Productivity benefits of urban transportation megaprojects: a general equilibrium analysis of «Projet du Grand Paris»

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How we model the Paris metropolitan region?

We use the Regional Economy Land Use-TRANsportation Computable General Equilibrium model (A multi-equation structural model unburdened by econometric restrictions, calibrated but capable of dealing with a variety of parameter values)
The Paris version of RELU-TRAN
Complete description in Appendix of this paper
Earlier published articles:
https://sites.google.com/site/alexanashomepage/the-relu-tran-model-and-its-applications

Polycentric urban model: jobs and population are endogenously determined and appear anywhere in the region

Consumers choose:
1) resident location,
2) workplace,
3) housing type & size,
4) labor supply,
5) non-work trips and work trips,
6) mode choice and route of travel for each trip

Firms choose: input combinations, purchases from each other, export/import, output level, CRTS, make zero profit

Developers: Build and demolish buildings of different types
Government: Collects taxes, sets congestion tolls, etc.
RELU-TRAN MODEL FLOWCHART (Anas and Liu, 2007)

Starting point:
- p, w, R, V, S, G, g

RELU-TRAN cycle:
- Update G and g for next cycle

RELU:
- RELU loops converged

RELU trips:

TRAN:
- TRAN iterations converged

Decision:
- G and g converged?
- p, w, R, V converged?
- Excess demands, profits converged?

YES
- RELU-TRAN cycles converged

NO

Flowchart overview:
- RELU
- TRAN
- Update G and g for next cycle
The RELU algorithm

START POINT
\( p, w, R, V, S, G, g \)

RELU LOOP

PRICES, \( p \)
\( (w, R) \rightarrow p \)

OUTPUTS, \( X \)
\( (p, w, R, S, V) \rightarrow X \)

WAGES, \( w \)
\( (p, X, R, S, V) \rightarrow w \)

RENTS, \( R \)
\( (p, X, w, S, V) \rightarrow R \)

VALUES, \( V \)
\( R \rightarrow V \)

STOCKS, \( S \)
\( V \rightarrow S \)

Update \( p, w, R, V \)
for next loop

p, w, R, V converged?
Excess demands converged?
Economic profits converged?

RELU loops converged

The RELU algorithm

RELU-TRAN MODEL (Anas and Liu, 2007) – RELU FLOWCHART
The TRAN Algorithm
Zone definitions in the Paris RELU-TRAN model

Dark pink (CDTs, Poles)

Light pink: Non-CDT inner suburbs

Yellow: Outer suburbs

City of Paris
The PGP megaproject
The PGP PUBLIC TRANSIT MEGAPROJECT IS BUILT

MEGAPROJECT REDUCES PUBLIC TRANSIT TRAVEL TIMES

TRIPS SWITCH TO PUBLIC TRANSIT

ROAD CONGESTION IMPROVES

CAR TRAVEL TIMES FALL

ACCESSIBILITY IMPROVES

MEGAPROJECT REDUCES PUBLIC TRANSIT TRAVEL TIMES

TRIPS SWITCH TO PUBLIC TRANSIT

ROAD CONGESTION IMPROVES

CAR TRAVEL TIMES FALL

ACCESSIBILITY IMPROVES

PRODUCTIVITY RISES

Real wages rise

CONSUMER UTILITY RISES

Real rents rise

JOBS & POPULATION AGGLOMERATE NEAR THE MEGAPROJECT

IN-MIGRATION

The causal structure of the PGP’s effects

(negative feedback on road congestion and on accessibility)

(negative feedback on utility)
How the TFP externality is treated in the production function.

Production function

\[ X_{rj} = A_{rj} F_{rj} \left( K_{rj}, L_{rj}, B_{rj} \right) \]

From Ciccone (2002) for France

\[ A_{rj} = C_{rj} \left( \sum_{i \forall} w_i d_i G_{ij}^{-\beta} \right)^{\alpha}, \quad \alpha = 0.045, \quad \beta = 3 \]

Gibbons and Graham (2019) provide a survey of estimates for many countries

Jobs density

\[ d_i = \frac{Jobs_i}{Area_i} \]

Weight of zones

\[ w_i = \frac{Jobs_i}{\sum_i Jobs_i} \]

Jobs \[
\text{endogenously determined}
\]

\[ Jobs_j = N \cdot Pr^e \sum_{ikr} P_{ikr}^e \left( w, R, p, G, g \right), \]

Wages, rents, prices, travel costs, travel times

Across modes composite travel times

\[ G_{ij} = PROB_{CAR|ij} \times \left( \tau_{ij} + \tau_{ji} \right) + \left( 1 - PROB_{CAR|ij} \right) \times \left( TIME_{PT|ij} + TIME_{PT|ji} \right) \]

Car choice probability

Congested car travel times

PGP travel times
Properties of the TFP equation

The productivity of jobs in a zone \( j \) is influenced more by the jobs in zone \( i \) than in zone \( i' \):

1) If \( i \) and \( i' \) are equally accessible to \( j \) and equally dense, and \( i \) has more jobs than \( i' \)
2) If \( i \) and \( i' \) are equally accessible to \( j \) and have equal jobs, and \( i \) is denser than \( i' \).
3) If \( i \) and \( i' \) are equally dense and have equal jobs, and \( i \) is more accessible to \( j \) than is \( i' \).
The three margins of the TFP externality

1. **Intensive marginal effect:** Higher TFP makes each worker more productive so fewer jobs are needed to produce the same output quantity. (An instance of Schumpetrian job destruction, overlooked by Marshall)

2. **Extensive marginal effect:** Higher TFP lowers cost and price so the quantity demanded increases and more jobs are created.

3. **Super-extensive margin:** As utility improves because of the TFP externality, in-migration increases population. The higher population increases the TFP and there is a positive feedback effect.
Comparison to literature’s simple partial equilibrium models

<table>
<thead>
<tr>
<th>Model</th>
<th>Traffic Congestion</th>
<th>TFP externality</th>
<th>Distortionary tax</th>
<th>Mono- or polycentric</th>
<th>Long run or short run</th>
<th>Non-work travel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parry &amp; Bento 2001</td>
<td>Yes</td>
<td>No</td>
<td>Income</td>
<td>Monocentric</td>
<td>Short run</td>
<td>None</td>
</tr>
<tr>
<td>Arnott 2007</td>
<td>Yes</td>
<td>Yes</td>
<td>None</td>
<td>Monocentric</td>
<td>Short run</td>
<td>None</td>
</tr>
<tr>
<td>Venables 2007</td>
<td>No</td>
<td>Yes</td>
<td>Income</td>
<td>Monocentric</td>
<td>Long run</td>
<td>None</td>
</tr>
<tr>
<td>Anas &amp; Chang 2020</td>
<td>Yes</td>
<td>Yes</td>
<td>Income &amp; sales</td>
<td>Polycentric</td>
<td>Short and long run</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Model</th>
<th>Wages/Income</th>
<th>Rents</th>
<th>Product prices</th>
<th>Exports/Imports</th>
<th>Production</th>
<th>Buildings</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parry &amp; Bento 2001</td>
<td>Exogenous/Endogenous</td>
<td>No</td>
<td>Exogenous (numeraire)</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Arnott 2007</td>
<td>Exogenous/Endogenous</td>
<td>Yes</td>
<td>Exogenous/Endogenous</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Venables 2007</td>
<td>Private average product</td>
<td>Yes</td>
<td>Exogenous/Endogenous</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Anas &amp; Chang 2020</td>
<td>Value of private marginal product</td>
<td>Yes</td>
<td>Endogenous</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Welfare analysis

\[ W \equiv \text{Welfare per consumer} = CV_{\text{consumer}} + CV_{\text{importer}} + \frac{\rho}{N} \left[ \sum_{i,k=0,\ldots,5} \left( S_{ik} V_{ik} - S_{ik}^\text{Base} V_{ik}^\text{Base} \right) \right] \]

\[ + \frac{1}{N} \left( \Delta \text{Toll Rev.} + \Delta \text{Tax Rev.} \right) \]

Social benefit-to-cost ratio

\[ \text{Social benefit-to-cost ratio} = \frac{W \times N}{\text{Annualized project cost}} \]
Effects of the PGP in the absence of congestion pricing

Curve A: Before PGP
Curve B: PGP without TFP externality
Curve C: PGP with TFP externality

Utility (CV in € per year per consumer)

Baseline +340 €
Baseline +162 €
Baseline

Regional population

Baseline
Baseline +1.8%
Baseline +4.53%
Effects of the PGP in the presence of congestion pricing

Curve A: Before PGP
Curve D: PGP without TFP externality
Curve E: PGP with TFP externality
Interactions among the market failures (MF)

- MF1: Traffic congestion
- MF2: TFP externality
- MF3: Distortionary taxes (income tax, sales tax)

1) There is weak interaction between the traffic congestion externality and the TFP externality.

2) There is a strong negative effect of the TFP externality on the income and sales tax revenues.

3) There is a strong negative interaction between congestion pricing and the TFP externality.
The effect of the TFP externality on sales tax revenue
The effect of the TFP externality on income tax revenue
### Change due to GPP with constant productivity

<table>
<thead>
<tr>
<th>Welfare [ = a + b + c + d + e]</th>
<th>GPP in 2035 - closed city</th>
<th>GPP in 2035 - open city</th>
<th>GPP in 2035 with congestion pricing - closed city</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change due to GPP with constant productivity</td>
<td>Additional change due to GPP with endogenous productivity</td>
<td>Change due to GPP with constant productivity</td>
<td>Additional change due to GPP with endogenous productivity</td>
</tr>
<tr>
<td>Welfare [ = a + b + c + d + e]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Consumer CV</td>
<td>162</td>
<td>178</td>
<td>-1</td>
</tr>
<tr>
<td>b. Real estate values</td>
<td>1</td>
<td>-15</td>
<td>61</td>
</tr>
<tr>
<td>c. Tax revenues</td>
<td>7</td>
<td>-84</td>
<td>-211</td>
</tr>
<tr>
<td>Sales tax</td>
<td>3</td>
<td>-44</td>
<td>-107</td>
</tr>
<tr>
<td>Income tax</td>
<td>4</td>
<td>-41</td>
<td>-105</td>
</tr>
<tr>
<td>d. Congestion toll revenue</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>e. Importer CV</td>
<td>5</td>
<td>236</td>
<td>147</td>
</tr>
<tr>
<td>Productivity externality</td>
<td>416</td>
<td>-5</td>
<td>410</td>
</tr>
<tr>
<td>Road congestion externality</td>
<td>513</td>
<td>3</td>
<td>520</td>
</tr>
<tr>
<td>GPP cost</td>
<td>132</td>
<td>0</td>
<td>130</td>
</tr>
<tr>
<td>Benefit-to-cost ratio [ = Welfare/GPP cost]</td>
<td>1.32</td>
<td>2.39</td>
<td>-0.031</td>
</tr>
<tr>
<td>Public cost recovery ratio [ = d/(GPP cost - c)]</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Welfare gain as a percent of average income</td>
<td>0.47</td>
<td>0.84</td>
<td>-0.011</td>
</tr>
</tbody>
</table>

### Welfare gain as a percent of average income

| Welfare gain as a percent of average income | 0.47 | 0.84 | -0.011 | 0.37 | 0.66 | 1.06 |
Welfare gains as a percent of average incomes

Constant population (short run)

- Of PGP without TFP externality = 0.47
- Of PGP with TFP externality = 1.31

Endogenous population (long run)

- Of PGP without TFP externality = -0.01
- Of PGP with TFP externality = 0.36

With congestion pricing

0.66
1.06
0.91
1.34
# Social benefit-to-cost ratios

<table>
<thead>
<tr>
<th>Constant population (short run)</th>
<th>With congestion pricing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Of PGP without TFP externality = 1.33</td>
<td>1.84</td>
</tr>
<tr>
<td>Of PGP with TFP externality = 3.71</td>
<td>2.95</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Endogenous population (long run)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Of PGP without TFP externality = -0.03</td>
</tr>
<tr>
<td>Of PGP with TFP externality = 1.04</td>
</tr>
</tbody>
</table>
Public cost recovery ratios
= Tolls/(PGP cost – tax revenue changes)

Constant population (short run)

• PGP without TFP externality = 1.02
• PGP with TFP externality = 0.81

Endogenous population (long run)

• PGP without TFP externality = 1.18
• PGP with TFP externality = 0.63
Conclusions

(i) The wider benefits are substantial when the megaprojects confer a TFP externality.
(ii) The super extensive margin of in-migration to the region in the long run is the most important.
(iii) The negative income effect of congestion pricing mitigates the in-migration induced by the project.
(iv) The TFP externality reduces nominal output prices and wages, but increases real wages and rents.
   (iv-a) The lower nominal output prices of traded goods confer benefits on those who import from the region as well as those in the region. BUT…
   (iv-b) A higher TFP causes the revenue from income and sales taxation to decrease.
   (iv-c) Negative income effects of congestion pricing on purchasing power cause lower revenue from the distortionary taxes.
(v) The TFP externality has a minor negative interaction with congestion pricing in the short run and a minor positive interaction in the long run.