Public and Private Infrastructure

Michael Kremer - *Harvard University*
Jack Willis - *Harvard University*

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Introduction

- Developing countries facing many infrastructure decisions.
  - Averaged 8.5% of GDP in China from 1992-2011, compared to 2.6% in USA

- Public and private infrastructure often complements or substitutes
  - Housing complements subway stations
  - Solar panels substitute for grid electricity

- Expectations over future public behavior affect private behavior, if infrastructure is durable

- In turn, private infrastructure affects demand for public infrastructure, and hence future public behavior
Dynamic coordination game between decentralized private agents and government can have multiple equilibria

If government can commit, potential benefit of early announcement of future public infrastructure investment

If government cannot commit, may be driven to second best policies, e.g.
- early construction of public infrastructure
- taxes of some types of private infrastructure
Introduction

- Easy to see when public and private infrastructure are complements
  - residential and commercial building with transport, water and electricity infrastructure
  - HD televisions with HD capable transmission networks
- Commitment to future location by government helps avoid:
  - mis-coordination
  - inefficient delays in private investment
We consider two cases when public and private infrastructure are substitutes

1. Public and private infrastructure perfect substitutes but public infrastructure has economies of scale
   - water filters vs. clean piped water
   - latrines vs. sewers
   - solar lanterns / panels vs. grid electricity

2. Government wishes to subsidize infrastructure, e.g. latrines due to health externalities
Setup

Preferences

- Individual utility $\int_{0}^{\infty} e^{-\rho t} (u(c_t) + u'_I) dt$. Constant intertemporal elasticity of substitution $\theta$
- Once installed, infrastructure gives flow utility $u_L$. No intensive margin. No depreciation.

Technology

- Private infrastructure has cost $p_p$, always available on perfectly competitive market.
- Public infrastructure has fixed cost $F$ and marginal cost of connection $< p_p$. Individuals can only connect once it is built.
- Constant exogenous rate of technical change $g > 0$ in standard Ramsey model of closed economy with perfect financial markets.
  - Steady state $\Rightarrow r = \theta g + \rho$
Setup

Government

- Government trying to maximize welfare. Assume marginal consumption weighted equally across two types at $t = 0$
- Choose when to build, when to announce, lump sum taxes, price of connection to public infrastructure
- We also consider case when no taxes and investment has to be budget neutral

Endowments

- Two type wealth distribution, h with wealth $w_H$, l with $w_L$

Solution concept

- Solve individual behavior given government policy, then optimal policy given individual behavior
- Typically results in fixed price of connection, $p_I$
Individual optimization problem, given prices

- Individuals choose consumption and infrastructure purchase plan function of initial endowment, taxes, time of public infrastructure installation and price of public infrastructure.

- Consumption grows at rate $g$ and satisfies intertemporal budget constraint. Implies growing demand for infrastructure.

- Consider case where only private infrastructure available
  
  - Optimal purchase time: $t^*(p) = \frac{1}{\theta g} \ln \left( \frac{u'(c_0)pr}{u_L} \right)$
  
  - Willingness to pay, at time 0, for the option to purchase in the future at price $p$: $v(p) = \left( \frac{u_L}{u'(c_0)} \right)^{r/\theta g} \frac{\theta g}{\rho} p^{-\rho/\theta g}$

- Consider case where public infrastructure available but no private
  
  - Willingness to pay for option depends on construction time, $t$.
  
  - Same as above until $t > t^*(p_I)$

  - $w_{NP}(t) = \begin{cases} v(p_I) & \text{if } t \leq t^*(p_I) \\ e^{-rt} \left( \frac{u_L}{\rho u'(c_I)} - p_I \right) & \text{if } t > t^*(p_I) \end{cases}$
Demand with both public and private infrastructure

- Willingness to pay, in units of time 0 consumption, for public infrastructure construction at $t$
  - reduced by outside option of private, $v(p_p)$
  - for $t > t^*(p_p)$, depends upon earlier beliefs on public infrastructure construction - may have purchased private infrastructure at $t^*(p_p)$
  - zero beyond a certain $t := \hat{t}(p_I, p_p)$, since prefer to buy private infrastructure at $t^*(p_p)$ instead

- Aggregate willingness to pay: $hw_I^H(t) + lw_I^L(t)$
Public infrastructure first best?

- Easier to work with willingness to pay at construction time

\[
w_C(t) = \begin{cases} 
\left( \frac{\theta g}{\rho} p_l^{\rho/\theta g} - \frac{\theta g}{\rho} p_p^{\rho/\theta g} \right) p_l^{r/\theta g} e^{r(t-t^*(p_l))} & \text{if } t \leq t^*(p_l) \\
\max \left\{ \frac{ppr}{\rho} e^{-\theta g(t^*(p_p)-t)} - \frac{p_p \theta g}{\rho} e^{-r(t^*(p_p)-t)} - p_l, 0 \right\} & \text{if } t > t^*(p_l)
\end{cases}
\]

- Note \( w^L_C(t) \) is just \( w^H_C(t) \) shifted to right by \( \frac{1}{\theta g} \ln \left( \frac{u'(c^L_0)}{u'(c^H_0)} \right) \)
Public infrastructure first best?

Public infrastructure built in first best if \( h w^H_c(t) + l w^L_c(t) > F \) for some \( t \)

Public infrastructure more likely if:

- Cost of public infrastructure low relative to private infrastructure
- Inequality low, since inequality pulls \( w_c \) curves apart
- Growth rate, \( g \), high
- Intertemporal elasticity of substitution, \( \theta \), high
- Impatience, \( \rho \), low
Equilibria

- Surplus from construction at time $t$, in willingness to pay at $t=0$:
  \[ S(t) = hw^H_I(t) + lw^L_I(t) - Fe^{-rt} \]
- First best: $t_{FB} = \arg\max_t S(t)$
- Suppose $S(t_{FB}) \geq 0$. Three cases for $t_{FB}$:

![Diagram with curves and points labeled A, B, and C representing $t^*(p_p)$ and $\hat{t}_H(p_I, p_p)$]
Equilibria

- **Case A** ($t_{FB} < t^*_H(p_p)$)
  - one equilibrium, all connect to public infrastructure

- **Case C** ($t_{FB} > \hat{t}_H(p_I, p_p)$)
  - efficient for H to install private infrastructure.

- **Case B** ($t_{FB} \in (t^*_H(p_p), \hat{t}_H(p_I, p_p))$)
  - Multiple equilibria if $lw_l^I(t) - Fe^{-rt} < 0 \ \forall t$:
    - both invest in private, H at $t^*_H(p_p)$ and L at $t^*_H(p_p)$, and public isn’t built
    - or, H waits for public and connects to it as soon as it is built.
Tools available to government

If it can, government will commit to \( t^\ast_H(p_p) \):

- If it has access to lump sum taxes, first best attained
- Assume instead infrastructure has to be budget neutral
  - If it can price discriminate by wealth, first best still attained
  - If it can only price discriminate by connection time, incentive compatibility constraint on \( H \)
    - Potential hold-up problem: ex-post, \( H \) willing to pay up to \( p_p \) for connection after \( t^\ast_H(p_p) \)
  - If it cannot price discriminate, may build public infrastructure later or tax private infrastructure to increase willingness to pay for public

If it cannot commit, government may:

- tax private infrastructure, first best in this example but potentially distortionary in more complex examples
- build public infrastructure early, at \( t^\ast_H(p_p) \)
Subsidies

- Assume one type of infrastructure technology and homogenous wealth
- Many types of infrastructure, such as latrines, have positive externalities $u_S$
- Standard response: Pigouvian subsidy
- Expectation over future rises in subsidy can delay investment
- Suppose subsidy $s$ can only be implemented at time $t$. As $t \to$ latest time individual is willing to wait for the subsidy, $\hat{t}(p - s, p)$:
  - Ignoring externality, associated delay in investment will dissipate benefit to individual completely
  - Accounting for externality, subsidy may actually lower welfare
- Consider general case: subsidies $s(t)$, so $p(t) = p - s(t)$
Demand: \( t^*(p(t)_{t \geq 0}) = \arg\max_t e^{-\rho t} \frac{u_L}{u'(c_0)} - e^{-rt} (p - s(t)) \)

Expectations of future increases in \( s(t) \) push back \( t^* \)

Socially optimal time: \( t^*_S = \frac{1}{\theta g} \ln \left( \frac{u'(c_0)pr}{u_L + u_S} \right) \)

Achievable with subsidies. Lower cost if can commit to a one-off subsidy, or at least a subsidy which is not rising

The contrasts the static viewpoint, where the subsidy should grow over time because the monetary value of the externality grows over time.

General point when subsidizing durables: important to consider impact on expectations of future subsidies

NGOs can make government commitment harder. Government may wish to regulate NGOs subsidies on durables
Conclusion

- Interactions of private investments with public infrastructure may result in a coordination game with multiple equilibria.
- Expectations over future public infrastructure are important.
- Commitment to future investments in public infrastructure ensures efficient outcome.
- Absent commitment, taxes on private infrastructure or early construction of public infrastructure may help.
  - Possible factor in China’s huge infrastructure push.
- Inequality leads to divergence in optimal times for infrastructure installation, making public infrastructure less likely.
  - Potential driver of segregation.
- For durables with externalities, expectations of future rises in subsidies may reduce welfare.