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Does Public Capital Crowd Out Private Capital?

Evidence from India

Luis Serven

In the long run, capital for public infrastructure projects crowds in private capital — capital for public projects similar to commercial and industrial projects has the opposite effect.

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Summary findings

A recent but rapidly growing empirical literature focuses on the relationship between public and private capital. But for the most part, it ignores the heterogeneity of public investment.

In many countries, especially in the developing world, public investment includes not only basic infrastructure projects but also commercial and industrial projects similar to those undertaken by the private sector. And those two types of public investment are likely to have quite different effects on the accumulation of private capital.

Using data from India, Serven examines this issue empirically by implementing a simple analytical model encompassing two types of public capital. The empirical results show that in the long run capital for public infrastructure projects crowds *in* private capital — other types of public capital have the opposite effect. But in the short run, both kinds of public investment may crowd out private investment.

This paper — a product of the Macroeconomics and Growth Division, Policy Research Department — is part of a larger effort in the department to understand the determinants of private investment. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Emily Khine, room N11-061, telephone 202-473-7471, fax 202-522-3518, Internet address kkhine@worldbank.org. May 1996. (36 pages)

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1 - Introduction

The relationship between public and private investment, a long-standing issue in macroeconomics and development economics, has attracted renewed attention in recent years. Two factors have been behind this re-examination. On the one hand, the worldwide shift of the 1980s towards a growth strategy underscoring market forces and private sector leadership -- whose major exponent was the collapse of centrally-planned economies -- led in many countries to a retrenchment of the public sector from production and to a redefinition of its role in the development process, under the guiding principle that the public sector should concentrate its resources in areas where it supports, rather than replacing, the activity of the private sector.

In the academic arena, on the other hand, the macroeconomic role of public investment was brought to center stage by Aschauer (1989a, b), who analyzed empirically the impact of public capital accumulation on US private investment and output, and found a sizable positive effect in both cases. Aschauer's work has been followed by a rapidly growing literature re-examining his results -- which remain controversial -- from both micro and macroeconomic perspectives (see Gramlich 1994 for extensive references) and extending his analysis to other countries (e.g., Berndt and Hansson 1992, Argimon *et. al.* 1995).

For the most part, however, this literature has focused on *aggregate* public investment, ignoring the important question of public investment heterogeneity.[1] Empirically, this approach may be adequate for some industrial countries (with the US as a leading example), where the public sector's involvement in conventional industrial and commercial activities is almost negligible. However, this is not the general case among developed economies (France or Italy would provide clear counter-examples), and much less so in developing countries. In the latter the state is frequently involved, through public enterprises, in multiple activities such as manufacturing, banking, commerce, and so on, in addition to its more conventional role as provider of public goods and infrastructure services. This heterogeneity of public capital implies that different types of public investment likely have opposing effects on private sector activity: public projects in areas such as basic infrastructure and human capital formation presumably tend to raise the profitability of private production and thereby encourage private investment, while public projects in more conventional activities -- where public enterprises basically replicate the actions of private firms -- might be expected to have the opposite effect, by competing with the private sector in

[1] A notable exception is the work by Easterly and Rebelo (1993), who investigate the impact of different types of public investment (as well as consumption) on private investment and growth in a cross-section of developing countries.

goods and factor markets.[2] In such conditions, attempts to identify a meaningful relationship between aggregate public and private capital are doomed to failure.

Another methodological pitfall plaguing most empirical studies of the macroeconomic impact of public investment is their failure to deal adequately with the non-stationarity of the variables of interest. In this vein, the large impact of public capital on real GDP found by some empirical studies using aggregate US data has been criticized as a spurious result that vanishes when the variables are expressed in first differences (Hulten and Schwab 1991). However, first-differencing is certainly not a solution, because it removes the long-run relationships that may be present in the data and that are precisely the main question at issue (Munnell, 1992).

This paper examines empirically the relationship between public and private investment in India. The heterogeneity of public capital is clearly visible in India, whose experience of the last four decades provides an extreme example of overexpansion of the public sector. In the context of a state-led, inward-oriented development strategy that lasted until the early 1990s, Indian public enterprises extended into virtually all sectors of the economy. Moreover, they were instrumental in generating increasingly large public deficits in the 1980s, which brought the country to the verge of a foreign exchange crisis in 1990/91 and eventually led to a radical reorientation of economic policy and the abandonment of the state-led growth model. From the policy viewpoint, the need for a substantial retrenchment of the public sector in India has underscored the importance of redefining public investment priorities in favor of those activities supportive of rapid private sector expansion.

Against this background, the paper revisits empirically the impact of public capital on private capital. The focus of the analysis is on the effects of the former on the profitability of the latter. This is the dimension that allows a meaningful distinction between public projects competitive, and complementary, with those of the private sector. The paper develops a simple analytical model embodying this distinction, and implements it using disaggregate public investment data for India. To avoid the methodological pitfalls of previous studies using aggregate time-series data, the empirical application follows a cointegration approach. In particular, because the available empirical sample is small, no attempt is made to model each of the different factors affecting the optimal private capital stock; instead, the analysis is based on a simpler conditional model, drawing from some recent results in the analysis of cointegrated systems. The consequences of this modeling strategy for the validity of the resulting parameter estimates are thoroughly explored.

[2] Even for the U.S., Aschauer (1989a) finds that 'core' infrastructure, comprising roads, water and sewage, is the type of public investment with strongest positive impact on private output.

The paper is organized as follows. Section 2 provides a brief background to public and private investment in India. Section 3 outlines a simple model of private and public capital. Section 4 presents the econometric implementation of the model to India. Finally, Section 5 concludes.

2 - Public and private investment in India: background

Like many other developing countries, in the late 1950s India embarked on a state-led, inward-oriented development strategy, which underwent only minor variations until the early 1990s. Its key ingredient was rapid industrialization centered on heavy, capital-intensive industries, under the guidance of central planning and the leadership of the public sector, in a general framework of national self-sufficiency.[3]

For over three decades, private investors had to face the complex regulatory system that was erected to pursue this strategy. It involved comprehensive licensing of firms' entry, expansion and diversification plans; reservation of entire productive sectors for the state; high barriers to foreign trade protecting domestic production from external competition; and mandatory credit allocation schemes imposed on the banking system. This was accompanied by the expansion of the public sector into most spheres of economic activity, encompassing not only those explicitly reserved to the state (which included basic infrastructure sectors such as telecommunications and power), but also industrial and commercial activities in which public firms competed with private firms.

This growth strategy was reflected in a steady increase in investment/GDP ratios, which measured at constant prices rose from under 16 percent in the early 1960s to over 20 percent in the late 1980s and early 1990s (Table 1). At current prices the increase was even more pronounced -- nominal investment rose from 13 to 22 percent of nominal GDP over the same period --, due to the steady rise in the relative price of investment (measured by the investment deflator relative to the GDP deflator). To a large extent, this relative price trend mirrored the gradual strengthening of barriers to capital goods imports that, along with the banning of most consumer imports, was a centerpiece of India's inward-looking policies. [4]

[3] See Dubey (1994) for an overview of India's development strategy since independence.

[4] Tariff collection on machinery and equipment imports rose steadily from around 6 percent of import value in the early 1960s to over 80 percent in the late 1980s; this was undoubtedly a major factor behind the steady increase in the relative price of equipment in India, which, according to cross-country evidence reported by DeLong and Summers (1993), was among the highest in the world during the 1980s.

The active role of the public sector was duly reflected in the large volume of public investment, which since the early 1960s had reached proportions similar to those of private investment, due primarily to the strong investment effort of public enterprises (Table 1). The latter gained momentum in the 1980s, during which the public investment/GDP ratio reached its peak at 9.5 percent. In that decade, the public enterprise sector became India's major investor, a role that had traditionally belonged to the informal private sector (households and unincorporated businesses).

These trends, however, were partially reversed after the fiscal crisis of 1990/91 and the ensuing reforms, which led to a retrenchment of public investment and a parallel expansion of private capital accumulation, due in appearance to booming private corporate investment. However, it should be noted that the breakdown of private investment data between the incorporated and unincorporated sectors is not entirely reliable (see Little and Joshi 1994, Ch. 13). The reason is that investment by the unincorporated sector is derived as a residual, so any over- (under-) estimation of private corporate investment is correspondingly reflected in under- (over-) estimation of investment by the informal sector. Indeed, the investment/GDP ratios of the two subsectors display a strong negative correlation (equal to -.74) in the period 1960/61-1994/95, for which there is no clear economic justification.[5]

As Table 2 shows, the massive investment effort of the public sector over the last three decades had a very heterogeneous nature. Part of it took the form of basic infrastructure capital in areas such as agricultural irrigation, transport, telecommunications and power. Another significant fraction corresponded to standard public sector activities such as public administration and defense. However, a rather substantial portion of total public investment was consistently devoted to industrial and commercial activities, notably in manufacturing, which in market economies are usually undertaken by the private sector (cf. the row labeled "other" in Table 2). In addition, this latter fraction of public investment expenditures showed an increasing trend until the late 1980s, rising from under 30 percent of total public investment in the 1960s to close to 40 percent in the second half of the 1980s.

The fact that vast public resources were employed in non-infrastructure projects certainly does not mean that India's infrastructure needs were satisfied. On the contrary, there is abundant evidence that inadequate roads and telecommunication networks and poor electricity supply continued to pose major obstacles to economic activity.[6] Indeed, the cross-country data presented in Table 3 clearly suggest that

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[5] The rates of growth of the corresponding sectoral capital stocks show a similarly negative correlation. The reliability of disaggregated private investment figures has recently been subject of controversy in India, as some observers have argued that the measured decline in household investment rates since 1990 is just a statistical artifact, likely due to the overestimation of private corporate investment. See Balakrishnan (1996) for further discussion.

[6] See World Bank (1993).

during the 1980s India's infrastructure investment effort did not keep pace with that of other LDCs -- not even those in the lower-income segment of the developing world.

It seems likely that India's heterogeneous public investment mix had opposing effects on private sector activity. Public investment in infrastructure sectors reserved to the state presumably contributed to raise the profitability of private production and had, *ceteris paribus*, a crowding-in effect on private investment.[7] By contrast, public investment in industrial and commercial sectors open to competition between private and public firms might have had the opposite effect: by competing with private firms for productive inputs and output markets (and investment licenses), the expansion of public capital may have crowded-out private investment. In any case, the important conclusion is that, to investigate the relationship between private and public investment in India, the heterogeneity of the latter needs to be taken into consideration -- an aspect often ignored in the empirical literature on the relationship between public and private investment. The next section outlines a framework to address this issue.

3 - Public capital and the profitability of private capital: a simple model

A simple model encompassing private capital along with heterogeneous public capital can be sketched along the following lines. Assume that the supply side of the economy consists of the public and the private sectors. The public sector produces two goods. The first one is an intermediate productive input used by private firms called 'infrastructure services'; for simplicity, assume further that such services are produced using only infrastructure capital (such as roads and public works), and that they are supplied free of charge to users.[8] The other good supplied by the public sector is a final good produced by non-infrastructure public enterprises using capital and labor. Finally, the private sector produces another final good using capital, labor and infrastructure services. The two final goods are imperfect substitutes in private consumption; thus, the degree of substitutability between them provides a measure of the extent to which non-infrastructure public enterprises compete with private firms in output markets.

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[7] In fact, this might apply as well to some public investments in manufacturing, to the extent that import restrictions and legal state monopolies made the public sector the sole supplier of some basic intermediate inputs (Joshi and Little, 1994, Chapter 13).

[8] Thus, the implicit assumption is that infrastructure services are financed via (lump-sum) taxes. This is the same approach adopted by Aschauer (1989a).

For simplicity, assume also that private and public capital accumulation make use only of privately and publicly-produced goods, respectively.[9]

The economy is populated by an infinitely-lived representative agent who consumes the two final goods, owns the private firms, and supplies inelastically her entire labor endowment, which for notational simplicity will be set equal to 1; however, at each instant the private agent has to decide how to allocate her labor between private and public firms. The agent's objective is to maximize the utility functional

$$\int_0^\infty e^{-rs} \frac{U(C_{pr}, C_g)^{1-\theta}}{1-\theta} ds \tag{1}$$

where the subscripts pr and g respectively denote private consumption of the privately and publicly produced final goods, r is the discount rate, the parameter θ is the inverse of the elasticity of intertemporal substitution, and for convenience it will be assumed that the instantaneous utility function U is homogeneous of degree one in its two arguments and displays a constant elasticity of (intra-temporal) substitution σ_C.

Maximization of (1) is subject to the constraints

$$Y + wL_g = C_{pr} + p_g C_g + \dot{K}_{pr} + T \tag{2a}$$

$$Y = H(Z)\, L_{pr}^{\alpha} K_{pr}^{1-\alpha} \tag{2b}$$

$$L_{pr} + L_g = 1 \tag{2c}$$

Here Y denotes real output of the privately-produced final good; w and p_g respectively are the real wage and the relative price of the publicly-produced final good, both in terms of the private good; T are lump-sum (net) taxes, which can be positive or negative; Z denotes infrastructure capital, and L_j is the agent's labor supplied to sector j. Equation (2a) is the agent's budget constraint, where capital stock depreciation

[9] Alternatively, we could assume that capital goods are a combination of private and public final goods. This would add some algebra without affecting the results.

has been ignored. In turn, (2b) describes the technology used in the production of the private good , which is assumed to display constant returns to scale over capital and labor.[10]

In addition to (2a)-(2c), the first-order conditions for an interior solution to this problem can be shown to include

$$U(C_{pr},C_g)^{-\vartheta}\,\frac{\partial U}{\partial C_{pr}}=\lambda \tag{3a}$$

$$U(C_{pr},C_g)^{-\vartheta}\,\frac{\partial U}{\partial C_g}=\lambda p_g \tag{3b}$$

$$\dot{\lambda}=\lambda\left[r-H(Z)(1-\alpha)\left(\frac{L_{pr}}{K_{pr}}\right)^{\alpha}\right] \tag{3c}$$

$$H(Z)\alpha\left(\frac{K_{pr}}{L_{pr}}\right)^{1-\alpha}=w \tag{3d}$$

Equations (3a) and (3b) characterize optimal consumption. The variable λ represents the marginal utility of wealth, and its time path is given by (3c). Finally, (3d) is the familiar marginal productivity condition determining employment in the private sector.

In turn, the public sector produces infrastructure services, using only capital, and a final good, using both capital and labor. Letting G denote output of the final good, the public-sector budget constraint is

$$T+p_g(G-\dot{K}_g-\dot{Z})=wL_g \tag{4}$$

where the term in brackets represents the net supply of the final good produced by the public sector. Its production technology is:

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[10] In Meade's (1957) terminology, this corresponds to the "atmospheric" characterization of public infrastructure services. Alternatively, constant returns over K, L and Z in private production would correspond to his "unpaid factor" model.

$$G = L_g^{\beta} . K_g^{1-\beta} \tag{5}$$

The trajectories of the infrastructure and non-infrastructure public capital stocks are assumed exogenous. Given the latter, public non-infrastructure firms determine their employment levels from standard profit maximization:

$$\beta \left(\frac{K_g}{L_g} \right)^{1-\beta} = \frac{w}{p_g} \tag{6}$$

Finally, the model is completed with the private-goods market-clearing condition[11] :

$$Y = C_{pr} + \dot{K}_{pr} \tag{7}$$

Equations (2)-(7) fully characterize equilibrium in the two-sector model. Given the trajectories of the public sector's infrastructure and non-infrastructure capital stocks, they determine the real wage and the allocation of labor between private and public firms, the levels of output and private consumption of the two final goods as well as their relative price, total taxes, and the trajectory of the private capital stock.

Long-run impact of changes in the public capital stocks

The model's steady state is characterized by constant stocks of the three kinds of capital and a constant λ. Thus, output of the two final goods is fully devoted to private consumption and, from (3c) above, the marginal product of private capital equals the real interest rate. This in turn ties down the private sector's long-run capital/output ratio.

The effects of changes in public capital on the model's steady state are easily found. Consider first the case of an increase in the non-infrastructure capital stock K_g,. Public firms' output G expands unambiguously, and its relative price p_g falls. What happens to private firms' output and capital stock ? Given the stock of infrastructure capital, private firms' capital/labor ratio, and hence the real wage in terms of private goods, are uniquely determined by the given real interest rate (from (3c) above). Hence,

[11] Walras' law ensures that when both budget constraints hold and the private goods market clears, the market for the final good produced by public firms clears as well.

private output, capital and employment must all move in the same direction: they must rise if public employment declines (thus freeing up labor for private firms), and fall in the opposite case. In turn, the change in public sector employment depends on two mutually opposing forces: on the one hand, the decline in p_g shifts final demand away from private firms' final good, and this tends to raise employment in the public sector, more so the larger the degree of substitutability in consumption between the two final goods. On the other hand, the decline in p_g raises the real wage in terms of public firms' output (recall that the real wage in terms of private goods does not change), which tends to lower public employment. The net result therefore depends on whether substitution on the demand side between the two final goods dominates substitution against labor in public firms' production.

Analytically, replacing (2a), (3c), (4) and (7) with their respective stationary version, some straightforward manipulations yield the following implicit equation for the long-run private capital stock:

$$\frac{\alpha}{\beta} H(Z)^{\frac{\sigma_C}{\alpha}} \left[\frac{1-\alpha}{r}\right]^{1+\sigma_C\left(\frac{1-\alpha}{\alpha}\right)} K_g^{(\sigma_C-1)(1-\beta)} = \frac{K_{pr}}{\left[1-\left(\frac{r}{H(Z)(1-\alpha)}\right)^{\frac{1}{\alpha}} K_{pr}\right]^{\beta+(1-\beta)\sigma_C}} \tag{8}$$

Differentiating this expression yields:

$$\frac{dK_{pr}}{dK_g} = \frac{K_{pr}}{K_g} \frac{(1-\sigma_C)(1-\beta)L_g}{L_g + L_{pr}[\beta + \sigma_C(1-\beta)]} \tag{9}$$

Thus, an increase in the non-infrastructure public capital stock raises (reduces) the long-run private capital stock and output if the elasticity of substitution in consumption between the two final goods is smaller (larger) than one.

Consider now the long-run consequences of an increase in the stock of infrastructure capital Z. This raises the productivity of capital and labor in the private sector; therefore, private firms' output must unambiguously expand, and its relative price falls (equivalently, p_g rises). Since private firms' capital/output ratio is given, the private capital stock expands along with output. From (3c) it is apparent that private firms' capital/labor ratio must rise, and therefore the real wage has to go up.

What happens to public firms' output ? Analogously with the previous experiment, the answer depends on whether long-run private employment rises or falls. As before, there are two forces at work: the rise in p_g, that shifts consumption demand towards the private sector, and the real wage increase, that tends to displace labor towards the public sector. Analytically, from (8) one gets:

$$\frac{dK_{pr}}{dZ} = \frac{K_{pr}H'(Z)}{\alpha H(Z)} \frac{\beta L_{pr} + \sigma_C (1 - \beta L_{pr})}{L_g + L_{pr}[\beta + \sigma_C (1 - \beta)]} > 0 \qquad (10a)$$

$$\frac{dG}{dZ} = \frac{GH'(Z)}{\alpha H(Z)} \frac{\beta (1 - \sigma_C) L_{pr}}{L_g + L_{pr}[\beta + \sigma_C (1 - \beta)} \qquad (10b)$$

Hence, symmetrically with (9), equation (10b) shows that an increase in the infrastructure public capital stock raises (reduces) public firms' output and employment if the elasticity of substitution in consumption between the two final goods is smaller (larger) than one.

In summary, this simple framework draws a sharp distinction between the public sector's infrastructure and non-infrastructure capital. An increase in public infrastructure capital raises the profitability of private production and thereby the long-run private capital stock. By contrast, an increase in non-infrastructure capital may raise or lower the private capital stock, depending on how close substitutes are the final goods supplied by the public and private sectors. The higher the degree of substitutability, the more likely that an expansion in public non-infrastructure capital will result in crowding-out of the private sector. It should be stressed that this kind of crowding-out is entirely due to the fact that the public and private sectors engage in similar productive activities, and is therefore completely unrelated to the conventional 'financial crowding-out' that extensively explored in the macroeconomic literature.[12]

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[12] Indeed, by assuming that the discount rate r is given, the model in the text rules out financial crowding out. In terms of the model, financial crowding out would arise if the public sector were allowed to finance its activities through debt issue, and the real discount rate were positively related to the outstanding public debt stock. However, this type of crowding-out would be a consequence of the public sector's overall deficit and financing strategy, rather than of public investment itself, which is the main focus here.

4 - Empirical implementation

4.1 Preliminary issues

In order to implement empirically to India the model just described, it is necessary to amend it in two ways. First, the model makes no distinction between the prices of capital goods and final goods. In reality, however, the relative price of investment goods has experienced large swings in India, due among other factors to the substantial changes in trade barriers to capital goods imports over the last two decades, to which reference was made earlier.[13]

More problematic is the question of finding an empirical counterpart for the real interest rate r. This is not only due to the fact that interest rates have remained tightly controlled in India over the last three decades but, more importantly, to the above-illustrated fact that the bulk of private investment is made by the informal sector, which lacks access to most financial markets. The main exception is credit supplied by banks under mandatory credit allocation rules (such as the so-called "Small Scale Industries" scheme) that reserve a prescribed fraction of overall bank credit for unincorporated businesses and independent operators at highly subsidized (and officially-determined) interest rates. This makes the observed interest rate a very poor indicator of the cost of financing to the informal sector. Thus, a better alternative is to measure it by the availability of financing, which, given the functioning of the subsidized credit schemes, can be proxied by the real stock of bank credit to the private sector.

With these modifications, an empirically suitable version of equation (8) may be written:

$$k_{pr} = \varphi\ (\underset{(?)}{k_g}, \underset{(+)}{z}, \underset{(-)}{p_k}, \underset{(+)}{cr_{pr}}) \tag{11}$$

where p_k is the relative price of capital goods (measured by the deflator of private investment relative to privately-produced GDP), cr_{pr} is the real stock of credit to the private sector, lowercase letters denote the

[13] It would be straightforward to introduce in the model of the previous section the distinction between capital goods and final goods prices, with an exogenous tax driving a wedge between them. Assume, for example, that a tax at rate τ is levied on capital goods purchases, and let $p_k \equiv 1+\tau$. It is straightforward to verify that, in the equation characterizing the long-run private capital stock (8), r would simply be replaced with rp_k. An increase in the tax rate, and hence in p_k, given the infrastructure stock z, would unambiguously reduce the long-run private capital stock.

natural logarithm of the corresponding variables, and the sign under each variable indicates the expected direction of its impact on the private capital stock.[14]

The available sample comprises annual data from 1960/61 to 1993/94[15]. The core of the data are the private and public real fixed capital stocks series, with the latter suitably disaggregated to permit implementation of the model outlined in the preceding section. The Appendix provides more details on their construction.

The empirical analysis below uses a narrow definition of public infrastructure investment, which includes power, water and sewage, and transport and communications. However, empirical experiments using narrower (excluding power and water) and broader (including public agriculture investment, whose major components are irrigation works and rural roads) aggregates led to similar qualitative results.

To find out if a long-run relationship such as (11) above exists, and estimate its parameters, the analysis below makes use of some recent developments in the econometrics of cointegrated time series. In this regard, an important methodological issue is the choice of modeling and estimation technique. In principle, the approach best suited for the purpose at hand would be Johansen's (1988) full-information procedure, which is asymptotically efficient. In the case at hand, it would involve the estimation of a fifth-order vector-autoregressive (VAR) error-correction model with k_{pr}, k_g, z, cr_{pr} and p_k as dependent variables. There are practical problems with this approach, however, especially in a small-sample context like the present one. On the one hand, parameter estimation and hypothesis testing in the framework of a five-equation system would be severely hampered by the limited degrees of freedom available (see e.g. Heargraves 1994). On the other, modeling and economic interpretation of the empirical relations in a large system is often problematic, since economic theory may not offer sufficient guidance for a 'complete' structural specification (Urbain, 1995). Further, a VAR is essentially a statistical model of the reduced form; if one is interested not only in the long-run parameters, but also in the short-run dynamics, the reduced-form parameters are of limited structural (and economic) interest.

For these reasons, the strategy adopted below relies on the specification and estimation of a conditional model, along the lines described by Johansen (1992) and Boswijk (1994, 1995). The strategy proceeds in three stages. First, likelihood ratio tests are used to determine the number of cointegrating relations in the full system. Next, a partial structural model is specified and estimated; as argued by

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[14] Notice that (direct) taxation is being ignored in (11). This is consistent with the fact that most investment is done by the informal private sector, which is not subject to corporate taxation and can be presumed to largely escape most other forms of direct taxation.

[15] The observations correspond to the Indian fiscal year, which runs from April to March.

Boswijk (1995), the choice of endogenous variables in the model should be guided by the outcome of the cointegration tests. Because estimation of the partial system is conditional on the variables left outside it, the third stage involves testing their (weak) exogeneity, to verify if the partial model's estimates carry over to the full system.

4.2 Integration and cointegration

A preliminary step is to explore the time-series properties of the variables in (11). Table 4 reports the results of tests of stationarity of each of the variables. The top half of the table reports augmented Dickey-Fuller (ADF) test statistics. Since capital stocks should be expected to display considerable inertia, the tests were performed adding three lags of the dependent variable to the ADF regression. As can be seen from the top row of Table 4, the null hypothesis of a unit root cannot be rejected for any of the series. In turn, the second row reports the statistics testing the null hypothesis that the series are I(2) -- in other words, the first differences of the original series still contain unit roots. The null can be rejected at the 5 percent level for all series except the private capital stock, for which the test statistic is significant only at the 10 percent level.

As a double check on the above results, the bottom half of Table 4 reports the results of the stationarity test proposed by Kwiatkowski-Phillips-Schmidt-Shin, whose null hypothesis is that the series do *not* possess unit roots -- i.e., the opposite to the null under the ADF test; like in the previous case, the test statistics were computed setting the lag truncation parameter equal to 3 (for details see Kwiatkowski *et. al.* 1992). As the table shows, the null hypothesis that the series are I(0) can be rejected in every case. By contrast, the bottom line of the table indicates that stationarity of the first-differenced series cannot be rejected at the 5 percent level, although the test statistics reveal some mild evidence that the first-difference of k_g may be non-stationary.

To summarize, the univariate tests agree that z, cr_{pr} and p_k are all I(1), and provide reasonable evidence in favor of k_{pr} being I(1) as well. For k_g the situation is somewhat less clear, since the two tests provide some conflicting evidence. Nevertheless, as a working hypothesis, for the analysis below k_g is also assumed to be I(1).

The next step is to investigate whether the series are cointegrated, so that a well-defined long-run relationship exists among them. Table 5 reports the results of Johansen's likelihood ratio cointegration tests. They are based on a vector autoregression including two lags of each of the five variables in (11); while use of longer lags might in principle be necessary to capture the full dynamics of the slow-moving capital stocks, they result in severe depletion of the available degrees of freedom. A linear trend was also included to provide a crude representation of the effects of labor force growth and technical progress on the capital stock, but was restricted to the cointegrating space since, as Table 4 showed, the first-differenced variables do not appear to display trends.

Because likelihood ratio tests of cointegration suffer from considerable small-sample bias (which typically results in their finding cointegration 'too often'), it is essential that the critical values be adjusted for sample size. Thus, the critical values presented in Table 5 were computed as indicated by Cheung and Lai (1993). In the present case, this results in an upward revision of the asymptotic critical values by roughly 46 percent.[16]

The first column of Table 5 lists the number of cointegrating vectors (R) under the null hypothesis. From the second and third columns, the hypothesis of no cointegration can be rejected at the 5 percent level, in favor of at most one cointegrating vector, without much evidence of more than one.

4.3 Estimation of the conditional model

Rather than pursuing the estimation of the full reduced-form VAR system, we turn to the estimation of a structural model of k_{pr}, conditional on the other variables.[17] Since Table 5 suggests that there is only one cointegrating relation in the full system, a single-equation structural model is sufficient to estimate the parameters of the long-run relation (11). Thus the structural model is of the form:

$$\Delta k_{pr,t} = B_0 \Delta w_t + \sum_{j=1}^{p-1} \left[\alpha_j \, \Delta k_{pr,t-j} + B_j \, \Delta w_{t-j}\right] - \lambda \left(k_{pr,t-1} - \beta' w_{t-1}\right) + \varepsilon_t \tag{12}$$

and is complemented with the reduced-form model of the conditioning variables:

$$\Delta w_t = C_0 \Delta w_t + \sum_{j=1}^{p-1} \left[A_j \, \Delta k_{pr,t-j} + C_j \, \Delta w_{t-j}\right] - \Lambda \left(k_{pr,t-1} - \beta' w_{t-1}\right) + \eta_t \tag{13}$$

where $w = (k_g, z, cr_{pr}, p_k)'$ is the vector of conditioning variables; α_j and λ are parameters, and A_j, β, B_i, C_i and Λ are parameter vectors; ε and η are random disturbances, and the term in round brackets in the

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[16] Asymptotic critical values were taken from Osterwald-Lenum (1992). Their (inappropriate) use in this small-sample context would lead to finding four cointegrating vectors.

[17] Here and in the rest of this section the term 'structural model' is used in the simultaneous-equation sense that the equation of interest (12) includes the current values of more than one variable.

right-hand side of (12) and (13) represents the long-run equilibrium relationship, given by equation (11) above.

From the results of Johansen (1992) and Boswijk (1995), it follows that OLS in (12) alone provides a super-consistent estimator of the long-run coefficient vector β and the speed of adjustment λ. However, other properties of the OLS estimator of the long-run parameters, such as its efficiency and asymptotic distribution, as well as the properties of the estimator of the short-run parameters in (12), depend critically on whether the conditioning variables w are (weakly) exogenous, an issue that will be taken up later.

Leaving this question aside for the time being, the starting point for the conditional analysis is an unrestricted autoregressive-distributed lag specification[18] for k_{pr}, including the current and two lagged values of the conditioning variables, plus the linear time trend. The OLS estimation results appear in Table 6. While the equation is clearly overparameterized, and individual coefficients are in some cases estimated imprecisely, the long-run solution is well-determined. It is of the form:

$$k_{pr} = constant + 0.045\,time - 0.839\,k_g + 0.659\,z + 0.162\,cr_{pr} - 0.213\,p_k \tag{14}$$

Thus, the estimates indicate that public infrastructure capital has a positive long-run effect on the private capital stock, while non-infrastructure capital has the opposite impact. Further, the estimated magnitude of these effects is numerically quite large (recall that, with all the variables in log form, the coefficients in (14) can be interpreted as elasticities). In addition, real credit to the private sector also affects the private capital stock positively, while the relative price of capital has the expected negative effect.

The bottom half of Table 6 reports a battery of diagnostic tests that reveal no signs of misspecification. According to the test statistics, the residuals show no traces of autocorrelation or autoregressive conditional heteroskedasticity (ARCH), and Ramsey's RESET test detects no functional form misspecification. At most, the Jarque-Bera statistic provides some mild suggestion of non-normality of the residuals.

The unrestricted equation in Table 6 can be re-arranged and simplified to arrive at an error-correction specification describing both the dynamics of the capital stock and its long-run determinants, along the lines of equation (13) above. This leads to the following model (standard errors in brackets):

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[18] This is what Hendry (1995) labels the "GUM" (General Unrestricted Model) specification.

$$\Delta k_{pr,t} = \underset{(0.592)}{2.454} + \underset{(0.134)}{0.322}\, \Delta k_{pr,t-1} - \underset{(0.104)}{0.414}\, \Delta k_{g,t} - \underset{(0.157)}{0.258}\, (\Delta z + \Delta z_{t-1})/2 + \underset{(0.020)}{0.054}\, \Delta cr_{pr,t} - \underset{(0.034)}{0.076}\, \Delta p_k$$

$$-\underset{(0.072)}{0.340}\, [\, k_{t-1} - \{\underset{(0.012)}{0.044}\, time - \underset{(0.288)}{0.948}\, k_{g,t-1} + \underset{(0.236)}{0.769}\, z_{t-1} + \underset{(0.068)}{0.192}\, cr_{pr,t-1} - \underset{(0.110)}{0.253}\, p_{k,t-1}\, \}] \tag{15}$$

$R^2 = 0.893$ SEE = 0.41% Sample: 1962/63-1993/94

The simplifications introduced in equation (15) relative to the GUM model of Table 6 are easily accepted by the data (F(4, 16) = 0.409, with a p-level of 0.800). The term in curly brackets in the second line of the equation is the model's long-run solution for the private capital stock, very similar to (14) above[19], and again indicating a strong favorable (adverse) effect of public infrastructure (non-infrastructure) capital on the private capital stock. In terms of the model of section 3, the implication is that the final goods produced by the private and public sector were, on the whole, relatively close substitutes.

In turn, the short-run coefficients in the top line of (15) show that public non-infrastructure investment also crowds-out private investment in the short run. Perhaps more interestingly, the short-run estimates also provide some mild evidence that even infrastructure investment has an adverse short-run impact on private investment; in fact, the estimates indicate that the effect of public infrastructure investment on private capital accumulation only becomes positive after a two-year lag. The adverse short-run impact could arise from the pressure of public investment programs on input markets -- a channel that was omitted from the model in section 3, where capital accumulation was assumed to require no labor.

Table 7 presents misspecification tests for equation (15). As before, they reveal no trace of residual autocorrelation, heteroskedasticity, ARCH effects and non-normality, and the estimated equation appears to forecast accurately. The estimated standard error is 0.41 percent, against a standard deviation of Δk_{pr} of 1 percent, so that the model provides a fairly accurate account of the variation in the dependent variable. Figure 1 plots the observed trajectory of the private capital stock and the fitted values from (15), along with the corresponding residuals. As can be seen, the tracking is quite precise; however, there is one large positive residual in 1990/91, just equal to two standard errors. That year witnessed a private investment boom (in fact, the peak of the dependent variable Δk_{pr} takes place in 1990/91, at over seven times its standard deviation), which might have been due in part to investors' anticipation of a tightening

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[19] Standard errors on the long-run parameters were computed along the lines described in Bardsen (1989).

of import barriers on capital goods as a remedy to the impending macroeconomic crisis -- a measure that took place effectively in 1991/92 -- and whose impact is not captured by the simple structural model above.

An important issue is the stability of the estimated equation. This can be checked through recursive estimation of its parameters, adding to the sample one observation at a time and verifying if the equation's forecasts show large errors or the estimated parameters display instability, either of which would suggest the existence of a structural break. Figure 2 presents the one-step ahead forecast errors from 1974/75 onwards obtained from recursive estimation of the parameters of (15), along with their two standard-error bands; forecast errors close or beyond those bands would indicate forecast failure and possible instability of the estimated specification. As the figure shows, prediction errors remain throughout within their approximate 95 percent confidence region.

Recursive parameter estimates, along with their two standard error bands, appear in Figure 3. To save space, only the long-run parameters are presented; however, the results for the remaining parameters are similar. As can be seen, the estimates display very little variation relative to their ex-ante standard errors, and their final (i.e., full-sample) 95 percent confidence intervals are contained in the initial ones virtually in full, so that on the whole no indication of instability arises.

A more formal check on the constancy of the model is the test of parameter stability proposed by Hansen (1992)[20]. However, the test is based on the assumption that the regressors are stationary, and thus cannot be used to check the constancy of the parameters of the cointegrating vector, itself a linear combination of I(1) variables. The solution to this problem is to impose the values of the long-run parameters and then test the constancy of the rest; this essentially amounts to testing the constancy of the parameters describing the model's dynamics -- including the speed of adjustment to the long-run equilibrium.

Following this procedure with equation (15) leaves a total of seven parameters, plus the model's estimated residual variance, whose stability is to be tested. Table 8 reports the individual tests on each of them as well as the joint test of stability of all eight parameters. The approximate 5 percent critical value for each individual test is 0.470, while that for the joint test is 2.11. As the table shows, all the computed test statistics are well below critical levels, so that test reveals no sign of instability.

[20] The test is based on the cumulative sums of orthogonality conditions between the regressors and the least-squares residuals obtained from estimating the model on the full sample. If the model is unstable, the cumulative sums should differ significantly from zero. The test statistic has a non-standard distribution, but critical values are reported by Hansen (1992).

4.4 Testing weak exogeneity

The empirical analysis so far has been based only on the structural model given by (12) above, ignoring the marginal model (13). The question arises of how the estimates thus obtained relate to those that would have resulted from full-information estimation in the complete model. The answer is that in general the properties of the OLS estimator obtained from the structural model alone -- i.e., its consistency, as well as the validity of the standard errors and testing procedures reported in Table 6 and equation (15) above -- depend crucially on whether the conditioning variables can be taken as weakly exogenous for the parameters of interest.

The relevant notion of weak exogeneity depends on the particular choice of 'parameters of interest'. If one is interested only in the long-run parameters of the structural model (i.e., the parameter vector β in (12), as well as the speed of adjustment λ), then the conditioning variables are weakly exogenous for the parameters of interest if and only if the marginal model contains no cointegration; i.e., all the elements of Λ in (13) are equal to zero (Johansen 1992). In such case, the OLS estimator of β and λ is asymptotically efficient and normally distributed. This in turn means that the standard errors and testing procedures on the long-run parameters reported above are indeed valid.

If, in addition, the parameters of interest include also those describing the structural model's dynamics (i.e.,α_j and B_j in (12)), then to ensure weak exogeneity of the conditioning variables one must add the requirement that the covariance between the disturbance in the structural model and those in the marginal model be equal to zero (Urbain 1992). Under such additional assumption, the OLS estimator of the short-run parameters is also consistent and asymptotically normally distributed.

These two requirements can be verified through standard variable-addition tests. As shown by Johansen (1992), weak exogeneity for the long-run parameters can be checked by testing the significance of the cointegrating vector(s) in a reduced-form regression of the conditioning variables on the past -- i.e., testing whether Λ in (13) is equal to a vector of zeros. Likewise, weak exogeneity for *all* the parameters in the structural equation can be checked by adding to it, as artificial regressors, the residuals from the reduced-form regression just described, and then testing the *joint nullity* of the coefficients of these artificial regressors in the structural equation, *and* the coefficients on the cointegrating vector(s) in the marginal equations (Boswijk and Urbain, 1994).

These weak exogeneity tests are reported in Table 9. The first two columns report the tests of weak exogeneity for the long-run parameters only, while the third and fourth columns report the tests for the entire set of parameters in the structural equation. In each case, the table presents the individual tests for each conditioning variable as well as the joint test for all four of them. The statistics are in all cases asymptotically distributed as χ^2, with degrees of freedom equal to the number of exclusion restrictions being tested (see the notes to Table 9). As can be seen, the tests provide very little evidence against weak exogeneity, which can be easily accepted in every individual as well as joint test. The conclusion is that the partial model given by equation (12) contains all relevant information about the parameters describing both the long-run capital stock as well as its short-run dynamics, and therefore the estimates, standard errors and inferences reported in the preceding subsection are indeed valid.

A final check on the overall dynamic specification of the estimated equation is provided by a test proposed by Boswijk (1994), which checks for the presence of unstable roots in the structural model. The test essentially amounts to examining the significance of the error-correction term in the structural equation; if it is sufficiently significant, the presence of unstable roots can be rejected. If, in addition, the conditioning variables are weakly exogenous (as appears to be the case here), the test is in fact a test of the null hypothesis of no cointegration. While the test statistic does not have a standard distribution, asymptotic critical values have been tabulated by Boswijk (1994). For the specification in equation (15) above, the computed test statistic was 40.80 well beyond the 1 percent critical value of 28.51, thus overwhelmingly rejecting the hypothesis of no cointegration.

To summarize, the estimation results reported in this section are, on the whole, rather supportive of the analytical specification in section 3. They provide strong evidence that in the long run public infrastructure capital crowds-in private capital, while other types of public capital have the opposite effect. Real credit and the relative price of capital goods have the expected effects on the private capital stock -- positive in the case of the former and negative for the latter. However, the favorable impact of public infrastructure investment on private capital accumulation takes two years to begin to materialize.

The empirical specification passes a battery of diagnostic tests, shows no sign of instability, and seems to provide an accurate description of the trajectory of the private capital stock. Further, the exogeneity tests clearly indicate that the partial-model approach adopted here is sufficient to capture all the relevant empirical information on the parameters describing the trajectory of the private capital stock.

5 - Concluding remarks

While the relationship between public and private investment is a long-standing issue in macroeconomics and development economics, few of the empirical studies addressing it draw the distinction between public infrastructure and non-infrastructure capital. This paper has argued that such distinction is essential in economies in which the state is actively involved in production, because public investment may play a dual role: public infrastructure projects raise the profitability of private production and encourage private investment, while non-infrastructure projects in areas where the public sector competes with private firms may have the opposite effect. The paper has sketched an analytical model highlighting these opposing effects of public capital.

The model is implemented empirically using investment data for India, which provides a good example of the dual role of public investment. The state-led development strategy adopted by India since the late 1950s resulted in an expansion of the public sector into virtually all spheres of economic activity. While basic infrastructure industries were legally reserved to the state, in others public firms competed with the private sector for productive inputs, customers, and investment licenses.

The empirical implementation follows a cointegration approach and makes use of a partial structural model of the private capital stock, that has important advantages in terms of transparency and tractability over the full-system reduced-form analysis, particularly in small-sample context like the present one. A battery of weak exogeneity tests shows that this simplified procedure entails no loss of information for the purpose of estimating the parameters describing the trajectory of private capital.

On the whole, the empirical results are quite supportive of the analytical model. The data provide convincing evidence of a positive and significant long-run effect of public infrastructure capital on the private capital stock, and an adverse effect of public non-infrastructure capital, after controlling for the effects of capital goods prices and real credit availability to the private sector. In the analytical framework outlined in this paper, this suggests that the goods supplied by public non-infrastructure enterprises and private firms likely were, on the whole, relatively close substitutes. The estimated model's dynamics also reveal that the adverse effect of public non-infrastructure investment on private capital accumulation operate quite rapidly, while the favorable impact of public infrastructure investment only arises after a two-year lag. The estimated equation has high explanatory power, passes a battery of diagnostic tests, and the parameter estimates appear constant over the sample period.

Since the early 1990s, India's economic policies have experienced a substantial change. An effort -- still incomplete -- at fiscal adjustment has been accompanied by a shift towards a market-oriented development model led by the private sector -- a change propitiated by the large fiscal imbalances of the late 1980s that resulted from the overexpansion of the public sector. The paper's results indicate that, to have a maximum impact on private investment, the ongoing fiscal retrenchment should be matched by a radical redefinition of public investment priorities in favor of infrastructure projects.

One final clarification may be in order. While the results in this paper underscore the favorable impact of infrastructure investment on private capital accumulation, there is obviously no reason why infrastructure services should be necessarily provided by the public sector. This has traditionally been the case in many countries (and certainly in India, where infrastructure industries were for many years off-limits for the private sector), but under an adequate regulatory framework those services, with the associated crowding-in effects, could be likewise provided by private firms. In fact, India, like other developing countries (notably those in Latin America), has recently started taking steps in that direction.

Appendix: data

The basic source are the Central Statistical Office's National Accounts, except for credit to the private sector, which was taken from the Report on Currency and Finance published by the Reserve Bank of India. The details are as follows.

Private capital stock: constructed on the basis of real net fixed investment by the private sector, making use of the March 1981 capital stock figures reported by Central Statistical Office (1992). While the 1994 National Accounts report capital stock estimates for the private sector for 1980/81-91/92, the figures are not consistent with the net investment data (the inconsistency corresponds to the household subsector), and therefore were not used.

Public infrastructure capital stock: sum of the real fixed capital stocks of the public sector in power, water and sewage, and transport and communications. From 1980/81 on, the figures are taken directly from the National Accounts. Prior to that year, public capital stock data are not available. However, the older National Accounts (base 1970/71, extended back to 1960/61) report real investment data at a comparable level of sectoral disaggregation. Thus, the disaggregated public capital stock series were extended applying to this sectoral investment data the same average depreciation rates of the more recent period; average depreciation rates were employed for each sector of use because the detailed asset structure of sectoral investment is not available.

Public non-infrastructure capital stock: defined as the real fixed capital stock of the public sector, taken directly from the National Accounts, minus the public infrastructure capital stock defined above.

Relative price of capital goods: defined as the deflator of real fixed investment of the private sector divided by the deflator of real private GDP, both taken from the National Accounts.

Real credit to the private sector: defined as the stock of credit from the banking system to the commercial sector, divided by the deflator of real private GDP.

Table 1

India: Real Gross Fixed Investment
(percent of real GDP)

	1960/61-69/70	1970/71-79/80	1980/81-84/85	1985/86-89/90	1990/91-94/95
Aggregate Investment	17.46	17.70	18.98	19.84	20.72
Public Investment	7.88	7.62	9.45	9.49	8.18
Government	1.96	1.88	2.17	1.93	1.57 a/
Enterprises	5.91	5.74	7.28	7.56	6.66 a/
Private Investment	9.58	10.08	9.53	10.35	12.54
Households	7.22	8.39	5.99	6.71	6.13
Corporations	2.36	1.68	3.54	3.64	6.41

Note: a/1990/91 to 1993/94
Source: Central Statistical Office and own calculations.

Table 2

India: Public Sector Real Gross Domestic Investment
(percent of real GDP)

	1960/61-69/70	1970/71-79/80	1980/81-84/85	1985/86-89/90	1990/91-92/93
Agriculture	0.88	1.03	1.23	0.77	0.54
Electricity, water and gas	1.36	1.66	2.31	2.62	2.50
Transport and communications	1.72	1.36	1.31	1.36	1.34
Public administration and defense	1.39	1.38	1.57	1.40	1.17
Other [a]	2.25	3.31	3.64	3.52	3.36
TOTAL	7.60	8.74	10.06	9.67	8.89

Notes: [a] Includes manufacturing, mining, construction, trade and finance.
Source: Central Statistical Office and own calculations.

Table 3

Public investment in transport and communications

(percent of GDP, 1981-1990)

Average of 31 LDCs *of which*:	2.2
Low income	1.9
Middle income	2.4
India	1.3

Source: own calculations using data from Easterly and Rebelo (1993).

Table 4

Stationarity tests

(a) Augmented Dickey-Fuller test statistics [a/]

Null hypothesis	k_{pr}	k_g	z	cr_{pr}	p_k
I (1)	-0.392	-1.027	-0.469	-1.089	-0.745
I (2)	-2.815*	-3.986**	-4.733**	-3.321**	-3.627**

(b) Kwiatkiowski-Phillips -Schmidt-Shin test statistics [b/]

Null hypothesis	k_{pr}	k_g	z	cr_{pr}	p_k
I (0)	0.561**	0.546**	0.551**	0.529**	0.488**
I (1)	0.125	0.415*	0.302	0.196	0.294

Notes: a/ Third-order ADF test statistics

b/ Computed setting the lag truncation parameter equal to 3.

* Significant at the 10 percent level.

** Significant at the 5 percent level.

Table 5

Maximum likelihood cointegration rank test statistics [a/]

Null hypothesis	Likelihood ratio	95% Critical value [b/]
R=0	128.4	127.9
R≤1	86.9	92.3
R≤2	56.9	62.2
R≤3	29.6	37.1
R≤4	7.5	11.0

Notes: a/ Derived from a vector autoregression with two lags of each variable, and including also a linear trend in the cointegration space.

b/ Adjusted for small-sample bias, following Cheung and Lai (1993).

Table 6

Autoregressive distributed lag representation for k_{pr}

(standard errors in brackets)

Variable	Lag 0	Lag 1	Lag 2	Sum
k_{pr}	-1	0.980	-0.347	-0.367
	(-)	(0.213)	(0.161)	(0.089)
k_g	-0.328	-0.121	0.142	-0.308
	(0.138)	(0.202)	(0.111)	(0.117)
z	-0.151	0.292	0.100	0.242
	(0.144)	(0.209)	(0.175)	(0.103)
cr_{pr}	0.039	0.014	0.006	0.059
	(0.025)	(0.028)	(0.021)	(0.030)
p_k	-0.059	-0.025	0.006	-0.078
	(0.036)	(0.040)	(0.034)	(0.055)
time	0.017			0.017
	(0.004)			(0.004)
constant	2.678			2.678
	(0.692)			(0.692)

$R^2 = 0.999$ SEE = 0.44% Sample: 1962/63-1993/94

Misspecification tests

Alternative hypothesis	Null distribution	Statistic	p-value
1st order autocorrelation	F (1, 15)	0.034	0.813
2nd order autocorrelation	F (2, 14)	0.159	0.857
ARCH	F (1, 14)	0.051	0.822
Non-normality	χ^2 (2)	3.851	0.146
Functional misspecification (RESET)	F (1, 15)	0.015	0.904

Table 7

Misspecification tests for equation (15)

Alternative hypothesis	Null distribution	Statistic	p-value
1st order autocorrelation	F (1, 19)	0.064	0.802
2nd order autocorrelation	F (2, 18)	0.229	0.798
ARCH	F (1, 18)	0.521	0.476
Heteroskedasticity	F (11, 9)	0.474	0.928
Non-normality	χ^2 (2)	2.223	0.329
Functional misspecification (RESET)	F (1, 19)	0.977	0.335

Table 8

Tests of parameter instability

Coefficient on:	Statistic
Constant	0.048
$\Delta k_{pr,\, t-1}$	0.038
$\Delta k_{g,\, t}$	0.049
$(\Delta z_t + \Delta z_{t-1})/2$	0.046
Δcr_{pr}	0.082
Δp_k	0.106
Error-correction term	0.048
Residual variance	0.145
Joint test	0.661

Note: The 5% critical value for the tests on the individual coefficients and the residual variance is 0.470. For the joint test it is 2.11 (see Hansen 1992).

Table 9

Tests of weak exogeneity

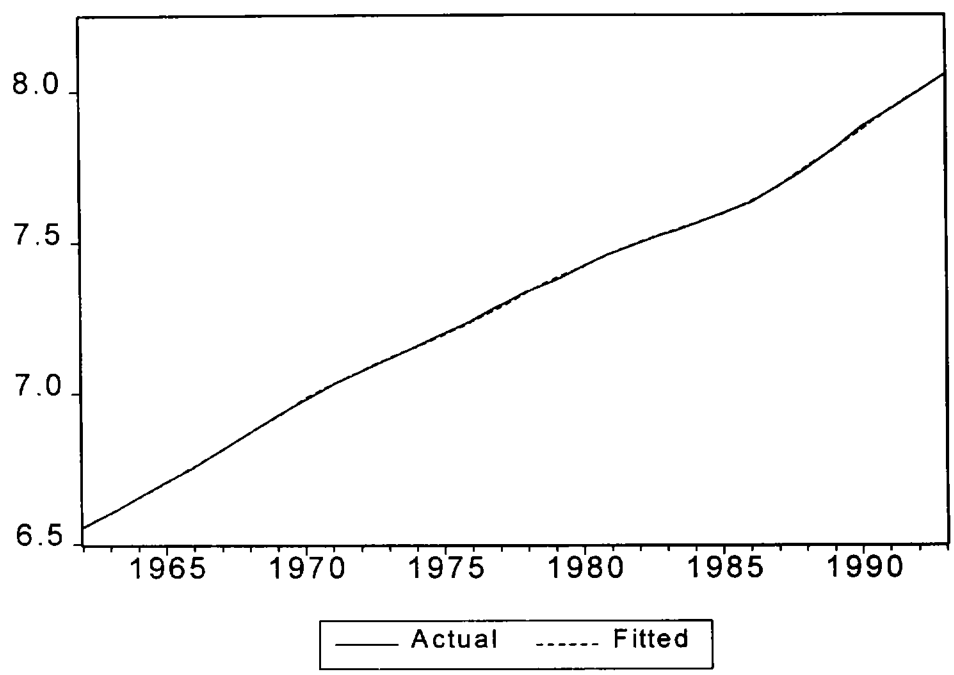
Test of exogeneity of:	For long-run parameters only[a/]		For both short and long-run[b/]	
	Statistic	p-value	Statistic	p-value
k_g	0.242	0.623	1.699	0.428
z	0.508	0.476	0.509	0.775
cr_{pr}	0.305	0.581	0.647	0.724
p_k	0.025	0.875	0.554	0.758
k_g, z, cr_{pr} and p_k	1.545	0.819	3.365	0.909

Notes: [a/] The statistics for the individual tests are distributed as χ^2 (1); the statistic for the joint test, as χ^2 (4).

[b/] The statistics for the individual tests are distributed as χ^2 (2); the statistic for the joint test, as χ^2 (8).

Figure 1

(a) Actual and fitted values from equation (15)



(b) Residuals from equation (15)

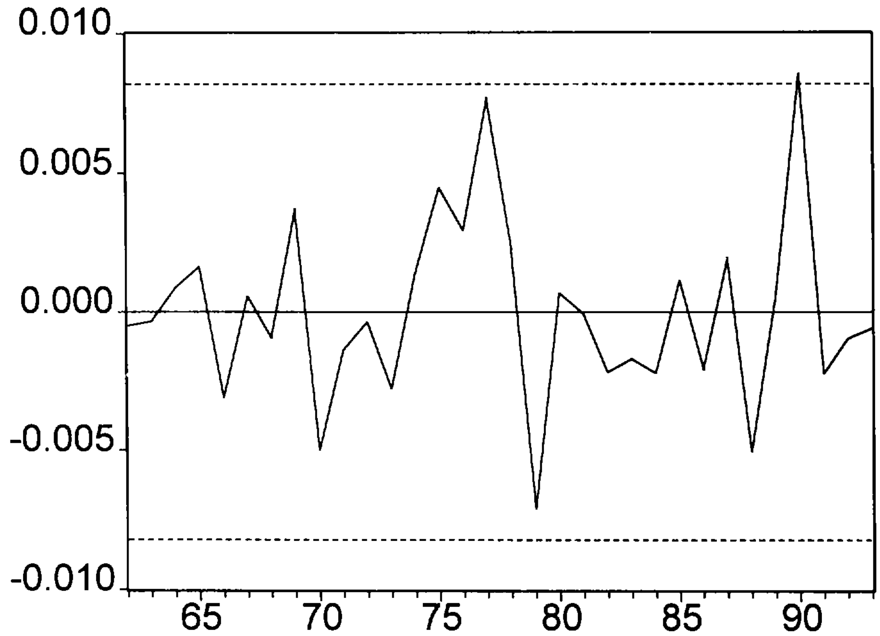


Figure 2

One-step ahead forecast errors from equation (15)

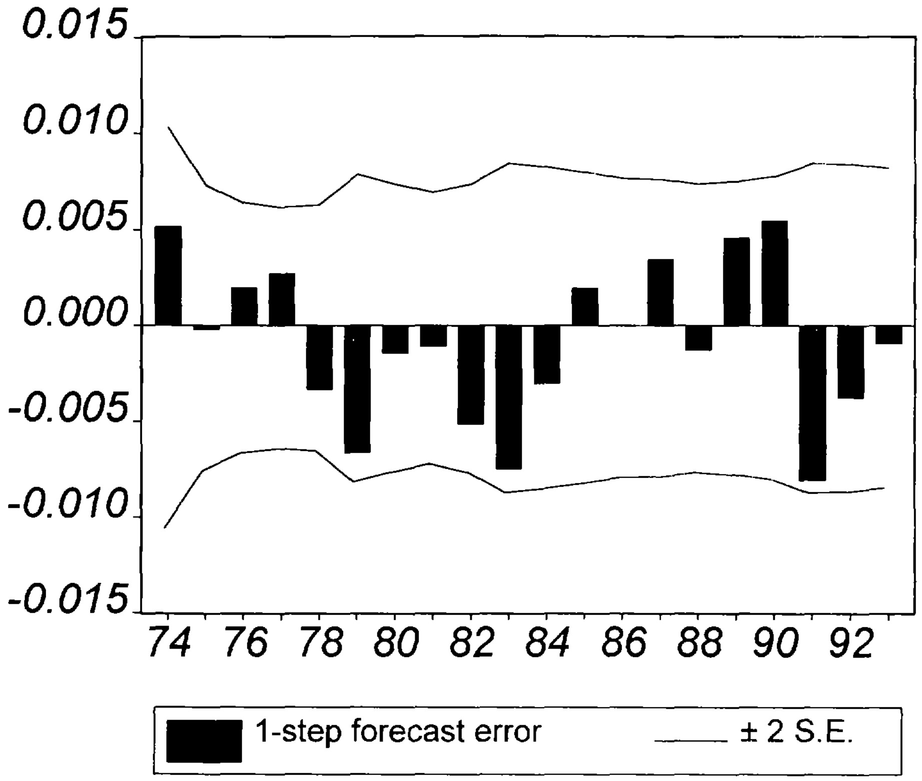
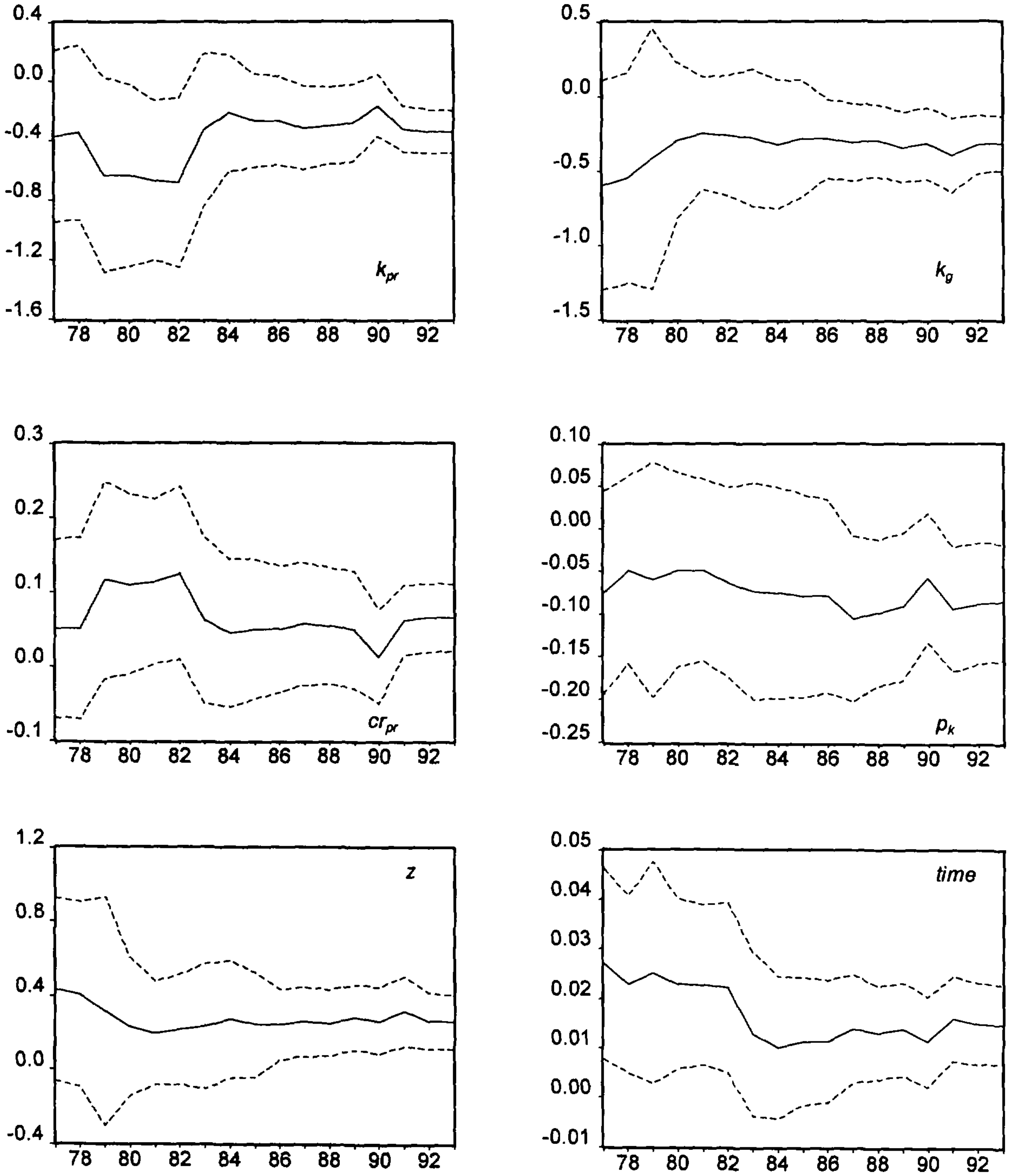


Figure 3

Recursive OLS estimates of the long-run parameters of equation (15)



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