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The Challenge of Operating and Maintaining Infrastructure

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Abstract
Operations and maintenance (O&M) are key but often overlooked components of infrastructure service delivery. O&M enhances the economy through three channels: it is an essential input in production of infrastructure services, increases the life of public capital, and expands the durability of private capital. O&M will be inefficiently set unless all three are considered in provision decisions. Optimal O&M decisions are further constrained by the technical and political economy environments in which they are made. The second-best world where most infrastructure is planned is likely to lead to overuse of infrastructure and under-provision of O&M, though what appears as insufficient O&M may be excessive investment that was encouraged by donors or reflect limitations on local resource mobilization. Decision-maker self interest also prevents decisions from being in the broad public interest. Straightforward and completely satisfactory solutions to these problems do not exist, but several steps to better O&M are discussed. Decisions, which could vary by infrastructure type and county, must be made on whether to privatize and/or decentralize O&M.

I. Introduction

1. Infrastructure is a key ingredient both to economic growth and quality of life. Infrastructure is "an umbrella term for many activities referred to as social overhead capital," and includes public utilities, such as power, piped water supply and sanitation and sewerage, public works, such as roads and dams, and other transport sectors, such as railways, urban transport, and airports (World Bank, 1994). This paper focuses on an essential component of an effective infrastructure network – the ability to operate and maintain the infrastructure properly. The tendency in much of the earlier infrastructure literature was to focus on infrastructure as capital investments and thus the core of the capital project cycle rather than to think of a series of infrastructure *services* that are produced using a set of inputs that includes physical capital.[1] In the production function context, operations and maintenance are another group of inputs that are essential to reaping the value of the services. Viewing operations and maintenance expenditures in this fashion highlights their role in service provision but also heightens the importance of political economy considerations and service assignment responsibilities in financing effective services.

2. The remainder of the paper is divided into six sections. The next section places operations and maintenance in the context of infrastructure service delivery. The second section examines the impact of operations and maintenance on production and welfare. Section three describes organizational options for operations and maintenance including decentralization and privatization. The following section evaluates decision making and efficiency of operations and maintenance in a social efficiency and political economy context. Section five identifies some options for improved operations and maintenance policy. The paper finishes with a conclusion.

II. Understanding the Role of Operations and Maintenance in Infrastructure Services

3. The contribution of infrastructure to production and economic growth has often been analyzed as if it is a series of capital investments[2] though more importantly users have a derived demand for the services that are produced using a combination of capital, labor and other inputs. The tendency to emphasize capital in infrastructure research likely stems from the easier capacity to quantify public sector capital expenditures combined with their sheer size as opposed to the difficulties of measuring some service flows and their quality. Also, the focus on capital may be because infrastructure services are often delivered as congestible public goods that operate as capital-intensive networks (Hulten, 1986).

4. The non-capital inputs in the production of infrastructure services are what we refer to as operations and maintenance. These inputs include labor, replacement parts and materials (potentially including some replacement capital), electricity (which is itself an infrastructure service), and many other infrastructure-specific factors. Straub (2008) is a recent example recognizing that infrastructure services are produced through a production process where the services cannot be defined simply by the public capital. Straub notes that empirical infrastructure

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1. See Aschauer (1989) for an earlier example of the technical literature on infrastructure and the economy.

2 The investments have often been termed public capital (though the services are generally congestible), which refers to publicly available infrastructure whether provided by the public or private sector. Private capital refers to investments like buildings and equipment that yield private benefits. Private agents may make more efficient operations and maintenance decisions because the benefits of these investments are internalized to the firm. We will follow this terminology.

research has increasingly moved from an emphasis on the capital stock to the use of physical indictors as the proxy for infrastructure. Nonetheless, these proxies are often difficult to use because the data are frequently not systematically available across time and countries, the indicators are often poor proxies for the services (e.g. miles of paved road), and the indicators fail to account for quality of infrastructure services.

5. Efficient delivery of infrastructure services relies on understanding that services are being produced using multiple inputs with the goal of optimally meeting users' demands. Operations and maintenance inputs and physical infrastructure investments work together both as substitutes and complements through the service production function. They are complements because greater capital investments generally require greater operations and maintenance. But, they are substitutes because altering the type of investment, such as building more expensive cement rather than asphalt roads, can sometimes reduce the necessary maintenance – that is, they are not simply components of a fixed proportions production function. Also, better maintenance can reduce future capital investments.

6. Good operations and maintenance practices when combined with appropriate capital investments affect the value of infrastructure services through several avenues. First, operations and maintenance is essential to allowing use of many types of infrastructure services – users obtain no benefits from a water system or electric network that does not operate. Thus, infrastructure investments that are otherwise adequate may be made inaccessible simply because of poor operations and maintenance. As a result, good operations and maintenance makes infrastructure capital investments more productive and expands the value of infrastructure investments. The World Bank World Development Report (1994) concluded that only 60 percent of electric generating capacity in developing countries is available, versus a best practice of 80 percent. The relationships are similar for improved water, where 70 percent of capacity is used in developing countries versus best practice of 85 percent. Operations and maintenance that expands the share of productive capacity can entail up-front costs but may reduce the need for additional investments as they make previous investments more productive. Second, the life cycle costs of infrastructure investments can often be lowered through good maintenance. Roads, for example, last much longer, and the total costs of providing roads can be lower, if proper maintenance occurs.

7. Finally, efficiently operating infrastructure lowers the private costs for users and makes it easier to access the infrastructure. This happens either because users may develop or identify alternative capacity to replace poorly functioning infrastructure services or because use of the infrastructure directly becomes more costly to users. For example, Clarke (2012) concludes that users regard reliability as the key attribute of some infrastructure, such as power, and they often must provide costly backup to ensure reliability. Similarly, people often must seek out alternative water supply because piped water is insufficient or unreliable even though the system appears to have sufficient capacity. Also, poorly maintained roads can damage vehicles and raise the fuel costs associated with travel. Nonetheless, some users may prefer bearing the private sector costs, even if this means higher society costs, if significant fees or charges would raise their share of public costs.

8. Several authors have concluded that the returns to maintenance are much higher than the returns to new infrastructure. For example, the World Development Report (World Bank, 1994) concluded that the rate of return to maintenance is often twice the return to new infrastructure investments. Hulten finds a significant effect of infrastructure on per capita country GDP, using

measures such as faults per 100 telephone calls, electricity generation losses and percent of paved roads in good condition, and observes the marginal benefits of better operations and maintenance are seven-times greater than making additional infrastructure capital investments. Indeed, he concludes that new infrastructure investments can have a perverse effect on national growth if they shift resources away from operations and maintenance of the existing capital stock. The relative magnitude of returns to operations and maintenance is not surprising given Clarke's finding that users are often more concerned with the quality than with the quantity of infrastructure – and quality of services is often determined by the extent of operations and maintenance. Clarke, (2012) found that firm managers are much more concerned about service quality and reliability than access to electricity.

III. Conceptualizing Operations and Maintenance

9. The conceptual literature on operations and maintenance, like the empirical literature, is relatively small but analyzes the impact of operations and maintenance on production, and welfare more broadly, through three avenues. This section describes the three channels and then briefly reviews how the literature has examined each. Again, these channels may be better thought of as how infrastructure services affect welfare, where operations and maintenance are inputs in the production of the services. First, operations and maintenance are inputs in the production of infrastructure services, such as electricity and water. Sufficient capital investments and appropriate operations and maintenance can ensure that services are of high quality and delivered to where users want them. The quality of services delivered across the network to the desired location will not consistently occur without good operations and maintenance, though earlier empirical literature has often effectively presumed that operations and maintenance will take place if capital investments are made.

10. The next two channels indicate that inadequate maintenance increases the operating and capital costs for both public and private investments and many ongoing forms of economic activity. Second, operations and maintenance increase the life of *public* capital, as evidenced by good maintenance expanding the life of roads. This is the sense in which public capital investments and operations and maintenance are substitutes.

11. Third, operations and maintenance expand the durability of private capital, as seen in good road maintenance enhancing the life of vehicles and consistent electric flow extending the life and usefulness of computers.[3] Effectively, this means that good infrastructure services can extend the life of *private* capital investment. Note that this channel applies both to infrastructure that users go to for the benefits, such as roads, and infrastructure that is delivered to the user, such as electricity and water.

12. The relationship between infrastructure and private capital is broader than is seen in some of the conceptual literature since not only is the life of private capital extended, but the amount of private investment can actually be lowered by good infrastructure services. Poor quality operations and maintenance and/or infrastructure may require private firms to self-produce infrastructure services, thereby requiring additional private investment and potentially expanding private operating costs. Reinikka and Svensson (2002) discuss how some firms must make private capital investments in electric generators as a backup to unreliable service capacity. The

3 Though, Straub observes that the simple access to infrastructure, such as electricity or roads, may be necessary for private investment to occur.

problem often is not that physical capacity of public infrastructure is inadequate, but that the quality of services flowing from the capital stock is too low or unreliable. The solution may be better operations and maintenance of the infrastructure, not more capital investments, but the best use of resources depends on the specific situation. Some have argued that good infrastructure services allow firms to shift investment to expanding productive capacity rather than providing backup for infrastructure, which simply means self-produced infrastructure services and expansion of productive capacity are often substitutes (see Agenor and Moreno-Dodson, 2006, for example). The scarcity of investment capital in developing countries should normally make alternative uses substitutes. Thus, better infrastructure services can increase overall production in the economy if the returns to productive capacity exceed those to self-production of infrastructure services. Still, as we note below, there may be instances where it is socially efficient to allow some self-production.

13. Straub (2006) identifies a series of other channels through which infrastructure affects production and welfare including impacts on labor productivity, human development and ability for the private sector to reap economies of scale and scope. Good operations and maintenance can influence welfare through these other avenues as well, but these have not been addressed in detail in the literature despite the fact that spillover benefits are known to exist. Considering these issues will allow a more comprehensive assessment of the returns to both capital investments and operations and maintenance.

14. Relatively little rigorous empirical work has taken place on operations and maintenance, and specifically on the tradeoff between more infrastructure capital investment and more operations and maintenance (or more broadly between operations and maintenance of infrastructure and other public services). Data are the major challenge in studying operations and maintenance, at least in part because much of the maintenance occurs outside of traditional markets, and inside individual enterprises that do not report on specific operations and maintenance activities (see McGrattan and Schmitz, 1999). Part of this is a reflection of budgeting and accounting practices that may show initial capital investments in a capital account and subsequent maintenance and operations embedded in a current expenditure account. Thus, recent work on operations and maintenance generally remains conceptual rather than econometric.

Theoretical Research

15. Several authors including Rioja (2003), Kalaitzidakis and Kaluvitis (2004), and Agenor (2009) have theoretically modeled operations and maintenance in the macro economy of developing countries. This section briefly summarizes these papers. Among the conclusions are that higher donor finance for public capital reduces the optimal maintenance, optimal expenditures on infrastructure occur where the last dollar spent on maintenance yields the same value to the public capital stock as the last dollar of investment, and optimal maintenance is greater than seen in traditional growth models because maintenance of public capital reduces depreciation of private capital. For example, Rioja identifies the optimal level of maintenance, defined as to maximize social welfare. He models output as a function of public and private capital and labor. Government imposes an output tax and uses the funds to finance operations and maintenance of public capital. Maintenance is presumed to lower the depreciation of public capital (thus maintenance and private capital are substitutes in production of infrastructure services). Donors are assumed to fully finance public capital, though the World Bank (1994)

notes that donor spending accounts for a little less than one-half of infrastructure investment. He finds that optimal maintenance depends on the amount of public capital, private capital and donor funding and concludes that the higher donor funding relative to public capital, the lower the optimal level of maintenance. In other words, countries will lessen domestic resources to maintain existing infrastructure as they receive more free public capital from outside.

16. Kalaitzidakis and Kaluvitis (2004) extend Rioja's model by creating an environment where the public sector finances both maintenance and new public capital. Government reduces the marginal product of private capital through taxation and raises it through infrastructure. The durability of public capital depends positively on the extent of maintenance and negatively on production in the economy. Optimal government occurs where the marginal cost of government (infrastructure) exactly equals the marginal benefits. The steady state growth rate of the economy is shown to increase with maintenance, if maintenance is relatively low, and fall with maintenance if maintenance is relative high, evidencing the benefits of choosing the optimal level of maintenance. An inverse relationship between maintenance and new public capital investment is evidenced, since the net increase in public capital for any particular expenditure rises with more maintenance. Kalaitzidakis and Kaluvitis demonstrate that optimal public investment occurs when the last dollar spent on maintenance has the same contribution to the public capital stock as the last dollar of public investment, which is consistent with infrastructure services (as measured by capital) being maximized for any level of expenditures . An important conclusion is that further maintenance can be productive in cases where additional public capital would not be. Indeed, simulations by Rioja (2003) evidence significant welfare gains from shifting resources from new projects to maintenance of existing projects.

17. The amount of investment and maintenance in the Kalaitzidakis and Kaluvitis model depends on the current tax rate. The optimal tax rate in the standard endogenous growth model equals the elasticity of public capital in the production function, but in this model the optimal tax rate is higher because of the positive effects of maintenance on the amount of public capital. The analysis assumes that these taxes can be levied and collected, which may be difficult in practice.

18. Agenor (2009) extends the basic framework by bringing in the effects of maintenance on the durability of private capital. He concludes that the growth maximizing share of public expenditures on maintenance rises with the marginal effect that maintenance has on the depreciation of private capital. The paper focuses on how maintenance affects depreciation of private capital, but does not address how poor quality infrastructure can require additional private investment for self-production. Taken together, these papers argue for greater public investment (and therefore a higher tax rate) than in the standard growth model because of the impact of maintenance on the amount of public and private capital.

IV. Organizing Operations and Maintenance

19. Designing and executing appropriate operations and maintenance should be a key consideration at every step of the project cycle. Indeed, decisions on public capital investments and operations and maintenance should be made simultaneously in the planning phase to achieve the best output for given life cycle costs. Such decisions should recognize the ability and willingness of different levels of government to generate resources for operations and maintenance and the capacity to execute operations and maintenance, and should not be made based on engineering designs and expectations alone. Similarly, consideration of operations and maintenance should carry through the entire project cycle and be part of the ex-post evaluation.

20. Several organizational structures can be selected for undertaking operations and maintenance and the choice between them should depend on the ability to motivate efficient and optimal service provision and to properly price services. The options include private, public, and community-based operations and maintenance. Community-based operations and maintenance is normally linked to small systems where limited expertise is necessary (though appropriate expertise may be available in the private sector or through central ministry staff) and where the user-base is well defined. Community-based systems by their very nature are decentralized, though they can be operated in either the public, private or not-for-profit sectors. The investments in infrastructure capital and operations and maintenance can be separated from the investments constructed or financed by central government entities (such as the Local Government Engineering Division in Bangladesh) or donors while the community-based organization is responsible for operations and maintenance. Ideally, community-provided services should be priced to fund operations and maintenance activities (and where possible infrastructure investments) and ration use of the service.

21. Private operations and maintenance can be linked with either public or private infrastructure ownership. Private sector operations and maintenance can help to introduce competition into infrastructure delivery, though public regulation may be necessary and can limit the ability to mimic the private market especially in the face of political influences on service contracting. Also, first mover advantages can be afforded to those private firms that get the initial contract to deliver infrastructure services and could yield some rents associated with specific knowledge learned from operating the network. Public sector operations and maintenance could be consistent with either public or private (through a leaseback) ownership of the capital. As discussed more below, public sector activities could be sited at the national, regional, or local level depending on the type of infrastructure and the ability to coordinate decisions across governments.

22. Two interconnected issues arise: is public or private sector operations and maintenance preferred and is it desirable to decentralize service delivery if public sector production is selected? The decision whether to decentralize operations and maintenance is related to but not precisely the same as the choice of whether to privatize since infrastructure functions can be privatized regardless whether the responsibilities have been decentralized.

23. Decentralization of government, which is taking place around the world, may improve infrastructure service delivery. Incentives for efficiently operating and maintaining infrastructure would appear to be higher if the responsibilities are more localized because the decisions will be closer to those fit most from service quality, and for many services the geographic spillovers will be modest. This is consistent with the subsidiary rule to which many public sector economists subscribe. At the same time there must be sufficient resources and/or willingness to pay to support operations and maintenance, and a political climate that can support effective service delivery.

24. Decisions of whether to decentralize are not all or nothing choices. Infrastructure services, like other public services, can be unbundled into a series of activities that can be delivered by different levels of government. For example, the national government may have responsibility for broad control over the national watershed and water supply and quality standards in the country. The national government may also set standards on water quality delivered to users. The regional government may regulate and oversee actual water service delivery. Finally, the operation of water systems may be more localized. Also, national roads

may be planned by the Ministry of Transportation and provided by national or cooperating regional authorities. Local roads can be planned and provided by city authorities. Unbundling can permit infrastructure activities with interregional spillovers to remain at the regional or national level while other components can be decentralized to where market and political incentives for good operations and maintenance are greater and lead to less cost shifting. Such unbundling has worked well with secondary and tertiary roads in Peru, and can be helpful in other cases as well. But problems of the tragedy of the commons can remain and require good leadership at the local level to ensure good maintenance occurs whether responsibilities fall on the public or private sector.

25. At least four factors should enter the decision of whether to decentralize operations and maintenance if public sector delivery is selected, including:[4]

- The desire for equalization and tolerance for cross-subsidies.
- Variation in preferences for services
- The potential for interregional spillovers
- The potential for economies of scale

26. The judgment on whether to decentralize will likely differ by infrastructure service since these four factors may point in different directions. First, decentralization is a better option if interregional cross subsidies in the country are undesirable, though grants can achieve cross subsidies and financial equalization even in a decentralized structure. Cross-subsidies are not an important concern if user fees finance the infrastructure, but cross subsidies could be more likely and important for roads, dams and other infrastructure where exclusion is more difficult and for public health services where there may be geographic externalities.

27. Second, variation in service demands makes decentralized service delivery a better option. Decentralization is a strong option in countries with differing regional or localized infrastructure demands because of topological diversity or varying consumer demands. Third, significant interregional spillover of public service benefits makes decentralized decision making less efficient as non-resident demands are likely to be ignored in service delivery decisions and full cost recovery may not be possible. This suggests that services such as large dams and national roads should be controlled at the national or regional level.[5] But, interregional spillovers will be less important for many infrastructure services including electricity, water, and local roads. These are broad conclusions whereas in practice the answer will depend on how localized operations and maintenance interacts with the infrastructure itself.

28. Finally, the potential for economies of scale or size in infrastructure service delivery/operations and maintenance is a key issue. Decentralized delivery is less effective as economies from larger size expand. Technological changes continue to allow more localized service delivery but, some services such as electricity probably cannot be decentralized to the extent of others. Water provides an example, where research (see Fox and Gurley, 2006) suggests there are economies of size to providing services across wider geographic areas. However, the extent of economies for any place depends on population density and other factors because water must be gathered and cleaned, which may benefit from economies, but the purified water must be distributed via pipes, which may not benefit from economies depending

4 See Fox and Wallich (1998).

5 Intergovernmental transfers can be used to create incentives for local governments to account for the spillover of service benefits.

on the location and density of users. Analysis in countries around the world has tended to focus on determining whether there are benefits to consolidation of infrastructure services, and the research suggests that economies will often not result from merging areas together. This is suggestive that any diseconomies from decentralizing will not be large if responsibilities are properly unbundled, but important transition costs may result from decentralization. Reorganization of supervisory responsibilities and staff is an example of transition costs that might arise from decentralization (or centralization) of services.

29. Diseconomies of delivering water (or electricity) through decentralized providers may be linked mostly to investments in collecting and cleaning water and may have little to do with operations and maintenance of the distribution systems. So, at least large local governments could purchase electricity or purified water from regional companies and distribute the services to constituents. Economies may exist for technical operations and maintenance staff, such as for engineering and information systems, but these can potentially be offset if technical skills can be obtained from regional offices of the appropriate ministry or purchased through the private sector.

30. Unbundling of services offers the potential for placing components of service delivery at the appropriate level and offers the opportunity to focus on assignment of services rather than the engineering project cycle. But, assigning components of infrastructure to different levels of government raises the potential for conflicts in decisions or policies because the incentives of national and local decision makers will often not align. For example, the national government may expand water and sewer systems in places that have low tastes for the services, or that feel they are unable to adequately operate and maintain the facilities. Separation of the decision makers on capital investments and operations and maintenance increases the likelihood of significant deviation of operations and maintenance from the efficient level from an engineering perspective because local governments (and private sector entities) may not have the technical or engineering resources or may not have the user demand and willingness to pay to support the required operations and maintenance. Thus, decentralization requires coordination and cooperation across levels of government.

31. Simply, centralized decisions on capital investments may not allow for variation in local preferences. Preference variation across a country likely will surface if local governments have control over operations and maintenance, and the operations and maintenance may be less related to engineering outcomes and more to local service taxes. Thus, the advantages of assigning different services to different levels of government must be balanced with the costs of inconsistencies in the decisions made by different levels of government. Thus, the desirability of decentralizing operations and maintenance depends heavily on the capacity of different levels of government to work together and coordinate decisions on every aspect of the planning and execution process and this could vary across regions and countries. This suggests that good operations and maintenance depends on changing processes throughout the project cycle, including the process through which decisions are made on what projects and where they are to be if operations and maintenance are to ensure the best life cycle cost use of resources. Below, we investigate the political economy of these issues in more detail.

V. Social Efficiency and Political Economy Considerations

32. Operations and maintenance levels are often deemed insufficient for a variety of reasons including (i) the infrequency of actual infrastructure breakdowns which may lead to the view that maintenance can be postponed, (ii) much of the repair is in areas not visible to politicians and service consumers and (iii) decision-making for capital investments and operations and maintenance are often separated (Pagano, 2011). As discussed here, it may not be socially efficient (given tastes and revenue capacity) to spend more on operations and maintenance. Even in cases where social efficiency could in principle be supported, there may be political economy factors that drive a wedge between actual policy decisions and socially-efficient outcomes.

33. Consider Straub (2008) who argues that maintenance of infrastructure networks is probably better analyzed with economic-engineering models than with traditional econometric analysis. He notes that surveys of actual practice could be undertaken to determine the appropriate amounts of maintenance that should take place over time as new investments are made. The survey approach provides an engineering answer to appropriate operations and maintenance, but the political economy environment likely determines the amounts that are actually undertaken. Moreover, there may be insufficient resources and revenue capacity to support engineering solutions m. The engineering perspective does not take into account the opportunity cost of resource use in either the public or private sectors. If the capacity for revenue mobilization is low, there will be high private opportunity costs associated with funding infrastructure operations and considerable competition for resource use within the public sector where other services are funded at low levels.

34. Here we consider the social planner and political economy views that place the operations and maintenance question in a broader social context. Each view has consequences for how one might evaluate the efficiency of operations and maintenance expenditures and points to different opportunities and bottlenecks for improving expenditure patterns and infrastructure service flow performance. The points raised below are not unique to developing countries—they could conceivably apply to any country. But the developing country context is arguably more challenging for a number of reasons, including extraordinarily depressed revenue capacity and weak institutional and governance structures.

Social Efficiency

35. The social planner perspective recognizes the multiple forms and heterogeneity of infrastructure capital and thus the uses to which operations and maintenance expenditures might be applied. The uses include capital that provides private service flows (in principle subject to exclusion and congestion), production processes characterized by economies of scale, as well as pure and impure public goods. Pure public goods raise the specter of the free rider problem while the introduction of impure public goods increases attention to the costs and practicality of exclusion and determination of the optimal number of users. These are not trivial considerations anywhere but they may be especially important in developing countries. Recognizing these classic problems would likely change optimality conditions and highlight differences across types of infrastructure and levels of operations and maintenance expenditure. The social planner must also balance the use of resources in support of infrastructure against their potential alternative uses in individual consumption and in public service supply (e.g. public safety)

funded by taxes and fees and at the expense of private consumption. In other words, infrastructure choices cannot be made in a vacuum that ignores other uses of resources.

36. A second-best perspective recognizes the political and technical/cost constraints associated with attempts to impose exclusion on access to infrastructure service flows, including services like electricity even if they are provided by private sector entities. The inability to exclude can lead to overuse and more rapid depreciation of the capital stock as a tragedy of the commons unfolds, necessitating ever-higher operations and maintenance expenditures to maintain system integrity. Rationing may arise as a consequence of use and overuse, through congestion, queuing and interrupted service flows. Even if exclusion is feasible from a cost perspective, there may be political constraints that limit the capacity for revenue mobilization from users whether services are privately or publicly provided. For example, there may be political pressures or threats of political instability if the population is denied access to services and it may prove impossible to charge marginal cost; even if charges are in place there may be difficulties with the collection of user fees and arrears. The end result may be a stressed infrastructure network with little revenue to support operations and maintenance. These problems are pervasive in developing countries and often render simple, classical solutions to the operations and maintenance problem unworkable. What in practice may appear to be an inefficient allocation of resources from an engineering perspective may instead simply reflect the practical constraints within the developing world.

37. A question arises whether resources should be devoted to operating and maintaining poorly selected infrastructure investments. Should roads that were not built in the optimal location be well maintained, should investments that differ from local tastes still be operated and maintained, and so forth? One would likely observe operations and maintenance spending that might be deemed “too low” in such situations. The response depends on the alternative uses of the funds, how poor the investments are and so forth. The investments should generally be seen as sunk costs (at least for their expected life) so the issue is whether the marginal benefits of operating and maintaining the capital offer a good return to the resources necessary. Capital costs would only enter the decision when replacement issues arise.

38. There are important lessons here. First, operations and maintenance expenditures cannot be considered in isolation, but must be evaluated against alternative uses of resources in both the private and public sectors. While it is likely that too little is spent on infrastructure maintenance, there are also likely cases where low levels of observed spending are consistent with the efficient use of resources especially in places with very low capacity for revenue mobilization where opportunity cost for funds in the public sector may be high. The other side of the problem may simply be too much capital demanding too much operations and maintenance spending, reflecting the generosity but also paternalism of outside donors. Second, because of the challenges associated with exclusion—whether related to technological or political considerations—operations and maintenance expenditures often must be evaluated in a second-best setting where standard engineering rules for best-practice maintenance may not be applicable.

39. It is also important to recognize that the demand for infrastructure services is derived from their use in market and home production processes where they can serve as either substitutes or complements to other inputs. Water and electricity are two examples of services that might be provided by private or public enterprises but also lend themselves to substitution and private provision. Observing private substitution is a necessary but not sufficient condition

that social inefficiency exists. Poor quality electricity service, characterized by voltage irregularities and service interruptions, may induce some firms to self-supply electricity and thus directly incur operations and maintenance expenditures for maintenance of a private capital stock. This will be costly to the firm and will in turn hamper competitiveness, particularly for firms engaged in the production of tradable goods and commodities. Greater operations and maintenance expenditures could reduce these costs, but these expenditures should be weighed against the private costs that would otherwise arise from individual action.

40. Households may also substitute and self-supply inputs to home production like water and electricity through the use of small-scale storage facilities and generators or may simply ration supplied use depending on service availability. Home production in developing countries will generally rely on time and labor intensive processes because of the low opportunity cost of labor relative to the cost of market-purchased inputs to production; consumption will also tend to be time rather than goods intensive. The nature of household production does not always necessitate the same high quality and continuous service flows that may be required of firms producing for market. For example, a firm may require continuity of electricity service throughout the day to maintain production while households may be able to change the timing of home production that relies on electricity to accommodate daily service interruptions.

41. These considerations suggest a mixed approach to service delivery that may yield different quality service flows and different levels of operations and maintenance expenditure for different consumer groups (or lower total operations and maintenance expenditures). For example, it may be best in certain circumstances to maintain high quality electricity service for business and industrial districts while offering poorer quality services to households, particularly when constraints limit the potential for local resource mobilization.

42. Efficiency in the use of operations and maintenance expenditures must be carefully balanced against opportunities and costs associated with private substitution (and complementary) possibilities. The goal of operations and maintenance expenditures should not be to minimize private sector costs per se, but to balance these cost reductions against the use of resources in supporting infrastructure, ongoing public services and private consumption. In other words, there are many margins to balance in practice.

43. Electricity and transportation services are examples of infrastructure outputs that can be complements to market and home production. Private costs will generally be lower when the quality of infrastructure services is higher. For example, a high quality road may greatly facilitate the transportation of goods thereby yielding substantial reductions in time costs and vehicle wear and tear. Private agents thus incur lower out-of-pocket and time opportunity costs from operations and maintenance expenditures... This is a margin that should be considered when determining the socially-optimal level of operations and maintenance expenditures. The practical importance will depend on the type of infrastructure and the type of user. For example, it may be appropriate to have lower operations and maintenance expenditures if complementary production processes are labor intensive and labor has a low opportunity cost. However, operations and maintenance spending should be higher, all else the same, the greater is the wear and tear on private capital.

Some Political Economy Considerations

44. It is well understood that a political process can only yield a socially-efficient level of output under the most unique circumstances and the same would apply to operations and maintenance expenditures. In practice, political processes in developing countries may be a significant impediment to efficiency. In many developing countries there is no viable public choice process so that decisions reflect the preferences of elites or sub-groups of the population. In countries with some form of democratic process, public sector choices will have some chance of capturing the preferences of those who vote, but the situation is greatly complicated by the fiscal hierarchy of government finance. Regardless of the institutions and processes that yield public sector outcomes, choices will reflect self-interest and the tastes and costs of decisionmakers. There is no reason to think that these outcomes will align with what is required from a social efficiency perspective.

45. Political gains, economic impacts and distributional consequences associated with infrastructure spending can easily interfere with optimal operations and maintenance spending. For example, political leaders may happily accept donor-financed infrastructure projects for the prestige and private economic gains (including private sector contracting) that are associated with facility construction, even if there is little social value placed on services or there is inadequate fiscal capacity to provide warranted operations and maintenance expenditures. So consistent with Rioja (2003), there may in some sense be too much infrastructure, the source of which is well-intentioned but paternalistic donor finance.

46. In a stylized public choice setting, agents must allocate income across own-consumption and the provision of public services, including infrastructure services, based on private sector prices and the public sector tax/fee structure. This will require equating the marginal benefits and costs of operations and maintenance expenditures, but also a more general equilibrium calculus across all forms of public and private consumption. The structure of tastes, prices and taxes may not be consistent with engineering notions of efficiency in operations and maintenance expenditures especially if there is too much capital. Efficient input *combinations* are still required but potentially at low operations and maintenance levels that would be socially inefficient. In other words, even if engineering standards are not pursued, operations and maintenance should be undertaken efficiently.

47. In general, one would expect less support for operations and maintenance expenditures where there is less citizen engagement in the processes that determined the initial capital investments. This outcome might reflect the decision of a benign but non-representative government, a despot, a benevolent but paternalistic leader or an international donor; in a country with a well-functioning democracy, the same outcome may occur if there is heterogeneity in tastes across places and regions. In all of these cases, preferences may compromise application of the optimal level of operations and maintenance expenditures from both an engineering and social planner perspective.

48. Even if infrastructure choices are made with the full consent of the population, myopia and high discount rates associated with the essential nature of current consumption in developing countries may hamper efforts to mobilize operations and maintenance resources. Of course the same problem arises to varying degrees in developed countries. The benefits of operations and maintenance expenditures may not be obvious especially if existing service flows are of

acceptable quality. So it will prove difficult to generate funding streams and allocate revenues, while earmarked fund balances might easily be diverted to competing uses.

49. Finally, it should be recognized that operations and maintenance expenditures represent an opportunity for rent extraction. Political and personal gain may accrue from the diversion of operations and maintenance expenditures to other uses. Even if operations and maintenance expenditures are incurred in support of infrastructure, there may be waste and inefficiencies through the contracting process and granting of contracts to friends, family and political supporters. This could lead to the wrong quality and mix of operations and maintenance inputs.

VI. Improving Operations and Maintenance Policy

50. Decisions regarding infrastructure investments and operations and maintenance expenditures are generally made or influenced by the political process. Hence the first step to ensuring sound decisionmaking is to allow for preference revelation through citizen engagement. Improving local resource mobilization so that preferences can be financed is an important aspect of getting preferences reflected in operations and maintenance and service flows. Once investment decisions are made, accountability in operations and maintenance spending can be promoted by providing information on service reliability and transparency in budgeting processes and resource allocation.

51. Infrastructure service decisions need to be made with a clear understanding of the life-cycle costs, including initial investments and on-going operations and maintenance, and in the context of overall public and private sector welfare maximization. This can only occur if operations and maintenance are part of the project cycle from the appraisal to the ex-post evaluation stages. Still, practical mechanisms may be appropriate to ensure that annual resources are consistent with longer-term plans. Several options could be considered for enhancing how operations and maintenance are to operate, particularly in the public sector.

Legislating an Operations and Maintenance Fund

52. Earmarking revenues can to some extent separate operations and maintenance from the vagaries of the annual appropriation process. A number of questions have been raised about the usefulness of earmarking including whether it actually influences decisions at the margin, whether it is good to separate some expenditures from annual appropriation decisions, particularly during times when general revenues are declining, and so forth. But, operations and maintenance decisions should be determined to a significant extent as part of the life-cycle choice for infrastructure services and this may call for protecting or highlighting the expenditures to some extent.

53. Earmarking user fees can provide an effective funding source if there is sufficient demand and fiscal accountability and helps ensure efficient consumption of infrastructure services. Earmarking is also possible when user fees are not the funding source. For example, the U.S. state of Utah requires a five-year capital plan that includes proposed projects, details about the projects and costs, and approaches to funding operations and maintenance (Pagano, 2011). Further, state law requires that 1.1 percent of the replacement value for existing state buildings be appropriated to a capital maintenance fund before any new capital projects are built. The required fund grows with the replacement cost of capital, which depends both on construction

costs and the amount of buildings. Utah restricts the approach to state buildings, but broader application can be envisioned so that the fund covers all fixed assets and in principle operating costs in addition to maintenance. The fixed percentage allocated to the fund is somewhat arbitrary, but an engineering analysis of requirements could be developed and used in project cycle planning.

54. The creation of the earmarked maintenance fund and articulation of the mechanism for depositing funds is an important signal, even if the fund cannot be enforced effectively through legislation. The requirement/existence of a maintenance fund can signify the importance placed on maintenance by government and demonstrates the intent to focus on good maintenance. It can also promote fiscal accountability if appropriately managed.

Assign Components of Infrastructure to Appropriate Delivery Units

55. Decisions should be made on the extent to which each broad infrastructure category should be unbundled and the services should be assigned to the appropriate entity. The decisions involve determining both appropriate service decentralization and the extent of privatization. Such decisions must be nuanced and based on subjective information because precise, quantitative information does not exist for some of the factors in the decisions. These decisions should consider the benefits and costs from allowing for local preferences in service choices, reaping efficiency in delivery of the functions, and experiencing losses from non-aligned decision making across multiple entities. The net effect of these factors must be weighed and balanced.

Pricing Infrastructure Services

56. Many infrastructure services, including electricity and water, are excludable private goods (potentially subject to congestion) and the resulting services can be priced. Economic efficiency will be maximized by setting marginal cost prices, even if two-part tariffs are necessary to accommodate the declining part of the average cost curve or to finance the distribution network. Pricing plays a key rationing role to ensure the optimal level of services is produced. User fees also provide a financing mechanism for operations and maintenance so the revenues must be earmarked for service delivery so that consumers link marginal benefits and marginal costs on well-functioning infrastructure.

57. User fee revenues are not always earmarked or spent for the priced service, particularly if the service is provided publicly, and this can distort the rationing function for infrastructure services and result in poor service levels. Palestinian municipalities, particularly in the West Bank, are reputed to divert electric and water revenues for general fund purposes (though this may not be true in many municipalities). Limitations on alternative general fund revenues may be a key reason because essentially all local revenues operate mostly as transfers. Further, it may be politically less costly to divert user fees and underprovide services than to levy and collect a set of small fees and taxes.

58. The price needs to be set regularly to ensure that all costs, including capital and operations and maintenance, are properly reflected in the pricing decision. Pagano (2011) notes that the public sector is often unwilling to price services properly because of a disconnect between capital and operations and maintenance budgets, the lack of visibility to users of the

capital stock, and a common pool resource problem. He observes that private sector providers are often better able to price services and will also be better at earmarking the revenues for service delivery, both of which create a significant advantage to privatization.

59. Pricing is complicated for infrastructure where exclusion is difficult, such as roads.[6] Second-best financing mechanisms can often be found even when marginal prices cannot be set, such as fees imposed on all property owners along a road. The fees are lump sum and do not offer rationing benefits since they are unrelated to usage but they provide a revenue source for operations and maintenance of the assets. In many such cases, general revenues and/or transfers may be required/used to finance operations and maintenance. Good operations and maintenance has less implication for linking marginal benefits and marginal costs when general revenues are used since consumers are not confronted with the true marginal costs (except through means such as congestion). But, the broader value of infrastructure services to welfare and production is not compromised.

60. Operations and maintenance funding is determined through the political process in competition with other service options when general fund revenues are used.[7] Resources to operate and maintain infrastructure will be allocated on an annual basis and would be consistent with user demand if the political system efficiently makes allocation choices. However, the inconsistent incentives in investment and operations and maintenance decisions and low capacity and resource constraints imposed on local governments may result in inappropriate funding of operations and maintenance (and other public services).

VII. Conclusion

61. Infrastructure services are essential to promoting economic growth and wellbeing in developing countries. Recent academic work has finally come to recognize what many practitioners already knew: operations and maintenance expenditures are key to meeting the demands of households and businesses and ensuring accessibility and viable service flows from the stock of infrastructure capital. Adequate operations and maintenance also reduces pressures on the capital stock itself and can provide cost savings for users, as with a good quality road that does not impose excess wear and tear on vehicles.

62. Recent theoretical contributions have greatly improved our understanding of the possible effects of operations and maintenance spending. Noteworthy is the finding that greater donor finance optimally means lower operations and maintenance spending. There is also formal recognition that poor operations and maintenance can reduce the durability of private capital. It is somewhat surprising that such findings are just now appearing in the literature.

63. Operations and maintenance activities could conceivably be undertaken by a higher level of government, a local government or the private sector. We believe that private sector options should be pursued to the extent possible as should decentralization of operations and maintenance. Competitive bidding and private sector competition offer the hope of lower costs and improved quality service. The proposed private sector solution is not a panacea. The private sector can be inefficient absent sufficient competition and private sector agents are prone to

6 Tolls and other marginal cost mechanisms can be imposed in some cases.

7 Of course, earmarking of revenues for excludable infrastructure does not strictly prevent government from reconsidering the expenditure uses during the budget process since the earmarking can often be changed by statute.

corruption and bribery as are many public sector officials. Moreover, private enterprises are not entirely free of pressures from the state in developing countries. But private sector entities may have greater motivation to price and charge (as feasible) for services and better ensure cost recovery and the ability to sustain service flows than the public sector.

64. We also ask for a broader perspective on the puzzle that considers the social efficiency of operations and maintenance expenditures that have typically been viewed in isolation of other public sector choices. Observed levels of operations and maintenance can easily be criticized as being too low. At the same time it is entirely possible that developing countries have too much of some forms of infrastructure relative to tastes, private sector consumption opportunities and the ability to support operations and maintenance.

65. Finally, we recognize the potential political economy problems that arise in setting operations and maintenance spending. These problems are nothing less than daunting and raise the specter of ongoing and potentially unavoidable compromises to proper funding of operations and maintenance. The private sector solution noted above offers the best hope of ensuring infrastructure service delivery.

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