & & \cdot & & \cdot & & & \cdot \\ \cdot & \cdot & & \cdot & \cdot & \cdot & & \cdot & & \cdot & & & \cdot \\ 0 & 0 & \dots & 0 & 0 & 0 & \dots & 0 & \dots & y_{i1} & y_{i2} & \dots & y_{i(T-2)} \end{pmatrix} \quad (3)$$

This matrix has $T-m-1$ rows and $\sum_{j=m}^{T-2} j$ columns.

However, it is found that estimations on first-differenced equations produce unsatisfactory results in both simulation and empirical studies (Mairesse and Hall 1996). Blundell and Bond (1998) proposed a system GMM method by combining the first-differenced and level equations and show it has a relatively better performance. In addition to the above instruments for the first-differenced equations, the system GMM method also takes into account instruments available for the levels equation (1). Because $(\Delta y_{i(m+1)}, \dots, \Delta y_{i(T-1)})$ are uncorrelated with $(y_{i(m+2)}, \dots, y_{iT})$, they can be used as instruments for levels equations (1) from period $m+2$ to T .

In order to fully exploit these instruments, the equations in first differences and equations in levels corresponding to the period $m+2, \dots, T$ are stacked as system equations for GMM estimations as follows:

$$y_i = W_i \boldsymbol{\alpha} + u_i, \quad (4)$$

where $\boldsymbol{\alpha}$ is a parameter vector including the α 's and $\hat{\alpha}$'s;

y_i is defined as $(\Delta y_{i(m+2)}, \dots, \Delta y_{iT}, y_{i(m+2)}, \dots, y_{iT})$, and W_i includes the lagged endogenous and predetermined variables in terms of both differences and levels.

The instrument matrix for the combined differenced and levels equation (4) is:

$$Z_i = \begin{pmatrix} Z_i^D & 0 & \dots & 0 \\ 0 & \Delta y_{i(m+1)} & \dots & 0 \\ \cdot & \cdot & & \cdot \\ 0 & 0 & \dots & \Delta y_{i(T-1)} \end{pmatrix} \quad (5)$$

If there are regressors other than lagged endogenous variables uncorrelated with individual effects α 's and the error terms, these regressors can be used as instruments together with the above Z_i .

Using these instruments and following the estimation strategy outlined by Blundel and Bond (1998)⁵, the coefficients for the lagged dependent variables and predetermined variables can be estimated for the purpose of causality tests.

The estimation was based on a pooled time-series (1971 to 1994) and cross-sectional (290 districts) data set from rural India with a total of 6,960 observations. The

⁵ We use a Gauss program "DPD98" to conduct the regressions (see Arellano and Bond, 1998 for details).

data were mainly compiled from official publications of the Indian central and local governments.⁶

Agricultural productivity growth is measured through a total factor productivity (TFP) index that is the ratio of total output to total input. The Törnqvist-Theil index (a discrete approximation to the Divisia index) is used to construct TFP growth.⁷ The infrastructure variable is road density measured as the length of roads in kilometers per thousand square kilometers of geographic area. All the variables used in the analysis are in natural logarithm form.

Figure 1 graphs the relationship between TFP and road density after regional fixed effects have been eliminated. It appears there is a positive correlation between TFP and road development, but this needs not be a causal relationship.

⁶ The data set was compiled by IFPRI in collaboration with the National Center for Agricultural Policy Research, New Delhi, and Jawaharal Nehru University, New Delhi.

⁷ The TFP growth index is constructed as follows:

$$\ln TFP_t = \sum_i 0.5 * (S_{i,t} + S_{i,t-1}) * \ln(Y_{i,t} / Y_{i,t-1}) - \sum_i 0.5 * (W_{i,t} + W_{i,t-1}) * \ln(X_{i,t} / X_{i,t-1})$$

Where $\ln TFP_t$ is the log of the total factor productivity index; $S_{i,t}$ and $S_{i,t-1}$ are output i 's share in total production value at time t and $t-1$, respectively; and $Y_{i,t}$ and $Y_{i,t-1}$ are quantities of output i at time t and $t-1$, respectively. Farm prices are used to calculate the weights of each crop in the value of total production. $W_{i,t}$ and $W_{i,t-1}$ are cost shares of input i in total cost at time t and $t-1$, respectively; and $X_{i,t}$ and $X_{i,t-1}$ are quantities of input i at time t and $t-1$, respectively. Thirty crops (rice, wheat, *jowar*, *bajra*, maize, *ragi*, barley, gram, other pulses, groundnut, sesame, linseed, rapeseeds and mustard, castorseed, safflower, nigerseed, coconut, soybeans, sunflower, potato, tapioca, sweet potato, banana, cashewnut, coffee, jute, sugarcane, onion, and fruits) and three major livestock products (milk, chicken, and sheep and goat meat) are included in total production. Farm prices are used to calculate the output shares.

Five inputs (labor, land, fertilizer, tractors and animals) are included. Labor input is measured as total female and male labor (including both family and hired) engaged in agricultural production. A conversion ratio of 0.7 has been used to convert female labor to its male labor equivalent. Land is measured as net cropped area; fertilizer input is measured as the total amount of nitrogen, phosphate, and potassium used; tractor input is measured as the number of four-wheel tractors (including both private- and government-owned); and animal input is measured as the number of draft animals (total buffalos). Wages of agricultural labor are used as the price of labor; rental rates of tractors and animals are used for their respective prices; and the fertilizer price is calculated as a weighted average of the prices of nitrogen, phosphate, and potassium. The land price is measured as the residual of total revenue net of measured costs for labor, fertilizer, tractors, and bullocks.

Figure 1—TFP and Road Density

CAUSALITY TEST RESULTS

For any causality test, the lag length is an important issue. Ideally, we should specify an arbitrarily long initial lag length. However, a considerably long lag length poses overidentification and estimation problems. According to Holtz-Eakin *et al.* (1988), the lag length should be less than $1/3$ of the total time period; otherwise, the covariance matrix cannot be correctly estimated due to over identification problem. Therefore, we set the maximum lag length as 7.

Table 1 presents the causality test results between productivity and infrastructure development with lag length ranging from one to seven years.

Table 1--Causality tests on TFP and road density, rural India

	TFP							Road Density						
Road(-1)	-0.034 (0.023)	-0.010 (0.147)	-0.235 (0.152)	-0.024 (0.150)	-0.110 (0.135)	-0.090 (0.142)	-0.054 (0.144)	0.981** (0.005)	1.074** (0.061)	1.047** (0.062)	1.055** (0.064)	1.030** (0.055)	1.005** (0.053)	1.116** (0.050)
Road(-2)		-0.027 (0.139)	0.301* (0.167)	0.301* (0.166)	0.148 (0.152)	0.112 (0.159)	0.061 (0.158)		-0.091 (0.061)	-0.046 (0.069)	-0.053 (0.071)	-0.026 (0.064)	0.004 (0.063)	-0.092 (0.063)
Road(-3)			-0.104** (0.042)	-0.057 (0.062)	-0.073 (0.066)	-0.063 (0.067)	-0.062 (0.069)			-0.017 (0.018)	-0.011 (0.023)	-0.007 (0.025)	-0.015 (0.033)	-0.031 (0.022)
Road(-4)				-0.038 (0.039)	-0.080 (0.057)	-0.094* (0.056)	-0.102* (0.055)				-0.005 (0.012)	0.026 (0.024)	0.040 (0.027)	0.040 (0.027)
Road(-5)					0.060* (0.036)	0.049 (0.046)	0.034 (0.054)					-0.035* (0.020)	-0.034 (0.035)	-0.045* (0.025)
Road(-6)						0.020 (0.048)	0.025 (0.062)						-0.008 (0.019)	-0.020 (0.018)
Road(-7)							0.037 (0.042)							0.026* (0.015)
TFP(-1)	0.653** (0.037)	0.437** (0.032)	0.345** (0.037)	0.326** (0.037)	0.327** (0.038)	0.297** (0.043)	0.292** (0.045)	0.007 (0.008)	0.008 (0.010)	0.013 (0.010)	0.016 (0.012)	0.016 (0.011)	0.022* (0.012)	0.002 (0.010)
TFP(-2)		0.225** (0.025)	0.305** (0.037)	0.321** (0.036)	0.331** (0.036)	0.367** (0.038)	0.369** (0.041)		0.001 (0.006)	-0.002 (0.007)	-0.005 (0.007)	-0.006 (0.007)	-0.008 (0.008)	-0.013* (0.007)
TFP(-3)			0.115** (0.029)	0.120** (0.029)	0.135** (0.032)	0.160** (0.031)	0.151** (0.034)			-0.003 (0.006)	-0.004 (0.006)	-0.007 (0.006)	-0.003 (0.008)	-0.007 (0.005)
TFP(-4)				0.012 (0.017)	-0.030 (0.017)	-0.017 (0.018)	-0.013 (0.018)				0.001 (0.001)	0.003 (0.007)	0.004 (0.008)	-0.010** (0.005)
TFP(-5)					0.090** (0.015)	0.050** (0.014)	0.087** (0.017)					-0.009 (0.006)	-0.022** (0.010)	0.007 (0.005)
TFP(-6)						0.034** (0.016)	0.063** (0.015)						0.005 (0.063)	0.012** (0.004)
TFP(-7)							-0.091** (0.016)							0.007** (0.004)
Wald tests	0.131	0.195	0.023	0.043	0.003	0.002	0.010	0.400	0.627	0.565	0.643	0.345	0.061	0.000
p-value														

Note: One and two asterisks indicate that estimates are significant at the 10% and 5% significance levels, respectively. Figures in the parentheses are standard errors. The estimations reported in this table include year dummies.

The Wald test for the null hypothesis that road development has no effect cannot be rejected until the lag length is more than two. It seems the impact of infrastructure development on TFP might not be instantaneously exerted. The result confirms the findings by Canning and Pedroni (1998) that the casual impact of road development on productivity exists as a long run rather than a short run relationship.

In the equations for TFP, similar results can be observed. When lag length is less than six years, we cannot observe a significant impact of TFP on road development. The p-value of the Wald test becomes significant if a six-year or seven-year lag is considered. This result suggests a possible long-run induced effect of productivity growth on infrastructure development. This might be because a fast growing region requires better infrastructure conditions and therefore more investment. On the other hand, the central government may target infrastructure investment to the high productivity regions because of higher growth potentials. The relatively short lag length of roads on TFP indicates investment in infrastructure has a more immediate impact on TFP, which in turn leads to more investment in infrastructure development in the longer run.

Because of multicollinearity problems among the lagged variables, the causality test cannot distinguish whether infrastructure development has a positive or negative effect on long-run productivity growth. Some have argued that public provision of infrastructure may crowd out private investment and generate negative effects on growth. Therefore, the sign and magnitude of the productivity effect of infrastructure development is still an empirical question subject to test. This issue will be discussed in the next section.

3. PRODUCTIVITY EFFECT OF INFRASTRUCTURE DEVELOPMENT

As shown in the previous section, the two-way causality correlation indicates that higher productivity regions may have more resources to spend on infrastructure than lower productivity regions, resulting in a greater stock of infrastructure capital and therefore contributing to regional divergences. In addition, the government may target its resources to high potential areas (Fan, Hazell, and Haque 2000). Taken together, the two-way causality and regional targeting may create endogeneity and heterogeneity problems that yield inconsistent estimates when using ordinary least squares to estimate the impact of infrastructure on productivity.

To control for the heterogeneity problem, we use district dummy variables to capture the regional-specific fixed effects. To account for nationwide shocks due to such factors such as macroeconomic and trade policy, we also add year-specific intercepts in our analysis. The year dummies will eliminate any common countrywide effects on the TFP variable. In addition to the fixed effects, we also include a rainfall variable and the adoption of high-yielding varieties to avoid any omitted variable problems and to model the productivity effect of these two variables.

The long-run impact of roads on TFP shown in the causality test justifies using levels instead of differences in estimation. We consider the following function as the starting point for our analysis:

$$tfp_{it} = \mathbf{b}_1 road_{it} + \mathbf{b}_2 HYV_{it} + \mathbf{b}_3 rain_{it} + \mathbf{g}_t + \mathbf{h}_i + v_{it} \quad (6)$$

where tfp_{it} , $road_{it}$, HYV_{it} , and $rain_{it}$ refer to the logarithm of total factor productivity, road density, the proportion of cropped areas planted to high yield varieties, and annual

rainfall in district i at year t , respectively. The error term is represented as v_{it} . As stated earlier, it is highly likely that the road variable is correlated with the error term v_{it} .

Table 2 presents the estimation results for various model specifications.

Regression (1) is in difference form and is estimated by the least squares dummy variable (LSDV) method.

Table 2--Estimation results of the productivity impact of infrastructure, rural India

	(1)	(2)	(3)	(4)	(5)
	Difference	Level	Level	Level + $\mathbf{r}$	Level + $\mathbf{r}$
	(LSDV)	(LSDV)	(GMM)	(LSDV)	(GMM)
Road	0.019 (.035)	0.078** (0.040)	0.048** (0.009)	0.069** (0.017)	0.043** (0.007)
HYV	0.044** (0.009)	0.061** (0.013)	0.053** (0.002)	0.044** (0.006)	0.073** (0.002)
Rainfall	0.100** (0.014)	0.035** (0.014)	0.053** (0.003)	0.037** (0.005)	0.050** (0.001)

Note:

1. One and two asterisks indicate that estimates are significant at the 10% and 5% significance levels, respectively. Figures in the parentheses are standard errors.
2. LSDV stands for least square dummy variable estimators. Column (1) includes only year dummies and all other columns include both year and district dummies.
3. One and two asterisks indicate that estimates are at the 10% and 5% significance levels, respectively.
4. The system GMM method uses historical values of the TFP and road variables with a lag up to 10 years and the current values of HYV and rainfall as instrumental variables.

The coefficient for roads is positive at 0.019 but is statistically insignificant.

Because regressions in difference form reflect a short-run relationship, this result is not surprising given our earlier findings from the causality test that roads do not have an immediate causality effect on TFP.

In regression (2), we estimate a level equation using the LSDV estimator. Both regional and year dummies are included. The productivity effect of roads is now high at

0.078 and is statistically significant. However, this regression is probably subject to estimation bias due to the endogeneity problem inherent in the road variable as shown in the causality test. Because road development is endogenous as shown in the causality test, a GMM approach is applied to overcome the endogeneity problem for equation (6). To be specific, historical values for TFP and roads up to period $t-3$, the current values for HYV and rainfall, and the dummy variables are used as instruments for the GMM estimation. Compared to the conventional instrumental variable estimator, the GMM method allows us to use more initial conditions and historical values as instruments, therefore having better estimation efficiency. Regression (3) presents the GMM estimation results with the endogeneity problem being taken into account. The coefficient for the road variable drops to 0.048 but it is still much larger than in regression (1) and remains statistically significant.

To further justify the rationale of not taking differences in the regression, we estimate a level equation with first-order autocorrelation using LSDV to check the autocorrelation coefficient ρ . If ρ is equal or close to 1, then differencing is required, otherwise not. Regression (4) reports estimation results with first-order correlation. The autocorrelation is significant at 0.454, far from 1, suggesting that it is not necessary to take the first difference. With autocorrelation being considered, the coefficient for roads declines from 0.078 to 0.069.

This level regression may also be subject to an endogeneity problem from reverse causality. Using the autocorrelation coefficient obtained from regression (4), we first take a quasi-difference to transform all the data series to eliminate the serial correlation in the error term and then apply the GMM method to overcome the endogeneity problem. This

two-stage estimation is asymptotically consistent (Greene, 1993). The coefficient for roads in regression (5) is significant at 0.043, less than that without autocorrelation being adjusted or endogeneity being eliminated.

The implication of using all the historical information for productivity and road variables as instruments in the GMM method is that governments can utilize all the available information prior to time t in making investment decisions. In sum, the results in Table 2 consistently show that infrastructure development has a positive effect on productivity growth. The actual magnitude of the effect may be lower after adjusting for autocorrelation and endogeneity problems than that for the standard two-way effects model. But it is definitely much higher than those from the differenced estimation approach.

4. CONCLUSIONS

In the first part of the paper, we conducted a causality test to investigate the relationship between technology and infrastructure using a panel data set at the district level in rural India from 1971 to 1994. The test allows for individual effects, and is estimated by applying a dynamic system GMM estimator to the autoregression equations. It is found that infrastructure development and productivity often affect each other in the long term but not in the short run. This finding has important implications for evaluating infrastructure investments.

In order to examine the magnitude of the productivity impact of infrastructure, we further explored different model specifications. In general, a model in levels yields positive and larger effects, while a model in differences gives insignificant results. This is consistent with findings in the literature. Because the autocorrelation coefficient is below

one, estimation in differences cannot be justified in our Indian data set. After further controlling for autocorrelation and accounting for possible endogeneity problems, we find that the magnitude of relationship decreases slightly. Nevertheless, infrastructure development has a significant and positive impact on growth in productivity.

REFERENCES

- Antle, John, 1984. Human Capital, Infrastructure, and Productivity of Indian Rice Framers. *Journal of Development Economics*, 66 (2): 414-421.
- Arellano, M. and S. Bond. 1991. Some tests of specification for panel data: Monte Carlo evidence and an application to employment equations. *Review of Economic Studies* 58: 277-297.
- Arellano, M. and S. Bond. 1998. Dynamic panel data estimation using DPD98 for Gauss: A guide for users. Memo.
- Aschauer, David, 1989. Is public expenditure productive? *Journal of Monetary Economics*. 23: 177-220.
- Baltagi, Badi and Chihwa Kao. 2000. *Nonstationary panels, cointegration in panels and dynamic panels: A survey processed*. Syracuse, New York, USA: Syracuse University.
- Binswanger, Hans, S. Khandker, and M. Rosenzweig. 1993. How infrastructure and financial institutions affect agricultural output and investment in India. *Journal of Development Economics*, 41: 337-366.
- Canning, David. 1999. *Infrastructure's contribution to aggregate output*. Policy Research Working Paper 2246. Washington, DC: World Bank.
- Canning, David and Peter Pedroni. 1998. *Does infrastructure cause economic growth?* Working paper. Washington, DC: World Bank.
- Blundell, Richard and Stephen Bond. 1998. Initial conditions and moment restrictions in dynamic panel data models. *Journal of Econometrics* 87: 115-143.
- Blundell, Richard and Stephen Bond. 1999. *GMM estimation with persistent panel data: An application to production functions*. Working Paper Series No. W99/4. London, UK: Institute for Fiscal Studies.
- Evans, Paul and Georgios Karras. 1994. Are government activities productive? Evidence from a panel of U.S. States. *The Review of Economics and Statistics*, February 76 (1): 1-11.
- Fan, S., P. Hazell, and S. Thorat. 2000. Government spending, growth, and poverty in rural India. *American Journal of Agricultural Economics* 82 (4): 1038-1051.

- Fan, S., P. Hazell, and T. Haque. 2000. Targeting public investments by agro-ecological zone to achieve growth and poverty alleviation goals in rural India. *Food Policy*, 25: 411-428.
- Garcia-Mila, Teresa, Therese J. McGuire, and Robert H. Porter. 1996. The effect of public capital in state-level production functions reconsidered. *The Review of Economics and Statistics*: 177-180.
- Gramlich, Edward M., 1994. Infrastructure investment: A review essay. *Journal of Economic Literature* 32: 1176-1196.
- Granger, C., 1969. Investigating causal relations by econometric models and cross-spectral methods. *Econometrica* 37: 434-439.
- Greene, W. 1993. *Econometric Analysis*. New Jersey: Prentice-Hall, Inc.
- Holtz-Eakin, D. W. Newey, and H. Rosen. 1988. Estimating vector autoregressions with panel data. *Econometrica* 56: 1371-1395.
- Holtz-Eakin, D. 1994. Public-Sector Capital and the Productivity Puzzle *The Review of Economics and Statistics*, 76 (1):12-21.
- Hsiao, Cheng, 1986. *Analysis of Panel Data*. Cambridge: Cambridge University Press.
- Jimenez, Emmanuel. 1995. Human and physical infrastructure: Public investment and pricing policies in developing countries. In *Handbook of Development Economics*, ed. Jere Behrman and T.N. Srinivasan, 3B: 2773-2843.
- Mariesse, J. and B. Hall. 1996. Estimating the productivity of research and development in French And US manufacturing firms: An exploration of simultaneity issues with GMM methods. In *International Productivity Difference and Their Explanations*, eds., Wagner, K. and B. Van Ark, Elsevier Science, 285-315.
- Munnell, Alicia H. 1992. Infrastructure investment and economic growth. *Journal of Economic Perspective*, 6(4): 189-198.
- Tatom, John A. 1993. *Paved with good intentions: The mythical national infrastructure crisis*. Policy Analysis. Washington, DC: Cato Institute. August 12.

EPTD DISCUSSION PAPERS

LIST OF EPTD DISCUSSION PAPERS

- 01 *Sustainable Agricultural Development Strategies in Fragile Lands*, by Sara J. Scherr and Peter B.R. Hazell, June 1994.
 - 02 *Confronting the Environmental Consequences of the Green Revolution in Asia*, by Prabhu L. Pingali and Mark W. Rosegrant, August 1994.
 - 03 *Infrastructure and Technology Constraints to Agricultural Development in the Humid and Subhumid Tropics of Africa*, by Dunstan S.C. Spencer, August 1994.
 - 04 *Water Markets in Pakistan: Participation and Productivity*, by Ruth Meinzen-Dick and Martha Sullins, September 1994.
 - 05 *The Impact of Technical Change in Agriculture on Human Fertility: District-level Evidence From India*, by Stephen A. Vosti, Julie Witcover, and Michael Lipton, October 1994.
 - 06 *Reforming Water Allocation Policy Through Markets in Tradable Water Rights: Lessons from Chile, Mexico, and California*, by Mark W. Rosegrant and Renato Gazri S, October 1994.
 - 07 *Total Factor Productivity and Sources of Long-Term Growth in Indian Agriculture*, by Mark W. Rosegrant and Robert E. Evenson, April 1995.
 - 08 *Farm-Nonfarm Growth Linkages in Zambia*, by Peter B.R. Hazell and Behjat Hoijsati, April 1995.
 - 09 *Livestock and Deforestation in Central America in the 1980s and 1990s: A Policy Perspective*, by David Kaimowitz (Interamerican Institute for Cooperation on Agriculture), June 1995.
 - 10 *Effects of the Structural Adjustment Program on Agricultural Production and Resource Use in Egypt*, by Peter B.R. Hazell, Nicostrato Perez, Gamal Siam, and Ibrahim Soliman, August 1995.
 - 11 *Local Organizations for Natural Resource Management: Lessons from Theoretical and Empirical Literature*, by Lise Nordvig Rasmussen and Ruth Meinzen-Dick, August 1995.
-

- 12 *Quality-Equivalent and Cost-Adjusted Measurement of International Competitiveness in Japanese Rice Markets*, by Shoichi Ito, Mark W. Rosegrant, and Mercedita C. Agcaoili-Sombilla, August 1995.
 - 13 *Role of Inputs, Institutions, and Technical Innovations in Stimulating Growth in Chinese Agriculture*, by Shenggen Fan and Philip G. Pardey, September 1995.
 - 14 *Investments in African Agricultural Research*, by Philip G. Pardey, Johannes Roseboom, and Nienke Beintema, October 1995.
 - 15 *Role of Terms of Trade in Indian Agricultural Growth: A National and State Level Analysis*, by Peter B.R. Hazell, V.N. Misra, and Behjat Hoijati, December 1995.
 - 16 *Policies and Markets for Non-Timber Tree Products*, by Peter A. Dewees and Sara J. Scherr, March 1996.
 - 17 *Determinants of Farmers' Indigenous Soil and Water Conservation Investments in India's Semi-Arid Tropics*, by John Pender and John Kerr, August 1996.
 - 18 *Summary of a Productive Partnership: The Benefits from U.S. Participation in the CGIAR*, by Philip G. Pardey, Julian M. Alston, Jason E. Christian, and Shenggen Fan, October 1996.
 - 19 *Crop Genetic Resource Policy: Towards a Research Agenda*, by Brian D. Wright, October 1996.
 - 20 *Sustainable Development of Rainfed Agriculture in India*, by John M. Kerr, November 1996.
 - 21 *Impact of Market and Population Pressure on Production, Incomes and Natural Resources in the Dryland Savannas of West Africa: Bioeconomic Modeling at the Village Level*, by Bruno Barbier, November 1996.
 - 22 *Why Do Projections on China's Future Food Supply and Demand Differ?* by Shenggen Fan and Mercedita Agcaoili-Sombilla, March 1997.
 - 23 *Agroecological Aspects of Evaluating Agricultural R&D*, by Stanley Wood and Philip G. Pardey, March 1997.
-

- 24 *Population Pressure, Land Tenure, and Tree Resource Management in Uganda*, by Frank Place and Keijiro Otsuka, March 1997.
 - 25 *Should India Invest More in Less-favored Areas?* by Shenggen Fan and Peter Hazell, April 1997.
 - 26 *Population Pressure and the Microeconomy of Land Management in Hills and Mountains of Developing Countries*, by Scott R. Templeton and Sara J. Scherr, April 1997.
 - 27 *Population Land Tenure and Natural Resource Management: The Case of Customary Land Area in Malawi*, by Frank Place and Keijiro Otsuka, April 1997.
 - 28 *Water Resources Development in Africa: A Review and Synthesis of Issues, Potentials, and Strategies for the Future*, by Mark W. Rosegrant and Nicostrato D. Perez, September 1997.
 - 29 *Financing Agricultural R&D in Rich Countries: What's Happening and Why?* by Julian M. Alston, Philip G. Pardey, and Vincent H. Smith, September 1997.
 - 30 *How Fast Have China's Agricultural Production and Productivity Really Been Growing?* by Shenggen Fan, September 1997.
 - 31 *Does Land Tenure Insecurity Discourage Tree Planting? Evolution of Customary Land Tenure and Agroforestry management in Sumatra*, by Keijiro Otsuka, S. Suyanto, and Thomas P. Tomich, December 1997.
 - 32 *Natural Resource Management in the Hillsides of Honduras: Bioeconomic Modeling at the Micro-Watershed Level*, by Bruno Barbier and Gilles Bergeron, January 1998.
 - 33 *Government Spending, Growth, and Poverty: An Analysis of Interlinkages in Rural India*, by Shenggen Fan, Peter Hazell, and Sukhadeo Thorat, March 1998. Revised December 1998.
 - 34 *Coalitions and the Organization of Multiple-Stakeholder Action: A Case Study of Agricultural Research and Extension in Rajasthan, India*, by Ruth Alsop, April 1998.
-

- 35 *Dynamics in the Creation and Depreciation of Knowledge and the Returns to Research*, by Julian Alston, Barbara Craig, and Philip Pardey, July, 1998.
 - 36 *Educating Agricultural Researchers: A Review of the Role of African Universities*, by Nienke M. Beintema, Philip G. Pardey, and Johannes Roseboom, August 1998.
 - 37 *The Changing Organizational Basis of African Agricultural Research*, by Johannes Roseboom, Philip G. Pardey, and Nienke M. Beintema, November 1998.
 - 38 *Research Returns Redux: A Meta-Analysis of the Returns to Agricultural R&D*, by Julian M. Alston, Michele C. Marra, Philip G. Pardey, and T.J. Wyatt, November 1998.
 - 39 *Technological Change, Technical and Allocative Efficiency in Chinese Agriculture: The Case of Rice Production in Jiangsu*, by Shenggen Fan, January 1999.
 - 40 *The Substance of Interaction: Design and Policy Implications of NGO-Government Projects in India*, by Ruth Alsop with Ved Arya, January 1999.
 - 41 *Strategies for Sustainable Agricultural Development in the East African Highlands*, by John Pender, Frank Place, and Simeon Ehui, April 1999.
 - 42 *Cost Aspects of African Agricultural Research*, by Philip G. Pardey, Johannes Roseboom, Nienke M. Beintema, and Connie Chan-Kang, April 1999.
 - 43 *Are Returns to Public Investment Lower in Less-favored Rural Areas? An Empirical Analysis of India*, by Shenggen Fan and Peter Hazell, May 1999.
 - 44 *Spatial Aspects of the Design and Targeting of Agricultural Development Strategies*, by Stanley Wood, Kate Sebastian, Freddy Nachtergaele, Daniel Nielsen, and Aiguo Dai, May 1999.
 - 45 *Pathways of Development in the Hillsides of Honduras: Causes and Implications for Agricultural Production, Poverty, and Sustainable Resource Use*, by John Pender, Sara J. Scherr, and Guadalupe Durón, May 1999.
 - 46 *Determinants of Land Use Change: Evidence from a Community Study in Honduras*, by Gilles Bergeron and John Pender, July 1999.
-

- 47 *Impact on Food Security and Rural Development of Reallocating Water from Agriculture*, by Mark W. Rosegrant and Claudia Ringler, August 1999.
 - 48 *Rural Population Growth, Agricultural Change and Natural Resource Management in Developing Countries: A Review of Hypotheses and Some Evidence from Honduras*, by John Pender, August 1999.
 - 49 *Organizational Development and Natural Resource Management: Evidence from Central Honduras*, by John Pender and Sara J. Scherr, November 1999.
 - 50 *Estimating Crop-Specific Production Technologies in Chinese Agriculture: A Generalized Maximum Entropy Approach*, by Xiaobo Zhang and Shenggen Fan, September 1999.
 - 51 *Dynamic Implications of Patenting for Crop Genetic Resources*, by Bonwoo Koo and Brian D. Wright, October 1999.
 - 52 *Costing the Ex Situ Conservation of Genetic Resources: Maize and Wheat at CIMMYT*, by Philip G. Pardey, Bonwoo Koo, Brian D. Wright, M. Eric van Dusen, Bent Skovmand, and Suketoshi Taba, October 1999.
 - 53 *Past and Future Sources of Growth for China*, by Shenggen Fan, Xiaobo Zhang, and Sherman Robinson, October 1999.
 - 54 *The Timing of Evaluation of Genebank Accessions and the Effects of Biotechnology*, by Bonwoo Koo and Brian D. Wright, October 1999.
 - 55 *New Approaches to Crop Yield Insurance in Developing Countries*, by Jerry Skees, Peter Hazell, and Mario Miranda, November 1999.
 - 56 *Impact of Agricultural Research on Poverty Alleviation: Conceptual Framework with Illustrations from the Literature*, by John Kerr and Shashi Kolavalli, December 1999.
 - 57 *Could Futures Markets Help Growers Better Manage Coffee Price Risks in Costa Rica?* by Peter Hazell, January 2000.
 - 58 *Industrialization, Urbanization, and Land Use in China*, by Xiaobo Zhang, Tim Mount, and Richard Boisvert, January 2000.
-

- 59 *Water Rights and Multiple Water Uses: Framework and Application to Kirindi Oya Irrigation System, Sri Lanka*, by Ruth Meinzen-Dick and Margaretha Bakker, March 2000.
- 60 *Community natural Resource Management: The Case of Woodlots in Northern Ethiopia*, by Berhanu Gebremedhin, John Pender and Girmay Tesfaye, April 2000.
- 61 *What Affects Organization and Collective Action for Managing Resources? Evidence from Canal Irrigation Systems in India*, by Ruth Meinzen-Dick, K.V. Raju, and Ashok Gulati, June 2000.
- 62 *The Effects of the U.S. Plant Variety Protection Act on Wheat Genetic Improvement*, by Julian M. Alston and Raymond J. Venner, May 2000.
- 63 *Integrated Economic-Hydrologic Water Modeling at the Basin Scale: The Maipo River Basin*, by M. W. Rosegrant, C. Ringler, D.C. McKinney, X. Cai, A. Keller, and G. Donoso, May 2000.
- 64 *Irrigation and Water Resources in Latin America and the Caribbean: Challenges and Strategies*, by Claudia Ringler, Mark W. Rosegrant, and Michael S. Paisner, June 2000.
- 65 *The Role of Trees for Sustainable Management of Less-favored Lands: The Case of Eucalyptus in Ethiopia*, by Pamela Jagger & John Pender, June 2000.
- 66 *Growth and Poverty in Rural China: The Role of Public Investments*, by Shenggen Fan, Linxiu Zhang, and Xiaobo Zhang, June 2000.
- 67 *Small-Scale Farms in the Western Brazilian Amazon: Can They Benefit from Carbon Trade?* by Chantal Carpentier, Steve Vosti, and Julie Witcover, September 2000.
- 68 *An Evaluation of Dryland Watershed Development Projects in India*, by John Kerr, Ganesh Pangare, Vasudha Lokur Pangare, and P.J. George, October 2000.
- 69 *Consumption Effects of Genetic Modification: What If Consumers Are Right?* by Konstantinos Giannakas and Murray Fulton, November 2000.
-

- 70 *South-North Trade, Intellectual Property Jurisdictions, and Freedom to Operate in Agricultural Research on Staple Crops*, by Eran Binenbaum, Carol Nottenburg, Philip G. Pardey, Brian D. Wright, and Patricia Zambrano, December 2000.
- 71 *Public Investment and Regional Inequality in Rural China*, by Xiaobo Zhang and Shenggen Fan, December 2000.
- 72 *Does Efficient Water Management Matter? Physical and Economic Efficiency of Water Use in the River Basin*, by Ximing Cai, Claudia Ringler, and Mark W. Rosegrant, March 2001.
- 73 *Monitoring Systems for Managing Natural Resources: Economics, Indicators and Environmental Externalities in a Costa Rican Watershed*, by Peter Hazell, Ujjayant Chakravorty, John Dixon, and Rafael Celis, March 2001.
- 74 *Does Quanyi Matter to NonFarm Employment?* by Xiaobo Zhang and Guo Li, June 2001.
- 75 *The Effect of Environmental Variability on Livestock and Land-Use Management: The Borana Plateau, Southern Ethiopia*, by Nancy McCarthy, Abdul Kamara, and Michael Kirk, June 2001.
- 76 *Market Imperfections and Land Productivity in the Ethiopian Highlands*, Stein Holden, Bekele Shiferaw, and John Pender, August 2001.
- 77 *Strategies for Sustainable Agricultural Development in the Ethiopian Highlands*, John Pender, Berhanu Gebremedhin, Samuel Benin, and Simeon Ehui, August 2001.
- 78 *Managing Droughts in the Low-Rainfall Areas of the Middle East and North Africa: Policy Issues*, Peter Hazell, Peter Oram, Nabil Chaherli, September 2001.
- 79 *Accessing Other People's Technology: Do Non-Profit Agencies Need It? How To Obtain It*, by Carol Nottenburg, Philip G. Pardey, and Brian D. Wright, September 2001.
- 80 *The Economics of Intellectual Property Rights Under Imperfect Enforcement: Developing Countries, Biotechnology, and the TRIPS Agreement*, by Konstantinos Giannakas, September 2001.
-

- 81 *Land Lease Markets and Agricultural Efficiency: Theory and Evidence from Ethiopia*, by John Pender and Marcel Fafchamps, October 2001.
 - 82 *The Demand for Crop Genetic Resources: International Use of the U.S. National Plant Germplasm System*, by M. Smale, K. Day-Rubenstein, A. Zohrabian, and T. Hodgkin, October 2001.
 - 83 *How Agricultural Research Affects Urban Poverty in Developing Countries: The Case of China*, by Shenggen Fan, Cheng Fang, and Xiaobo Zhang, October 2001.
-