Endogenous Transport Investment, Geography, and Growth Take-offs

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Motivation: Geography Matters

- Industrial revolution: why Britain?
- Why do some countries manage growth take-off – and some don’t?

- Stylized fact: inter alia, growth take-off is associated with rapid urbanization / agglomeration
  (cf. e.g. recent World Bank WDR 2009)

- Economic Geography attributes both effects to falling transport costs - but does not explain how these obtain.
Motivation: Transport matters

### Economic Geography (NEG) Approach

- **Economic Geography (Krugman, 1991, ...)**, theoretical:
  - Spatial concentration depends on exogenous transport cost parameter:
    - Two symmetric regions: Initially static gains from trade.
    - If transport costs sink below a certain threshold: agglomeration
      - All modern firms cluster in one region (beneficial / 'take-off')

### Critique

- In NEG, transport costs are causal to economic growth
- Transport cost change is exogenous, arbitrary, and even for free!
- NEG does not explain why transport costs fall and
  - *if*, *why* and *when* the threshold is reached
Transport & Growth: Literature

- Empirical findings:
  - Transport infrastructure hardly causal to growth (e.g. Bose & Haque 2005)
  - Transport infrastructure is costly - not easy to afford
  - Historically, a decrease in physical transport costs – not tariffs – is related to industrial revolution (O'Rourke 2000)

- Analytical models:
  - coordinate investment into one technology with externalities (EoS): 'Big Push' – result is trivial
### Paper Strategy

**Objective:** Model that features

1. Static benefits from economic integration
2. Agglomeration-enhanced innovation
3. Endogenous transport that comes at a cost

1 & 2: Use Baldwin, Martin and Ottaviano (2001) NEG & growth model
**Paper Strategy**

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3: Integrate endogenous transport

Note: Features borrowed from Baldwin et al. (2001) marked in grey
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Endogenize Transport

- Trade Costs $\tau$
- Trade Benefits
- Spillovers
- Agglomeration

Welfare, Growth
Endogenize Transport

Endogenize Transport Infrastructure

Trade Costs $\tau$

Trade Benefits

Spillovers

Exogenously

Agglomeration

Welfare, Growth

Trade Costs and Spillovers are endogenized through transport infrastructure.

Trade Costs are influenced by exogenous factors and resources.

Spillovers are influenced by exogenous factors and resources.

Agglomeration affects welfare and growth.

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Endogenize Transport

Endogenize Transport Infrastructure

Trade Costs \( \tau \)

Trade Benefits

Spillovers

Agglomeration

Welfare, Growth
Endogenize Transport: Fleet Investment

This paper concentrates on ‘fleet investment’: private, bottom-up transport capital, no (direct) externalities
Each private firm builds improves its own ‘fleet’ of vehicles

- Why private bottom-up?
  - In 19th century Europe and poor countries, fixed transport infrastructure mostly built privately (Keller & Shiue 2008)
  - Most large infrastructure projects designed to meet private demand

- Why no externalities?
  - Majority of transport investment is in rolling stock (US) – should apply even more to poor countries.
  - In 18th century Britain, transport improvements financed by private ventures and local merchants
Overall Transport Investment in the US

Investment in transport capital by household, private business, and government sector

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Model Set-up: borrowed from Baldwin et al. (2001)

- Two regions, symmetrical endowments
- Two production factors: labor $L$, $L^*$ and capital $K + K^* = K^w$
- Three sectors:
  - Consumer good *Agriculture* ($A$): numéraire, perfect competition
  - Consumer good *Manufacturing* ($M$): monopolistic competition, standard mark-up pricing, profits accrue to capital owners
  - *Innovation* sector ($I$): AK productivity with localized spillovers
    \[ A \equiv \frac{K}{K^w} + \lambda \frac{K^*}{K^w} = s + \lambda(1 - s) \quad \lambda \in (0, 1) \]
- Representative consumer: Cobb-Douglas between $A$ and $M$, CES over manufacturing products (elasticity $\sigma > 1$)
Geography: Iceberg Costs

- Trade agricultural goods at no cost (equalizes wages)

- Immobile $L$ & $K$, $K$ has to be employed where it is constructed

- *Iceberg costs* for manufacturing goods:
  - Need $\tau \geq 1$ goods shipped for 1 unit to arrive in South ($\tau^* \text{ v.v.}$)
  - Thus export price $p^* = \tau p$ ($\tau$ times domestic price)
  - Define free-ness of trade $\phi \equiv \tau^{1-\sigma} \in (0, 1]$ ($\phi^* \text{ v.v.}$)
Fleet Investment

- Each firm $i$ ships its goods by its own 'fleet'
- Fleet capital mapped to individual $\phi_i \in (\underline{\phi}, 1)$:
  - minimum value $\underline{\phi}$ and depreciation rate $\delta_T$
  - capital law of motion mapped to $\dot{\phi}_i$
  - fleet investment rate $Q_i$, with quadratic adjustment costs
- Firm’s transport capital problem:

$$\max_{Q_i} \int_0^\infty e^{-rt} \left( \pi_i(\phi_i) - a_T Q_i^2 \right) dt$$

s.t. $\frac{\dot{\phi}_i}{(1 - \phi_i)} = (Q_i - \delta_T (\phi_i - \underline{\phi}))$

$\Rightarrow$ Dynamic system in $\phi_i$ and $Q_i$, unique steady state $(\hat{\phi}, \hat{Q})$
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- Firm’s transport capital problem:

  $$\max_{Q_i} \int_0^\infty e^{-rt} \left( \pi_i(\phi_i) - a_T Q_i^2 \omega_L \right) dt$$

  s.t. $\frac{\dot{\phi}_i}{(1 - \phi_i)} = (Q_i - \delta_T(\phi_i - \underline{\phi}))$

$\Rightarrow$ Dynamic system in $\phi_i$ and $Q_i$, unique steady state $(\hat{\phi}, \hat{Q})$
Fleet Investment Phase Diagram

\[ \dot{Q} = 0 \]

\[ \dot{\phi} = 0 \]
Fleet Investment Phase Diagram

\[ Q = 0 \]

\[ \dot{\phi} = 0 \]

\[ \dot{Q} = 0 \]
Equilibrium and Steady State

Two kinds of steady state:

- **Interior Equilibrium:** \( \frac{\dot{K}}{K} = \frac{\dot{K}^*}{K^*} \)
- **Core-Periphery (CP) Equilibrium:** \( s \equiv \frac{K}{K^w} = 1 \) or \( s = 0 \)

Two relations must hold in Steady State:

**'EE' Relation**

\[ \Rightarrow \text{Northern income share } s_{EE}^E(s) = \frac{E(s)}{E^w(s)} \text{ strictly increasing in } s \]

**'nn' Relation**

\[ \Rightarrow \text{From equal return on capital (in interior equilibria): } s_{EE}^{nn}(s) \]

\[ \Rightarrow \text{Dynamics: CP and Symmetric } (s_{EE}^{nn} = s_{EE}^{EE} = \frac{1}{2}) \text{ are always solution, but may be stable or unstable} \]
Equilibrium and Steady State

Two kinds of steady state:

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Two relations must hold in Steady State:

- **'EE' Relation**
  \( \Rightarrow \) Northern income share \( s_E^{EE}(s) = \frac{E(s)}{E^w(s)} \) strictly increasing in \( s \)

- **'nn' Relation**
  \( \Rightarrow \) From equal return on capital (in interior equilibria): \( s_E^{nn}(s) \)

\( \Rightarrow \) Dynamics: CP and Symmetric \( (s_E^{nn} = s_E^{EE} = \frac{1}{2}) \) are always solution, but may be *stable or unstable*
Steady State: Phase Diagram
Isolation vs. Agglomeration

Initial Stage $\phi = \phi$

Start from symmetric (stable) equilibrium $\phi = \phi$

capital / real wage growth $g_{iso} = bL^w \frac{1+\lambda}{2} - \Theta$

Intermediate Integration $\hat{\phi}_{sym} > \phi$

If $L^w, \phi$ low: Firms build fleets $\phi_{sym}$, remain in symmetric steady state:

Diverts resources from innovation to transport, lose on growth

growth $g_{sym} < g_{iso}$
**Isolation vs. Agglomeration**

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*If $L^w$, $\phi$ low:* Firms build fleets $\phi_{sym}$, remain in symmetric steady state:
Diverts resources from innovation to transport, lose on growth

growth $g_{sym} < g_{iso}$

### Rapid Agglomeration $\hat{\phi}_{CP} > \hat{\phi}_{sym}$

*Only if $L^w$, $\phi$ large enough:* large $\hat{\phi}_{CP}$ renders CP stable
growth $g_{CP} \geq g_{sym}$

$\Rightarrow$ For virtually all parameter schedules: $g_{sym} \leq g_{iso} \leq g_{CP}$
Isolation vs. Agglomeration

**Initial Stage** \( \phi = \overline{\phi} \)

Start from symmetric (stable) equilibrium \( \phi = \overline{\phi} \)

- capital / real wage growth \( g_{\text{iso}} = bL^w \frac{1+\lambda}{2} - \Theta \)

**Intermediate Integration** \( \hat{\phi}_{\text{sym}} > \overline{\phi} \)

*If* \( L^w, \phi \) *low:* Firms build fleets \( \phi_{\text{sym}} \), remain in symmetric steady state:
- Diverts resources from innovation to transport, lose on growth
  - growth \( g_{\text{sym}} < g_{\text{iso}} \)

**Rapid Agglomeration** \( \hat{\phi}_{CP} > \hat{\phi}_{\text{sym}} \)

*Only if* \( L^w, \phi \) *large enough:* large \( \hat{\phi}_{CP} \) renders CP stable
- growth \( g_{\text{CP}} \geq g_{\text{sym}} \)

\[ \Rightarrow \text{For virtually all parameter schedules: } g_{\text{sym}} \leq g_{\text{iso}} \leq g_{\text{CP}} \]
Simulation: From Isolation to Agglomeration

Parametrization: $\delta_T = \delta = 0.05, \rho = 0.04, \lambda = 0.3, L^w = 2, \phi = 0.45, \frac{\mu}{\sigma} = 0.5$
Policy Implications

- This paper presents an endogenous growth model with growth take-offs – which may occur without government intervention.

- Rather a role for government: complement private initiative, to push the economy to the CP steady state.

- Raising $\phi$: for instance, investing in *complementary public good* transport infrastructure ('ports'), removing obstacles, …

- Decreasing fleet maintenance cost $\delta_T$

- Reasons for lack of rolling infrastructure (e.g. Congo river, some rail lines)
Conclusion

- Endogenized transport infrastructure in Economic Geography via 'fleet investment': decentral, local, and endogenous

⇒ resolves causality shortcomings in the literature

- Result: Economic density $L^{w}$ vs. $\phi$ determines if, why, when & where economies reach an 'agglomeration threshold' / 'take-off'

- Note: Case with transport monopoly (same technology) yields broadly similar results
Appendix

6 Credit Constraints

7 Data

8 Model

9 Steady State

10 Simulation

11 Alternative Transport Sector
References


Firms may not be able to embark on their investment trajectory right away due to credit restrictions:

**Export profitability constraint (EPC)**

Operating profits from export $\pi_i^*(\phi_i)$ larger than fleet maintenance cost

$$\pi_i^*(\phi_i) \geq a_TQ_i^2$$
Fleet Investment with Export Profitability Constraint

\[ \pi^*(\phi) \leq a_T Q^2 \]
Firms may not be able to embark on their investment trajectory right away due to credit restrictions:

**Export profitability constraint (EPC)**

Operating profits from export $\pi_i^*(\phi_i)$ larger than fleet maintenance cost

$$\pi_i^*(\phi_i) \geq a_T Q_i^2$$

In case initial investment costs too expensive, firms invest little and move along the EPC until they hit the standard saddle path

⇒ will severely delay time until steady state is reached

⇒ but has no effect on the position of steady state $\hat{\phi}$, CP or symmetric (since EPC is never binding in steady state)
Backup: Urbanization and Growth go Hand-in-Hand

Backup: Economic Density and Growth are Concurrent

Backup: Take-off vs. Economic Density

Backup: Infrastructure Stocks and GDP/cap.

Note: size of data points indicates urbanization share

Backup: Fleet Dynamics

\[ \dot{Q}_i \text{ from f.o.c.:} \]

\[ \dot{Q}_i = (\rho + \delta_T (1 - \phi)) Q_i - \frac{\partial \pi(\phi) (1 - \phi)}{\partial \phi} \frac{1 - \phi}{2a_T w_L} \]

Loci:

\[ Q_i(\phi_i)|_{\dot{\phi}_i=0} = \delta_T (\phi_i - \phi) \]
\[ Q_i(\phi_i)|_{\dot{Q}_i=0} = \frac{\partial \pi(\phi)}{\partial \phi} \frac{(1 - \phi)}{2a_T w_L (\rho + \delta_T (1 - \phi))} \]
Backup: Transport Capital I

- Suppose transport capital $K_i^T$ s.th. $\phi_i(K_i^T) : [0, \infty) \rightarrow (0, 1]$, monotone

- Firm’s problem:

$$\max_{p_i,t,p_i^*,t,Q_i,t} \int_0^\infty e^{-rt} (x_i(p_i,t)p_i,t + x_i^*(p_i^*,t, \phi(K_i^T))p_i^* - F - w_L a_M (x_i(p_i,t) + \tau x_i^*(p_i^*,t, \phi(K_i^T)) - C(Q_i,t,K_i^T,w_L) dt$$

s.t. $\dot{K}_i^T = Q_i - \delta_T K_i^T$

- Under no uncertainty, simultaneous optimization equivalent to sequential optimization:

$$\max_{Q_i} \int_0^\infty e^{-rt} \left( \pi_i(\phi_i(K_i^T)) - C(Q_i,K_i^T,w_L) \right) dt$$

s.t. $\dot{K}_i^T = Q_i - \delta_T K_i^T$
Backup: Transport Capital II

- Specific parametrization:
  \[ \phi_i = \frac{K_i^T}{K^T + 1} \Rightarrow K_i^T = \frac{\phi - \phi}{1 - \phi} \]
  \[ C(\bar{Q}_i, K_i^T) = a_T \left( \frac{\bar{Q}}{K + 1} \right)^2 \]

- As \( \phi_i \) is bijective to \( K_i^T \), express \( K_i^T \) in terms of \( \phi_i \)

- Redefine \( Q_i \equiv \frac{\bar{Q}_i}{K_i + 1}, \delta_T \equiv \frac{\bar{\delta}_T}{1 - \phi} \)

⇒ Reduced problem:

\[
\max_{Q_i} \int_0^\infty e^{-rt} \left( \pi_i(\phi_i) - w_L a_T Q_i^2 \right) dt \\
s.t. \quad \phi_i = (1 - \phi_i) \left( Q_i - \delta_T (\phi_i - \phi) \right)
\]
Fleet Investment: Additional Assumptions

Spillovers: capital stock $K$ eases transport

- Basic Assumption: spillovers from capital stock extend to fleet investment
- Technical Assumption: for analytical tractability, specific transport capital productivity $(s + \phi(1 - s))K^w$, i.e. akin to capital spillovers

Transport: Constant Returns to Scale

The transport capital technology is CRS with respect to the number of shipped goods
Backup: Market Clearing

- Free trade in agriculture \(\Rightarrow\) agricultural price equals wage:
  \[ w_L = w_L^* = 1 \]
  \[ \Rightarrow \text{ 'mill price' of manufacturing good normalized to } p_i = 1, \]
  Southern import price \(\tau_i \geq 1\)

- Northern manufacturing firm operating profits:
  \[ \pi = \frac{\mu}{\sigma} \frac{E^w}{K^w} \left( \frac{s_E}{s + \phi^*(1 - s)} + \phi \frac{(1 - s_E)}{\phi s + (1 - s)} \right) \]

- Northern consumption expenditure
  \[ E = \frac{L^w}{2} + (\pi - a_T Q^2) s K^w - L_i \]
At any steady state: firm present value $v$ equals capital cost $a_I$ for North and South:

$$v = \frac{\pi - a_T Q^2}{\rho + \delta + g} = \frac{1}{AK^w} = a_I \quad v^* = a^*_I$$

⇒ Pins down expenditure in both interior and CP steady state:

$$E(s) = \frac{L^w}{2} + \rho \frac{s}{A} \quad E^*(s) = \frac{L^w}{2} + \rho \frac{(1 - s)}{A^*}$$

⇒ Returns $\hat{\phi}, \hat{Q}$ as a function of $s$
At any steady state: firm present value $v$ equals capital cost $a_I$ for North and South:

$$v = \frac{\pi - aTQ^2}{\rho + \delta + g} = \frac{1}{AK^w} = a_I \quad v^* = a_I^*$$

$\Rightarrow$ Pins down expenditure in both interior and CP steady state:

$$E(s) = \frac{L^w}{2} + \rho \frac{s}{A} \quad E^*(s) = \frac{L^w}{2} + \rho \frac{(1 - s)}{A^*}$$

$\Rightarrow$ Returns $\hat{\phi}$, $\hat{Q}$ as a function of $s$
Backup: Steady State – Fleet

\[
(1 - \hat{\phi}(s)) = -\frac{b}{2\delta_T^2} E^* + \frac{\rho}{\delta_T} - (1 - \phi) + \\
\sqrt{\left(\frac{b}{2\delta_T^2} E^* + \frac{\rho}{\delta_T} - (1 - \phi)\right)^2 + \frac{\rho}{\delta_T} (1 - \phi)}
\]

\[
\hat{Q}^2 = (\hat{\phi} - \phi)\delta_T \left(\delta_T (1 - \phi) + \rho\right) - \frac{b}{2} \left(\frac{L^w}{2} + \rho \frac{(1 - s)}{A^*}\right) (1 - \hat{\phi}) = E^*
\]
From $E(s)$: ⇒ market clearing (’EE’) relation $s_{EE}^{E}(s) = \frac{E}{E^w}$ as a strictly increasing function of $s$

\[
s_{EE}^{E} = \frac{\frac{1}{2}L^w + \rho \frac{s}{A}}{L^w + \rho \left( \frac{s}{A} + \frac{(1-s)}{A^*} \right)}
\]
Backup: Steady State – ’nn’ relation

- From \( \nu = a_I, \nu^* = a_I^* \) at all interior equilibria:
  innovation sector earnings equalization:

\[
A(\pi - a_T Q^2) = A^*(\pi^* - a_T^* Q^*2)
\]

⇒ Defines ’nn’ relation \( s^{nn}_E(s) \)

\[
s^{nn}_E(s) = \frac{1}{bE_w} \left( A\Delta \hat{Q}^2 - A^*\Delta^* \hat{Q}^*^2 \right) + \Delta \left( (1 - \hat{\phi}\lambda) - (1 + \hat{\phi})(1 - \lambda)s \right) \left( 1 - \hat{\phi}\hat{\phi}^* \right) (A^*s + A(1 - s))
\]

Dynamics

- if \( s^{nn}_E(s) < s^{EE}_E(s) \), then \( \dot{s} > 0 \) (due to \( \frac{\nu}{a_I} > \frac{\nu^*}{a_I^*} \))
Backup: Steady State – ’nn’ relation

- From $v = a_l$, $v^* = a_l^*$ at all interior equilibria:
  innovation sector earnings equalization:

  $$A(\pi - a_T Q^2) = A^*(\pi^* - a_T^* Q^*2)$$

$\Rightarrow$ Defines ’nn’ relation $s_{E}^{nn}(s)$

$$s_{E}^{nn}(s) = \frac{1}{bE_w} \left( A\Delta \hat{Q}^2 - A^*\Delta^* \hat{Q}^*2 \right) + \Delta \left( (1 - \hat{\phi}\lambda) - (1 + \hat{\phi})(1 - \lambda)s \right) \left( 1 - \hat{\phi}\hat{\phi}^* \right) (A^*s + A(1 - s))$$

Dynamics

- if $s_{E}^{nn}(s) < s_{E}^{EE}(s)$, then $\dot{s} > 0$ (due to $\frac{v}{a_l} > \frac{v^*}{a_l^*}$)
Backup: Threshold for Agglomeration

Parameter settings for which the symmetric steady state is unstable (above the surface)

Parametrization for this figure: $\delta = 0.05$, $\rho = 0.02$, $\lambda = 0.5$, $b = \frac{\mu}{\sigma} = 0.2$
Backup: Isolation Trap

Parameter settings for which the export profitability constraint
\[ \pi_i^* \geq a_T Q_i^2 \]
is binding (below the surface)

Parametrization for this figure: \( \delta = 0.05 \), \( \rho = 0.02 \), \( \lambda = 0.5 \), \( b = \frac{\mu}{\sigma} = 0.2 \)
Monopolist with toll and no CRS: revenue accruing to shipper per firm: \((\theta - 1)\tau x_i^*\); \(\tau x_i^*\) is exported goods of firm i.

Results: firm profits downweighted by \(\left(\frac{\sigma}{\sigma - 1}\right)^{1-\sigma} \Rightarrow \hat{\phi}_{monop} < \hat{\phi}_{fleet}\).

Moreover in sym. and CP steady state: \(E_{monop} < E_{fleet}\).

Broadly, mechanics are quite similar.

Did not manage to analytically solve for \(s_{nn}^E\) and \(s_{EE}^E\) i.e. steady state.

seems that all growth rates are lower since \(bE^w\) term is downweighted.

Downsides with my formulation:

- Also at \(\phi\) there is toll
- monopolist does not take effect on price level into account (i.e. one monopolist per firm)