Transportation and Land Use are Interdependent Shapers of Urban Form
The Sequence of Development?

This extension of the railway system by means of feeder lines means that in many ways the early development of the system can be viewed, not in terms of booms and slumps, but in rational steps. By the end of 1833, three of the five English provincial towns with a population of more than 100,000 had railway links with London under construction; by the end of 1836 only Portsmouth remained among English towns of over 50,000 population without a line authorized; and by the end of 1837 most towns of more than 20,000 inhabitants were on or close to the route of an authorized railway. - M.C. Reed
Orderliness Hypothesis:

Places will be connected to the network roughly in order of their population density.
The places that have the highest population per unit area (or population density) will get the network first.
Background

1836 London and Greenwich Railway
1846 Royal Commission on Railway Termini
1854 Metropolitan Railway chartered
1863 Metropolitan Railway opens
1884 “Circle” closed
1890 City and South London Railway (first tube)

Railways not permitted to be developers except Metropolitan Railway --> Metro-Land

Greenbelt
Station Density (stations per km²)

- Surface rail station density in Periphery
- Surface rail station density in Core
- Underground rail station density in Periphery
- Underground rail station density in Core

Correlation between Rail Station Density Rank and Population Density Rank

(including City of London)  (excluding City of London)
Correlation Between
Underground Station Density Rank & Population Density Rank

(including City of London)  (excluding City of London)
<table>
<thead>
<tr>
<th>Year</th>
<th>Boroughs with Stations (N)</th>
<th>Notable Boroughs (in top N of density) without service at time which eventually get service.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1871</td>
<td>8</td>
<td>Tower Hamlets (2), Southwark (7), Hackney (8)</td>
</tr>
<tr>
<td>1881</td>
<td>14</td>
<td>Tower Hamlets (1), Southwark (6), Hackney (7), Lambeth (9), Lewisham (13), Wandsworth (11)</td>
</tr>
<tr>
<td>1891</td>
<td>23</td>
<td>Hackney (6), Greenwich (15), Waltham Forest (16)</td>
</tr>
<tr>
<td>1901</td>
<td>23</td>
<td>Hackney (6), Greenwich (16), Waltham Forest (15) missing</td>
</tr>
<tr>
<td>1911</td>
<td>23</td>
<td>Hackney (5), Waltham Forest (15), Greenwich (16), Redbridge (22)</td>
</tr>
<tr>
<td>1921</td>
<td>23</td>
<td>Hackney (4), Waltham Forest (15), Greenwich (17), Redbridge (20)</td>
</tr>
<tr>
<td>1931</td>
<td>23</td>
<td>Hackney (4), Waltham Forest (15), Greenwich (17), Redbridge (20)</td>
</tr>
<tr>
<td>1941</td>
<td>25</td>
<td>Greenwich (16), Redbridge (20), Waltham Forest (14)</td>
</tr>
<tr>
<td>1951</td>
<td>27</td>
<td>Greenwich (19)</td>
</tr>
<tr>
<td>1961</td>
<td>27</td>
<td>Greenwich (18)</td>
</tr>
<tr>
<td>1971</td>
<td>27</td>
<td>Greenwich (18)</td>
</tr>
<tr>
<td>1981</td>
<td>27</td>
<td>Greenwich (17)</td>
</tr>
<tr>
<td>1991</td>
<td>27</td>
<td>Greenwich (18)</td>
</tr>
<tr>
<td>2001</td>
<td>28</td>
<td>Greenwich (18)</td>
</tr>
</tbody>
</table>

Boroughs without Underground Service
# Leads and Lags

<table>
<thead>
<tr>
<th>Developed Area</th>
<th>Transport Leads Land Use</th>
<th>Transport Follows Land Use</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B) Development densifies in urban area after construction of new transport infrastructure</td>
<td>(A) Constructing new (higher speed) mode in existing urbanized area (e.g. London Transport in early years)</td>
<td></td>
</tr>
</tbody>
</table>

| Undeveloped Area | (C) Constructing new (higher speed) mode in greenfields, to promote development | Still waiting … |
Hypotheses: Population Density

(a) Population density in the periphery is positively associated with the lagged increase in density of new (i) surface and (ii) Underground rail stations.
(b) Population density in the periphery is positively associated with the lagged population density of the nearest borough between it and London. (Neighbor effect)
(c) Population density in the periphery is positively associated with the lagged network density of the nearest borough between it and London. (Neighbor effect)
(d) Population density in the core is negatively associated with the lagged increase in density of new (i) surface and (ii) Underground rail stations. (Commercial uses substitute for residential)
Hypotheses: Network Density

(a) Network density in the periphery is positively associated with the lagged increase in population density.
(b) Network density in the periphery is positively associated with the population density of the nearest borough between it and London. (Neighbor effect)
(c) Network density in the periphery is positively associated with the network density of the nearest borough between it and London. (Neighbor effect)
(d) Underground and surface rail act as substitutes in the periphery, areas with more of one would get less of the other.
(e) Network density in the core is negatively associated with the lagged increase in population density.
Model

\[ D_{i,t} = D_{i,t-1} \varphi + W D_{t-1} \rho + X_{i,t-1} \beta + W X_{t-1} \chi + Z_i \zeta + T_{t-1} \psi \]

Where:

- \( D_{i,t} \) is the density (population, Underground station, surface rail station) of area \( i \) at time \( t \).
- \( W \) is a matrix of spatial interaction weights.
- \( X_{i,t-1} \) is a vector of variables that change with both time and area.
- \( Z_i \) is a vector of area-specific variables that do not change with time.
- \( T_{t-1} \) is a vector of time-specific variables that do not change with area.
- \( \varphi, \rho, \beta, \psi, \chi \) and \( \zeta \) are parameters to be estimated.
Modeling Issues

- Stratification: Core vs. Periphery
- Time Period: 1841 (1871) - 2001
- Lag Structure (10 years)
- Log Transformation (tested)
- Neighbor Definitions (neighbor nearest London)
- Statistical Techniques (cross-section/time series (OLS/PWR with PCSE))
<table>
<thead>
<tr>
<th></th>
<th>Log(PopDens)</th>
<th>Surface Rail Station Density</th>
<th>Underground Density</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Periphery</td>
<td>Core</td>
</tr>
<tr>
<td>Surface Density (L10)</td>
<td>+S</td>
<td></td>
<td>+S</td>
</tr>
<tr>
<td>Underground Density (L10)</td>
<td>-S</td>
<td></td>
<td>+S</td>
</tr>
<tr>
<td>∆Population Density (L10)</td>
<td>-S</td>
<td></td>
<td>+S</td>
</tr>
<tr>
<td>∆Regional Surface Rail Stations (L10)</td>
<td>+S</td>
<td></td>
<td>+S</td>
</tr>
<tr>
<td>∆Regional Underground Stations (L10)</td>
<td>+S</td>
<td></td>
<td>+S</td>
</tr>
<tr>
<td>Log(Population Density) (L10)</td>
<td>+S</td>
<td></td>
<td>+S</td>
</tr>
<tr>
<td>Log(Population Density) (L20)</td>
<td>-S</td>
<td></td>
<td>-S</td>
</tr>
<tr>
<td>∆Regional Population</td>
<td>+S</td>
<td></td>
<td>+S</td>
</tr>
<tr>
<td>∆Surface Rail Density (L10)</td>
<td>+S</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>∆Underground Density (L10)</td>
<td>+S</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>∆Neighbor Surface Rail Density (L10)</td>
<td>+S</td>
<td></td>
<td>+S</td>
</tr>
<tr>
<td>∆Neighbor Underground Density (L10)</td>
<td>-S</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Neighbor Log(Population Density) (L10)</td>
<td>+S</td>
<td></td>
<td>-S</td>
</tr>
<tr>
<td>∆Neighbor Population Density (L10)</td>
<td>-S</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Distance to City of London</td>
<td>NS</td>
<td></td>
<td>+S</td>
</tr>
<tr>
<td>North of River Thames</td>
<td>NS</td>
<td></td>
<td>NS</td>
</tr>
<tr>
<td>Constant</td>
<td>NS</td>
<td></td>
<td>+S</td>
</tr>
</tbody>
</table>

+S - positive and statistically significant at 10% level or better
-S - negative and statistically significant at 10% level or better
NS - not statistically significant at 10% level or better
<table>
<thead>
<tr>
<th>Elasticities</th>
<th>Periphery</th>
<th>Core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rail (Combined) on Population Density</td>
<td>0.0023</td>
<td>-0.0038</td>
</tr>
<tr>
<td>Change in Population Density on Surface Rail Density</td>
<td>0.0023</td>
<td>-0.0065</td>
</tr>
<tr>
<td>Change in Population Density on Underground Rail Density</td>
<td>0.0027</td>
<td>-0.0041</td>
</tr>
</tbody>
</table>
Qualitative Model

Rail first inter-city: connect outside -> in

Underground first connects termini, then other points in developed area, and finally connects to new suburbs: inside -> out

Has a decentralizing effect for residences, lowering population density in center, increasing it in suburbs.

Other factors: entrepreneurs, construction costs, South vs. North (income, rail embeddedness, geology, competition, south already more local than north (London in south of England))
Conclusions

Rail causes (precedes and is positively and statistically related to) suburban residential development. Induced Demand

Development causes (precedes and is positively and statistically related to) rail infrastructure. Induced Supply
Twin Cities
LEGEND

- Interstate
- Undivided Highway
- Divided Highway
- No Construction Log
Cumulative Opportunity 10 Min (Jobs)

Number of Jobs
- 133 - 25000
- 25001 - 50000
- 50001 - 100000
- 100001 - 300000
- 300001 - 500000
- 500001 - 700000
- 700001 - 900000
- 900001 - 1100000
- 1100001 - 1350000

Data Sources
Travel time: Met Council
Employment Data: CURA University of Minnesota
GIS Files: US Census 2000

Projection: NAD 1983 UTM Zone 15N
Cumulative Opportunity 20 Min (Jobs)

Number of Jobs
- 133 - 25000
- 25001 - 50000
- 50001 - 100000
- 100001 - 300000
- 300001 - 500000
- 500001 - 700000
- 700001 - 900000
- 900001 - 1100000
- 1100001 - 1350000

Data Sources
Travel time: Met Council
Employment Data: CURA University of Minnesota
GIS Files: US Census 2000
Cumulative Opportunity 30 Min (Jobs)

Number of Jobs
- Green: 133 - 25000
- Light Green: 25001 - 50000
- Yellow: 50001 - 100000
- Light Yellow: 100001 - 300000
- Orange: 300001 - 500000
- Light Orange: 500001 - 700000
- Brown: 700001 - 900000
- Medium Brown: 900001 - 1100000
- Red: 1100001 - 1350000

Data Sources:
- Travel time: Met Council
- Employment Data: CURA University of Minnesota
- GIS Files: US Census 2000

Projection: NAD 1983 UTM Zone 15N
Cumulative Opportunity 50 Min (Jobs)

Number of Jobs
- 133 - 25000
- 25001 - 50000
- 50001 - 100000
- 100001 - 300000
- 300001 - 500000
- 500001 - 700000
- 700001 - 900000
- 900001 - 1100000
- 1100001 - 1350000

Data Sources
Travel time: Met Council
Employment Data: CURA University of Minnesota
GIS Files: US Census 2000

Projection: NAD 1983 UTM Zone 15N
Accessibility to Jobs
(Auto 1990)
Accessibility to Jobs
(Auto 2000)

Number of Jobs Within 15 Minutes of Travel Time

Mode: Auto
Year: 2000

Number of Jobs
- 0 - 50000
- 50001 - 100000
- 100001 - 200000
- 200001 - 400000
- 400001 - 600000
- 600001 - 750000
- 750001 - 1000000
- 1000001 - 1250000
- 1250001 - 1550000

Data Sources:
- Travel Time: Metropolitan Council
- Selection: Mn/DOT
- GIS Files: US Census 2000

Projection: NAD 1983 UTM Zone 15N
Accessibility to Jobs (Transit 1990)

Number of Jobs Within 15 Minutes of Travel Time

Mode: Transit
Year: 1990

Number of Jobs
- 0 - 50000
- 50001 - 100000
- 100001 - 200000
- 200001 - 400000
- 400001 - 600000
- 600001 - 750000
- 750001 - 1000000
- 1000001 - 1250000
- 1250001 - 1550000

Data Sources:
- Travel time: Met Council
- Selection: Mn/DOT
- GIS Files: US Census 2000

Projection: NAD 1983 UTM Zone 15N
Accessibility to Jobs (Transit 2000)

Number of Jobs Within 15 Minutes of Travel Time

Mode: Transit
Year: 2000

Number of Jobs
- 0 - 50000
- 50001 - 100000
- 100001 - 200000
- 200001 - 400000
- 400001 - 600000
- 600001 - 750000
- 750001 - 1000000
- 1000001 - 1250000
- 1250001 - 1550000

Data Sources:
- Travel time: Met Council
- Selection: MnDOT
- GIS Files: US Census 2000
Access to Destinations Project: Measure and Map the following:

<table>
<thead>
<tr>
<th>Year</th>
<th>JOBS</th>
<th>SCHOOLS</th>
<th>PARKS</th>
<th>SHOPPING</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Automobile**
- **Transit**
- **Bicycling**
- **Walking**
Thank You

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