Economics of Equity in Infrastructure Investments

Application to Broadband Expansion and Digital Equity Planning

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Introduction to HDR

• HDR Overview
  • Top global engineering and architecture firm
  • Plans, designs, builds essential infrastructure (transportation, water, energy, waste, etc.)
  • Multidisciplinary broadband services
  • HDR Fellowship (supported this research)

• HDR Economics and Finance Group
  • 40+ economists in the U.S. and Canada
  • Conducted hundreds of BCAs and related analyses, using best available information and methods
  • Established Sustainable Value Analysis approach
Agenda

1. Background and Overview of BCA
2. Introduction to Weighted BCA
3. Completed Project Examples
4. Conceptual Application to Broadband
5. Discussion
Infrastructure, Distributional Effects, and Equity

- Dramatic rise in income inequality since 1980s
- Infrastructure has inherent distributional effects
  - **Access**: Infrastructure serves individuals who have access to it
  - **Service quality**: Safe and reliable service can vary area
  - **Targeted improvements**: Some improvements for target groups
  - **Barriers**: Differences arise among individuals’ abilities to pay
  - **Externalities of use**: Infrastructure can impact non-users
  - **Project scale**: Large projects are infrequently implemented
  - **Budget constraints**: Financial constraints limit implementation
  - **Cost burden**: More people contribute to costs than benefit
- Agencies seek sound, defensible methods to assess equity and distributional impacts
- Key Question: What role can economics play?
Standard BCA Methods

• **Standard Approach**
  - Follows federal BCA guidelines
  - Analytical focus: “market” value of improvements
  - Applied on major projects for decades
    - Build vs. Base Case
    - Benefits and costs over planning horizon
    - Measurable, monetizable
    - Multiple benefit categories
  - **Standardized methods** for different infrastructure

• **BCA results and contribution to decisions**
  - Increasingly **required in Federal grants**
  - **Ignores differences** in people, such as income
  - **BCA provides no input** on equity evaluation
  - **Distributional analyses** => alongside BCA

### Elements of Benefit Calculations:

<table>
<thead>
<tr>
<th></th>
<th>Scale Factors</th>
<th>Impact Factors</th>
<th>Valuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transit (travel time benefits)</td>
<td># of users</td>
<td>Travel / wait time savings</td>
<td>Value of time per trip</td>
</tr>
<tr>
<td>Flood Risk (residences)</td>
<td># of properties</td>
<td>Depth of damage</td>
<td>Property value</td>
</tr>
<tr>
<td>Energy conversion</td>
<td># of kWh of production</td>
<td>Pollutant emissions per kWh</td>
<td>Value per ton of pollutant</td>
</tr>
<tr>
<td>Broadband (labor market)</td>
<td># of employable pop (over 16)</td>
<td>% increase in job placement</td>
<td>Value of jobs (wages)</td>
</tr>
</tbody>
</table>
Alternative Approach: Weighted BCA

- Theoretically sound framework, similar to BCA
- WBCA incorporates information on the value of projects to people relative to incomes
- *Weights are computed based on value of $ to a person, according to that person’s income*
- Weights multiply with estimated benefits $B_{ij}$ and costs $C_{ik}$ to determine weighted net present value (wNPV)

\[
w_{NPV} = \sum_i \left[ \sum_j w_i^\alpha \cdot B_{ij} - \sum_k w_i^\alpha \cdot C_{ik} \right]
\]

\[
w_i^\alpha = \left( \frac{y_\alpha}{y_i} \right)^\varepsilon
\]

- $\varepsilon$ = elasticity of marginal utility of income
- $y_\alpha$ = benchmark income of region
- $y_i$ = income group $i$ in region
Analytical Summary

Standard BCA

<table>
<thead>
<tr>
<th>Category</th>
<th>Present Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time Savings</td>
<td>$6.5</td>
</tr>
<tr>
<td>Cost Savings</td>
<td>$4.46</td>
</tr>
<tr>
<td>Safety</td>
<td>$1.80</td>
</tr>
<tr>
<td>Emissions</td>
<td>$0.80</td>
</tr>
</tbody>
</table>

Weighted BCA

Income-based Weights

Key Concept: $ means more to lower income persons than higher income persons
Project Example – Transit Improvement, Lynn, MA

- Location: Lynn, MA, a northern, suburb of Boston
- Multi-modal improvements
- Local area is low-income
- Regional median inc.= $94k
- Benefits differ by mode and affected population
- Source of costs are state and federal grant funding
- Benefit categories: time savings, cost savings, safety, amenities, emissions, O&M

<table>
<thead>
<tr>
<th>Category</th>
<th>BCA Totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Time Savings</td>
<td>$6.52</td>
</tr>
<tr>
<td>Safety Benefits</td>
<td>$1.30</td>
</tr>
<tr>
<td>Emissions</td>
<td>$1.12</td>
</tr>
<tr>
<td>Amenity Benefits</td>
<td>$8.88</td>
</tr>
<tr>
<td>O&amp;M Costs</td>
<td>-$3.47</td>
</tr>
<tr>
<td>Total Benefits</td>
<td>$18.8</td>
</tr>
<tr>
<td>Cost</td>
<td>$24.83</td>
</tr>
<tr>
<td>BC Ratio</td>
<td>0.76</td>
</tr>
<tr>
<td>NPV</td>
<td>-$6.0</td>
</tr>
</tbody>
</table>

Note: Net present values, at 7% discount rate
Evaluation of Example Results

• BCA:
  • Negative NPV: it is not a project that people would be willing to pay for

• Weighted BCA:
  • Positive W-NPV: *value of benefits to users* exceeds *value of money raised from taxpayers (and fee payers)*
  • Weighted BC ratio > 1 provides compelling case of a positive *societal value-for-money*
  • **Magnitude of differences** of weighted benefits versus benefits differs by income
  • Low threshold elasticity (compared to baseline value of 1.2) indicates that these results are robust

<table>
<thead>
<tr>
<th>BCA Metric</th>
<th>BCA (PV 7% $M)</th>
<th>Weighted BCA (PV 7% W$M)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benefits</td>
<td>$22.3</td>
<td>W$54.9</td>
</tr>
<tr>
<td>Costs</td>
<td>$28.3</td>
<td>W$28.3</td>
</tr>
<tr>
<td>NPV</td>
<td>-$6.0</td>
<td>W$26.6</td>
</tr>
<tr>
<td>BC Ratio</td>
<td>0.8</td>
<td>1.9</td>
</tr>
<tr>
<td>Threshold Elasticity</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing benefits, costs, and net benefits for Standard BCA and Weighted BCA](image)
• Potential flood risk to properties (green shaded zone)

• Residential and commercial properties at risk

• Flood damages have been evaluated for several return periods

• Analysis supported a FEMA grant application

• Multiple census tracts affected

• Benefit categories: structures, agricultural crops, life loss, O&M response

Project Example – Flood Risk Reduction, Marysville, CA
## Benefits Comparison

<table>
<thead>
<tr>
<th>Recurrence Interval (varies in Pre- and Post-)</th>
<th>Total Damages - BCA</th>
<th>Total Damages - WBCA</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pre-Mitigation Damages</td>
<td>Post-Mitigation Damages</td>
</tr>
<tr>
<td></td>
<td>Annual ($M)</td>
<td>Annual ($M)</td>
</tr>
<tr>
<td>1</td>
<td>$5.24</td>
<td>$3.36</td>
</tr>
<tr>
<td>2</td>
<td>$5.27</td>
<td>$0.18</td>
</tr>
<tr>
<td>3</td>
<td>$5.61</td>
<td>$4.87</td>
</tr>
<tr>
<td><strong>Total Annualized</strong></td>
<td><strong>$16.11</strong></td>
<td><strong>$8.41</strong></td>
</tr>
<tr>
<td><strong>Ann. Net Benefits</strong></td>
<td><strong>$7.7</strong></td>
<td><strong>$32.2</strong></td>
</tr>
<tr>
<td><strong>PV Benefits</strong></td>
<td><strong>$106.0</strong></td>
<td><strong>$444.0</strong></td>
</tr>
<tr>
<td><strong>PV Costs</strong></td>
<td><strong>$236.6</strong></td>
<td><strong>$236.6</strong></td>
</tr>
<tr>
<td><strong>BCR</strong></td>
<td>0.45</td>
<td>1.88</td>
</tr>
<tr>
<td><strong>NPV</strong></td>
<td>-$130.6</td>
<td>$207.4</td>
</tr>
</tbody>
</table>

### Annualized Benefits, by Property Type per Quintile

![Annualized Benefits, by Property Type per Quintile](chart.png)
Summary of Research

• Relevant form of distributional analysis (differences: across geographical areas, and targeted to income groups)

• Weights are evidenced based, but some details need to be developed

• Weights can be integrated with results from standard methods

• Weighted benefits for low-income users are substantially higher than standard

• Results can influence the investment location and type (e.g. level of protection)

• Research areas: better understand nuances in approach and local agency perspectives

Potential Use Cases:

• Transit: service routes; mode choice
• Roadways: facility expansion, toll road access
• Flood mitigation: neighborhood protection
• **Digital Inclusion: benefits of access**
• Water: affordability analyses; siting
• Waste management: service provision
• Energy: residential energy efficiency or solar
• Public health facilities: access to services

Data Needs

• Facility / service location & description
• Distribution of incomes / wealth of beneficiaries
• Project (notional) scope and benefits
Exploration – BCA of Broadband Expansion

- Characteristics of program
  - Location characteristics
  - Baseline level of broadband access (speed)
  - Change in level of broadband access

- Scale of impact
  - Determine numbers of persons affected
    - Existing number of users
    - % annual growth in users
  - Characteristics of households
    - Household size
    - Demographics (e.g. % working age, % school age)
    - Current income distribution

- Value of impact
  - Adapt results of economic research
  - Standardize economic valuation parameters

<table>
<thead>
<tr>
<th>Estimated Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>% increase in income levels by sector</td>
</tr>
<tr>
<td>% of Employed (among working age)</td>
</tr>
<tr>
<td>Consumer Cost Savings Rate (%)</td>
</tr>
<tr>
<td>Property Value Increase (%)</td>
</tr>
<tr>
<td>Change in Service Level (Speed)</td>
</tr>
<tr>
<td>Number of Benefitting Households (per year)</td>
</tr>
<tr>
<td>Baseline Population Growth (per year)</td>
</tr>
<tr>
<td>Number of Households in Service Area (current)</td>
</tr>
<tr>
<td>% of Households (per year)</td>
</tr>
</tbody>
</table>
**Benefits and Valuation Sources**

- **BCA models:**
  - Census data on beneficiaries
  - Initial valuation parameters
  - Long run trend assumptions

- **Distributional analyses:**
  - Identify income distributions of affected population
  - Estimate and apply weights

- **Sensitivity analyses:**
  - Identify key parameters
  - Model uncertainty
  - Assess robustness of results

<table>
<thead>
<tr>
<th>Benefit Category</th>
<th>Impact</th>
<th>Affected Persons</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Willingness To Pay</td>
<td>“Catch all” measure of value that accounts for improvements in speed, reliability, etc.</td>
<td>Households</td>
<td>Rabbani, Bogulski, Eswaran, Hayes, 2023</td>
</tr>
<tr>
<td>Economic development</td>
<td>Increases in higher median household income</td>
<td>Employees (over 16)</td>
<td>Gallardo, and Strover, 2014</td>
</tr>
<tr>
<td>Farm profits</td>
<td>Increase in sales, expenditures, and profits</td>
<td>Farmer Households</td>
<td>Kandilov, Kandilov, Liu, Renkow, 2017</td>
</tr>
<tr>
<td>Education and Income</td>
<td>Long-range wage growth of access at primary &amp; secondary levels</td>
<td>School children (under 18)</td>
<td>Chen, Mittal, and Sridhar, 2020</td>
</tr>
<tr>
<td>Consumer pricing</td>
<td>Annual consumer savings: from $500 - $1500 / year per HH</td>
<td>Households</td>
<td>Greenstein and McDevitt, 2012</td>
</tr>
<tr>
<td>Property Values</td>
<td>Rural single-family homes sell for 2.5% higher price</td>
<td>Homeowners</td>
<td>Molnar, Savage, &amp; Sicker, 2019; Deller, Whitacre, 2019</td>
</tr>
</tbody>
</table>
Illustrative Results – KS Broadband Acceleration Grants

- Location: Seward County, KS
- Number of households: 250
- Income eligibility (up to ~$54k)
- Impact: Increase from average 10 to 25 MBps
- WTP - higher speed: ~$31.44 (Rabbani, et al, 2023)
- Capital cost only (state): $1.19 M
- Weighting parameters factors: $w_i^\alpha = \left(\frac{y_i}{y_a}\right)^\varepsilon$
  - Elasticity 1.2
  - Benchmark income: $108k
  - Avg beneficiary incomes: 2\textsuperscript{nd} quintile (average $46k)
  - Weight = 2.82

![Comparative BCA and Weighted BCA](chart.png)
Illustrative Results – ACP Subsidy

- Location: Seward County, KS
- Income eligibility (up to ~$30k)
- Baseline number of households: 250
- Growth in number of users: 75
  - Baseline cost: $50 average
  - Program impact: lower cost by $30/month
  - Valuation: elasticity of demand: -0.5% (Ford, 2021)
- Annual program cost impact (federal): $0.12 M
- Weighting parameters factors: $w_i^\alpha = \left(\frac{y_i^\alpha}{y_i}\right)^\varepsilon$
  - Elasticity 1.2
  - Benchmark income: $145k
  - Avg beneficiary incomes: 1st quintile (average $30k)
  - Weight = 6.1
Discussion on Application for Broadband

• Would this form of distributional analysis support decisions?
  • If so, where and when, relative to digital equity plans and goals?
  • Is this approach more relevant at federal or state levels?

• What are potential (or perceived) limitations in applications?
  • Data availability?
  • Assumptions in valuation?
  • Viability of alternative – based on weights of quantitative impacts (e.g. # of students)?

• Can we identify case studies for an actual demonstration?
  • Which agencies have interests in results and access to data?
  • Are there potential funding sources / contracting options?
Thank you

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