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Linking Public Capital to Economic Performance

Public Capital:
The Missing Link Between
Investment and Economic Growth

Sharon J. Erenburg

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Summary

Past research by J. Bradford DeLong and Lawrence Summers provided evidence that a robust statistical relationship exists between private sector investment in plant and equipment and productivity. Private sector investment in plant and equipment can therefore be considered an engine of economic growth. In this issue of the *Public Policy Brief* Sharon J. Erenburg argues that there is also a connection between public spending and economic growth by showing that public investment in infrastructure stimulates private sector investment in plant and equipment. In doing so she provides empirical proof that public and private investment are complements in production. Erenburg's findings, therefore, serve as the missing link that explicitly ties public infrastructure to economic growth.

Erenburg's research is key in the debate over whether the public sector should play an active role (for example, through incentives) or be a passive spectator in encouraging private sector investment. Research and policy proposals advocating direct public spending focus on the benefits derived from certain types of expenditures, namely, those that would increase U.S. productivity or provide investment incentives to the private sector. Public sector capital could, in theory, make private sector operations more efficient, even stimulating new private sector investment. On the other hand, critics of public investment charge that both sectors would be competing for the same pool of resources, and an increase in public capital spending would reduce the level of private sector investment, an outcome called the "crowding out" effect.

Erenburg's research attempts to find whether crowding out exists and, if so, whether it is outweighed by any positive effect of public spending (that is, any "crowding in" effect). Her empirical results for the short run show that the net effect (crowding out less crowding in effects) of each 1.0 percentage point increase in public infrastructure spending would be an estimated 0.6 percentage point increase in private sector equipment investment per year. Long-run estimates indicate that a 1.0 percentage point increase in infrastructure investment would result in an estimated 0.4 percentage point annual increase in

private equipment investment. Erenburg's forecast reveals that if the average annual rate of growth of the public capital stock experienced between 1947 and 1966 had continued between 1967 and 1990, the growth rate of private sector equipment investment would have been 4.0 to 6.0 percentage points higher than the actual growth rate. Applying these potential gains in private sector investment, Erenburg states that annual growth rates of gross domestic product (GDP) could have been 1.3 to 1.9 percentage points higher, productivity 2.4 to 2.9 percentage points higher, and real wages 2.0 to 2.8 percentage points higher than they actually were.

In addition, by confirming the connection between public capital and the real wage, Erenburg also shows that the lack of public infrastructure investment during the last 15 to 20 years has adversely affected the level of real wages in the United States. She first verifies the existence of a statistical relationship between public capital and productivity in both the short and long run and then concludes that stagnant productivity levels in the past can be considered a function of the lack of public investment. Since productivity directly affects wage levels, the decline in productivity resulting from too low a level of public infrastructure investment has contributed to a decline in real wages and, therefore, a reduction in earnings.

If it is true, as critics of public investment allege, that crowding out exists, then it is important from a policy standpoint to determine if these effects are exceeded by any crowding in effects. Erenburg's research confirms that in both the short and long run the positive effects of adding to the public capital stock are greater than any negative effects of crowding out. Hence, these results suggest that appropriate decisions about the magnitude, nature, and timing of public investment can make a positive contribution to the level of real wages in the United States.

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Preface

If fiscal policy is to be used as an economic stabilizer in the current atmosphere of budget restraint, the question arises as to what type of spending might achieve given economic and social goals. If the goal is to bolster growth through additions to private sector investment, one possible answer to the question is a program of public investment.

In this issue of the *Public Policy Brief*, Research Associate Sharon J. Erenburg demonstrates that public and private investment (specifically, public capital spending and private equipment investment) are complementary, meaning that an increase in public investment will lead to a rise in private investment in equipment. Since private equipment investment has been shown to raise private sector productivity, then fiscal policy could be used to stimulate such productivity.

By empirically confirming the relationship between public and private investment, Erenburg refutes the argument that public investment limits, or "crowds out," private investment by drawing from the pool of funds available for all types of investment in the economy. Her estimates show that the crowding out effect is smaller than the "crowding in" effect; in other words, the stimulating effects of public investment on private investment are larger than any limiting effects.

Finally, Erenburg asserts that past low levels of public investment have limited earnings growth and stunted U.S. living standards. She substantiates this claim by confirming both short- and long-run relationships between public capital spending and productivity. Erenburg uses this relationship to serve as the core of her argument that past productivity declines were a function of the lack of public investment. Consequently, since wages are a function of productivity, stagnant levels of public investment have contributed to flat wage growth and the relative decline in U.S. earnings.

A recent surge in private investment, particularly in equipment spending, has been one of the bright spots in the economy and has contributed to robust productivity growth over the past 18 months. According to the Bureau of Economic Analysis, private sector equipment investment has increased 16 percent since the first quarter of 1993.

The surge in equipment spending does not, however, lessen the merits of a program of public investment aimed at enhancing America's long-term competitiveness. A good deal of the boost in equipment investment can be attributed to pent-up demand following a lingering recession during which private fixed investment as a share of GDP had hit a postwar low. Indeed, even as gross private fixed investment as a share of GDP has climbed above 14 percent, this level is still at the low end of the postwar range. According to David A. Levy, director of the Institute's Forecasting Center, it would be a flawed inference to conclude from the recent data on equipment investment that the U.S. economy is currently in a period of widespread business expansion. In a climate of slow growth and intense global competition, firms are reluctant to take on major capacity expansion projects that would require building new factories and hiring additional workers.

While current public discourse is rightfully focused on fiscal responsibility and reducing wasteful spending in government, Erenburg's research gives reason to consider the composition of federal spending as well as its aggregate size.

Dimitri B. Papadimitriou
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September 1994

Public Capital: The Missing Link Between Investment and Economic Growth

I. Introduction

One of the primary measures by which a country is judged is its ability to provide a high and rising standard of living for its population relative to other countries. A rising standard of living—accompanied by increases in new businesses, employment opportunities, and real wages—is supported by economic growth. The prime components of economic growth are the capital stock (and the technology embodied therein) and the labor force.

In a modern, capitalist economy private sector investment, which consists of firms' expenditures on plant and equipment, is vitally important because it adds to the capital stock, thereby providing the physical ability of an economy to grow. In order to stimulate economic growth, public policy generally focuses on the need for the private sector to increase its purchases of plant and equipment. Such an addition to the capital stock boosts economic growth, productivity, and real wages. For example, the United States experienced strong economic growth after World War II as the result of a rise in private investment activity; as the capital stock increased, higher productivity levels and gains in real hourly wages led to a rise in living standards.

Economic policy, therefore, is regularly employed as an instrument to improve our standard of living. The identification and development of effective policies are difficult, however, because these tasks require a clear and accurate understanding of the complex economic relationships that underlie economic growth. Any attempt to develop policies aimed at stimulating economic growth assumes not only that policymakers understand these complex relationships, but more importantly, that implementing public spending programs for the government provision of goods and services in a mixed capitalist system is beneficial.

To undertake a rigorous examination of the relationships and to gain a better understanding of the timing, direction, and magnitude of public infrastructure investment that would be effective, this paper separates the effects of the stock and flow of public capital. A change in the level of public infrastructure spending could, for example, have a short- or long-run negative effect on private investment if both sectors are competing for the same pool of resources. An increase in public capital spending might reduce the level of private sector investment, the so-called crowding out effect. Much to the chagrin of laissez-faire proponents, this research confirms that, in both the short and long run, the positive effect of public capital investment exceeds any negative effect of crowding out.

These findings have particular significance in light of previous research (such as that by DeLong and Summers) that showed a significant and positive correlation between increases in private sector equipment investment and GDP growth rates. By revealing a strong relationship between public capital and private equipment investment, these results serve as the missing link in demonstrating a clear, empirical relationship between public infrastructure investment and private sector productivity.

Further, by confirming the links among public capital, private investment, and aggregate productivity, the findings also indicate a relationship (through the productivity gain) between public capital and real wages. Therefore, not only has the decline in public infrastructure investment contributed to the deterioration of aggregate economic measures, it has also contributed to the relative stagnation of real wages and living standards in the United States over the past two decades.

II. The Role of Public Goods in a Capitalist System

During the 1980s limiting government involvement in the U.S. economy was viewed as an important prerequisite for economic growth. It was thought that reducing government involvement would encourage economic efficiency and private investment spending. The problem with this idea is best expressed as a "fallacy of limited decisions." The idea assumes that the number of decisions made in a market economy is fixed and that decreasing the number of decisions made by the government necessarily increases the number of decisions made by the private sector. It also assumes that government decisions are inherently inefficient, so the fewer the number of government decisions (or the greater the number of private sector decisions), the greater the economic efficiency and, therefore, the greater the productivity in the aggregate economy.

An efficient market economy, however, produces not only private goods, but public goods. The fallacy in the reasoning is that it ignores the fact that the government provides public goods. Once the production of these goods is taken into consideration, the assumption about the inefficiency of government decisions no longer holds.

Private goods are goods that are produced for individual consumption, and only the consumers who pay for the goods benefit. When a consumer buys a car, for example, he or she pays for the car and receives all of the benefits of owning that car. Public goods, however, are goods that cannot be broken down into units small enough to be consumed by individuals equally, regardless of whether or not they pay for that good. A classic example of a pure public good would be national defense, as it is available for all members of the population to "consume" whether or not they pay for it. Since national defense cannot be furnished in units small enough for individual consumption and nonpaying consumers cannot be prevented from benefiting from it, it is not profitable to provide this good, and so the private sector will not do so. The government can provide national defense because it has the power of taxation; that is, it has the power to tax the total population (the aggregate that benefits from the presence of national defense), thereby compelling all to pay for the good. This is an example of private market failure in that the private market fails to produce a good (in this case, a pure public good) in the optimal amount.

In addition, decisions made by private markets alone will not ensure an efficient use of resources when production is characterized by decreasing costs (when cost per unit declines as output increases). This decline occurs in the case of a natural monopoly. If there is more than one firm in this type of market, aggregate industry output will be produced at a higher cost than if it were produced by a single firm, which clearly is an inefficient and costly use of resources. However, if, in order to capture economies of scale, a single, unregulated firm is allowed to exist, that firm is likely, because of the lack of competition, to furnish a level of output that is below the socially optimal amount at a correspondingly higher-than-optimal price. This is also an inefficient allocation of resources. The private market will fail to provide any adjustment toward the optimal level of output, a competitive price, or a more efficient use of resources. When the government produces or regulates the production of such goods or services, a more efficient use of existing resources will result than if the private market works independently. If a good or service can be produced at a lower cost through government provision or regulation, then total available resources in the economy at any point in time will be used more efficiently, and this increase in efficiency enhances productivity.

Public infrastructure, such as roads, bridges, sewer and water systems, and fiber-optic communication networks, are examples of these types of goods. They are classified as near-public goods because they are jointly consumed, even though nonpaying users can be excluded. A more efficient use of existing resources occurs when the government provides infrastructure because costly duplication of resources is avoided and economies of scale are exploited.

In response to private market failure, then, the government takes responsibility for the provision of certain goods by contracting with the private sector. In doing so, the government plays a significant role in facilitating a more efficient movement of goods, people, services, and information.

Identifying that portion of government spending representing the purchase of public capital is important as it directly affects the productivity of the private capital stock. For example, private businesses need a modern, well-maintained network of highways, sewer systems, mass transit, and so forth. They would operate much less efficiently if this network were not publicly provided, and attempts by them to provide their own networks would also result in duplication and waste of scarce economic resources. Indeed, when a good or service is provided by government, it affects firms' individual cost functions. When a private firm utilizes a publicly provided and maintained highway system to receive and ship its products, the productivity of that firm rises because it combines its own capital with public capital, thereby cutting the cost per unit of output. The more efficient the highway system, the less the transportation time and the greater the decline in input costs. This effect is easily seen in the dramatic reduction in shipping time and costs that occurred when the system of roads that existed prior to the 1950s was replaced by the modern interstate highway system.

The reduction in supply costs is true at the firm level and in the aggregate as total output per unit of input increases when government-provided infrastructure results in a more efficient use of existing resources. Unfortunately, it is precisely on this point that the critics of mixed capitalism become confused: While there is merit to their argument that a more efficient pricing mechanism (such as a system of user fees composed of tariffs and tolls) will make better use of the existing infrastructure, it addresses only the issue of the best way to price the use of existing infrastructure, not the question of the best way to provide additional public capital or to renovate the existing infrastructure. More importantly, such an argument cannot be used to support the claim that infrastructure should be provided by the private sector, as it ignores the nature of social goods and private market failure and, therefore, bypasses the pivotal aggregate issues of decreasing costs, externalities, and resource reallocation. For example, the argument that private firms are most efficient in a competitive market is irrelevant if the market is a natural monopoly. The underlying assumption that other firms will provide the same goods or services and thus furnish the competition necessary to break up monopoly control is both false and naive. To claim without quantification that the private sector can better provide infrastructure because the profit motive encourages private firms to cut costs and use resources more efficiently ignores the fact that many private sector firms themselves are characterized by waste, poor management, and inefficiency. The positive effects exerted by public capital on productivity and, therefore, on private investment activity is indeed a separate issue.

III. Private Investment, Public Investment, and Economic Growth

A. A Review of Existing Research

Infrastructure, economic growth, and productivity all determine our competitive position in the international economy. As documented by DeLong and Summers (1991), private business investment expenditures, particularly on plant and equipment, are a strategic factor in economic growth. Using data from the United Nations Comparison Project and the Penn World Tables, they found a much stronger link between private investment in equipment and economic growth than any other components of private investment. They asserted that the relationship is causal, that is, that higher equipment investment drives faster growth, not vice versa. They argued that “In neoclassical models steady-state growth rates are independent of investment rates. However, investment rates may influence growth rates as shifts in investment rates cause economies to transit between steady-state growth paths." Testing this premise, they found that for the years 1960 to 1985, each extra percentage point of GDP invested in equipment was associated with an increase in aggregate annual GDP growth of one-third of a percentage point. The association was much stronger than between growth and any other investment component. In addition, Jorgenson (1988, 1990), using U.S. data, demonstrated a strong correlation between private equipment investment and total factor productivity growth, and Helliwell (1993) found investment in physical capital a critical source of Asian growth, statistically more important than even education.

The relationship between changes in total government spending and changes in aggregates (such as growth, employment, and inflation) has been the subject of many theoretical and empirical studies. Work such as that by David Aschauer (1989a, 1989b) has once again stimulated interest in the connection between government spending on public capital and various measures of aggregate economic activity.

Many of the empirical studies of the effect of infrastructure investment on aggregate variables focus on the relationship between government spending on the core infrastructure and economic growth at national, regional, and state levels. The statistical results of these analyses have, however, been mixed. For example, studies by Aschauer (1989a), Eberts (1986), and Munnell (1990) indicated a statistically significant, positive relationship between public investment and growth. The estimates of the elasticity of output with respect to public infrastructure capital and economic growth varied widely, with the reported elasticities in studies that used national time series data being larger than in studies that used state data. This difference may be due to the fact that the state and regional studies may have attempted to measure productivity effects using a geographic area too small to register all of the external benefits emanating from public infrastructure capital. In essence, although the precise size of the correlation between public infrastructure and productivity may be in dispute, there appears to be near consensus that a significant correlation does exist.[1]

Other studies, including Dalenberg and Eberts (1992), Morrison and Schwartz (1992), and Nadiri and Mamuneas (1991), have examined the relationship between public capital and the costs of private production and found that investment in public capital resulted in a significant reduction in private sector costs. Lynde and Richmond (1992) indicated that private and public capital are complements in production and that public capital has a positive marginal product. A study by Lynde (1993) established a direct relationship among public capital, productivity, and profits.

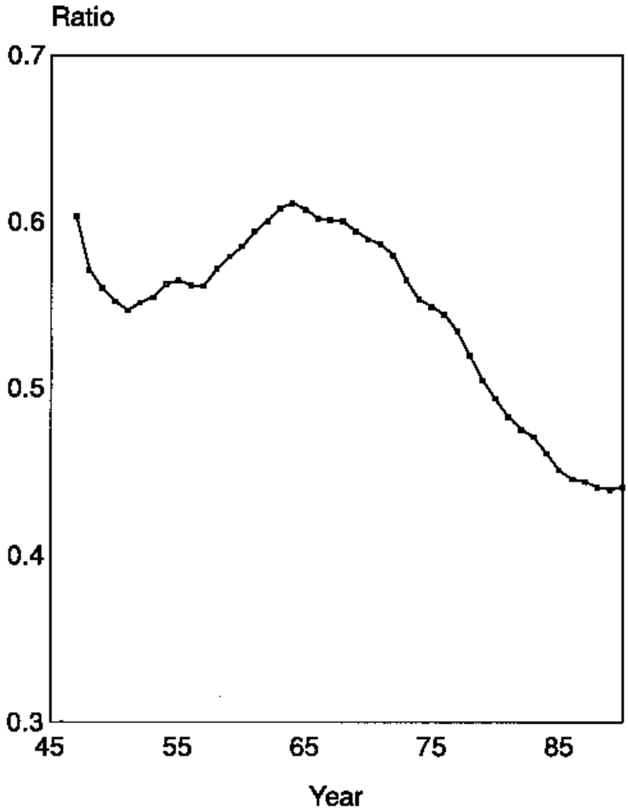
The idea that infrastructure capital affects private investment activity and economic growth is discussed by Buiter (1977). He asserted that a complementary relationship between public and private investment was obvious, citing as examples public investment in projects such as dam construction and highways. As Munnell (1992) has argued, "everyone agrees that public capital investment can expand the productive capacity of an area, both by increasing resources and by enhancing the productivity of existing resources."

Finally, Aschauer (1989b) and Erenburg (1993a) found a positive correlation at the aggregate level between the provision of public infrastructure and private investment activity. Erenburg's (1993b) research, utilizing the major private investment models, found a direct relationship between private investment activity and the government's provision of nonmilitary public capital.

B. The Historical Record of Private and Public Investment

When conducting any historical analysis of economic data, it obviously must be kept in mind that the structural characteristics of the macroeconomy today are dramatically different from those of the 1920s, the global depression of the 1930s, and certainly the war years of the 1940s. Much of public investment in the 1940s involved the production of war goods. During that period government spending as a percentage of gross national product (GNP) peaked at 49 percent, much of which was expenditure on public capital. As a result of this massive spending program, and the fact that the nation was operating at full employment, private investment was restricted until the peace time conversion from war goods to consumer goods production. (Some

Figure 1 Public Capital–to–Private Capital Stock Ratio, 1947–1990

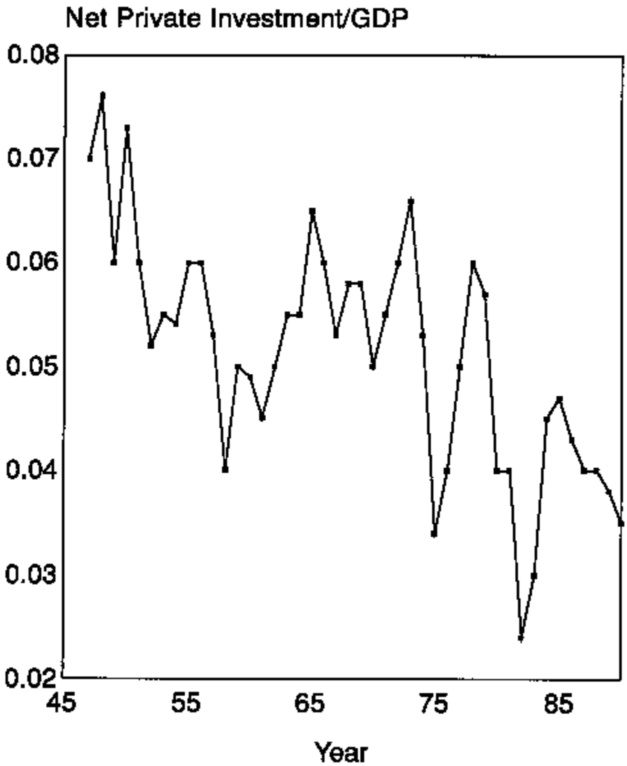


Source: Bureau of Economic Analysis (1992).

of the public capital stock that was used to produce war goods, however, became part of the private capital stock after the war ended.)

As shown in Figures 1 and 3, the growth of the public capital stock has not kept pace with the growth in the private capital stock. Private net fixed investment as a share of GDP also has declined (see Figure 2). The relationship between private investment and economic growth has clear policy implications if private investment decisions are affected by the provision of the public capital stock: If public infrastructure directly affects private investment in plant and equipment decisions, the slowdown in the growth of the government's provision of public infrastructure may account for the recent decline in private

Figure 2 Net Private Investment as a Share of GDP, 1947–1990

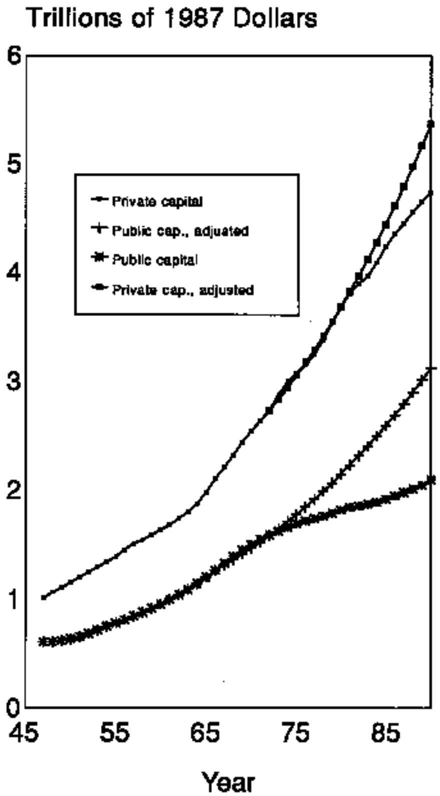


Source: Bureau of Economic Analysis (1992).

equipment investment and, therefore, the recent decline in the productivity of the U.S. economy.

From 1947 through 1990 there was a dramatic decline in the ratio of the public capital stock to the private capital stock (refer again to Figure 1). Between 1967 and 1990 the ratio, on average, would have been 10 percentage points higher if the growth rate of government infrastructure had remained at its 1947 to 1966 average; this assertion is illustrated in Figure 3, which compares the actual public capital stock (in constant dollars) to estimates of what the public capital stock would have been if the historic rate of growth had been maintained. All else constant, the adjustment depicted in the two figures implies that if the rate of growth of the public capital stock had remained the

Figure 3 Private and Public Capital Stocks, 1947–1990 (actual and adjusted)



Source: Author's calculations based on Bureau of Economic Analysis (1992).

same as its historic average (instead of declining), private equipment investment also would have grown at a faster rate. (This point is discussed further in the following section.)

C. The Role of Public Investment in Stimulating Economic Growth

Standard private investment models in the current literature have, for the most part, ignored the possible effect of public capital on private investment decisions. If the provision of public infrastructure capital increases the productivity of private capital and the profitability of private investment, then the effect of government spending on public capital should be modeled separately in order to capture such effects. If both the public and private sectors are competing for the same resources for private and public investment projects, current public investment spending could result in a decline in private investment spending, the crowding out effect. At the same time, the existing public capital stock, used as an input, may crowd in private investment spending. Modeling private investment decisions in this manner is an attempt to determine both how and to what extent private investment decisions are affected by public infrastructure decisions. Accordingly, these private investment models also include public sector investment spending and public capital stock variables.

In this study the public capital stock and government investment spending were incorporated into the major investment models. (For a technical discussion of the models used, see Appendix A.) The findings reveal a stronger relationship between private investment in equipment and the public capital stock and government spending than any other components of private investment. The statistical outcomes of these models resulted in rejecting the hypothesis that the government's provision of public infrastructure has no economic effect, a statistical correlation that was confirmed in both the short run and the long run. (See Appendix A for the empirical results.)

Herein lies the key to understanding part of the complex economic relationships that drive economic growth. Because government's provision of public capital stimulates private equipment investment, policy can be formulated to stimulate such growth. The importance of these links is obvious when combined with the strong association found by DeLong and Summers (1991) between equipment investment and growth discussed earlier. Applying their estimates of the effect of increased equipment investment on GDP growth to the United States, higher public capital investment would have elevated private sector equipment investment by 0.4 to 0.6 percentage point, which translates to an increase in GDP growth of between 0.125 to 0.2 percentage point per year. Increasing public infrastructure by 10.0 percentage points (a figure based on the historic average) would have swelled private sector equipment investment by between 4.0 to 6.0 percentage points; applying DeLong and Summer's estimates to these figures yields an increase in annual GDP growth of 1.3 to 1.9 percentage points above their actual rates.

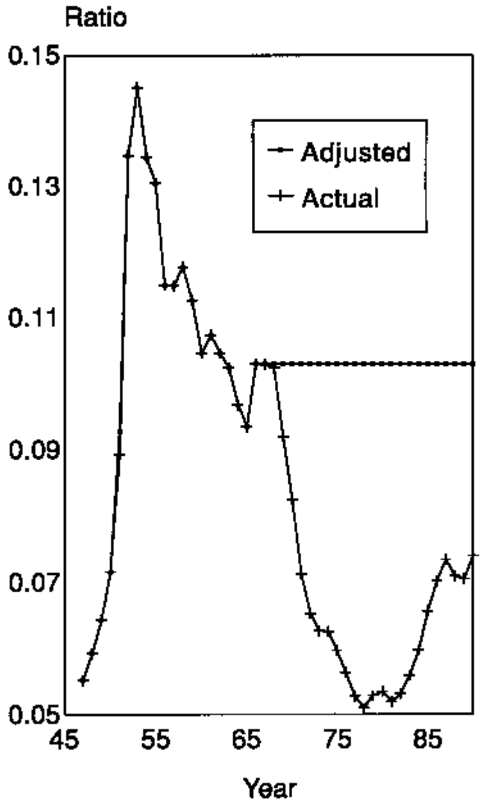
This assertion is borne out by the findings of this study, specifically the calculations included in Table 1, which compare recent public and private investment spending to the high-growth period experienced in the United States from 1947 to 1966. What is striking about the ratios is that they all indicate a decline in public investment relative to the public capital stock, the private capital stock, and total government spending.

For example, government spending on infrastructure has decreased as a percentage of total government spending at all levels of government, and infrastructure expenditures have declined as a share of the private capital stock and GNP. As a result, today there exist smaller stocks of both public and private capital than would have existed had annual government expenditures on infrastructure been larger. Specifically, if the historic ratio of public investment to public capital (10 percent) had been maintained through 1990, average total government investment spending would have been $233 billion in 1990 rather than the actual $155 billion; this represents a shortfall to the public capital stock in that year alone of $78.7 billion (see Table 1). In 1990 our public capital stock was $662 billion below its historical average when comparing the public capital stock to private capital stock.

Furthermore, spending on public and private investment relative to the private capital stock has been decreasing since 1967. Public investment spending has decreased from 10 percent during the 1947 to 1966 period to 7 percent during the 1967 to 1990 period when compared to the growth rate of the public capital stock. We have been below the historic growth average since 1967. Figure 4 shows the actual and adjusted public investment–to–public capital stock ratios over time, after increasing the public capital stock and public investment spending rate to their historic growth rates (so that the public investment–to–public capital stock ratio is equal to its historic average of 10 percent).

In terms of annual public investment spending, the United States was $120 billion below its historic ratio of public investment spending to the private capital stock. In addition, private investment expenditures grew at less than the historic rate, falling $66.7 billion

Figure 4 Public Investment–to–Public Capital Stock Ratio, 1947–1990 (actual and adjusted)



Source: Author's calculations based on Bureau of Economic Analysis (1992).

below what they would have been if the 1947 to 1966 average annual rate of spending growth had been maintained. The estimates show that if the public capital stock had remained at its 1947 to 1966 pace (rather than declining), productivity would have been 2.4 to 2.9 percentage points higher and real wages 2.0 to 2.8 percentage points higher. These projections translate into a potential increase in per capita GDP and a higher, rather than stagnating, standard of living.

Indeed, recent research by Erenburg (1993c) supports the hypothesis of a direct relationship between private equipment investment and public infrastructure, while finding no statistical evidence that

Table 1
Actual U.S. Investment and What It Would Have Been If at Historical Rates, Selected Periods

Ratios	1947–66	1967–90	1990	Actual (billions of 1987 dollars)	At Historic Rate	Shortfall
Public capital–to–private capital	.58	.48	.44	$2,089	$2,750	($662.0)
Public investment–to–public capital	.10	.066	.07	155	213	(58.5)
Public investment–to–public capital (historical)				155	233	(78.7)
Public investment–to–private capital	.06	.03	.03	155	275	(120.0)
Private investment–to–private capital	.12	.11	.10	502	569	(66.7)
Public investment–to–total government spending	.21	.16	.14	155	195	(40.7)

Source: Bureau of Economic Analysis (1992 and personal communication); Citibase.

changes in private equipment investment induce changes in public investment. Additionally, research by DeLong and Summers (1991) supports a causal relationship between private investment in equipment and economic growth, with no evidence of reverse causation.

However, critics, such as Holtz-Eakin (1993), of a similar study by Aschauer (1989a) raised a question regarding the possibility of a problem of spurious correlation.[2] One way to deal with this problem is to difference the data so that it is in a stationary form. Differencing the data, though, to eliminate the possibility of spurious correlation, while yielding short-run relationships, precludes the possibility of examining any long-term relationship between private and public investment. As Munnell (1992) has suggested, “researchers should examine not just whether variables grow over time, that is, the extent to which they are non-stationary, but also whether they grow together over time and converge to their long-run relationship, that is, the extent to which they are co-integrated" (p. 192). In order to respond to this suggestion, in this study long-run as well as short-run relationships were statistically examined by the 1989 Stock-Watson method.

IV. The Relationship Among Infrastructure, Economic Growth, and the Real Wage

The research discussed thus far establishes a statistical relationship between public infrastructure and private investment behavior. Erenburg (1993c) has also examined the relationship among public infrastructure, the real wage, and productivity in the United States using measures of the effects of both public and private capital on productivity.

Both neoclassical and Keynesian theories predict that real wages rise with technical progress and expansions in the capital stock and move inversely over the course of the business cycle. Empirical studies have not confirmed whether real wages are cyclical or countercyclical. Although models include changes in the capital stock when measuring changes in productivity, the effects of productivity changes have been limited to those induced by changes in the private capital stock. For example, Canzoneri's research indicates that "real [Canadian] wages are strongly counter-cyclical when the level of the [private] capital stock is controlled for" (Canzoneri 1978, pp. 20–21). Recent work by Aschauer (1989a, 1989b), Erenburg (1993a, 1993b), Munnell (1990), and Lynde and Richmond (1992) has shown that both the public capital stock and the private capital stock are correlated with various measures of economic activity such as output, private investment, and productivity growth. Aschauer's empirical estimates show a strong positive relationship between output per unit of private capital and the public capital–to–private capital stock ratio, with the coefficients of the labor-to-capital ratio and the public capital–to–private capital stock ratio both positive and significant.[3]

Other areas of research have focused on the effect of public capital on the costs of private production. Lynde and Richmond (1992) have found that the marginal productivity of public capital is positive, suggesting that public and private capital are complements in production. In their examination of the relationship between public capital and the costs of private production, Nadiri and Mamuneas (1991) found, among other results, a statistically significant contribution of public capital to labor productivity.[4]

If the real wage is a function of productivity, then a decline (increase) in productivity will be associated with a decline (increase) in real wages. The data indicate that, when controlling for the capital stock, real wages are countercyclical. (See Appendix B for a description of the statistical models used and the resulting empirical findings.) In addition, estimates from the real wage equation indicate that a long-run relationship exists between real wages and labor productivity and the public capital–to–private capital ratio.[5]

V. Conclusions

Overall, these results confirm a statistical relationship between public capital and productivity in the United States, while addressing the problem of spurious correlation. These results also add to the statistical evidence cited by Aschauer (1989a) and Erenburg (1993c) that public capital directly affects not only productivity and private investment decisions, but also real wages via productivity effects.

These results also can be applied to our pursuit of a competitive position in the global economy. As Joseph P. Quinlan (1993) stressed in an editorial in *The Wall Street Journal* concerning Southeast Asian markets:

> To tap these burgeoning markets, U.S. companies should carefully assess . . . infrastructure. Severe infrastructure limitations have raised the cost of operating in Asia, prompting some multinationals to invest elsewhere. Following five years of strong growth, the physical infrastructure of the region is straining at the seams—the roads are crowded, the ports are clogged and the airports are jammed. Pollution and environmental degradation compound matters. The upshot is infrastructure gridlock, which threatens not only to strangle growth and trade, but also to curtail new foreign investment. (p. A10)

As the global economy expands, global firms will seek to locate in the most profitable environment. It becomes mandatory, then, for the United States to provide an up-to-date, well-functioning infrastructure in order to continue to attract new foreign capital.

The public policy implications of this research are obvious: If the decline in public capital spending has contributed to the dip in U.S. productivity during the last two decades, then the decline has also contributed to the lack of real wage growth—a prime determinant of living standards—during the same period.

Mounting statistical evidence supports the contention that public infrastructure has a positive effect on economic growth, private sector equipment investment, and real wages. The strength of these conclusions is derived from the evidence that the effects of public capital are felt not just in the short run, but in the long run as well.

It is incorrect to argue that infrastructure has negligible productivity effects, that public investment crowds out private investment, or that the government provision of public capital is inefficient. Transferring $1 of investment from the private to the public sector does not result in an analogous decline in productive private investment with no corresponding benefits. The argument that policies to increase private sector investment have a better chance to improve U.S. competitiveness is incomplete because it ignores the stimulative effect of public infrastructure on private investment and disregards the effects of efficiency gains from public goods.

It is not a matter of choosing either one type of investment or the other. Rather, there are benefits to be derived from both types. Indeed, the findings suggest a complementary relationship between public and private investment, with additions to public capital acting as a catalyst for private equipment spending. Armed with an understanding of the links between public infrastructure and private equipment investment and economic growth, cost-benefit studies should be used to determine what magnitude, nature, and timing of infrastructure projects would yield the most economic benefits in terms of geographic area and concomitant user needs.

It will take at least a decade to raise the public capital stock to the levels prevalent in the period following World War II. However, the need for long-run planning should not be taken as a reason to neglect infrastructure investment in the short run. When spending on public infrastructure is increased, assets are created in both the private and public sectors, and these assets stimulate national economic growth. This type of public policy, based on providing public infrastructure, is ideal in the sense that additional expenditures on infrastructure have positive effects in both the short run and long run: In the short run they provide employment through the private sector by stimulating the construction industry; in the long run they stimulate private investment in the United States, thereby enhancing productivity and economic growth.

The domestic policy implications are clear. Neglecting infrastructure has a deleterious effect on private sector equipment investment, economic growth, and living standards. Admittedly, the U.S. economy has witnessed a recent boost in private equipment investment, with an accompanying increase in productivity. Much of this recent spurt, though, is a result of many years of record-low levels of private sector investment and of obsolescence and depreciation of old equipment. If the private sector is expected to sustain a healthy pace of equipment investment over the long run, a structural change, namely, a strong commitment to public infrastructure, must act as a catalyst.

Appendix A

Estimating the Effects of Public Capital on Private Investment

The Models Used in This Study

The private investment models incorporated in this study include the accelerator–cash flow model, the securities valuation–cash flow model, and the neoclassical investment model. Data from 1952 to 1990 were used for the accelerator and neoclassical investment models; data from 1960 to 1987 were incorporated in the securities valuation model. A longer time series, beginning in 1925, is available for public investment and public capital stock data.

The Accelerator–Cash Flow Model

In the accelerator–cash flow model, firms adjust their investment decisions in response to changes in demand and internal cash flow. The basic accelerator model is expressed as

$$(1)\quad KT^{d} = aY + \mu KG$$

where

KT^{d} = desired private capital stock
KG = public capital stock
Y = output

In this basic model, adjustments to changes in output are not immediate, but rather, take place over a number of time periods.

Adding a lagged term to represent replacement investment, a public capital term to represent infrastructure in place (in order to measure any productivity effect), and dividing through by the private capital stock *(KT)* yields a public capital augmented accelerator investment model:

$$(2)\quad \frac{I}{KT} = \frac{\alpha}{KT} + \sum_{i=0}^{N} b\frac{\Delta Y_{-i}}{KT_{-i}} + d\frac{KT_{-1}}{KT_{t}} + \sum_{i=0}^{N} e\frac{IG_{-i}}{KT_{-i}} + f\frac{KG_{t}}{KT_{t}} + u$$

where

I = private sector investment
IG = public sector investment
KT = actual private capital stock
u = error term

Adding cash flow as a measure of available internal funds (versus external finance) or a profits variable as a measure of future profitability of a firm (and its concomitant effect on future output) yields a public capital augmented accelerator–cash flow model:

$$(3) \quad \frac{I}{KT} = \frac{\alpha}{KT} + \sum_{i=0}^{n} b \frac{\Delta Y_{-i}}{KT_{-1}} + \sum_{i=0}^{n} c \frac{CF_{-i}}{KT_{-i}} + d \frac{KT_{-1}}{KT_{t}} + \sum_{i=0}^{n} e \frac{IG_{-i}}{KT_{-i}} + f \frac{KG_{t}}{KT_{t}} + u$$

where

CF = cash flow

The basic concept of the augmented accelerator–cash flow model is that adjustments occur not only in reaction to changes in output, but also to changes in public investment spending and public capital. If the public capital stock increases the productivity of private investment projects, then private investment activity also should increase.

In order to capture adjustments made over the course of the business cycle, many empirical studies include the idea of adjustment to changes in actual output relative to potential output (the "demand gap"), rather than to changes in output alone. In this study capacity utilization was used as a measure of the demand gap. In addition, the ratio of the public capital stock to the private capital stock was adjusted for the capacity utilization rate.[6] The ratio of after-tax profits, adjusted for inventory valuation and capital consumption allowance, to corporate income (in real terms) was used as the cash flow variable. Since taxes represent the price firms must pay for the provision of public goods, the effect of taxation was addressed by using tax-adjusted profits.

The Securities Valuation–Cash Flow Model

The securities valuation investment model differs from many other investment models (including the two others used in this study) in that investment is assumed to occur on a financial basis, that is, in terms of the firm's portfolio balance and expected profitability. The key variable in the model is the *q* ratio, which is the ratio of the market value of a firm's outstanding stocks and bonds to the replacement cost of a firm's capital stock. When a firm acts to maximize the value of shareholder equity, the market value of the firm's outstanding equities will rise. When the market value of shares exceeds the replacement cost of the capital goods, investment will occur.

The use of the *q* ratio in an investment model allows for expected profitability. Following Fazzari, Hubbard, and Petersen (1988), cash flow also has been added. Augmenting the securities valuation–cash flow model with public capital yields a public capital augmented securities valuation–cash flow model:

$$(4)\quad \frac{I}{KT} = \alpha + \sum_{i=0}^{N} m q_{-i} + \sum_{i=0}^{N} c \frac{CF_{-i}}{KT_{-i}} + \sum_{i=0}^{N} e \frac{IG_{-i}}{KT_{-i}} + f \frac{KG_{t}}{KT_{t}} + u$$

The *q* ratio used in this study is a tax-adjusted variable constructed by McMillin and Parker (1990) for the years 1961 to 1987.

The Neoclassical Investment Model

In the neoclassical model, private investment is determined in part by the cost of capital and in part by cash flow. Jorgenson (1971) and others have developed an investment model using a Cobb-Douglas production function, which reflects the neoclassical principle that factor inputs should be a function of their relative prices. Adding public capital to the neoclassical expression of desired capital stock yields

$$(5)\quad KT^{d} = \gamma \frac{pY}{C} + \mu KG$$

where

γ = share of capital in output
p = output price
C = cost of capital

Analogous to the adjustment process in the previous investment model, a public capital term is included to represent infrastructure already in place, yielding a public capital augmented neoclassical investment model:

$$(6)\quad \frac{I}{KT} = \frac{\alpha}{KT} + \sum_{i=0}^{N} c \frac{CF_{-i}}{KT_{-i}} + \sum_{i=0}^{N} g \frac{r_{s}/r_{t}}{KT_{-i}} + \sum_{i=0}^{N} e \frac{IG_{-i}}{KT_{-i}} + f \frac{KG_{t}}{KT_{t}} + u$$

where

r_k = nominal rate of return to capital
r_c = real rate of return to capital

This model includes separate variables for cash flow and the relative cost of capital, an empirical form based on Jorgenson's development of the reduced form of the optimal demand for capital. This form "allows the demand for capital to be expressed as a function of the relative cost of capital services alone; the effect of other factor prices is captured by including the level of output or sales in the model. In this case, the neoclassical model with partial-adjustment assumptions takes a form similar to the accelerator model" (Fazzari, Hubbard, and Petersen 1988). The tax-adjusted profits variable and the ratio of the return to capital to the cost of capital also are included in this model.

The proxy used for the rate of return to capital was the price-dividend ratio of Standard and Poor's Composite Index; the real rate used was the 10-year U.S. Treasury rate adjusted for inflation. This latter measure was utilized in order to allow for changes in both the nominal rate and the real rate of return to capital.[7] If the increase in the nominal rate of return to capital is greater than the increase in the cost of capital (measured by the real rate), private investment should rise.

Empirical Results

Tables A1, A2, and A3 provide the empirical results of estimating the relationships between private investment and public investment spending and the public capital stock using the models described above. Table A3 includes results for the securities valuation model only, as that model yielded the best statistical results (in terms of adjusted R^2, statistical significance, and standard errors) compared to the accelerator and neoclassic models.

Empirical Analysis

Critics of public investment often ask how public capital affects private investment activity. As the industrial sector combines its capital stock with the public capital stock, productivity rises, causing the value of firms to increase. Consequently, as the expected (future) value of a firm rises, capital investment expands. In terms of new private investment, assuming that firms judge the profitability of an investment project based on its internal rate of return, the following benefit-cost expression can be used to examine how the return to private investment projects is enhanced by public infrastructure:

$$(7) \quad \sum_{j=0}^{n} \frac{B_j - C_j}{(1+r)^j} = 0$$

where

B_j = total benefits associated with investment project j
C = total costs associated with investment project j
r = rate of return associated with firm n

There are clear costs and benefits associated with public infrastructure. Start-up costs are lower when public infrastructure is provided (for example, improved transportation lowers materials costs). If benefits are greater than costs (that is, the future stream of income of firms is higher because of infrastructure), then the rate of return to private investment will be greater. Simply put, this suggests that there will be more private investment with infrastructure than without infrastructure. Holding everything else constant, infrastructure investment increases the net present value of any investment project, expands private investment activity, and enhances the future growth of real income, given limited resources.

Using the standard investment models outlined above, a direct relationship between private investment in equipment and the public capital stock was found in the short run, with a point estimate of 0.89. At the same time an inverse relationship between private equipment investment and government investment spending was found, with a point estimate of –0.30. The latter result may indicate financial sector crowding out, or it might be that if firms that benefit from public capital believe that the stock of public infrastructure will be larger in the future, they may postpone equipment investment to take advantage of the increase in the expected future rate of return when the public capital is put in place.

Table A1
Comparisons of Private Investment in Equipment, Structures, and Total Investment Using Three Investment Models (Δ log levels)

	Accelerator–Cash Flow[a]			Securities Valuation–Cash Flow			Neoclassical		
	Total	Equipment	Structures	Total	Equipment	Structures	Total	Equipment	Structures
	Without Government Capital Ratios								
Adjusted R^2	.78	.92	.82	.38	.51	.74	.38	.56	.82
Constant	–2.15*	–2.33*	–.38	–1.06	–1.10	.55	–.68	–.63	–.57**
	(.60)	(.67)	(.51)	(.87)	(1.20)	(.87)	(.41)	(.73)	(.24)
Profits–to–corporate income ratio	–.01	.02	–.04	–.03	.11	–.03	–.09	.01	.03
	(.05)	(.04)	(.08)	(.10)	(.12)	(.10)	(.07)	(.10)	(.06)
Lagged one period	–.005	–.07	.08	.05	–.13	.13	.12	–.01	.17**
	(.05)	(.05)	(.08)	(.10)	(.12)	(.11)	(.07)	(.10)	(.07)
Capacity utilization[b]	.01*	.017*	.005**	–.06	–.07	–.006	–.60	–.59	–.70
	(.001)	(.001)	(.002)	(.05)	(.07)	(.06)	(1.42)	(1.9)	(1.40)
Lagged one period	–.002	–.007*	-.003	.08	.12	–.01	–3.54*	–4.17**	–1.59
	(.002)	(.002)	(.003)	(.06)	(.05)	(.07)	(1.43)	(1.90)	(1.39)
Lagged dependent variable	.53*	.76*	.72*	.37***	.72*	.63*	.44*	.74*	.65*
	(.15)	(.09)	(.11)	(.21)	(.20)	(.16)	(.16)	(.15)	(.10)

	Accelerator–Cash Flow[a]			Securities Valuation–Cash Flow			Neoclassical		
	Total	Equipment	Structures	Total	Equipment	Structures	Total	Equipment	Structures
With Government Capital Ratios									
Adjusted R^2	.89	.96	.85	.80	.95	.77	.72	.90	.80
Constant	–1.94*	–3.04*	.85	1.29	.08	3.58**	.47	.08	–.40
	(.52)	(.53)	(.66)	(1.32)	(.91)	(1.72)	(.65)	(.59)	(.32)
Profits–to–corporate income ratio	.03	.06**	.02	.04	.06	.04	–.06	–.03	.02
	(.04)	(.03)	(.08)	(.07)	(.04)	(.11)	(.05)	(.05)	(.09)
Lagged one period	–.01	–.08**	.10	.14**	.05	.27**	.14**	.05	.20**
	(.04)	(.03)	(.08)	(.07)	(.05)	(.13)	(.05)	(.05)	(.09)
Capacity utilization[b]	.04*	.03*	.03***	–.006	–.01.	–.01	–.026	.38	–.36
	(.008)	(.007)	(.017)	(.04)	(.02)	(.07)	(.97)	(.92)	(1.50)
Lagged one period	–.03*	–.017**	–.029	.11*	.15*	.07	–1.63	–1.59***	–1.13
	(.008)	(.007)	(.02)	(.04)	(.03)	(.08)	(1.02)	(.96)	(1.56)
Public capital–to–private capital stock ratio	–2.29*	–1.18***	–2.39	.40	.79*	–.08	.81*	1.26*	.11
	(.73)	(.64)	(1.50)	(.24)	(.16)	(.46)	(.15)	(.13)	(.25)

Lagged one period	2.30*	1.26**	2.11	–.42	–.66*	–.24	–.70*	–1.04*	–.16
	(.72)	(.61)	(1.51)	(.29)	(.18)	(.37)	(.18)	(.15)	(.22)
Public investment spending–to–private capital stock ratio	–.06	–.12***	–.23	–.31	–.27**	–.47	–.22**	–.18**	–.12
	(.08)	(.06)	(.17)	(.21)	(.13)	(.36)	(.10)	(.09)	(.12)
Lagged one period	–.05	.01	.21**	–.06	–.11	.09	.09	.97*	.09
	(.05)	(.05)	(.11)	(.18)	(.11)	(.27)	(.08)	(.10)	(.10)
Lagged dependent variable	.32*	.48*	.81*	.77*	.80*	.95*	.84*	.52*	.73*
	(.13)	(.09)	(.12)	(.22)	(.10)	(.21)	(.17)	(.18)	(.13)

[a]Lagged values of the private capital stock are included in the public capital stock–to–private capital stock ratio. No statistical significance is indicated when the lagged private capital stock is included as a separate independent variable.
[b]Figures listed under the securities valuation–cash flow model are analogous to Tobin's *q*; figures under the neoclassical model represent *RK/RC*.
Standard errors in parentheses.
* = .01 level of significance.
** = .05 level of significance.
*** = .10 level of significance.
Source: Bureau of Economic Analysis (1992 and personal communication); Citibase; McMillin and Parker (1990).

Combining these two point estimates yields a net positive point estimate of 0.59, which indicates that each 1.0 percentage point increase in public infrastructure and government investment spending was associated with approximately a 0.6 percentage point rise in private sector equipment investment per year.

In order to address the problem of spurious regression, the Stock-Watson (1989) estimation method, which also allows for the testing of long-run relationships, was applied to the data. The results indicate that a long-run relationship between private sector equipment investment and public infrastructure and government spending does indeed exist. The positive effect of the public capital stock on private equipment investment (0.91) was greater than the negative effect of government investment spending (–0.52); combining these two point estimates yielded a long-run relationship of 0.39, indicating that each additional 1.0 percentage point increase in public infrastructure and government investment spending is associated with approximately a 0.4 percentage point increase in private sector equipment investment. There was no evidence of a statistically significant short-run relationship with private investment in structures and public infrastructure, but a significant (0.43 point estimate) long-run relationship was found.

These strong statistical results indicate that, for the time period examined, public infrastructure had an overall short- and long-run stimulative effect on private equipment investment in the United States. These results confirm those of Aschauer (1989b) while addressing concerns of spurious correlation.

Appendix B

Modeling the Relationship Between Public Capital and the Real Wage

The following aggregate labor demand function, expressed in terms of the real wage, incorporates the effect of productivity, φ_t.

$$(8)\quad (W/P)_t = G((W/P)_{t-1}, \varphi_t)$$

Table A2
Comparisons of Private Investment in Equipment, Structures, and Total Investment Using Three Investment Models (Δ log levels)

	Accelerator–Cash Flow[a]			Securities Valuation–Cash Flow			Neoclassical		
	Total	Equipment	Structures	Total	Equipment	Structures	Total	Equipment	Structures
Without Government Capital Ratios									
Adjusted R^2	.78	.86	.34	.61	.71	.16	.40	.37	.23
Constant	.002	.004	–.001	.0170***	.020*	.004*	.017***	.020**	.006
	(.005)	(.005)	(.010)	(.009)	(.009)	(.014)	(.009)	(.010)	(.010)
Profits–to–corporate income ratio	.030	.055	.007	.16*	.25*	.06	.08	.15***	–.01
	(.040)	(.040)	(.070)	(.06)	(.06)	(.10)	(.06)	(.08)	(.07)
Lagged one period	.05	.013	.09	.16*	.13*	.19**	.26*	.27*	.23*
	(.04)	(.04)	(.07)	(.06)	(.06)	(.09)	(.05)	(.07)	(.06)
Capacity utilization[a]	.010*	.015*	.005**	–.060	–.060	–.050	.300	.860	–.550
	(.001)	(.001)	(.002)	(.040)	(.040)	(.060)	(1.040)	(1.270)	(1.180)
Lagged one period	.003**	.001	.004**	.11*	.16*	.04	–1.46	–1.48	–1.74
	(.001)	(.002)	(.002)	(.04)	(.04)	(.06)	(1.07)	(1.32)	(1.21)
Lagged dependent variable	.12	.26***	.14	.30**	.32**	.24	.17	.16	.20
	(.13)	(.13)	(.15)	(.15)	(.14)	(.19)	(.15)	(.16)	(.15)

	Accelerator–Cash Flow[a]			Securities Valuation–Cash Flow			Neoclassical		
	Total	Equipment	Structures	Total	Equipment	Structures	Total	Equipment	Structures
With Government Capital Ratios									
Adjusted R^2	.86	.91	.48	.77	.93	.13	.77	.86	.33
Constant	–.0005 (.005)	–.0005 (.005)	–.0003 (.009)	.008 (.008)	.01** (.006)	–.002 (.016)	.005 (.006)	.007 (.005)	.002 (.01)
Δ Profits–to–corporate income ratio	.035 (.03)	.05 (.03)	.018 (.06)	.075 (.06)	.10* (.04)	.05 (.11)	.003 (.04)	.018 (.04)	–.013 (.07)
Lagged one period	.01 (.03)	–.03 (.03)	.06 (.07)	.06 (.06)	.01 (.04)	.13 (.11)	.04 (.04)	–.004 (.04)	.09 (.09)
Δ Capacity utilization[a]	.026* (.006)	.018* (.006)	.04* (.01)	–.03 (.03)	–.04** (.02)	–.0007 (.065)	.01 (.66)	.27 (.62)	–.52 (1.14)
Lagged one period	–.013*** (.007)	.001 (.007)	–.03* (.01)	.06 (.04)	.09* (.03)	.04 (.08)	–.97 (.66)	–1.03 (.64)	–1.36 (1.14)
Δ Public capital–to–private capital stock ratio	–1.30** (.53)	–.24 (.53)	–2.92* (1.04)	.55** (.21)	.89* (.14)	.04 (.44)	.86* (.12)	1.24* (.12)	.38*** (.20)

Lagged one period	1.33*	.24	2.99*	.27	–.06	.40	.26***	.05*	.38**
	(.54)	(.53)	(1.06)	(.22)	(.20)	(.31)	(.14)	(.17)	(.18)
Public investment spending–	–.10**	–.15*	–.04	–.16	–.13**	–.22	–.16**	–.16*	–.16
to–private capital stock ratio	(.06)	(.05)	(.11)	(.14)	(.09)	(.28)	(.07)	(.06)	(.12)
Lagged one period	.005	–.05	.10	–.14	–.17**	–.08	–.015	.38*	.07
	(.05)	(.05)	(.10)	(.13)	(.08)	(.26)	(.07)	(.14)	(.11)
Lagged dependent variable	.11	.14	.21*	.24	.36**	.21	.23	.52*	.21
	(.11)	(.12)	(.14)	(.20)	(.16)	(.23)	(.15)	(.18)	(.16)

[a] Figures listed under the securities valuation–cash flow model are analogous to Δ Tobin's q; figures under the neoclassical model represent Δ *(RK/RC)*.
Standard errors in parentheses.
* = .01 level of significance.
** = .05 level of significance.
*** = .10 level of significance.
Source: Bureau of Economic Analysis (1992 and personal communication); Citibase; McMillin and Parker (1990).

$$(9)\quad \varphi_t = h(N_t, K_t, G_t)$$

where

W/P = real wage
N = aggregate employment of labor
K = private nonresidential capital
G = public capital

Productivity is measured assuming a generalized Cobb-Douglas form for the production technology, competitive product and factor markets, and constant returns to scale across all factors of production. This yields the aggregate production function (10) and the productivity of private capital equation (11).

$$(10)\quad Y = A(t)f(N, K, G)$$

where

Y = aggregate output
A = technical change

Taking logs and rearranging yields

$$(11)\quad y_t - k_t = a_t + b_n(n_t - k_t) + b_g (g_t - k_t)$$

where lower case indicates logs.

The following two equations specify the real wage in terms of productivity φ_t (defined as output per unit of capital) as developed in equation (11) plus a time variable. Business cycle effects are also added to equation (11) by adding the log of capacity utilization.

$$(12)\ (w_t - p_t) = \alpha_0 + \alpha_1(w_t - p_t)_{t-1} + \alpha_2 (y_t - k_t) + e_{1,t}$$

$$(13)\ (y_t - k_t) = \mu_0 + \mu_1 t + \mu_2(n_1 - k_1) + \mu_3(g_1 - k_1) + \mu_4 cu_t + e_{2,\mathrm{t}}$$

Table A3

Long-Run Estimates of Private Investment in Equipment and Structures (log levels and Δ log levels)

	Securities Equipment	Valuation–Cash Flow Structures
Adjusted R^2	.88	.75
Constant	–4.66*	–4.53**
	(.69)	(1.09)
Profits–to–corporate income ratio	–.06	–.17**
	(.06)	(.08)
Tobin's *q*	.15*	.03
	(.04)	(.06)
Public capital–to–private capital stock ratio	.91*	.43**
	(.15)	(.21)
Public investment–to–private capital stock ratio	–.52*	.35*
	(.08)	(.12)
Δ Dependent variable		
(+1)[a]	–.64*	
	(.16)	
(–1)		.45***
		(.23)
Δ Profits–to–corporate income ratio		
(–1)	.11***	
	(.06)	
Δ Tobin's *q*		
(–1)	–.085**	
	(.04)	
Δ Public investment–to–private capital stock ratio		
(+1)		.72**
		(.31)
(–1)	.34**	
	(.16)	

[a] (+1) and (–1) indicate one lead or lag period, respectively.

Standard errors in parentheses.

* = .01 level of significance.

** = .05 level of significance.

*** = .10 level of significance.

Source: Bureau of Economic Analysis (1992 and personal communication); Citibase; McMillin and Parker (1990).

Table B1

a. Estimation of the Real Wage and Labor Productivity Equations (log levels)

Real Wage Equation (14) Variable	Coefficient	Productivity Equation (15) Variable	Coefficient
Constant	.04* (.01)	Constant	–4.97 (.39)
Time	.0016 (.002)	Time	.57* (.12)
(n – k)	–.29* (.125)	*(n – k)*	.44* (.07)
(g – k)	.225* (.076)	*(g – k)*	.50* (.05)
Capacity utilization	.09* (.04)	Capacity utilization	.006* (.002)
Real wage (lagged one period)	.68* (.09)		
CRS = .98 Durbin-Watson = 1.07		CRS = .998 Durbin-Watson = 1.91	

b. Estimation of the Real Wage and Labor Productivity Equations, Adjusted for Business Cycle Effects (log levels)

Real Wage Equation (14a) Variable	Coefficient	Productivity Equation (15a) Variable	Coefficient
Constant	.51* (.17)	Constant	–6.12 (.12)
Time	.001 (.001)	Time	–.002* (.0008)
(n – ka)	–.32* (.08)	*(n – k)*	.21* (.04)
(g – ka)	.22* (.06)	*(g – ka)*	.24* (.03)
Real wage	.67* (.09)		
CR2 = .96 Durbin-Watson = .80		CR2 = .997 Durbin-Watson = 1.91	

Standard errors in parentheses.

* = .01 level of significance.

Source: Author's calculations based on data in Bureau of Economic Analysis (1992 and personal communication); Citibase.

Table B2

a. Estimation of Real Wage and Labor Productivity Equations as a Nonlinear System with Constrained Coefficients

	Coefficient	Standard Error
γ_0 =	0.58*	(.25)
γ_1 =	0.67*	(.09)
γ_2 =	0.002	(.002)
γ_3 =	–0.30*	(.12)
γ_4 =	0.23*	(.07)
γ_5 =	0.10*	(.04)
μ_0 =	–4.67*	(.37)
μ_1 =	0.006*	(.002)
μ_2 =	0.57*	(.11)
μ_3 =	0.44*	(.07)
μ_4 =	0.09*	(.04)

Equation (14): CR2 = .998;
Durbin-Watson = 1.90

Equation (15): CR2 = .98;
Durbin-Watson = 1.08

b. Estimation of Real Wage and Labor Productivity Equations as a Nonlinear System with Constrained Coefficients, Adjusted for Business Cycle Effects

	Coefficient	Standard Error
γ_0 =	0.528*	(.17)
γ_1 =	0.67*	(.09)
γ_2 =	0.0001	(.0009)
γ_3 =	–0.32*	(.08)
γ_4 =	0.22*	(.06)
μ_0 =	–6.12*	(.11)
μ_1 =	0.002*	(.0008)
μ_2 =	0.21*	(.04)
μ_3 =	0.24*	(.03)

Equation (14a): CR2 = .998;
Durbin-Watson = 1.90

Equation (15a): CR2 = .96;
Durbin-Watson = 0.79

* = .01 level of significance.

Source: Author's calculations based on data in Bureau of Economic Analysis (1992 and personal communication); Citibase.

Table B3

Long-Run Estimates of Real Wage and Labor Productivity Equations (log levels and Δ log levels)

Real Wage Equation (14)		Productivity Equation (15)	
Constant	3.36* (.34)	Constant	–6.07* (.23)
(n – ka)	–.44* (.10)	*(n – ka)*	.24* (.075)
(g - ka)	.28* (.09)	*(g – ka)*	.29* (.07)
Δ real wage(2)	–.41* (.09)	Δ *(y – ka)*(2)	.25* (.09)
Δ real wage(1)	–.66* (.08)	Δ *(y – ka)*(1)	–.61* (.09)
Δ *(n – ka)*(2)	–.18*** (.11)		
Δ *(g – ka)*(2)	–.04*** (.02)	Δ *(g – ka)*(2)	.25* (.10)
Δ *(g – ka)*(1)	–.05*** (.03)	Δ*(g – ka)*(–1)	.26* (.06)
Δ rho	.95* (.004)	Δ rho	.91* (.04)
CR2 = .998		CR2 = .996	
Durbin-Watson = 1.30		Durbin-Watson = .68	

Standard errors in parentheses.
* = .01 level of significance.
** = .05 level of significance.
*** = .10 level of significance.
Source: Author's calculations based on data in Bureau of Economic Analysis (1992 and personal communication); Citibase.

Combining equations (12) and (13) yields

$$(14)\ (w_t - p_t) = \gamma_0 + \gamma_1(w_t - p_t)_{t-1} + \gamma_2 t + \gamma_3\,(n_t - k_t) + \gamma_4\,(g_t - k_t) + \gamma_5 cu_t + \eta_t$$

$$(15)\ (y_t - k_t) = \mu_0 + \mu_1\,t + \mu_2(n_1 - k_1) + \mu_3(g_1 - k_1) + \mu_4 cu_t + \varepsilon_2$$

The real wage as specified as in equation (14) is similar to Canzoneri's specification (Canzoneri 1978). However, equation (14) not only controls for the private capital stock (Canzoneri's term $n_t - k_t$) while allowing for the identification of the effects of diminishing returns to labor, but also allows for the identification of the separate effects of public capital ($g - k$). If public capital raises aggregate productivity, then a direct relationship between the real wage and the public capital term would be found.

Countercyclical wage movements were modeled as changes in the labor productivity variable. For simplicity, time was used as a proxy for technological change not captured in the capital stock.[8]

Procyclical wage movements were modeled as changes in capital utilization.[9] Entering capacity utilization as a separate variable incorporates the effect of variation in capital stock utilization over the business cycle.[10] However, since changes in capacity utilization also change the utilization of the capital stock, another way to measure the effect of the business cycle is to adjust the capital stock for actual capital employed. This adjustment was made by multiplying the capital stock by the capacity utilization rate, thereby indicating that the flow of capital services—and therefore the amount of capital stock per worker—changes over the business cycle.[11] Equations (14a) and (15a) below incorporate the concept of the capital stock adjusted for capacity utilization (*ka*)

$$(14a)\ (w_t - p_t) = \gamma_0 + \gamma_1(w_t - p_t)_{t-1} + \gamma_2 t + \gamma_3\,(n_t - ka_t) + \gamma_4\,(g_t - ka_t) + \eta_t$$

$$(15a)\ (y_t - ka_t) = \mu_0 + \mu_1 t + \mu_2(\mathrm{n}_t - ka_t) + \mu_3(g_t - ka_t) + \varepsilon_t$$

Notes

1. Tatom (1991) found no statistical correlation between infrastructure spending and economic growth, and Holtz-Eakin (1993), in a state-specific approach, found no productivity gains to justify the spending of "scarce economic resources" on public infrastructure.

2. Spurious correlation, a problem that occurs when time series data are used, arises when an independent variable is found to be significant (statistically different from zero), implying that there is a relationship between the dependent and independent variables even when no relationship exists.

3. Point elasticity estimates measure 0.35 and 0.39, respectively. Estimates made excluding public capital reveal problems with serial correlation, unexpected signs, and statistical insignificance.

4. See also Shah (1992) who examines the relationship between public infrastructure and productivity in Mexico.

5. To address concerns about stationarity, estimates were taken from the productivity equation that establish a long-run relationship between productivity (measured as output per unit of capital) and the employment-to-capital ratio and the public capital–to–private capital ratio.

6. See Hulten and Schwab (1990) and Nadiri and Mamuneas (1991).

7. Other interest rate variables were used (including the real rate alone and the ratio of sales to the real rate); none of these variables performed well.

8. The idea that technology is embodied in the capital stock is argued by Richard R. Nelson (1973).

9. According to Merrick (1984), variation in capital utilization shifts the marginal product of labor.

10. This technique was employed by Aschauer (1989a) and Erenburg (1993a).

11. See, for example, Tatom (1991).

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