PUBLIC INFRASTRUCTURE AND GROWTH: NEW CHANNELS AND POLICY IMPLICATIONS

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This paper provides an overview of the various channels through which public infrastructure may affect growth. In addition to the conventional productivity, complementarity and crowding-out effects typically emphasized in the literature, the impact of infrastructure on investment adjustment costs, the durability of private capital and the production of health and education services are also highlighted. Effects on health and education are well documented in a number of microeconomic studies, but macroeconomists have only recently begun to study their implications for growth. Links between health, infrastructure and growth are illustrated in an endogenous growth model with transitional dynamics and the optimal allocation of public expenditure is discussed. The conluding section draws implications of the analysis for the design of strategies aimed at promoting growth and reducing poverty.

1. Introduction

Much of the current international debate on ways to spur growth, reduce poverty and improve the quality of human life in low-income developing countries has centered on the need to promote a large increase in public investment. Reports by the United Nations Millennium Project (2005), the Blair Commission (2005) and the World Bank (2005*a*, 2005*b*) have indeed dwelt on the importance of a "Big Push" in public investment in core infrastructure, financed by generous debt relief and a substantial increase in aid.

A common argument for a large increase in public spending on infrastructure is that infrastructure services may have a strong growth-promoting effect through their impact on the productivity of private inputs and the rate of return on capital – particularly when, to begin with, stocks of infrastructure assets are relatively low.[1] In that regard, low-income countries are at a particular disadvantage. In Sub-Saharan Africa for instance, only 16 per cent of roads are paved, and less than one in five

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A Technical Appendix containing the solution of the model presented in Section IV is available upon request.

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[1] Infrastructure in this paper is broadly defined to include transport, water supply and sanitation, information and communication technology (ICT), and energy.

Africans has access to electricity. The average waiting time for a fixed telephone connection is three and a half years. Transport costs are the highest of any region. A 1999 study by the African Development Bank on exports of the region to the United States found that freight charges, as a proportion of cif value, are on average 20 per cent higher for exports of poor countries of the region than for comparable products from other low-income countries. Given that prospects for public-private partnerships (PPPs) in infrastructure investment for the region, and low-income countries in general, are limited (if not inexistent, in many cases), closing the infrastructure gap will indeed require a substantial increase in public investment.[2]

At the same time, recent analytical and empirical research has highlighted the fact that public infrastructure, in addition to its direct effects on the productivity of private inputs and the rate of return on private capital, may spur growth through a variety of other channels. For instance, it has been argued that good public infrastructure (such as a reliable power grid or well-maintained roads), by reducing the need for the private sector to spend on maintenance of its own stock of physical capital, may raise the rate of capital formation and spur growth. A significant body of microeconomic evidence suggests also that infrastructure may have a significant impact on health and education outcomes. Moreover, this impact tends to be magnified through interactions between health and education themselves. In particular, better health has been shown to have a strong impact on the ability to learn and study, in addition to enhancing the productivity of workers.

Surprisingly enough, development macroeconomists and international institutions involved in providing policy advice to low-income countries have only recently begun to study, analytically and empirically, the implications of these channels for growth. In its review of the links between public investment and growth, the International Monetary Fund (2004) did not even mention any of these channels. Similarly, most recent empirical studies that have attempted to gauge the link between infrastructure and growth – such as those of Balducci *et al.* (2004), Calderón and Servén (2004), and Estache, Speciale and Veredas (2005) – did not attempt to account for some of the externalities associated with infrastructure.

This paper provides an overview of the recent literature in this area, with a particular emphasis on the interactions between public infrastructure, education and health outcomes. In that sense, our coverage is broader than earlier surveys on the role of infrastructure and growth, such as those of Gramlich (1994), Kessides (1996) and more recently Romp and de Haan (2005). Unlike these studies, we focus squarely on the evidence on (and policy lessons for) developing countries and

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2 The need to enhance infrastructure is not limited, of course, to low-income countries. A report by Fay and Morrison (2005) on infrastructure in Latin America and the Caribbean (LAC) found that the region is currently spending less than 2 per cent of its GDP on infrastructure, down from 3.7 per cent during 1980-85. They estimate that spending would need to reach 4-6 per cent a year for infrastructure to catch up. Moreover, the value of LAC infrastructure with private participation dropped to $16 bn in 2003, down from a peak of $71 bn in 1998. By total project value, 93 per cent of private investment in LAC infrastructure over 1990-2003 went to just six countries (Argentina, Brazil, Chile, Colombia, Peru and Mexico), and mostly into telecommunications and energy.

address econometric issues only sparingly – essentially to highlight the biases created by an inadequate account of the various ways through which public infrastructure may affect economic growth. However, we do not address issues associated with the political economy of infrastructure investment decisions – a topic that has attracted much interest in industrial countries in recent years (see, for instance, Valila and Mehrotra, 2005, and Cadot, Roller and Stephan, 2006).

The remainder of the paper is organized as follows. Section 2 briefly reviews the "conventional" channels through which public infrastructure is deemed to affect growth, namely, productivity, complementarity and crowding-out effects. Section 3 identifies several other channels through which public capital in infrastructure may have an impact on growth. These include an indirect effect on labor productivity, an effect on adjustment costs associated with private investment, an impact on the durability of private capital and an effect on education and health outcomes. In addition, we also highlight the fact that the impact of infrastructure on growth may be magnified as a result of interactions between health and education.

Dwelling on this discussion, Section 4 illustrate the links among health, infrastructure and growth in an endogenous growth model with transitional dynamics. After a brief description of the model and a characterization of the balanced growth path, we examine the short- and long-run effects of a revenue-neutral reallocation of public spending from health to infrastructure and discuss how these effects depend on the technology for producing goods and health services. We then derive the optimal (growth-maximizing) allocation of public expenditure and examine the properties of the optimal rule. Section 5 draws together some of the practical policy implications of the analysis for the design of strategies to promote growth and reduce poverty in low-income countries.

2. Conventional channels

Macroeconomists typically emphasize three "conventional" channels through which public infrastructure may affect growth: a direct productivity effect on private production inputs, a complementarity effect on private investment, and a crowding-out effect on private spending through the financial system.

2.1 Productivity of private inputs

The direct productivity effect of infrastructure is the argument that is most commonly proposed to account for a growth effect of public capital. If, as it is normally the case, production factors are gross complements, a higher stock of public capital in infrastructure would tend to raise the productivity of other inputs, such as labor and the stock of private capital, thereby reducing unit production costs.[3] Given decreasing returns, the magnitude of this effect would depend, of course, on the initial stock of public capital. In mature economies, productivity effects are likely to be limited; but in low-income countries, they could be substantial. In turn, the increase in the productivity of private capital may raise the rate of private investment (given that the return to capital is higher) and spur growth.

To illustrate this effect, suppose for instance that the production function of the private sector takes the Cobb-Douglas form:

$$Y = (K_I)^{\alpha} L^{\beta} (K_P)^{1-\alpha-\beta} \tag{1}$$

where Y is output, KI the stock of public capital in infrastructure, L labor, KP the stock of private capital, and $\alpha,\beta \in (0,1)$. Constant returns to scale therefore prevail in all factors. The marginal product of private capital is given by $(1-\alpha-\beta)(K_I/K_P)^{\alpha}(L/K_P)^{\beta}$, whereas the marginal product of labor is given by $\beta(K_I/K_P)^{\alpha}(K_P/L)^{1-\beta}$. Thus, a higher stock of public capital (relative to private capital) increases the marginal product of both inputs – although it does so at a decreasing rate, given that $\alpha < 1$. In the endogenous growth model that we present in Section 4, we will show that the (steady-state) growth rate itself, in addition to the level of output, depends positively on the public-private capital ratio, K_I/K_P.

Of course, the positive effect of public capital on the marginal productivity of private inputs may hold not only for infrastructure but also for other components of public capital – such as in education and health, which may both affect the productivity of labor (see the discussion below). Moreover, other components of public spending, related for instance to the enforcement of property rights and maintenance of public order, could also increase productivity and exert a positive effect on private investment and growth, despite the fact that they may not be considered as being directly "productive". But, as noted earlier, infrastructure capital may have a particularly large effect in countries where initial stocks are low and basic infrastructure services (such as electricity and clean water) are lacking, as is the case in many low-income countries.[4] Conversely, a study by the African Development Bank suggests that transport and energy costs, at 16 and 35 per cent respectively, represent by far the largest share of firms' indirect costs in Sub-Saharan Africa. A large fraction of these costs is the result of the poor quality of basic infrastructure. For instance, because of inadequate transport facilities and unreliable supply of electricity, firms often incur additional expenses in the form of more expensive transportation means and onerous energy back-up systems.[5]

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3 Several country-specific studies based on the estimation of cost functions have found indeed that public infrastructure typically entails cost reductions in private production. See for instance Cohen and Paul (2004), and Teruel and Kuroda (2005).

4 For instance, data from China (1978-97), India (1970-93) and Uganda (1992-99), countries that have managed to stimulate growth and reduce poverty on a large scale, show that the marginal returns to public incremental expenditures on rural roads were always among the highest.

5 Firms that do not undertake these additional investments may still incur costs in the form of lost production resulting from equipment breakdowns.

The productivity and cost effects of public infrastructure may be magnified in the presence of externalities associated with the use of some production factors, such as, for instance, learning-by-doing effects resulting from a high degree of complementarity between physical capital and skilled labor. As shown by Torvik (2001) in particular, by enhancing labor productivity and lowering (unit) labor costs, learning by doing may magnify the growth effect of public infrastructure. Indeed, an increase in public capital may affect the rate of total factor productivity growth, independently of its effect on private capital accumulation.

2.2 Complementarity effect on private investment

Another channel through which public capital in infrastructure can exert a positive effect on growth is private capital formation. As noted earlier, public infrastructure increases the marginal productivity of private inputs. In so doing, it raises the perceived rate of return on, and may increase the demand for, physical capital by the private sector.[6] For example, the rate of return to building a factory is likely to be much higher if the country has already invested in power generation, transportation and telecommunications.

The complementarity effect has been well documented in the empirical literature on private capital formation in developing countries (see Agénor, 2004, Chapter 2). Albala-Bertrand and Mamatzakis (2004) for instance found that in Chile, public infrastructure capital had a significant positive effect on private investment. In Vietnam, the decision to improve National Highway No. 5 and rehabilitate the port of Haiphong in the early 1990s led to a massive increase in investment (much of it foreign) in major industrial zones, spurring growth and employment in the northen part of the country in general (Mitsui, 2004).

Conversely, the study of Uganda by Reinikka and Svenson (2002) illustrates well how inadequate public infrastructure may adversely affect private investment. A survey of 243 manufacturing firms conducted in 1998 in that country showed that the lack of adequate electricity sources was ranked as the most important constraint to investment. Firms on average did not receive electricity from the public grid for 89 operating days on average, which led to 77 per cent of large firms (in addition to 44 per cent of medium and 16 per cent of small firms) purchasing generators, representing 25 per cent of their total investment in equipment and machinery in 1997. The same survey showed that for a firm without a privately-owned generator, a one per cent increase in the number of days without power results in a 0.45 per cent reduction in investment.

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6 Greater availability of public capital in infrastructure could in principle also reduce the demand for private inputs, at a given level of output (net substitution effect). But if inputs are gross complements, higher availability of public capital will normally increase the marginal productivity of private inputs, as noted earlier, and thus demand for these inputs. The evidence suggests indeed that public infra-structure and private physical capital tend to have a high degree of complementarity, that is, a small elasticity of (net) substitution.

In the short run, public capital in infrastructure may also affect private capital formation indirectly, through changes in output and relative prices. As noted earlier, public capital in infrastructure may raise the marginal productivity of all factor inputs (capital and labor), thereby lowering marginal production costs and increasing the level of private production. In turn, this scale effect on output may lead, through the standard accelerator effect, to higher private investment – thereby raising production capacity over time and making the growth effect more persistent.

Another indirect channel is through the effect of public infrastructure on the price of domestic consumption goods relative to the price of imported goods, that is, the (consumption-based) real exchange rate. An increase, for instance, in public investment in infrastructure would raise aggregate demand and put pressure on domestic prices. If the nominal exchange rate does not depreciate fully to offset the increase in domestic prices, the domestic-currency price of imported consumption goods will fall in relative terms (that is, the real exchange rate will appreciate), thereby stimulating demand for these goods. The net effect on domestic output may be positive or negative, depending on the intra-temporal elasticity of substitution between domestic and imported goods. If this elasticity is low (as one would expect in the short run), the net effect may well be positive. Again, through the accelerator effect, private investment may increase, and this may translate into a more permanent growth effect.

At the same time, to the extent that the increase in government spending on infrastructure raises the relative price of domestic capital goods, and the switch in private consumption demand toward imports translates into a nominal appreciation, the domestic-currency price of imported capital goods may fall in relative terms, resulting in a drop in the user cost of capital. If a large fraction of the capital goods used by the private sector are imported (as is often the case in developing countries) this may lead to an increase in private investment. Moreover, this relative price effect is not only short term in nature; it may translate into a growth effect, as suggested by the evidence reported in Sala-i-Martín, Doppelhofer and Miller (2004).

2.3 Crowding-out effects

In the short term, an increase in the stock of public capital in infrastructure may have an adverse effect on activity, to the extent that it displaces (or crowds out) private investment. This short-run effect may translate into an adverse growth effect if the drop in private capital formation persists over time.

Crowding-out effects may take various forms. For instance, if the public sector finances the expansion of public capital through an increase in distortionary taxes, the reduction in the expected net rate of return to private capital, may lower the propensity to invest. A similar, and possibly more detrimental, effect on private capital formation may occur if the increase in public infrastructure outlays is paid for by borrowing on domestic financial markets, as a result of either higher domestic interest rates (in countries where market forces are relatively free to operate) or a greater incidence of rationing of credit to the private sector. Moreover, if an investment-induced expansion in public borrowing raises concerns about the sustainability of public debt over time and strengthens expectations of a future increase in inflation or explicit taxation, the risk premium embedded in interest rates may increase.[7] By raising the cost of borrowing and negatively affecting expected after-tax rates of return on private capital, an increase in the perceived risk of default on government debt may have a compounding effect on private capital accumulation. In particular, private investors may revise downward their investment plans because of anticipated hikes in tax rates to cover the increase in public investment.

In principle, crowding-out effects associated with public infrastructure should be short term in nature; to the extent that an increase in the public capital stock raises output growth in the medium and longer term, future government borrowing needs may actually fall as a result of higher tax revenues. In that sense, deficits today will pay for themselves tomorrow, a common logic when discussing tax cuts and increases in expenditure in a growth context (see, for instance, Ireland, 1994, and Agénor and Yilmaz, 2006). However, as noted earlier, these effects may also persist beyond the short term, and turn into longer-run (adverse) effects on growth. For instance, if higher tax rates create permanent incentives for tax evasion, lower resources may reduce durably the government's capacity to invest in infrastructure and other areas in the future, or its ability to ensure adequate maintenance of the public capital stock (as discussed later). If so, then, despite the complementarity effect mentioned earlier, the net effect of an increase in public infrastructure may well be to hamper, rather than foster, economic growth.

3. New channels

Recent research has identified several channels, other than those identified in the previous section, through which public infrastructure may have an impact on growth. This section provides an overview of these "new" channels, which include an indirect effect on labor productivity, an effect on adjustment costs associated with private investment, an impact on the durability of private capital, as well as an effect on education and health outcomes.

3.1 Indirect effect on labor productivity

Independently of its direct effect on the marginal product of factor inputs in the production process (as discussed earlier), public infrastructure may have an

[7] In a small open economy with open capital markets facing a fixed world interest rate, crowding-out effects through a rise in domestic interest rates cannot occur. But for small developing countries, the supply curve of foreign capital is upward-sloping rather than horizontal. In such conditions, and if the risk premium faced on world capital markets is positively related to the debt-to-GDP ratio, an increase in domestic public debt induced by a rise in public investment in infrastructure may still lead to both lower credit to the private sector and higher domestic interest rates.

indirect, additional impact on labor productivity. The idea, first suggested by Ferreira (1999, p. 544) and elaborated upon by Agénor and Neanidis (2006*b*), is that with better access to roads and other means of public transportation (such as railways), workers can get to their job more easily, therefore spending less time commuting from home or moving across different work locations. This would tend to reduce traffic-related stress, which can be detrimental to concentration on the job. With greater access to electricity and telecommunications, workers can perform a number of tasks more rapidly (such as checking price quotations), as well as additional tasks away from the office (such as checking work-related e-mails from home). In turn, higher productivity would tend to enhance growth.

3.2 Effect on adjustment costs

Implicit in the view that public infrastructure and private investment are positively related is the idea that public capital may reduce the incidence of adjustment costs associated with increases in private capital formation. Some of the recent literature has clarified the nature of these adjustment costs as well as the mechanisms through which public infrastructure may affect them.

Adjustment costs typically represent frictions that prevent firms from adjusting their capital stock fully and instantaneously in response to, say, a demand shock, a change in the relative price of capital, or an increase in productivity.[8] It has been increasingly recognized that poor infrastructure, particularly in low-income countries, may be an important cause for these frictions.[9] For instance, an expansion in the road network may not only reduce congestion on highways and facilitate the shipment of goods across regions (thereby reducing unit production costs, as noted earlier) but also reduce expenses associated with the construction of a new factory or the transportation of heavy equipment for installation to a new, remote production site. In large and sparsely populated countries, the impact on the cost of investment can be fairly substantial. Thus, by lowering not only production costs but also adjustment costs related to investment, public capital in infrastructure will tend to raise expected rates of return and therefore stimulate private capital formation. This positive effect may be particularly important for small firms. As documented by Tybout (2000) and Bigsten *et al.* (2005) for instance, in low-income countries the size distribution of firms is often heavily skewed to the right, with a high proportion of very small firms. These firms tend to be especially affected by adjustment costs. Indeed, in the study of Uganda by Reinikka and Svenson (2002) mentioned earlier,

8 They include therefore costs associated with the sale, purchase or productive implementation of capital goods, over and above the price of these goods. Such costs are associated with, for instance, searching for, and deciding upon, the proper type of equipment needed for a particular purpose, scrapping obsolete machines, installing the new capital stock, and reorganizing and training the workforce (see Hamermesh and Pfann, 1996). Note also that, with time-to-plan and time-to-build constraints, investment itself (rather than the stock of capital) could be subject to adjustment costs; see, for instance, Gertler and Gilchrist (2000).

9 Other factors, such as underdeveloped or poorly functioning capital markets, may of course be equally (if not more) important in these countries.

only a small fraction of small firms (less than 20 per cent, compared to almost 80 per cent for large firms) were able to purchase generators to alleviate a chronic lack of access to government-provided electricity. Similarly, in a study of the constraints imposed by deficiencies in public infrastructure on manufacturing industries in Nigeria, Indonesia and Thailand, Lee, Anas and Oh (1999) found that small firms bear a significantly greater burden than large firms.

The link between public capital in infrastructure and adjustment costs was formalized by Turnovsky (1996) and Agénor and Aizenman (2006). To illustrate the argument, suppose that a typical firm faces adjustment costs that are a convex function of the rate of change of the firm's capital stock. In the absence of depreciation, this rate is simply $I = dK_P/dt$, where I is investment and K_P the private capital stock. In standard models of investment, the adjustment cost function, $C(I,K_P)$, is often taken to be a continuously differentiable function in the investment rate, I/K_P, and to satisfy the conditions $C(0) = 0$, $C'(0) = 0$, and $C'' > 0$. These assumptions imply therefore that it is costly for the firm to increase or decrease its capital stock, and that the marginal adjustment cost is increasing in the size of the adjustment. A function satisfying these properties is:

$$C(I,K_P) = I\cdot\{1 + \kappa(K_I/K_P)\cdot(I/K_P)/2\} \tag{2}$$

where K_I denotes again public capital in infrastructure.[10] The function $\kappa(K_I/K_P)$ captures the impact of public infrastructure (scaled by the stock of private capital) on adjustment costs. Assuming that firms maximize the present value of all future cash flows, it can be shown that the optimal rate of accumulation of private capital is:

$$I/K_P = (q - 1)/\kappa(K_I/K_P)$$

where q is the shadow value of capital (or Tobin's q).

Both Turnovsky (1996) and Agénor and Aizenman (2006) assume that the function $\kappa(K_I/K_P)$ has the properties are $\kappa' < 0$ and $\kappa'' > 0$. Thus, the above equations imply that an increase in public capital (at a given level of private capital) tends to reduce costs and facilitate the accumulation of private capital; but the reduction in adjustment costs occurs at a declining rate. Put differently, the benefit of a higher stock of public infrastructure on private investment is subject to diminishing returns. Nevertheless, there is again, in a sense, a complementarity effect between public capital in infrastructure and private investment, but this time it operates through overall adjustment costs, rather than exclusively through the direct rate of return on private capital.

Another channel through which public capital may reduce adjustment costs is by facilitating the reallocation of capital from one sector to another (from, say, the nontradable to the tradable sector), in response to changes in relative prices. Put

[10] Note that in equation (2) adjustment costs are assumed to be quadratic. With that specification, the marginal cost is constant in the investment rate. This implies that the firm will adjust to the long-run equilibrium gradually, by making continuous, small adjustments every period.

differently, if shifting capital across activities is (very) costly, greater availability of public infrastructure may help to reduce these costs substantially.

To illustrate the argument, let K_P denote now the economy's total stock of private capital, and let K_{PT} (respectively, K_{PN}) denote the stock of private capital in the tradable (respectively, nontradable) sector. The assumption that capital is costly to reallocate across sectors can be captured by specifying a factor transformation curve between the components of the overall capital stock:

$$K_P = F(K_{PT}, K_{PN})$$

where $F(\cdot)$ is a CES function. Suppose now that the elasticity of substitution between K_{PT} and K_{PN} is positively related to the ratio of public capital in infrastructure to total private capital, K_I/K_P. This may be because shifting capital from the nontradable sector (say, cash crops in rural areas) to the traded sector (say, export crops) is made easier by the existence of public assets such as wells (which facilitate irrigation) and rural roads (which allow faster shipment to ports and foreign markets). Then an increase in public capital would reduce adjustment costs faced by the private sector if, for instance, following a shock, capital must be reallocated between sectors. By enhancing the ability of the private sector to respond to price signals, lower adjustment costs may be accompanied by efficiency gains, which may translate into permanent growth effects.

3.3 *Effect on the durability of private capital*

Good public infrastructure may have a positive effect on growth by improving the durability of private capital. This has important implications for spending on maintenance and the quality of public capital.[11] Lack of public spending on infrastructure maintenance has been a recurrent problem in many developing countries. According to the World Bank (1994, p. 1), technical inefficiencies in roads, railways, power and water in developing countries caused losses equivalent to a quarter of their annual investment in infrastructure in the early 1990s. Paved roads, in particular, deteriorate fast without regular maintenance. Insufficient maintenance of a railroad system will cause frequent breakdowns and lower its reliability, creating potentially severe losses for users. Thus, increasing maintenance spending, by reducing power losses, telephone faults and so on, would help to enhance the productivity effects of public infrastructure on private production. For instance, in Vietnam, the World Bank (1999, p. 44) estimated that reducing a road's roughness from 14 IRI (International Roughness Index) to 6 IRI would save between 12 and 22 per cent in vehicle operating costs. A reduction from 14 IRI to 3 IRI would save from 17 to 33 per cent in those costs. More dramatically perhaps, Gyamfi and Guillermo (1996, p. 5) estimated that for Latin America and the Caribbean, each

[11] Hulten (1996) argued forcefully for paying more attention to the quality of infrastructure capital in the growth process; and Calderón and Servén (2004) found a link (albeit weak) between indicators of infrastructure quality and the rate of economic growth in a cross-country study. Appendix 2 discusses issues associated with the measurement of the quality of public infrastructure.

dollar not spent on road maintenance leads to a $3.0 increase in vehicle operating costs as a result of poor road conditions. Thus, to the extent that public expenditure on maintenance affects the durability, as well as the quality, of private physical capital, it may have a sizable impact on growth.

A formal analysis of the impact of public infrastructure maintenance on private investment and growth is provided by Agénor (2005*c*), who developed an endogenous growth framework in which maintenance expenditure not only increases the durability of public capital, as in Rioja (2003) and Kalaitzidakis and Kalyvitis (2004), but also raises the efficiency and durability of private physical capital. The key assumption of the model is that the rate of depreciation of private capital depends on both the amount of maintenance spending on infrastructure by the government and "usage", as measured by the stock of private capital itself. The underlying idea is that expanding and maintaining the quality of public roads, for instance, enhances the longevity of trucks and other means of transportation used by the private sector to move goods and workers across regions within a country or across borders. With a more reliable power grid, electrical equipment may last longer. Put differently, if maintenance spending increases the reliability of publicly-provided sources of energy, machines and other equipment (such as trucks and computers) used by private sector firms may break down less often.

The implication of the model is that, as long as the effect of maintenance expenditure on the efficiency and/or durability of the public capital stock is sufficiently high, the higher the marginal effect of maintenance spending on the depreciation rate of private capital, the higher should be the growth-maximizing share of spending on maintenance, and the lower should be the share allocated to new investment in infrastructure. Put differently, the share of resources that should be allocated to maintenance expenditure depends positively not only on the marginal effect of that category of spending on the rate of depreciation of public capital (as is conventionally assumed), but also on its ability to enhance the durability of the private capital stock. Neglecting this effect may result in a sub-optimal allocation of resources toward new investment in infrastructure.

Another implication of the analysis dwells on the fact that the quality of the private capital stock depends also on spending by the private sector *itself* on maintenance. To the extent that the government spends sufficiently to keep roads, for instance, in good condition, the private sector would need to spend less on maintaining its trucks in good working order to transport goods and workers across destinations. Such spending could then be reallocated to new investment. Thus, by by reducing the need for private spending on maintenance, an increase in public spending on maintenance could have an additional positive growth effect.

3.4 Impact on health and nutrition

It is now well recognized that infrastructure may have a sizable impact on health outcomes in developing countries. As documented in the various micro-economic studies summarized by Brenneman and Kerf (2002), access to safe water and sanitation helps to improve health, particularly among children. Recent surveys suggest that in some African cities, the death rate of children under five is about twice as high in slums (where water and sanitation services are poor, if not inexistent), compared to other urban communities. More formal studies by Behrman and Wolfe (1987), Lavy *et al.* (1996), Lee, Rosenzweig and Pitt (1997), Newman *et al.* (2002), Leipziger *et al.* (2003), and Wagstaff and Claeson (2004, pp. 170-74) found that access to clean water and sanitation infrastructure helps to reduce infant mortality. In their study of Bolivia, for instance, Newman *et al.* (2002) found that investments in water systems led to declines in under-five mortality that were similar in size to those associated with health interventions. Greater access to clean water and sanitation also has a significant effect on the incidence of malaria, as documented by McCarthy, Wolf and Wu (1999).

Access to electricity, by reducing the cost of boiling water, helps to improve hygiene and health as well. Availability of electricity is essential for the functioning of hospitals and the delivery of health services; vaccines, for instance, require continuous and reliable refrigeration to retain their effectiveness.[12] Getting access to clean energy for cooking in people's homes (as opposed to smoky traditional fuels, such as wood, crop residues and charcoal) improves health outcomes, by reducing indoor air pollution and the incidence of respiratory illnesses (such as asthma and tuberculosis). According to World Bank estimates, more than half of the population in the developing world still relies on traditional biomass fuels, such as wood and charcoal, for cooking and heating (see Saghir, 2005). In Sub-Saharan Africa alone, the proportion cooking on biomass is over 90 per cent. Traditional sources of energy represent serious health hazards; Warwick and Doig (2004) estimated that indoor air pollution from the burning of solid fuels kills over 1.6 million people (predominantly women and children) a year. More efficient electric stoves would reduce this death toll, which is almost as great at that caused by unsafe water and sanitation, and greater than that caused by malaria.

Better transportation networks also contribute to easier access to health care, particularly in rural areas. Recent data produced by national Demographic and Health Surveys in Sub-Saharan Africa show that a majority of women in rural areas rank distance and inadequate transportation as major obstacles in accessing health care (see African Union, 2005). In Morocco, a program developed in the mid-1990s to expand the network of rural roads led – in addition to reducing production costs and improving access to markets – to a sizable increase in visits to primary health care facilities and clinics (see Levy, 2004). In Malaysia and Sri Lanka, the World Bank (2005*c*, p. 144) found that the dramatic drop in the maternal mortality ratio (from 2,136 in 1930 to 24 in 1996 in Sri Lanka, and from 1,085 in 1933 to 19 in 1997 in Malaysia) was due not only to a sharp increase in medical workers in rural and disadvantaged communities, but also to improved communication and transportation services – which helped to reduce geographic barriers. Transportation

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12 As noted by the World Health Organization (2005, p. 36) lack of safe water and electricity has not only hampered the provision of health services in poor countries but also raids their cost.

(in Malaysia) and transportation subsidies (in Sri Lanka) were provided for emergency visits to health care centers. Moreover, in Malaysia, health programs formed part of integrated rural development efforts that included investment in clinics, roads and schools. A similar approach was followed in Sri Lanka – better roads made it easier to get to rural health facilities. At a more formal level, Wagstaff and Claeson (2004, pp. 170-74) found, using cross-section regressions, that road infrastructure (as measured by the length of the paved road network) had a significant effect on a number of health indicators, such as infant and female mortality rates.

3.5 Impact on education

A large body of evidence, based predominantly on microeconomic studies, has also documented the existence of a significant link between infrastructure and educational attainment. As summarized by Brenneman and Kerf (2002), these studies have found a direct positive impact of various types of infrastructure services (namely, roads, electricity, water and sanitation and telecommunications) on learning indicators.

Studies have indeed found that a better transportation system and a safer road network (particularly in rural areas) help to raise school attendance. In the Philippines, for instance, after rural roads were built, school enrollment went up by 10 per cent and dropout rates fell by 55 per cent. A similar project in Morocco raised girls' enrollments from 28 per cent to 68 per cent in less than 10 years (see Khandker, Lavy and Filmer, 1994, and Levy, 2004). The quality of education also improved, as greater accessibility made it easier to hire teachers and facilitate commuting between rural and urban areas.

Similarly, researchers have found that greater access to safe water and sanitation in schools tends to raise attendance rates (particularly for girls) and the ability of children to learn, by enhancing their health. In many developing countries, the sanitary and hygienic conditions at schools remain appalling, with inadequate water supply and hand washing facilities. Schools that lack access to basic water supply and sanitation services tend to have a higher incidence of major childhood illnesses among their students. Improvements in those areas tend therefore to have a high payoff. In Bangladesh, for instance, girls' attendance rates in schools went up by 15 per cent following improved access to water and sanitation facilities. In Morocco, the sharp increase in girls' enrollment rates mentioned earlier was in part due to improved access to water and sanitation in schools.

A number of micro studies have also found that access to electricity helps to improve the learning process, by allowing children to spend more time studying and by providing more opportunities to use electronic equipment. Computers, for instance, may enhance the quality of learning by improving access to information. In purely quantitative terms, access to electricity can make a sizable difference in terms of its impact on schooling. In the late 1990s in Nicaragua, 72 per cent of children living in a household with electricity were attending school, compared to only 50 per cent for those living in a household without electricity (see Saghir, 2005).

3.6 Magnification effect through health and education

It is increasingly recognized that health and education are interlinked in their contribution to growth. Higher levels of education increase public awareness and the capacity of families to address their health needs. At the same time, better health enhances the effective and sustained use of the knowledge and skills acquired through education, while reducing at the same time the rate of depreciation of that knowledge. We begin by reviewing some of the recent evidence on interactions between health and education and then examine how infrastructure can magnify its impact on growth by enhancing these outcomes, as described earlier.

3.6.1 Impact of health on education

Several studies have found that health can have a sizable indirect effect on growth through education and the accumulation of human capital. Indeed, good health and nutrition are essential prerequisites for effective learning. Healthier children tend to do better in school, just like healthier workers perform their tasks better. Conversely, inadequate nutrition, which often takes the form of deficiencies in micronutrients, reduces the ability to learn and study. Poor nutritional status can therefore adversely affect children's cognitive development, and this may translate into poor educational attainment (see Behrman, 1996, and Bundy *et al.*, 2005). Poor health (often taking the form of respiratory infections in developing countries) is also an important underlying factor for low school enrollment, absenteeism and high dropout rates.

In Bangladesh for instance, the Food for Education program, which provided a free monthly ration of food grains to poor families in rural areas if their children attended school, was highly successful in increasing school enrollment (particularly for girls), promoting attendance and reducing dropout rates (see Ahmed and Arends-Kuenning, 2006). In Tanzania, the use of insecticide-treated bed nets reduced the incidence of malaria and increased attendance rates in schools (Bundy *et al.*, 2005, p. 2). In Western Kenya, deworming treatment improved primary school participation by 9.3 per cent, with an estimated 0.14 additional years of education per pupil treated (see Miguel and Kremer, 2004). McCarthy, Wolf and Wu (1999) found that malaria morbidity (viewed as a proxy for the overall incidence of malaria among children) has a negative effect on secondary enrollment ratios. Bloom, Canning and Weston (2005) found that children vaccinated against a range of diseases (including measles, polio and tuberculosis) as infants in the Philippines performed better in language and IQ scores at the age of ten, compared to unvaccinated children – even within similar social groups. Thus, (early) vaccination appears to have a significant effect on (subsequent) learning outcomes.

Thus, increasing the health of individuals may also increase the effectiveness of education, as in the "food for thought" model of Galor and Meyer (2004). Bundy *et al.* (2005), in their overview of experience on the content and consequences of school health programs (which include for instance treatment for intestinal worm infections), have emphasized that these programs can raise productivity in adult life not only through higher levels of cognitive ability, but also through their effect on school participation and years of schooling attained. At a more aggregate level, the cross-country regressions of Baldacci *et al.* (2004) show that health outcomes (as proxied by the under-five child mortality rate) have a statistically significant effect on school enrollment rates.

Another channel through which health can improve education outcomes and spur growth is through higher life expectancy and reduced pressures to reallocate time among household members. Increases in life expectancy tend to raise the incentive to invest in education (in addition to increasing the propensity to save), because the returns to schooling are expected to accrue over longer periods. Thus, at the individual level, to the extent that spending on health increases the individual's lifespan, it may also raise the returns (as measured by the discounted present value of wages) of greater expenditure on education. Conversely, intra-family allocations regarding school and work time of children tend to be adjusted in the face of disease within the family; in turn, these adjustments may influence the aggregate rate of accumulation of physical and human capital and thus the rate of economic growth. For instance, as discussed by Corrigan, Glomm and Mendez (2005), when parents become ill, children may be pulled out of school to care for them, take on other responsibilities in the household, or work to support their siblings. Indirect evidence suggesting that reallocation of family time may indeed be important in practice is provided by Kalemli-Ozcan (2006), who found that AIDS lowered school enrollment rates in many countries in Sub-Saharan Africa between 1985 and 2000. Hamoudi and Birdsall (2004) also provide evidence that AIDS reduced schooling rates in Sub-Saharan Africa. These results are consistent with the view that the risk that children may be infected by AIDS tends to deter parents from investing in their education, as argued by Bell, Devarajan and Gerbasch (2006). Put differently, an environment where there is great uncertainty about child survival may create a precautionary demand for children, with less education being provided to each of them. In turn, the lack of human capital accumulation may hamper economic growth, as illustrated by Arndt (2006) in his study of AIDS and growth in Mozambique.

3.6.2 Impact of education on health

A significant body of research (at both the micro and macro levels) has shown that higher education levels can improve health outcomes.[13] The positive effect of education on health works partly through income; but there are other channels as

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[13] Glewwe (2002) reviews the evidence on how schooling affects adult and child health.

well. Several studies have found that where mothers are better educated (and presumably more aware of health risks to their children), infant mortality rates are lower and attendance rates in school are higher (see Glewwe, 1999 and 2002, as well as the cross-country regressions of Baldacci *et al.*, 2004, and Wagstaff and Claesson, 2004). Better-educated women tend, on average, to have more knowledge about health risks.[14] In developing countries in general, during the period 1970-95, improvements in female secondary school enrollment rates are estimated to be responsible for 43 per cent of the total 15.5 per cent reduction in the child underweight rate (see Smith and Haddad, 2000). For Sub-Saharan Africa as a whole, it has been estimated that five additional years of education for women could reduce infant mortality rates by up to 40 per cent (see Summers, 1994). In the cross-section regressions for developing countries reported by McGuire (2006), average years of female schooling have a statistically significant impact on under-five mortality rates.[15] In Niger alone, researchers have found that infant mortality rates are lower by 30 per cent when mothers have a primary education level, and by 50 per cent when they have completed secondary education. Similarly, Paxson and Schady (2005), in a study of Ecuador, found that the cognitive development of children aged 3 to 6 years varies inversely with the level of education of their mother.

A low level of education may also lead to *maternal* malnutrition, with dire consequences for children. Inadequate intakes of nutrients during pregnancy have been found to have irreversible effects on children. Recent research at the National institute of Health in the United States, for instance, has shown that the children of mothers who ate food with little omega-3 fatty acids had a lower IQ than children who did. In addition, they also lacked physical coordination and had greater difficulties to engage in normal social relations. Inadequate diets may also have adverse effects on mental health (and therefore the ability to raise children), as argued in a report by the Mental Health Foundation (2006).

3.6.3 Magnification effect

The foregoing discussion suggests that the close interactions between health and education can magnify the effects of an increase in public infrastructure on growth. By investing in roads, for instance, governments may not only reduce production costs for the private sector and stimulate investment, but also improve education and health outcomes, by making it easier for individuals to attend school and seek health care. With their health improving, individuals become not only more productive, but they also tend to study more. In turn, a higher level of education

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14 However, as noted by Fuchs (2004, p. 658), the observed high correlation between women's education and the health of children in developing countries may be the result of omitted variables. For instance, countries where women have the greatest opportunities to acquire an education may also have other traditions and policies in place that are more favorable to them; in turn, these traditions and policies could have an independent effect on health.

15 In a study based on a large sample of industrial and developing countries over the period 1850 to 1990, Tamura (2006) found that higher levels of human capital (as measured by the number of years of schooling of the average 25-year old) tend also to lower the mortality rate of young adults.

makes individuals more aware of potential risks to their own health and that of their family members. Moreover, investment in infrastructure, by improving health and life expectancy, may reduce uncertainty about longevity and the risk of death, thereby increasing the propensity to save. As a result of these various effects, the impact of infrastructure on growth is compounded.

4. Implications for growth and public spending allocation

The foregoing analysis suggests that it is crucial, in designing growth-promoting strategies, to account for the variety of channels, direct and indirect, through which infrastructure affects the economy. This is important because the complementarities that appear at the micro level among infrastructure, health and education (as discussed earlier) may give way to potential trade-offs at the macro level. The reason is that the provision of any type of services requires the use of (limited) public resources. Understanding the nature of these trade-offs is essential for determining the composition of public spending in a growth context.

To illustrate the issues involved, this section examines the optimal allocation of government spending between health and infrastructure in an endogenous growth framework where public capital is an input in the production of final goods as well as the production of health services.[16] Put differently, what matters to produce health services is not only spending on health *per se*, but the combination of public spending on health and infrastructure. As noted earlier, to function properly, hospitals need access to electricity. With inadequate water, sanitation and waste disposal facilities, hospitals cannot provide the services that are expected from them. The model also assumes, more conventionally, that individuals can provide effective services from human capital only if they are healthy. Thus, by enhancing productivity, health influences growth indirectly.[17]

The first part of this section presents the framework, which assumes that all public services are provided free of charge and financed by a distortionary tax on output. It also gives the expression for the balanced growth path. The second examines the short- and long-run effects of a budget-neutral increase in spending on infrastructure. The third derives the optimal (growth-maximizing) allocation rule between spending on infrastructure and health. The issue that we address is whether (given that the production of health services depends on infrastructure) a rise in public spending on infrastructure is the most efficient method to stimulate growth.

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16 Barro (1990) was one of the first to propose a formal analysis of the link between public infrastructure and growth. See Zagler and Durnecker (2003) for an overview of some of the literature spawn by Barro's contribution. Our focus here is on the links between infrastructure and health.

17 Although we focus here solely on the link between infrastructure and health, similar arguments can be made regarding the link between infrastructure and education. Agénor (2005b, 2005c, 2005d) developed a variety of models in which the production of human capital requires not only teachers and public spending on education services, but also access to infrastructure capital. We will return to these models later on.

As noted earlier, the provision of each category of services requires resources and this (given the overall constraint on revenues) creates potential trade-offs.

4.1 The health-infrastructure link: an endogenous growth framework

Despite the compelling nature of the microeconomic evidence, the link between health and infrastructure has not received much attention in the existing literature on government spending and endogenous growth. In what follows we extend the model presented in Agénor (2005*f*) to account for a "stock" effect of public capital. We begin with a brief description of the model and continue with a discussion of the balanced growth path.[18]

4.1.1 The model

Consider an economy with a constant population and an infinitely lived representative household who produces and consumes a single traded good. The good can be used for consumption or investment. The government spends on infrastructure and health. It provides health services free of charge and levies a flat tax on output to finance its outlays.

Output, Y, is produced with private physical capital, K_P, public infrastructure capital, K_I, and "effective" labor, defined as the product of the quantity of labor and productivity, A. As emphasized for instance by van Zon and Muysken (2001), human capital is embodied in workers; as a result, people can provide "effective" human capital services only if they are healthy. Health is thus labor augmenting.

Normalizing the population size to unity and assuming that technology is Cobb-Douglas, yields:[19]

$$Y = (K_I)^{\alpha} A^{\beta} (K_P)^{1-\alpha-\beta} \tag{1}$$

where $\alpha, \beta \in (0,1)$.

Productivity depends solely on the availability of health services, H, with a unit elasticity:[20]

$$A = H \tag{2}$$

Combining (1) and (2) yields

$$Y = (K_I/K_P)^{\alpha} (H/K_P)^{\beta} K_P \tag{3}$$

which implies that in the steady-state, with constant ratios of K_I/K_P and H/K_P, the output-private capital ratio is also constant.

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18 Detailed derivations are relegated to a Technical Appendix, available upon request.

19 The time index t is omitted in what follows to simplify notations.

20 A more general specification would be to relate productivity not only to health but also directly to infrastructure, as noted earlier. See Agénor and Neanidis (2006b) for a formal treatment.

The household's discounted utility function is:

$$V = (1-1/\sigma)^{-1}\int_0^{\infty}[(C_I)^{\kappa}H^{1-\kappa}]^{1-1/\sigma}\exp(-\rho t)dt \quad (4)$$

where C is consumption, $\rho > 0$ the discount rate, $\kappa \in (0,1)$ and $\sigma \neq 1$ is the intertemporal elasticity of substitution. Coefficient κ (respectively, $1-\kappa$) measures the relative contribution of consumption (respectively, health) to utility, whereas σ is the elasticity of intertemporal substitution. This specification implies that utility is non-separable in consumption of goods and health services; an increase in consumption of health services raises the utility derived from consuming final goods. There is therefore gross complementarity.[21]

The household maximizes V in (4) subject to the resource constraint:

$$C + dK_P/dt = (1-\tau)Y \quad (5)$$

where $\tau \in (0,1)$ is the tax rate on income. For simplicity, the depreciation rate of private capital is assumed to be zero.

Production of health services requires combining government spending on health, G_H and public capital in infrastructure. Assuming also a Cobb-Douglas technology yields:

$$H = (K_I)^{\mu}(G_H)^{1-\mu} \quad (6)$$

where $\mu \in (0,1)$.

The government spends on infrastructure and health services, and levies (as noted earlier) a flat tax on output at the rate τ. It keeps a balanced budget at each moment in time. The government budget constraint is thus:

$$G_H + G_I = \tau Y \quad (7)$$

Both categories of spending are taken to be a constant fraction of tax revenue:

$$G_h = \upsilon_h \tau Y \quad (8)$$

where $\upsilon_h \in (0,1)$ and $h = H,I$. Using (8), equation (7) can therefore be written as:

$$\upsilon_H + \upsilon_I = 1 \quad (9)$$

Finally, assuming no depreciation for simplicity, the government stock of public capital in infrastructure changes over time according to:

$$dK_I/dt = \phi G_I \quad (10)$$

where $\phi \in (0,1)$ is an efficiency parameter that measures the extent to which public investment creates public capital. As discussed at length by Agénor *et al.* (2005), the

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21 We also assume that the discount rate ρ is constant; Agénor (2006) considers the case where, instead, the degree of impatience (and thus the propensity to save, as discussed earlier) is inversely related to the consumption of health services.

case $\phi < 1$ reflects the fact that investment outlays are subject to inefficiencies, which tend to limit their positive impact on the public capital stock.[22]

4.1.2 The balanced growth path

The model can be manipulated to give a system of two non-linear differential equations in $c = C/K_P$ and $k_I = K_I/K_P$. These equations, together with an initial condition on $k_I(0)$ and a transversality condition on the private capital stock, characterize the dynamics of the economy.

As established in the Technical Appendix, the long-run equilibrium is saddle-point stable and the balanced growth path (BGP) is unique. Along that path, consumption and the stocks of both private and public capital grow at the same constant rate γ, which can be written in two equivalent forms, one of which is:

$$\gamma = \phi \upsilon_I \tau^{1/\Omega} \upsilon_H^{(1-\mu)\beta/\Omega} (k_I^{SS})^{-\eta/\Omega} \tag{11}$$

where $\Omega \equiv 1 - (1-\mu)\beta > 0$, $\eta \equiv 1 - \alpha - \beta > 0$ and k_I^{SS} denotes the (constant) steady-state value of k_I. It can be established from this result that the higher the efficiency of public investment in infrastructure, the higher the steady-state growth rate.

The long-run equilibrium is shown in the phase diagram depicted in Figure 1. Curve KK corresponds to the combinations of $\{c,k_I\}$ for which k_I is constant over time (that is, $dk_I / dt = 0$), whereas curve CC corresponds to the combinations of (c,k_I) for which c is constant over time (that is, $dc/dt = 0$). Both curves are strictly increasing and strictly concave, but saddlepath stability requires that the slope of KK be steeper than the slope of CC (see the Technical Appendix). The saddlepath, denoted SS, also has a positive slope and is flatter than CC. The initial balanced growth equilibrium obtains at point A.

4.2 Revenue-neutral increase in spending on infrastructure

Let us now examine the short- and long-run effects of a revenue-neutral shift in government spending from health to infrastructure, that is, $d\upsilon_I = -d\upsilon_H$. In general, a shift of this type has an ambiguous effect on the growth rate, γ, as well as the steady-state values of the consumption-private capital ratio, c^{SS}, and the public-private capital ratio, k_I^{SS}, depending on the elasticity of the production of health services with respect to infrastructure, μ, the parameters characterizing the goods production technology, α and β, and the structure of preferences, as captured by the coefficient κ in the objective functional (4).

Consider first the "standard" case where $\mu = 0$ and the health production technology depends only on the flow of government spending on health. In that

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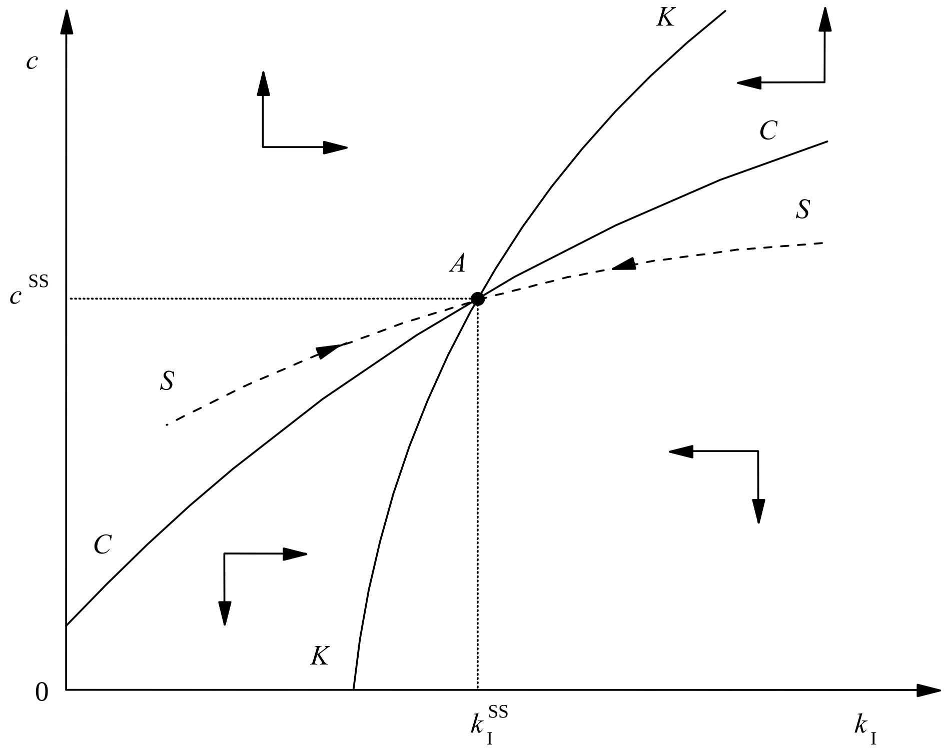
22 Arestoff and Hurlin (2005), for instance, estimate the value of φ to vary between 0.4 and 0.6 for a group of developing countries.

Figure 1

The Balanced-growth Equilibrium



Source: Adapted from Agénor and Yilmaz (2006).

case, the long-run value of the public-private capital ratio rises unambiguously, whereas the consumption-private capital ratio may either increase or fall. The reason is the complementarity between health services and private spending. The production of health services tends to fall (as can be inferred from (6) and (8)), despite the fact that the increase in public capital tends to raise output. In turn, the reduction in supply of health services tends to lower consumption, as well as labor productivity. At the same time, a higher rate of public investment in infrastructure tends to raise the economy's stock of public capital relative to private capital (despite the fact that lower consumption increases savings and private investment), and the growth rate increases if the adverse effect on labor productivity is not too large. This tends to raise consumption. If health services have no effect on utility (that is, if $\kappa = 1$ in equation (4)), the positive effect is likely to dominate.

Consider now the case where $\mu \neq 0$ and the health production technology depends also on the public capital stock in infrastructure. Long-run effects are now potentially less negative. The reason is that the production of health services does not necessarily fall, in contrast to the previous case. In fact, as can be inferred again from (6) and (8), the reallocation of government spending from health to infrastructure may actually lead to a *higher* output of health services, if μ is sufficiently high. If this is indeed the case, then labor productivity and consumption would unambiguously increase, together with the public-private capital ratio. The steady-state growth rate is also likely to increase. Put differently, if μ is sufficiently high, the structure of preferences (as summarized by κ) matters less for long-run outcomes.

Transitional dynamics are illustrated in Figure 2. Graphically, curve KK shifts to the right, whereas curve CC can shift in either direction, depending on the parameters of the model. If, as noted earlier, μ is relatively low and κ is close to unity, or conversely if μ is relatively high (close to unity), CC shifts to the left, as depicted in the upper panel. At the new equilibrium (point A'), both the public-private capital ratio and the consumption-capital ratio are higher. By contrast, if μ is relatively low (with, at the same time, a low value of κ), CC shifts to the right (as illustrated in the lower panel of the figure), and the new equilibrium (point A') will be characterized by a higher public-private capital ratio and a lower consumption-capital ratio. In both cases the adjustment path corresponds to the sequence ABA'.

The important implication of the foregoing analysis is thus that, if public infrastructure is sufficiently "productive" in the health production technology (in the sense that the elasticity of output of health services with respect to public capital is sufficiently high), the positive effect of an increase in infrastructure spending may outweigh the negative effect of lower public spending *per se* on health services on consumption and growth. Put differently, the best strategy for increasing the supply and consumption of health services in the long run and stimulate growth may not be to increase direct government spending on health, but rather to increase spending on other "production" inputs, in this particular case infrastructure.[23] This is an important policy message, to which we will return in the next section.

4.3 Growth-maximizing allocation rule

Setting $d\gamma / d\upsilon_I = 0$ in equation (11), it can readily be established that the growth-maximizing share of spending on infrastructure, υ_I^*, is given by:[24]

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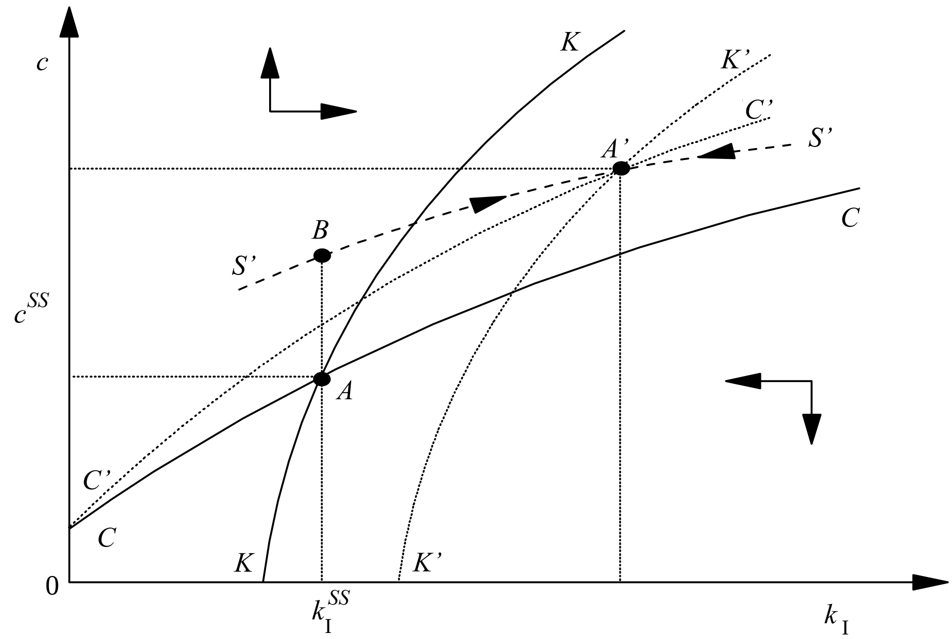
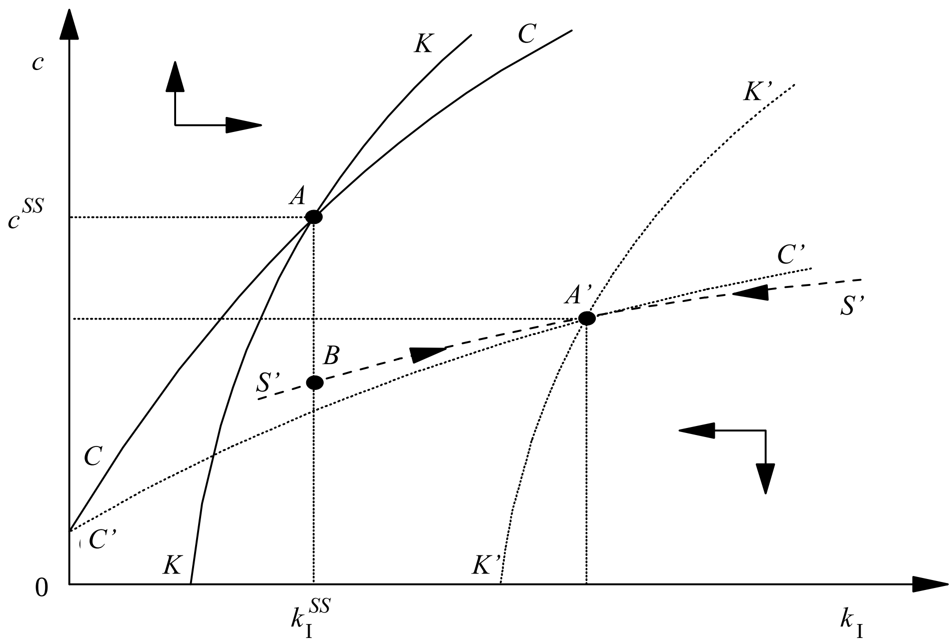
23 Our results may also help to understand why several empirical studies (such as Filmer, Hammer and Prichett, 2000) found no significant correlation between public health spending and health outcomes; this may be because infrastructure may have been a binding constraint.

24 See Agénor (2005f) and Agénor and Neanidis (2006a) for a derivation of the welfare-maximizing allocation in related models, as well as a comparison with the growth-maximizing solution.

Figure 2

Revenue-neutral Shift in Spending from Health to Infrastructure





$$\upsilon_I^* = (\alpha+\mu\beta)/(\alpha+\beta) \tag{12}$$

so that, from (9), $\upsilon_H^* = 1-\upsilon_I^*$. Formula (12), first established in Agénor (2005*f*), has the following properties. If $\mu = 0$, that is, in the "standard" case where health services are produced only with government spending on health, $\upsilon_I^* = \alpha / (\alpha+\beta)$. This essentially indicates that the share of spending on infrastructure must be equal to the elasticity of goods output with respect to public capital in infrastructure, divided by the sum of the elasticities with respect to public capital and effective labor (α and β).[25] By contrast, if $\mu = 1$, all spending should be allocated to infrastructure ($\upsilon_I^* = 1$). More generally, the higher is the elasticity of output of health services with respect to infrastructure capital, the lower should be the share of spending on health. This result is consistent with the analysis of a revenue-neutral shift in spending described earlier: the best way to increase production of health services, raise output growth and improve welfare, may not be to increase direct spending on health but rather to invest more on infrastructure.

Although our focus in the foregoing discussion was solely on the link between infrastructure and health, similar arguments can be made regarding the link between infrastructure and education. Indeed, Agénor (2005*a*, 2005*c*, 2005*e*) has developed several models in which the production of human capital (or, more specifically, educated labor) requires not only teachers and public spending on education services, but also access to infrastructure capital. In an extension of these models, Agénor and Neanidis (2006*a*) have accounted for not only the effect on infrastructure on education, but also the effect of health on education. The implicit view in all of these models is that access to infrastructure services such as roads, electricity and telecommunications, may enhance the ability of individuals to study and acquire skills. As noted earlier, this is a particularly important consideration for low-income developing countries, where the lack of an adequate network of roads makes access to schools (particularly in rural areas) difficult; dropout rates tend to be higher when children must walk long distances to get to schools. The lack of access to electricity hampers the ability to study, both in the classroom and at home. In some countries, the lack of adequate toilet facilities for girls in rural area schools has led many parents to deny an education to their daughters. Accounting for the impact of infrastructure on the schooling technology has important implications for the determination of the optimal allocation of government expenditure between education and infrastructure. Again, depending on how "productive" public infrastructure is in the education technology, the best way to accumulate human

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[25] If the supply of labor is fixed, and health has no effect on the efficiency of labor, formula (12) gives $\upsilon I^* = \alpha$, which corresponds to Barro's (1990) result. See Agénor (2005a, 2005c) for a more detailed discussion. Note also that formula (12) shows that the optimal allocation of spending between health and infrastructure does not depend on the degree of efficiency of investment, that is, the parameter ϕ in equation (10), despite the fact that (as noted earlier) changes in ϕ affect the steady-state growth rate. The reason is fairly intuitive: what matters is the productivity effect of the stock of public capital in the goods and health production technologies (relative to the productivity effect of effective labor), not the flow of spending. The result would be different, of course, if we were to consider the efficiency of the public capital stock itself (see Agénor, 2005d).

capital and spur growth in a sustained fashion may not be to increase direct spending on education, but rather to spend more on infrastructure.

The foregoing analysis also has important methodological implications for the empirical analysis of the determinants of growth, based on either standard growth accounting techniques, or (reduced-form) cross-country regressions. Many existing studies based on cross-country growth regressions tend to focus on *flow* variables, by considering either investment ratios (as, for instance, in Devarajan, Easterly and Pack, 2003) or capital expenditure (see Devarajan, Swaroop and Zou, 1996). As made amply clear in previous sections, a proper assessment of the supply-side effects of public infrastructure should be based on *stocks*, not spending flows. In tne same vein, growth accounting exercises that do not account separately for public and private capital accumulation cannot begin to ascertain with any degree of precision the respective impact of these two components on growth, given the possibility of large complementarity and crowding-out effects.[26]

Moreover, existing studies (even those based on stocks of infrastructure assets) usually do not capture the externalities associated with public infrastructure, through for instance their impact on the durability of private capital (and thus the rate of return on private invetment) or their effect on health and education. Consequently, they are likely to underestimate the contribution of public infrastructure to growth. This is a key limitation of the studies of Bhargava *et al.* (2001), Balducci *et al.* (2004), Calderón and Servén (2004), Loayza, Fajnzylber and Caldéron (2004), and Estache, Speciale and Veredas (2005).

On a related point, several cross-country studies have found that health outcomes have a sizable impact on growth (see Appendix 1 for a brief overview of the recent evidence). As can be inferred from the discussion in the previous sections, this may still underestimate the true impact of health, which may operate through a variety of indirect channels – such as the impact of better health on the incentives to acquire skills and accumulate human capital, and the effect of a higher expected lifetime on the rate of time preference and the propensity to save. At the same time, however, improvements in health outcomes themselves may be the consequence of greater access to public infrastructure, for the reasons outlined earlier. Because most cross-country studies do not account for these indirect effects, the true contribution of infrastructure to growth tends to be underestimated. Country-specific studies, such as the analysis of long-run growth in South Africa by Fedderke, Perkins and Luiz (2006), suffer from the same shortcomings.[27] Simulation exercises aimed at

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[26] One reason why, for instance, Devarajan, Easterly, and Pack (2003) do not find public investment rates to be significantly associated with growth in Sub-Saharan Africa may be the fact that much of public investment outlays were subject to waste (as noted earlier), implying that only a fraction of them contributed effectively to public capital accumulation. In addition, looking at total investment rates is not adequate to assess the importance of infrastructure investment *per se*, given that non-infrastructure investment may generate large crowding-out effects.

[27] Some of these studies suffer from other limitations as well. In particular, they do not always account for the fact that the impact of public spending on growth depends on how the increase in outlays is financed. Ignoring the government budget constraint invalidates the use of the model for a number of purposes, such as calculations of investment needs. Moreover, existing studies do not provide an adequate treatment of

(continues)

evaluating, say, infrastructure needs and their impact on growth are bound to be misleading, because they are based on mispecified models.

Future work based on cross-country growth regressions must provide a more careful attempt to disentangle the various channels through which infrastructure affects growth, possibly through the use of simultaneous equations models. An alternative approach is to develop country-specific structural macroeconomic models, which have considerable advantages (compared to small econometric models), given the flexibility that they provide to account explicitly for the various externalities associated with public infrastructure. Important classes of models in this area are the SPAHD models developed by Agénor, Bayraktar and El Aynaoui (2006), and Agénor *et al.* (2005), or the more advanced IMMPA framework described in the contributions contained in Agénor, Izquierdo and Jensen (2006). A key feature of both types of models is indeed an explicit account of the composition of public capital (with at the same time a proper distinction between "efficiency-adjusted" flows and stocks), as well as the type of interactions described earlier among infrastructure, health and education. By their very nature, these models provide an ideal setting for capturing the microeconomic complementarities and macroeconomic trade-offs, involved in designing growth-promoting, medium-term public investment programs in developing countries (see Agénor, Bayraktar and Pinto Moreira, 2006).

5. Implications for growth strategies and poverty reduction

The foregoing analysis suggests that public infrastructure can affect economic growth by *a*) enhancing indirectly the productivity of workers, in addition to the direct effect on the productivity of labor used as input in the production function; *b*) facilitating adjustment costs associated with private capital formation and its mobility to relatively more profitable activities; *c*) enhancing the durability of private capital; and *d*) improving health and education outcomes, as well as compounding their effect on growth. These channels operate in parallel with the more traditional productivity and complementarity effects associated with infrastructure.

From a policy standpoint, the "new" channels provide important lessons. Facilitating road transportation and communications can translate into higher productivity of workers, even when maintaining the same capital to labor ratio in the infrastructure sector. For instance, in Kenya and Uganda, facilitating access to communications allowed farmers to be better informed about international commodity prices and was conducive to higher agricultural productivity.

non-linearities – which may be quite important in assessing the impact of infrastructure on growth, as a result of network effects. See Agénor (2006), Hurlin (2006), and Arestoff and Hurlin (2005) for a discussion of this last point.

Eliminating infrastructure constraints, such as water shortages, electricity outages and difficult road access, can facilitate the process of shifting private resources to more productive sectors, for instance from nontradables to tradables, or from agriculture to services and manufacturing. Similarly, by facilitating movement of people and goods, improved infrastructure can lead in the medium term to higher investments in the rural sector and greater agricultural diversification. Farmers must be able to obtain inputs at reasonable costs, and also to sell their outputs at remunerative prices. Transportation costs, in particular, are crucial for them to decide whether or not to engage in certain activities. For instance, while China increased agricultural productivity in rural areas, investments in infrastructure, coupled with labor mobility, increased flows of labor and capital to urban centers and facilitated growth in the manufacturing and services sectors.

With respect to the durability of private capital, infrastructure plans, when they present an appropriate balance between capital and current expenditures (in such as way that they ensure rehabilitation and maintenance), can promote the profitability of all (public and private) existing investments and assets. This is a critical policy issue for many low-income countries. While many rural roads have been built in these countries, the cost of maintaining them in good condition has often not been considered as a priority in national spending plans. As noted earlier, expanding and maintaining the quality of public roads would enhance the durability of private vehicles and encourage mobility across regions and areas. Similarly, eliminating or reducing electricity outages may encourage private investments, because firms would be less concerned about the functioning (and durability) of their equipment and the need to prevent them from deteriorating in the longer term.[28] In practice, unfortunately, policymakers have a perverse incentive: given their higher visibility, new public investment projects are politically more attractive than economically crucial, but politically less rewarding, spending on infrastructure maintenance. It is therefore important to insulate maintenance budgets in public expenditure programs and make them consistent with the overall investment budget.

As described at length earlier, when better access to schools and hospitals is provided to the population (not only to the ones in need but also to health and education workers), the quality of services is enhanced.[29] Thus, public infrastructure spending can exert strong positive effects on health and education outcomes. Furthermore, better infrastructure can improve the durability and profitability of existing investments in education and health. In fact, as illustrated by our analytical framework, the best way to improve the provision of health services may not necessarily be to engage exclusively in direct spending on health but also to allocate

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[28] The need for increasing operations and maintenance expenditures, to ensure the durability of capital, may be equally important in middle-income countries (such as those in Eastern Europe and Central Asia) where infrastructure investments have already achieved wide country coverage.

[29] As noted earlier, recent surveys in a number of Sub-Saharan African countries show that around 60 per cent of households in the bottom two income-quintiles find distance to health services a major obstacle to accessing them, exacerbated in some countries by difficulties in securing transport; see African Union (2005).

a significant share of resources to building infrastructure capital. The same conclusion holds with respect to the production and delivery of education services.

More generally, in order to trigger the desired results, the composition of public spending in infrastructure must take into account the needs of the population in education and health, and not be biased by political priorities. Infrastructure network plans must be inclusive of remote areas where the neediest live. In many low-income countries, priority has often been given to infrastructure spending in urban and politically visible regions, somehow neglecting rural and isolated areas. Growth-promoting infrastructure strategies should assess what might be needed for the poor to access health and education services, as opposed to deciding *ex post* how infrastructure could be used by the poor. Tailoring infrastructure projects by incorporating the voice of the poor into the planning process can bring more benefits to them. Lack of adequate consultation with citizens in the planning process has been seen as a cause of unsatisfactory outcomes in previous public infrastructure projects. The success of the rural roads program in Morocco is mainly due to its multidimensional nature, inclusive of health and education needs, and its focus on "access" as opposed to "number of roads/miles built", coupled with its very participatory nature to capture the preferences of the beneficiaries (see Moreno-Dodson, 2005).

Priority should be given to rehabilitate and improve demand-driven infrastructure services, which already serve the population, sometimes at a very high cost in terms of risk, time and poor quality, or have the potential to do so immediately. On the contrary, a realization that there is no road to go from point A to B should not be an argument strong enough to recommend building a new one, unless there is solid evidence to predict that it will be used.[30] In other words, as numerous examples of low profitability infrastructure investments in the past suggest, supply does not necessarily create demand. Infrastructure planning should take place in an integrated manner, particularly taking into account education and health needs, and income earning potential opportunities. Otherwise, when infrastructure assets are being underused, their contribution to economic efficiency and growth is jeopardized. They can even become a liability for the population (often associated with borrowing and/or taxes) particularly when they are not well maintained and mobility across areas and regions becomes more difficult.

A key policy lesson also is that traditional efficiency analysis should not underestimate the immediate benefits of promoting access to rural roads for health and education outcomes. For instance, reducing the time needed to take a pregnant woman or a sick child requiring urgent treatment to a hospital nearby, by improving the condition of the road, can translate into lower maternal and infant mortality rates. Adequate transportation can also ensure reliable availability of supplies such as drugs, vaccines, bednets and spare parts of water systems, all of them critical to improve the quality of health services. Infrastructure spending can also improve the

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30 Capital spending often receives a disproportionate share of outlays on infrastructure from politicians (as noted earlier) and donors, given their relatively higher visibility and political importance.

profitability of existing investments in the health sector. In many countries, it is striking to see the relatively low use of some rural health centers, which sometimes results into closing them in spite of the initial fixed costs already paid.[31] These developments suggest the possibility that the productivity of public spending in health may be increased, by facilitating access to basic infrastructure and transportation to those centers. Therefore, allocating additional public funds to improve the infrastructure network could increase their utilization rates. Similarly, facilitating travel mobility for qualified nurses and doctors could translate into higher health service quality and higher attendance. Increasing collaboration between transport and health authorities should focus on the logistics of drug distribution, qualified staff participation and patient access.

Similarly, in the education sector, easier, cheaper and physical movement is often associated with improved attendance at primary and secondary schools. For instance, as noted earlier, in Morocco the presence of paved roads in rural areas led to a sharp increase in girls' school attendance rate. Infrastructure planners need to take into account education goals per region and district, and participate in the monitoring of their attainments. Infrastructure planning based on a basic access approach would give priority to least-cost interventions, which provide reliable, all-season access to infrastructure to as many villages as possible (see Lebo and Schelling, 2001).

As important as the amounts of public spending allocated to infrastructure, a second critical element to take into consideration when planning infrastructure spending and trying to predict its effects on growth and the well being of the population relates to regulations, procedures, controls and even illegal activities resulting in corruption, which may reduce any potential benefits (see World Bank, 2006). For instance, if a rural producer traveling from the village to town to sell agricultural products in the market saves time and trouble because of the existence of a well-maintained road but needs to stop several times because of illegal controls, the social benefit from building the road will be lower than desirable. Government regulatory frameworks must be comprehensive and set up a solid implementation track record in order to eliminate these artificial obstacles. Improvements in regulations affecting infrastructure should be introduced hand-in-hand with any increases or reallocations in public spending.

Another important policy issue is how to avoid the potential crowding-out effects associated with financing of any additional public spending in infrastructure. The key here is to consider alternatives financing options that may weaken crowding-out effects and mitigate adverse effects on private investment and growth. For instance, the government may use earmarked taxes (such as gasoline taxes to finance road maintenance), instead of general tax revenues, use road tolls or water and electricity tariffs (user fees) to cover part of the expenses, as a way to establish a link between the users and the costs (the benefit principle). Another option is to use

[31] Unless these centers are not being used because they were built too far from markets and schools – in which case improving infrastructure alone would not trigger the desired effects.

"betterment taxes", or taxes levied on the increased value of the properties resulting from building the infrastructure assets.

Although from a macroeconomic standpoint the effect of levying these taxes may be less distortionary than the effect associated with general taxation, there is an issue of who ultimately bears the burden of those taxes/fees, given that those who pay them may shift them to others, such as the final consumers of the transported goods. In addition, user fees raise equity concerns when the payers benefiting from those services (access to water, electricity and roads) belong to low-income groups. More generally, if higher taxes distort private behavior, as a result for instance of increased incentives to engage in tax evasion, they could mitigate significantly the benefits of higher spending on infrastructure.

Governments could also choose to allow a private operator to build, finance and operate an infrastructure project for some time and then return the asset to the private sector, in which case tolls or fees usually help to recover the cost. There is also the option of promoting complete private provision of infrastructure or entering into a public-private partnership. However, the recent experience does not suggest that these are realistic options for many low-income countries. In fact, as noted in the introduction, even in middle-income countries the value of infrastructure investment with private participation has fallen significantly in recent years.

For low-income countries, the most sensible approach, particularly if a large-scale program in public infrastructure is to be considered, is to rely, at least partially, on grants or highly concessional aid. However, grants soften budget constraints and may create moral hazard with respect to tax collection, for instance. And because funds are fungible, they may encourage unproductive spending. They also contain an element of unpredictability (or volatility), due to changes in donor preferences, which can be detrimental to the design of medium-term investment programs (see Agénor, Bayraktar and Pinto Moreira, 2006). In the end, as discussed by González-Páramo and Moreno-Dodson (2003), the ultimate impact will depend on whether they affect positively the allocation of public resources and lead to better policies in the sectors they finance.

Finally, an issue worth thinking about is the sequencing of infrastructure investment. The foregoing discussion has argued that essentially all components of infrastructure may generate large positive externalities. Should we conclude therefore that countries should invest simulatenously in all components at the same time? Or, on the contrary, is there an optimal sequencing of investment between railways, roads, telecommunications, and water and sanitation? The evidence suggests that in poor countries, the share of spending on water/sanitation tends to be higher than in middle- and high-income countries, whereas investment in telecommunications and power tend to be higher in middle- and high-income countries (World Bank, 1994). As noted by Fedderke, Perkins and Luiz (2006, p. 1054), this may suggest that "phases" of infrastructure investment may (or should) reflect the transformation of a country's production structure, such as a shift away from agriculture and mining, toward manufacturing and services.

APPENDIX 1
THE IMPACT OF HEALTH ON ECONOMIC GROWTH: RECENT EVIDENCE

The effect of health on economic growth has been the subject of much recent empirical and analytical research. A key premise of the literature is that good health enhances worker productivity and stimulates growth.

Regarding productivity effects, two important studies are those of Sohn (2000) and Bloom and Canning (2005). Sohn (2000) found that improved nutrition increased available labor inputs in South Korea by 1 per cent a year or more during 1962-95. Using a production function approach, Bloom and Canning (2005) found that a one per centage point in adult survival rates raises labor productivity by 2.8 per cent – a somewhat higher value than the (calibrated) value of 1.7 per cent used by Weil (2005).

Regarding growth effects, the evidence is quite compelling. Wagstaff (2002) noted that up to 1.7 per cent of annual economic growth in East Asia between1965 and 1990 (about half the total GDP increase for the period) has been attributed to massive improvements in public health. Bloom, Canning and Sevilla (2004), in a sample consisting of both developing and industrial countries, found that good health (proxied by life expectancy) has a sizable, positive effect on economic growth. A one-year improvement in the population's life expectancy contributes to an increase in the long-run growth rate of up to 4 percentage points. Sala-i-Martín, Doppelhofer and Miller (2004) also found that initial life expectancy has a positive effect on growth, whereas the prevalence of malaria, as well the fraction of tropical area (which may act as a proxy for exposure to tropical diseases) are both negatively correlated with growth.

Lorentzen, McMillan and Wacziarg (2005) found that countries with a high rate of adult mortality also tend to experience low rates of growth – possibly because when people expect to die relatively young, they have fewer incentives to save and invest in the acquisition of skills.[32] They also found that the estimated effect of high adult mortality on growth is large enough to explain Africa's poor economic performance between 1960 and 2000. Indeed, in the 40 countries with the highest adult mortality rates in their sample of 98 countries, all are in Sub-Saharan Africa, except three.

Jamison, Lau and Wang (2004), using a sample of 53 countries, found that improvements in health (as measured by the survival rate of males aged between 15 and 60) accounted for about 11 per cent of growth during the period 1965-90. In countries like Bolivia, Honduras and Thailand, health improvements added about

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[32] They measure adult mortality as the probability for a fifteen-year old of dying before reaching the age of sixty. They argue that such an indicator provides a quite distinct proxy for health, compared to life expectancy and infant mortality. In fact, they found that adult mortality is a robust and economically significant predictor of economic growth, investment and fertility even when infant mortality is controlled for.

half of a percentage point to the annual rate of growth in income per capita. According to the estimation results of Gyimah-Brempong and Wilson (2004), between 22 and 30 per cent of the transition growth rate of per capita income in Sub-Saharan Africa can be attributed to health factors. Along the same lines, Weil (2005), using microeconomic data (such as height and adult survival rates) to build a measure of average health, found that as much as 22.6 per cent of the cross-country variation in income per capita is due to health factors – roughly the same as the share accounted for by human capital from education, and larger than the share accounted for by physical capital. Conversely, estimates by the United Nations (2005) suggest that malaria (which claims each year the lives of 1 million people in poor countries and infects 300 million more) has slowed economic growth in Sub-Saharan Africa by 1.3 percentage point a year. According to a recent report on HIV-AIDS by the same institution, in Sub-Saharan Africa – a region where on average 7 out of 100 adults, and up to a quarter of the population in the southern part of the continent, are HIV-positive – the epidemic has reduced annual growth rates by anywhere between 0.5 to 1.6 percentage point (see UNAIDS, 2004).[33] McCarthy, Wolf and Wu (1999) found that malaria morbidity is negatively correlated with the growth rate of output per capita across countries. In Sub-Saharan Africa, a one-percentage point in the morbidity rate associated with the disease tends to reduce the annual growth rate per capita by an average of 0.55 per cent. McDonald and Roberts (2006) found similar results; HIV prevalence and the proportion of the population at risk of malaria tend to affect negatively health outcomes in sub-Saharan Africa, and through that channel the rate of economic growth.

The link between nutrition, health and growth has also received much emphasis in recent research (see Strauss and Thomas, 1998, and Hoddinott, Alderman and Behrman, 2005). Inadequate consumption of protein and energy as well as deficiencies in key micronutrients (such as iodine, vitamin A, and iron) are key factors in the morbidity and mortality of children and adults. The United Nations estimate that 55 per cent of the nearly 12 million deaths each year among under five-year-old children in the developing world are associated with malnutrition (Broca and Stamoulis, 2003). Iron deficiency is also associated with malaria, intestinal parasitic infestations and chronic infections. Moreover, the chronically undernourished may be so unproductive that they do not get hired at any wage. If poor people are so badly nourished that they are too weak to perform up to their physical potential, a “nutrition-based” poverty and low-growth trap may emerge. Inadequate nutrition may thus engender poor health, low productivity and continued low incomes (Mayer-Foulkes, 2005). Malnutrition reduces life expectancy and may therefore have an adverse, indirect effect on growth. Arcand (2001) and Wang and Taniguchi (2003) have found indeed that better nutrition enhances growth, in addition to improving human welfare, directly through the impact of

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33 It should be noted, however, that with respect to industrial countries, some studies have found evidence of reverse causation. By raising real incomes, economic growth may enable individuals to spend more on health services. In addition, as shown by Benos (2004), there is also evidence of non-linearities in the relationship between health and growth.

nutrition on labor productivity, as well as indirectly through improvements in life expectancy and possibly by speeding up the adoption of new production techniques.[34]

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34 Jamison, Lau and Wang (2004), however, conluded that differences in the impact of health on growth across countries were unlikely to be the result of differences in the endogenous effect of health on the rate of technical progress.

APPENDIX 2
QUALITY OF PUBLIC CAPITAL AND CONGESTION COSTS

Improving the quality of public capital in infrastructure, even without increasing its actual stock, can reduce adjustment costs and exert a positive growth effect.[35] In practice, however, measuring the quality (or efficiency) of the public capital stock in practice is quite difficult. A common procedure to estimating the quality of public infrastructure capital is to calculate the index proposed by Hulten (1996). His composite measure of public capital efficiency is based on four basic indicators: mainline faults per 100 telephone calls for telecommunications; electricity generation losses as a percent of total electricity output; the percentage of paved roads in good condition; and diesel locomotive utilization as a percentage of the total rolling stock. In practice, researchers have found that these individual quality indicators tend to be highly correlated with the quantities of each type of infrastructure.[36] Thus, much of the variation in infrastructure quality may be well captured by variations in its quantity.

The individual quality indicators proposed by Hulten (1996) are subject to limitations. For instance, electric power losses include both "technical" losses, reflecting the quality of the power grid, and theft; in general, the breakdown between the two components is not available. Moreover, these series tend to fluctuate significantly over time, and these fluctuations are not always easy to interpret as changes in quality as opposed to, say, measurement errors or "abnormal" shocks.

Agénor, Nabli and Yousef (2005) defined two alternative quality indicators. The first is an "ICOR-based" measure. Aggregate ICORs (calculated as the ratio of total domestic investment divided by the change in output) are commonly viewed as a measure of the efficiency of investment. They apply this idea to public infrastructure, by calculating an ICOR coefficient defined as public capital expenditure on infrastructure divided by the change in GDP. They take a 3-year moving average, in order to smooth out the behavior of the series over time.

Their second indicator is an "excess demand" measure. The idea is that, if growth in the demand for infrastructure services tends to exceed growth in supply, pressure on the existing public capital stock will intensify and quality will deteriorate. To construct these indicators proceeds in two steps. First, individual

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35 Guasch (2004, p. 5) has argued that poor quality and reliability of infrastructure forces firms in Latin America to maintain higher inventory levels (often by a factor of two) than those observed in industrial countries. By tying up (expensive) capital, this raises unit production costs and lowers productivity. However, there are a number of alternative reasons why firms may choose to hold high levels of inventories – most notably a high (expected) degree of demand volatility.

36 Calderón and Servén (2004a, p. 19) found a high degree of correlation between the individual quality indicators listed above with the related quantities of infrastructure (that is, between power generation capacity and power losses, or between road density and road quality, the latter measured by the proportion of paved roads in total). In a companion study (Calderón and Servén, 2994b, p. 11) they obtain the same result with their two synthetic indicators of quantity and quality of infrastructure. Esfahani and Ramírez (2003, p. 446) also note the existence of a close correlation between stocks of infrastructure capital and quality in their sample.

indicators of "excess demand" are calculated for alternative categories of infrastructure services (such as electricity; telephone mainlines; and paved roads). To estimate demand for infrastructure service *h*, the annual growth rate of real GDP per capita can be applied to the stock of public capital in *h* at the base period. Elasticity values may vary, depending on available estimates.[37] Actual stocks are used to estimate supply of each type of infrastructure services. Individual indicators of excess demand for each component of infrastructure services are then calculated, by taking the ratio of supply to "predicted" demand. This ratio gives therefore an indicator of adequacy between supply and demand; a fall in the ratio would indicate excessive pressure on existing infrastructure and therefore a deterioration in quality. Second, a "composite" excess demand indicator is calculated. To do so they use the same procedure used by Hulten (1996) to calculate his quality index, that is, we standardized each of the three series (by subtracting the mean and dividing by the standard error) and calculated the unweighted, arithmetic average of the standardized series.

Much research has examined the issue of quality and congestion costs in infrastructure and their implications for private capital formation and the optimal allocation of public expenditure. But almost none has focused on congestion costs in education. This is a particularly important factor in determining the quality of schooling in low-income countries, where (according to recent data from UNESCO and the World Bank) student-teacher ratios may dramatically exceed average ratios in industrial countries. For instance, at 44 to 1, the pupil-teacher ratio in Sub-Saharan Africa is on average three times higher than that of developed countries; moreover, one in four countries in the region has ratios above 55 to 1 (see UNESCO, 2005).

Similarly, quality and congestion costs may be important in assessing the effect of health capital on growth. A recent press release by the World Health Organization noted that hospitals in Sub-Saharan Africa are "getting worse in terms of both the scope and quality of health care they provide". For instance, the number of hospital beds per 1,000 people varies only from 0.9 to 2.9 in the region, compared to 4.0 in the United States and 8.7 in France. Similarly, the number of doctors per 100,000 people is 16 in Sub-Saharan Africa, compared to between 33 and 48 in South Asia, and 200 and 300 in developed countries. Pressure on health capital may alter the quality of the services being produced, and therefore mitigate their growth-enhancing effects.

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[37] Agénor, Nabli and Yousef (2005) used an elasticity of unity in each case. In their estimation of demand functions for infrastructure services based on panel data, Fay and Yepes (2003, p. 8) found long-term elasticities of 0.375 for electricity, 0.5 for telephone mainlines, and 0.14 for paved roads. However, the regressions on which these estimates are based do not include a price (or user cost) variable, so the estimated income elasticities may be biased.

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