American Economic Review: Papers & Proceedings 2016, 106(5): 77–82
http://dx.doi.org/10.1257/aer.p20161095

INFRASTRUCTURE AND DEVELOPMENT[‡]

Infrastructure, Incentives, and Institutions[†]

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The cities of the West were once places of death. Twenty thousand perished in Paris during the second cholera pandemic during the 1830s. Chicago lost one-twentieth of its population in 1854 during the third cholera pandemic.[1] Today, life expectancies in New York City are three years longer than in the rest of the country.

The transition from urban illness to health is often linked to great infrastructure achievements, like New York's Croton Aqueduct or Haussmann's Parisian Sewers. This received lesson of engineering triumphalism has led toward an infrastructure-intensive approach toward health in developing-world cities, including the Millennium Challenge Corporation's recent US$350 million investment in water infrastructure in the city of Lusaka.

Yet, engineering alone did not bring health to the cities of the West. New York's 1866 cholera epidemic occurred 25 years after Croton brought clean water to the city. Poorer New Yorkers weren't willing to pay the connection fees that would have brought piped water directly to their home. They weren't even willing to walk to the free hydrants. We see the same behavior in the developing world today, where expensive infrastructure fails because of the "last-mile problem"—the inability to connect the infrastructure with the final user.

In the next part of this paper, we present a model in which the average cost of health-related infrastructure is less than the total social benefits but greater than private willingness to pay. Standard economic reasoning suggests that either Pigouvian penalties or subsidies can induce people to internalize the external benefits and adopt the infrastructure. But the ability to impose penalties fairly and effectively depends on capable police and judges. The ability to run a subsidized sewer system without massive waste requires executive competence.

The model highlights the complementarity between infrastructure and institutions. It emphasizes that property rights are important, not just for empowering owners, but for imposing social obligations—like sewers—on the land. Contrary to Becker (1968), the model also suggests that for a wide range of parameter values fines should be small, not large, to reduce the incentive to extort the innocent.

We follow the model with a brief historical section on nineteenth century New York. After Croton, New York had a significant last-mile problem in which poor people didn't connect with the infrastructure. The city initially tried to subsidize, but its public hydrants were too few to drive out the reliance on shallow wells. New York only became healthy when it imposed penalties, typically on large property owners, which were enforced by an independent health agency.

In the final section, we turn to twenty-first century Zambia, which also has a last-mile problem. We are unsure about the appropriate

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[†] Go to http://dx.doi.org/10.1257/aer.p20161095 to visit the article page for additional materials and author disclosure statement(s).

[1] Rosenberg (1962) is the classic treatment of the American experience with cholera.

mix of subsidies and penalties in Zambia, but engineering without incentives has revealed significant challenges. As in New York, we suspect that the infrastructure will only become effective when the institutions are upgraded.

I. A Simple Model

We now present a simplified version of the lengthier infrastructure and institutions model in Ashraf, Glaeser, and Ponzetto (2016). This model examines the decision to switch from a cheaper, less expensive technology (a latrine or a shallow well) to a safer, more expensive technology (sewers and piped water). The switch is publicly beneficial, but not privately optimal without either a Pigouvian penalty or subsidy.

The two technologies create two types of costs: the physical costs of infrastructure adoption and the health costs of disease. Individuals attempt to minimize the sum of these costs. We let $B(D)$ denote the per capita health benefits minus adoption costs of switching from the cheap technology to the expensive technology and we assume that $B(D) > 0$ and $B'(D) > 0$. We also let $G(D)$ denote the gap between average cost and private benefit at the point of full adoption, with $G'(D) < 0$. These functions are micro-founded in Ashraf, Glaeser, and Ponzetto (2016).

If $G(D) \leq 0$, then a no-subsidy equilibrium exists with full adoption. We restrict our attention to cases where $G(D) > 0$, which means that some government intervention beyond coordination is needed to ensure adoption. Our interest is not in the externality from adoption, but in the difficulties that occur when weak governments try to correct externalities. For example, the simplest means of ensuring adoption is to use taxes to subsidize adoption. The minimum effective subsidy equals G.

But we add the assumption that subsidies are not costless, either because the tax system is distortionary, or because subsidies weaken the incentive to cost-minimize by the infrastructure builder, or because a subsidized system will be corrupt, or because allowing subsidies in one area, like water, means opening the floodgates for subsidies in other areas that are socially wasteful. To capture these costs we assume that the social cost of subsidies equals $1 + \delta$ times the subsidy amount. Hence, full adoption with subsidies dominates no adoption if and only if $\delta G > B$.

Most recent discussions of clean water in developing-world cities have focused on subsidies, but, as we discuss in the next section, subsidies weren't largely the path to healthier cities in the West. To consider the trade-off between subsidies and penalties, we now introduce a second public policy option: fining individuals who use the individual technology.

We assume the penalty technology imposes an administrative cost of g per household. Second, if individuals bribe inspectors, there is a social cost of z times the bribe level. The technology of inspection involves a probability μ that a property will actually be inspected, and a probability ϕ that the owner can be identified. This second parameter is meant to capture the obvious difficulties in enforcing penalties against slum dwellers whose property rights are poorly defined. If the owner is not identified, he cannot be fined.[2] Cities without property ownership face extra challenges in reducing externalities.

If the owner is found, then the inspector can accuse him of violating the regulations. If no accusation is made, then nothing happens. If an accusation is made, then the accused must pay F if he is convicted and nothing if he is not convicted. With identical probability $1/(1 + A)$ the courts wrongly convict the innocent and wrongly acquit the guilty. The inspector receives a small benefit bF for each accusation that leads to a conviction and pays a cost i for each accusation that leads to acquittal.

The inspector may solicit a bribe to drop the charge with a take-it-or-leave-it offer, and if the accusation threat is credible then the bribe demand will be met as long as it is not greater than the expected cost of going to court. An accusation threat is credible if and only if the expected value of going to court is strictly positive for the inspector.

Social costs are piecewise linear in the size of the fine with a break at Ai/b, so the optimal fine to induce full adoption can be zero, Ai/b, or a fine level that is high enough to ensure adoption with no subsidies. Imposing a fine of Ai/b and subsidies can be optimal if and only if A is greater than $\underline{A} = \left[gG + \sqrt{gG(gG + 4\Pi B)}\right]/(2\Pi B)$. Pure fines are better than non-adoption if and

[2] This point echoes Glaeser and Shleifer's (2001) emphasis on observability in designing the appropriate response to a negative externality.

only if A is greater than $\overline{A} = 1 + zG/(B - g)$. A fine of Ai/b or less can insure adoption without subsidies if and only if A is greater than $A^* = \left[G + \sqrt{G(G + 4\Pi)}\right]/(2\Pi)$. Our parameter assumptions, which follow, imply that $1 < \underline{A} < \overline{A} < A^*$.

Pure subsidies dominate non-adoption if and only if $\delta < \delta_{S\sim N} = B/G$. A fine that doesn't generate extortion of the innocent plus subsidies (as needed) dominates pure subsidies if and only if $\delta > \delta_{S\sim F}(A) = \max\left\{g(1+A)/\left(\Pi A^2\right), g/G\right\}$, which reaches its minimum of g/G if and only if $A \geq A^*$. Pure fines dominate fines plus subsidies if and only if $\delta > \delta_{F\sim E}(A) = zG(1 + A)/\left\{\left[G(1 + A) - \Pi A^2\right](A - 1)\right\}$. Non-adoption dominates fines plus subsidies if and only if $\delta > \delta_{F\sim N}(A) = (B - g)(1 + A)/\left[G(1 + A) - \Pi A^2\right]$.

While we consider the full range of cases in Ashraf, Glaeser, and Ponzetto (2016), here we choose a particularly illustrative range of parameter values to showcase our main results. We assume that $2G > \Pi$, $2gG/\Pi > B > g + 2z\Pi G/\left[G - 2\Pi + \sqrt{G(G + 4\Pi)}\right]$ and $z/g \geq 1/G + 1/\Pi - 3/\sqrt[3]{4\Pi G^2}$. Then optimal public action is characterized in Figure 1.

When legal and executive quality are both low, then non-adoption is the best policy. As in Djankov et al. (2003), there is a battle between the private losses from uncorrected externalities and the public losses from corruption and waste, and when governments are extremely inept, the private losses may be the lesser evil. When executive quality is high (low values of δ), then subsidies are the right strategy, especially when legal quality is particularly poor (low values of A).

Even when the judiciary is mediocre, it can be optimal to use a combination of fines and subsidies, but the level of fines must be small enough to deter abuse of the innocent. When executive waste is sufficiently large, as long as $A > \overline{A}$, then it is optimal to have fines even with extortion of the innocent. Finally, when the judicial branch is sufficiently strong, then fines without extortion are sufficient to induce adoption of the healthier collective technology. The model emphasizes the strong complementarity between infrastructure and institutions.

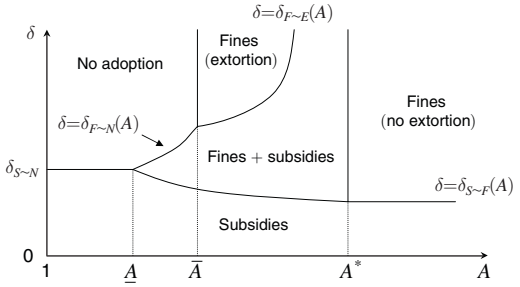

FIGURE 1. OPTIMAL POLICY AS A FUNCTION OF LEGAL AND EXECUTIVE QUALITY

II. Disease and Infrastructure in Nineteenth Century New York

In 1924, the director of the Museum of the City of New York wrote that "the year 1842 marked what was perhaps the greatest forward stride in the city's history—the general introduction of running water" (Brown 1924, p. 83). That great forward stride may have been missed by the over 7,500 New Yorkers who died of Cholera in the decade after 1842 (Condran 1995). Death rates were high for another quarter century after the engineering marvel brought clean water 41 miles from upstate.

For decades after the Croton infrastructure was built, New York City had its own version of the last-mile problem that afflicts most developing countries today. Croton water was available, but households often continued to use the deadly shallow wells because of a combination of convenience and cost. The cost of connecting to Croton was $10 per household plus an annual water fee. Poorer households were provided free water by hydrants, but by 1860 there were only 2,307 hydrants in New York, about one for every ten acres. Consequently, poorer families continued to use shallow wells and to pour waste and excrement into wood-lined privies that infected those wells.

The landmark 1865 *Report of the Council of Hygiene and Public Health of the Citizens' Association of New York* reports on each ward two decades after the Croton Aqueduct opened. In poorer wards, "the use of water from wells into which the putrid soakage of filth had percolated, are clearly proven to be the causes of the diarrheal diseases of that district;" "in some of these houses the Croton-water and

waste-pipes have been introduced, but in most of them the Croton-water is introduced only to the court-yard, or area;" and "where the Croton hydrants are too far away, and the ground is marshy, the water is obtained from holes dug a little below the surface" (Citizens' Association of New York 1865, p. cviii, p. 25, p. 300). The 1865 Citizens' Association *Report* is replete with discussions of "accumulating" and "exposed" sewage made up of "putrefying organic materials" and "street-filth." The ratio of social benefits to private benefits is even higher with sewers than with piped water.

New York was not blind to the downsides of being a city of filth. Just as our model suggests, reformers advocated for both fines and subsidies. John Griscom had been health inspector of New York City in 1842, when he issued a path-breaking report on the city's poor sanitary conditions that supported subsidized (free) Croton water. Griscom also demanded an urban "health police" who would monitor sanitary conditions. If a tenement owner failed to fix unsanitary conditions, Griscom recommended that he should be fined $50 plus the cost of the public fixing the problem directly. Griscom's report favored professionalizing the health inspectors and making them independent of local politics.

Stephen Smith realized Griscom's dream by spearheading the campaign that established the Metropolitan Board of Health in 1866, a year after the cholera outbreak of 1865. The Board's enforcement powers were tied to Tenement Acts, passed in 1867, 1879, and 1901, which imposed on property owners requirements relating to water provision, sewerage, and ventilation. The Board could also issue rules, such as its 1869 ban on roaming pigs and goats.

The Board's independent but public institutional structure was a popular mainstay of nineteenth-century reformers. Earlier attempts at clean water provision in New York City had unsuccessfully tried private provision with the Manhattan Water Company. Public, but independent, entities were seen as avoiding the pitfalls of profit-maximizers, who would put profits ahead of public health, and political machines, which would appoint incompetent hacks. Yet this model also has limitations. Parastatal enterprises in sub-Saharan Africa today are more often accused of corruption than competence.

Legal requirements and penalties were politically palatable because they were imposed on presumably wealthier property owners, not on the poorer tenants themselves. Naturally, standard economic logic suggests that tenants ultimately paid the costs, but such equilibrium effects may not have been obvious to voters. Landlords may also have been strong enough to avoid extortion by corrupt police. New York could apply penalties on landlords because it was a city of renters and typically well-defined property rights, but this solution is less likely to be available in the cities of the developing world, where property rights are poorly defined. New York's bigger buildings may have also made enforcement easier than Lusaka's dispersed dwellings.

By the 1920s, New York had become essentially as healthy as the nation as a whole because of the decline in contagious disease, which was partially the result of clean water (Cutler and Miller 2005).

This history teaches that infrastructure is necessary but not sufficient. Incentives were needed as well. New York moved from subsidies (free hydrants) to fines, which reflected a realization that subsidies were insufficient, at least at the scale that New York City was prepared to provide. More subsidies would have also encouraged even more migration to New York City. New York's fine system was accompanied by a move for institutional improvements.

III. Disease and Infrastructure in Twenty-First Century Zambia

Zambia's capital city of Lusaka has a population of over 1.8 million, and it is projected to grow to five million residents by 2035. Zambia has also been one of the world's fastest growing economies over the past decade, with an average real GDP growth rate of 6.4 percent per annum. Despite this, however, Zambia continues to experience regular outbreaks of waterborne diseases in urban areas—-the last cholera outbreak in Lusaka occurred as recently as 2016. Not only do such crises bring significant health problems, but the often dilapidated state of the system's core infrastructure also forces Lusaka's residents and businesses to waste substantial time resolving water supply shortages and delays (Ashraf et al. 2016).

Major piping infrastructure was built in Lusaka in the 1960s and 1970s, and the system's infrastructure is now often outdated and broken.

A baseline study in 2005 found that out of the approximately three million people surveyed, "four out of five people were found to live in areas close to utility networks, yet the majority were not being served by the utilities" (Blume et al. 2015, p. 25). Water and sanitation services are available, but as in 1865 New York, people don't connect.

In the 1970s, water and sanitation interventions focused on rehabilitating the physical infrastructure, and as in New York, accompanying institutional reform. Unlike in New York, international partners supported investment in both infrastructure and institutions, and dictated how and when tariffs were introduced. In the years 1975–1983, the World Bank funded the Lusaka Squatter Upgrading and Sites and Services Project to expand the water and sewage infrastructure into the peri-urban areas and to improve the institutional capacity of the Lusaka Urban District Council (World Bank 1983).

The project included an expansion of the water and sewer network and upgrading of approximately 26,000 households (with access to communal taps). Another 1,000 plots were developed to contain homes with the possibility of private connections to water and sewer. While plot owners applied for their water connections, no connections had been made for sewer services at the time of the completion report (World Bank 1983). This suggests that a project that cost about $53 million in 2015 dollars had little effect on sanitary conditions, because of the last-mile problem.

The project faced institutional challenges. Issuing property titles took a long time. Even when water services were actively sought, the utility mostly failed to collect water service fees. In the years 1982–1983, collected fees represented only 10 percent of actual operational costs (World Bank 1992). While our model suggests an active choice between subsidy and fee-for-service, the Zambian example suggests that when institutions are really weak, free services may be the only feasible option. Subsequent projects tried to improve institutional capacity by training accountants, but the Government of Zambia failed to provide the accounting personnel to be trained (World Bank 1992).

As institutional weaknesses prevented the water sector from advancing (Nyambe and Feilberg 2009), health risks loomed. While a smaller cholera outbreak was recorded in 1977, Zambia experienced a major outbreak between the years 1990 and 1993, with 13,154 cases reported in 1991 and 11,657 cases reported in 1992 (Nyambe and Feilberg 2009). Another major cholera outbreak followed ten years later, recording 2,529 cases and 128 deaths due to cholera.

These outbreaks gave water and sanitation improvements a sense of urgency, which resulted in the Water and Sanitation Act of 1997, which established a separate regulatory body, the National Water Supply and Sanitation Council, commercialized the water and sanitation service delivery, and established the Devolution Trust Fund, which supported solutions to the last-mile problem in the peri-urban areas (Nyambe and Feilberg 2009). While this reform tried to foster financial sustainability for the utilities, subsidies remain. As of 2009, international partners provided 70 percent of the budget for the commercial utilities (Nyambe and Feilberg 2009).

In 2012, there were 22,000 sewer connections in Lusaka serving a population of more than 1.8 million; the US government, through the Millennium Challenge Corporation, contributed $354,757,640 to create the Lusaka Water Sewage Sanitation Delivery project. Eighty percent of this grant is for infrastructure activity; the remaining 20 percent is distributed as: 8 percent for institutional strengthening, 11 percent for program administration and audit, and 2 percent for monitoring and evaluation. Given the experience of both Lusaka's history in the twentieth century and New York's experience in the nineteenth century, the proportion of attention and resources (including political resources) to spend on institutional development versus infrastructure appears quite important in determining whether the infrastructure investment will work.

The last-mile problem remains in Lusaka, and it seems likely to continue unless the city finds a mean of using either sanctions or subsidies to close the gap between willingness and ability to pay and service cost. The Lusaka Water and Sanitation Company estimates the cost of connection at $960, in an area where the average monthly income is approximately $440.

The willingness to invest in water and sewer connections falls when residents do not actually own the property and will not reap the long-run returns from any investment. The New York City history suggested that penalizing landlords can

be more politically acceptable than penalizing tenants, but ill-defined property rights in Lusaka make it difficult to know who has de facto control over a piece of land. There is qualitative evidence from settlement projects in Lusaka that when building new concrete block homes on existing sites, families "chose the house design which allows two families to stay with shared services, making it possible for them to sublet and recoup the additional expenditure through higher rents" (World Bank 1983, p. 13). This suggests that there is an underlying value for these services which can be partially recouped though market rents.

IV. Conclusion

Health-related infrastructure, like water pipes and sewers, generates positive externalities. Consequently, even if the public benefit from that infrastructure exceeds its physical costs, those costs may still exceed private willingness to pay. The economist's ancient answers to this problem—Pigouvian taxes or subsidies—become difficult to implement when institutions are weak. Hence, there is a fundamental complementarity between infrastructure and institutions that is central to improving quality of life in the developing world.

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