Is infrastructure capital productive?

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*The World Bank*

The Economics of Infrastructure in a Globalized World
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**Motivation**

From development perspective, two reasons to care about infrastructure:

- **Infrastructure and growth**
  - Infrastructure raises productivity / reduces cost of private production

- **Infrastructure and poverty / inequality**
  - Infrastructure expansion has a disproportionate effect on the income / welfare of the poor
    - Reduces their cost to access markets (e.g., labor)
    - Raises the return on their assets (e.g., land)
    - Facilitates human capital accumulation directly (sanitation, water effect on health) or indirectly (transport to school etc)
Infrastructure and growth

How important is infrastructure for economic growth?

• Old question – even in Adam Smith’s *Wealth of Nations*
• Empirically revived after Aschauer (1989) – who found huge rates of return on public capital in U.S.
• Big macro literature since then using various approaches and econometric techniques
  – Also micro studies looking at firm-level growth, investment, TFP

• Two common approaches
  – Growth regressions augmented with infrastructure measures
  – Infrastructure as another input in an aggregate production function (or its dual, the cost function)

Infrastructure and growth

On balance, majority of studies – especially recent ones on developing economies – find significant positive effects

But major caveats with most:
1. Multidimensionality of infrastructure: not just telephones (omitted variable bias?)
2. Monetary measures of infrastructure often misleading (Pritchett 2000; Keefer-Knack 2007)
3. Non-stationarity of aggregate output and infrastructure capital *(spurious regression* problem; Gramlich 1994)*
4. Reverse causality: richer countries / times demand more infrastructure services
5. Potential heterogeneity in cross-country estimations
Calderón, Moral-Benito and Servén (2010)

Methodological approach addressing these caveats:
1. Considers the multidimensionality of infrastructure by using a synthetic index of telecom, transport and power.
2. Uses physical measures of infrastructure assets, rather than cumulative expenditures (Canning; Roller-Waverman)
3. Panel time-series approach to deal with non-stationarity of the variables.
4. Verifies that only one long-run relationship (= the aggregate production function) exists among the variables.
5. Allows for unrestricted short-run heterogeneity, and tests for homogeneity across countries of the long-run parameters.

Calderón, Moral-Benito and Servén (2010)

• Focus on the contribution of infrastructure to labor productivity (GDP per worker)
• Production function approach (under CRS):
  \[
  Y/L = f(K/L, H/L, Z/L)
  \]
  where \( Y, K, H \) and \( Z \) are GDP, physical capital, human capital, and infrastructure capital.
• Data from 88 industrial and developing countries, 1960-2000 (> 3,500 obs)
• \( Z \) measured by synthetic infrastructure index – 1st principal component of road density, telephone density and power generation capacity [details]
• \( f(.) \) viewed as a long-run cointegrating relation whose parameters may be different across countries
Production function approach

- Cobb-Douglas technology: in log per worker terms,
  \[ y = \alpha k + \beta h + \gamma z \]
- Infrastructure capital appears twice in the equation (as part of \( k \), and separately as \( z \)). [details]
- The parameter \( \gamma \) captures the “excess return” on infrastructure relative to other capital.
- The marginal product of infrastructure is higher the lower are infrastructure endowments per unit of output \( z – y \)

Empirical strategy

Three-step approach – based on recent panel time-series literature.
(1) Test for (non-)stationarity of the variables
(2) Test for cointegration and for a common cointegrating rank across countries [details]
(3) Estimate the cointegrating relation(s), and test for parameter homogeneity across countries
Estimation approach

- Tests reveal a common cointegrating rank of 1 [details]
- To estimate the cointegrating relation, use Pooled Mean Group estimator (Pesaran, Shin and Smith 1999)
  - Test for weak exogeneity, so single-equation approach suffices
  - Intercepts, error variances and short-run dynamics can differ freely across countries
    - Frictions and adjustment costs may vary across countries
    - Experiment with alternative dynamic specifications
    - Allow for cross-country error correlation (common shocks)
  - Long-run coefficients restricted to be equal for all countries
    - Test the restrictions through individual and joint Hausman tests of parameter homogeneity

Basic estimation results

<table>
<thead>
<tr>
<th>Column</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
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<tbody>
<tr>
<td>Max # of lags</td>
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<td>2</td>
<td>1</td>
<td>4</td>
<td>2</td>
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<td>Information criterion</td>
<td>SBC</td>
<td>AIC</td>
<td>Imposed</td>
<td>SBC</td>
<td>SBC</td>
<td>SBC</td>
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<tr>
<td>Common factors</td>
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<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
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<td>Physical Capital</td>
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<td>0.36</td>
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<td>0.34</td>
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<td>t-ratio</td>
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<td>30.5</td>
<td>22.7</td>
<td>31.4</td>
<td>32.4</td>
<td>33.4</td>
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<tr>
<td>Hausman p-value</td>
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<td>0.95</td>
<td>0.43</td>
<td>0.78</td>
<td>0.44</td>
<td>0.52</td>
</tr>
<tr>
<td>Human capital</td>
<td>0.10</td>
<td>0.12</td>
<td>0.10</td>
<td>0.12</td>
<td>0.11</td>
<td>0.12</td>
</tr>
<tr>
<td>t-ratio</td>
<td>15.6</td>
<td>14.8</td>
<td>8.09</td>
<td>18.7</td>
<td>17.1</td>
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<tr>
<td>Hausman p-value</td>
<td>0.24</td>
<td>0.19</td>
<td>0.21</td>
<td>0.19</td>
<td>0.20</td>
<td>0.64</td>
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<tr>
<td>Infrastructure</td>
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<td>0.07</td>
<td>0.10</td>
<td>0.08</td>
<td>0.08</td>
<td>-0.02</td>
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<td>t-ratio</td>
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<td>6.73</td>
<td>6.58</td>
<td>8.33</td>
<td>8.77</td>
<td>-1.49</td>
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<tr>
<td>Hausman p-value</td>
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<td>0.18</td>
<td>0.16</td>
<td>0.40</td>
<td>0.88</td>
<td>0.40</td>
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<tr>
<td>Joint Hausman p-value</td>
<td>0.44</td>
<td>0.38</td>
<td>0.24</td>
<td>0.25</td>
<td>0.45</td>
<td>0.85</td>
</tr>
<tr>
<td>Average R²</td>
<td>0.36</td>
<td>0.40</td>
<td>0.48</td>
<td>0.28</td>
<td>0.42</td>
<td>0.35</td>
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<tr>
<td>Observations</td>
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<td>3432</td>
<td>3432</td>
<td>3520</td>
<td>3256</td>
<td>3432</td>
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</tbody>
</table>
Basic estimation results

- Estimates are robust across specifications
  - Except if cross-country error correlation ignored
  - Little changed when using alternative measures of infrastructure, $h$ and $k$ [details]
- Coefficients on standard variables (physical and human capital) in line with literature (around 0.35, 0.10)
- Infrastructure coefficient in range 0.07 to 0.10
- No evidence of cross-country parameter heterogeneity
  - Accords with empirical evidence on stability of factor shares (Gollin 2002)
  - But country-specific estimates are noisy (especially in poorer countries)

Further homogeneity tests

- No evidence of (general) parameter heterogeneity across countries – but tests may have low power
- Same conclusion from (more powerful) tests for specific forms of heterogeneity: [details]
  - By income level: infrastructure elasticity could be different in rich and poor countries
  - By level of infrastructure endowment: nonlinear effects of infrastructure (network effects?) [details]
  - By population size: economies of scale / congestion effects.
  - By quality of policy framework: high / low distortions – (close to 10% significance)
Further homogeneity tests
Output elasticity of infrastructure vs. per capita GDP

Economic significance
Direct increase in output per worker from infrastructure catch-up to OECD median (percent)

<table>
<thead>
<tr>
<th>Region</th>
<th>Increase in output per worker</th>
</tr>
</thead>
<tbody>
<tr>
<td>East Asian Tigers</td>
<td>11.5%</td>
</tr>
<tr>
<td>Eastern Europe</td>
<td>8.3%</td>
</tr>
<tr>
<td>Latin America</td>
<td>13.7%</td>
</tr>
<tr>
<td>Middle East &amp; N. Africa</td>
<td>15.5%</td>
</tr>
<tr>
<td>South Asia</td>
<td>26.0%</td>
</tr>
<tr>
<td>Sub-Saharan Africa</td>
<td>36.3%</td>
</tr>
</tbody>
</table>
From analysis to action

- All this is about the benefit side – what about the cost?
- Cost-benefit comparison needed to determine extent of under-provision of infrastructure – and whether it is greater than that of other inputs (e.g., H)
  - Limited evidence on this (e.g., Canning and Pedroni 2008: no generalized infrastructure shortage across countries / sectors)
  - Calderón and Servén (2010): big income impact of infrastructure catch-up in Africa – but massive cost involved [details]
  - Loayza and Odawara (2010): big income impact in Egypt too – but only if much of the cost is financed by spending cuts elsewhere
- Quality (not only quantity) of spending matters
  - Impact on assets/services depends on government technical capacity, fiscal institutions, governance

Summary

Robust evidence of a positive contribution of infrastructure to GDP / productivity – a 10% rise in infrastructure assets directly raises GDP per worker by 0.7 to 1%.
The effect is highly significant and robust to alternative empirical specifications.
Little evidence that it varies across countries – so the returns to infrastructure are higher where the endowment is lower.
Effects are economically significant – potentially big income gains, especially for poor countries.
But careful before calling for big infrastructure spending rise – extent of underprovision unclear; reforms needed to enhance the link between spending and assets.
Data

- Output given by real PPP GDP from PWT 6.2
- Physical capital: perpetual inventory method with investment from PWT 6.2
- Human capital from Barro and Lee (2000)
- Infrastructure capital: power, transport and telecom
  - Electricity Generating Capacity (EGC) from United Nations Energy Statistics
  - Telephone lines from ITU
  - Road length in km from IRF
- These three infrastructure assets are summarized in a synthetic index constructed through a principal-component procedure. [back]
Production function approach

- Cobb-Douglas technology: in log per worker terms,
  \[ y = \alpha k + \beta h + \gamma z \]
- Infrastructure capital appears twice in the equation (as part of \( k \), and separately as \( z \)).
- Let \( \tilde{k} \) denote non-infrastructure physical capital. Then:
  \[ k = (1 - \theta)\tilde{k} + \theta z \quad \text{and} \quad \frac{\partial y}{\partial z} = \alpha \theta + \gamma \quad \text{where} \quad \theta = \frac{p_z Z}{p_z Z + p_k K} \]
- The parameter \( \gamma \) captures the "excess return" on infrastructure relative to other capital. Note also \( \theta \) is usually a small number.

Empirical strategy

Test for the existence of long-run relation(s):
- How many cointegrating relations are there?
- Is the number the same for all countries?
  - Find the minimum across countries (LR-bar test)
  - Find the maximum across countries (PC-bar test)
  - Test if they are equal

[back]
### Cointegration test results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Test Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>GDP</td>
<td>-6.20</td>
</tr>
<tr>
<td>Physical Capital</td>
<td>-7.08</td>
</tr>
<tr>
<td>Human capital</td>
<td>-1.77</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>-3.35</td>
</tr>
</tbody>
</table>

#### PANEL B: Panel LR-bar Test

<table>
<thead>
<tr>
<th>Maximum rank</th>
<th>Test Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>9.03</td>
</tr>
<tr>
<td>1</td>
<td>0.85</td>
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</tbody>
</table>

#### PANEL C: Panel PC-bar Test

<table>
<thead>
<tr>
<th>Minimum rank</th>
<th>Test Statistic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.21</td>
</tr>
</tbody>
</table>

5% critical value for the null hypothesis is 1.96 in all cases.

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### Further homogeneity tests

Output elasticity of infrastructure vs. infrastructure per worker

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![Graph showing the output elasticity of infrastructure vs. infrastructure per worker.](image)
Further homogeneity tests

Break sample into high / low along the relevant dimension – and test for equality of mean infrastructure coefficient

<table>
<thead>
<tr>
<th></th>
<th>Per Capita Income (A)</th>
<th>Per Capita Income (B)</th>
<th>Infrastructure Endowment</th>
<th>Total Population</th>
<th>Distortions</th>
</tr>
</thead>
<tbody>
<tr>
<td>High</td>
<td>0.054</td>
<td>0.044</td>
<td>0.059</td>
<td>-0.016</td>
<td>-0.156</td>
</tr>
<tr>
<td>Low</td>
<td>0.059</td>
<td>0.062</td>
<td>0.055</td>
<td>0.131</td>
<td>0.271</td>
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<tr>
<td>p-value</td>
<td>0.985</td>
<td>0.94</td>
<td>0.988</td>
<td>0.576</td>
<td>0.102</td>
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</tbody>
</table>

Additional results: alternative explanatory variables

<table>
<thead>
<tr>
<th>Column</th>
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<th>(4)</th>
<th>(5)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable Changed</td>
<td>Base</td>
<td>Total Phone Lines</td>
<td>Roads plus Rails</td>
<td>Paved Roads</td>
<td>Physical Capital</td>
</tr>
<tr>
<td>Physical Capital</td>
<td>0.34</td>
<td>0.35</td>
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<td>0.34</td>
<td>0.33</td>
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<td>32.8</td>
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<td>26.6</td>
<td>18.0</td>
</tr>
<tr>
<td>hausman p-value</td>
<td>0.54</td>
<td>0.80</td>
<td>0.48</td>
<td>0.58</td>
<td>0.05</td>
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<tr>
<td>Human Capital</td>
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<td>0.07</td>
<td>0.10</td>
<td>0.05</td>
<td>0.10</td>
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<tr>
<td>t-ratio</td>
<td>15.6</td>
<td>6.84</td>
<td>15.8</td>
<td>3.98</td>
<td>10.3</td>
</tr>
<tr>
<td>hausman p-value</td>
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<td>5.45</td>
<td>7.51</td>
<td>5.20</td>
<td>5.53</td>
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<td>0.14</td>
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<td>0.43</td>
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<td>0.20</td>
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<tr>
<td>Average R²</td>
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<td>0.37</td>
<td>0.36</td>
<td>0.35</td>
<td>0.35</td>
</tr>
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</table>
Sub-Saharan Africa: cost of infrastructure catch-up

Investment required for halving the infrastructure quantity gap with other regions