Demographic Transitions Across Time and Space

Matt Delventhal[1] Jesús Fernández-Villaverde[2] Nezih Guner[3]

February 26, 2019

[1]Claremont McKenna College

[2]University of Pennsylvania

[3]CEMFI

Motivation

- Demographic transitions are a key feature of global economic history during the last 250 years.
- We want to understand the move from a regime of high fertility/high mortality to a regime of low fertility/low mortality:
  1. To make sense of modern economic growth.
  2. To forecast future evolution of structural economic transformation.
  3. To design optimal policies.
- Questions we focus on today:
  1. Do demographic transitions all look alike?
  2. What do they tell us about underlying mechanism of structural transformation?

What do we do?

- Construct a data set on demographic transitions for 186 countries.
- We estimate a textbook 4-state model of demographic transitions.
- Findings:
  1. Nearly the whole globe has started the mortality and fertility transitions. "Peak child" most likely happened in 2016.
  2. Real GDP per capita at the start of the mortality and fertility transitions is roughly constant.
  3. Transitions are becoming faster.
  4. For a country, a key correlate of the start of the fertility transition is the number of neighbors that have already started their transitions. Less important for the mortality transition.
- Build a theoretical model of demographic transition with a quality-quantity trade-off and diffusion of technology from a frontier country to the rest of the world to account for facts.

Data

- Collect data on vital statistics (CDR, CBR) for 186 countries.
  - Several Sources: World Bank Development Indicators, United Nations Population Division, Chesnais (1992), Mitchell (2007), ...
  - Data goes back several centuries for some European countries.
  - For most (developing) countries it covers the 20th and 21st centuries.
- Why do we focus on CDR and CBR instead of life expectancy or TFR?
- Data on real GDP per capita:
  - 2018 version of Maddison's database with some additional imputations.

The 4-states framework

- The textbook demographic transition has 4 stages:

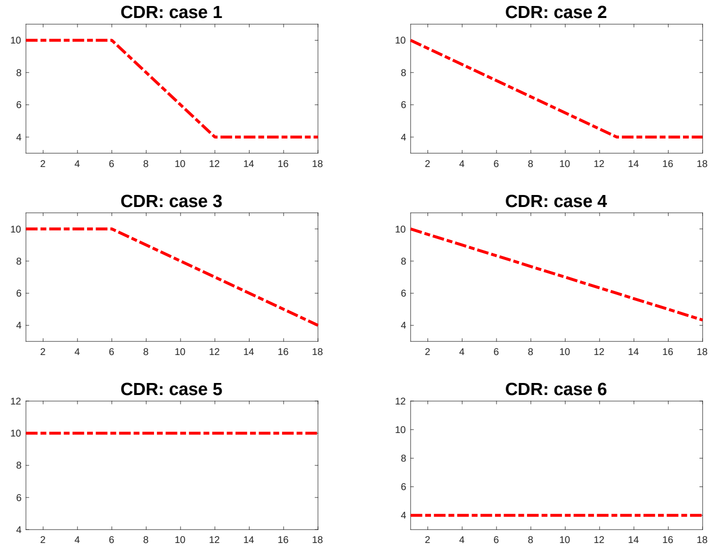
  1. Both CDR and CBR are high and stationary.
  2. The CDR starts to decline while CBR stays high.
  3. The CBR also starts to decline.
  4. Both CDR and CBR are stationary at a lower level.

- Caveat: current fertility in some countries is *terra incognita*.

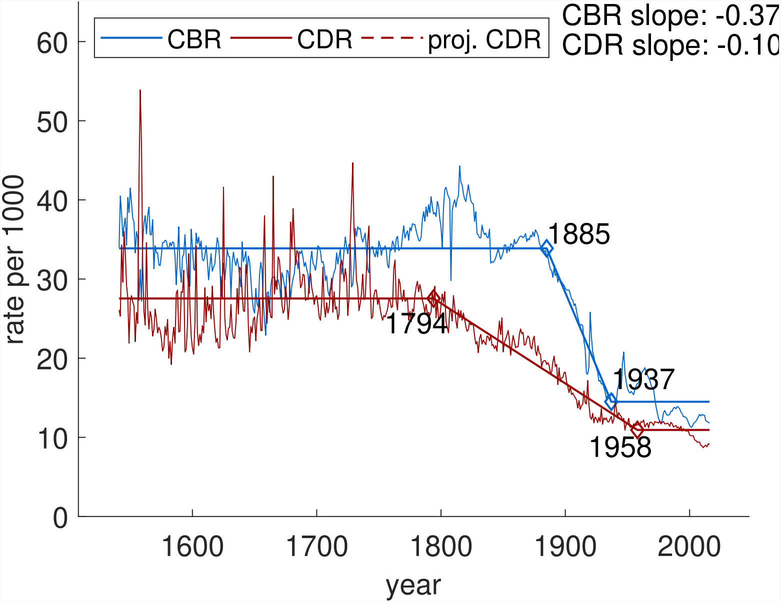
Estimating the demographic transition

- We take the 4-stage benchmark to available data for each country.
- For each CDR and CBR series in our sample, we estimate:
  1. An initial (pre-transition) level.
  2. The start date of the decline.
  3. The end date of the decline.
  4. A final (post-transition) level.
- For each country, we look for 4 parameters that best describe the data on the CDR and 4 parameters that best describe the data on the CBR.
- OLS with search for break-points to minimize quadratic distances. We over-ride a few cases to be more conservative.

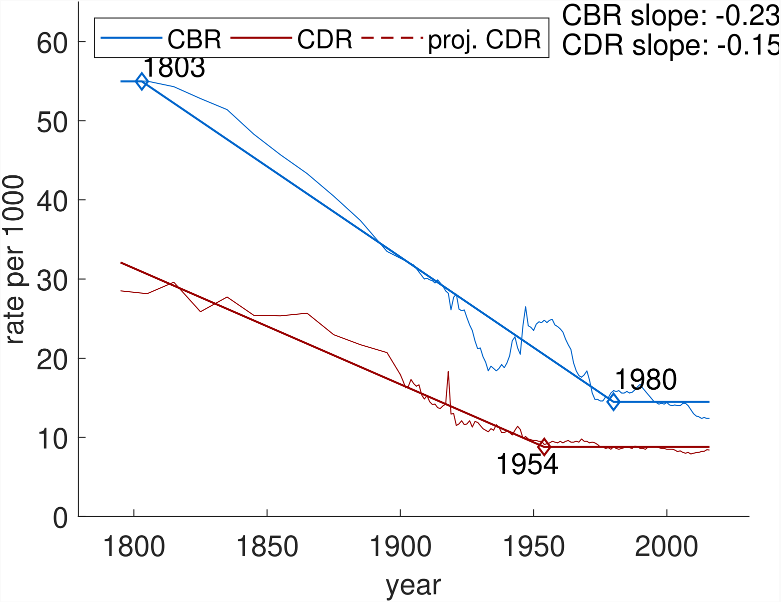
6 cases


CDR: case 1
CDR: case 2
CDR: case 3
CDR: case 4
CDR: case 5
CDR: case 6
2 4 6 8 10 12 14 16 18
4 6 8 10 12

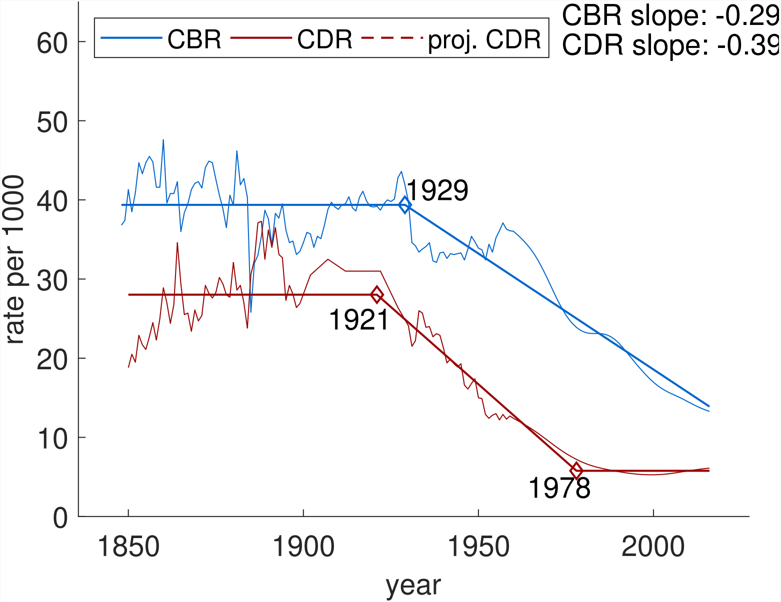
Case 1: Great Britain/UK



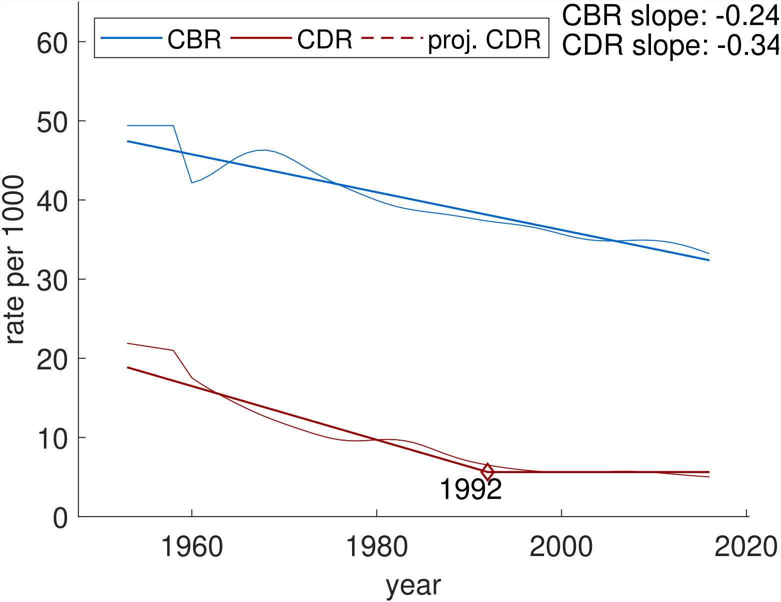
Case 2: United States



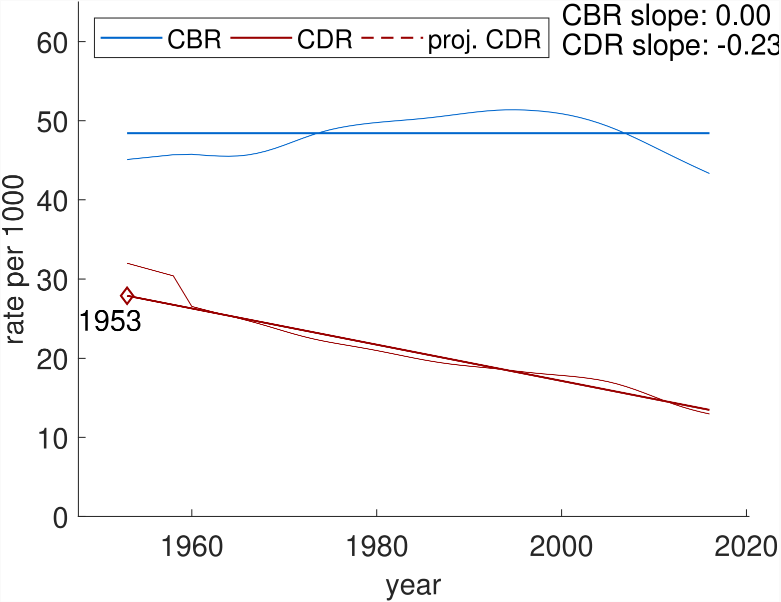
Case 3: Chile


CBR
CDR
proj. CDR
CBR slope: -0.29
CDR slope: -0.39
1929
1921
1978
rate per 1000
year
0
10
20
30
40
50
60
1850
1900
1950
2000

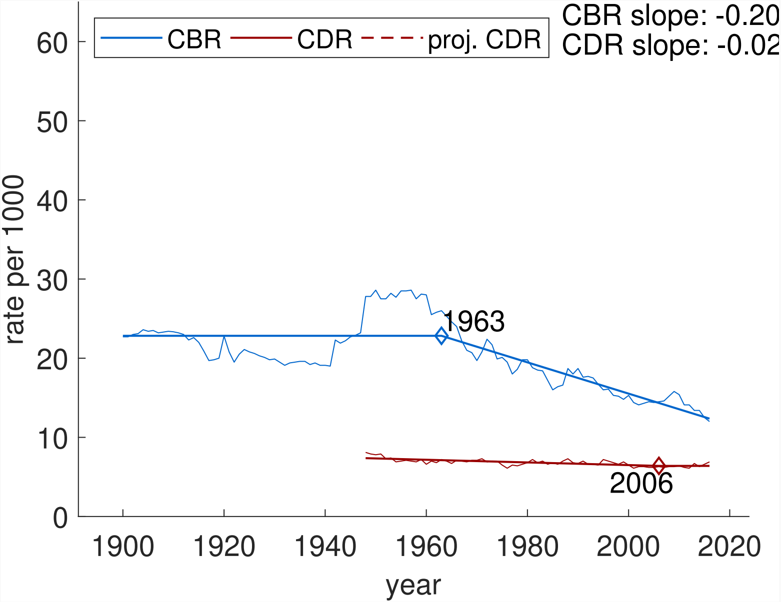
Case 4: Iraq


CBR
CDR
proj. CDR
CBR slope: -0.24
CDR slope: -0.34
60
50
40
30
20
10
0
rate per 1000
1992
1960
1980
2000
2020
year

Case 5: Chad


CBR slope: 0.00
CDR slope: -0.23
CBR
CDR
proj. CDR
60
50
40
30
20
10
0
rate per 1000
1953
1960
1980
2000
2020
year

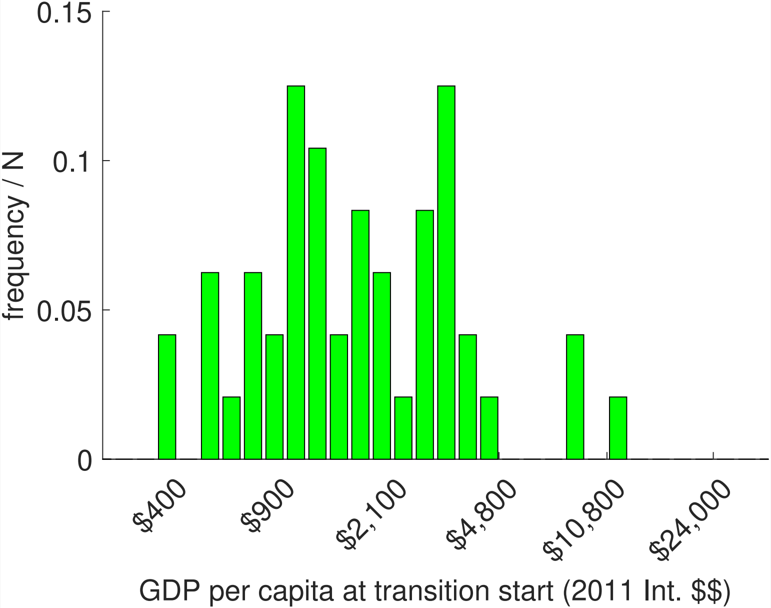
Case 6: Iceland



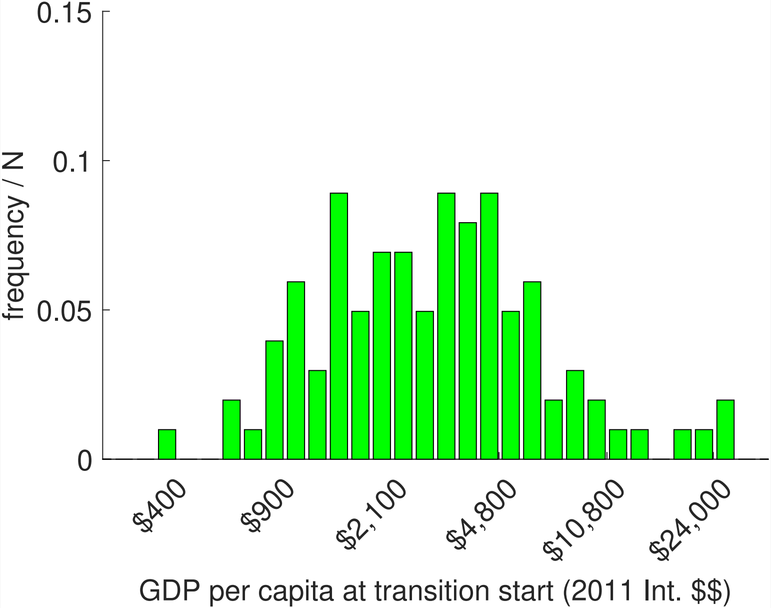
Case counts

CDR \CBR	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Total
Case 1	27	0	17	0	0	0	44
Case 2	26	20	79	6	0	0	131
Case 3	0	0	1	0	1	0	2
Case 4	0	0	2	0	0	0	2
Case 5	0	0	0	0	0	0	0
Case 6	0	7	0	0	0	0	7
Total	53	27	99	6	1	0	186

Income at the start of the CDR transition



Income at the start of the CBR transition

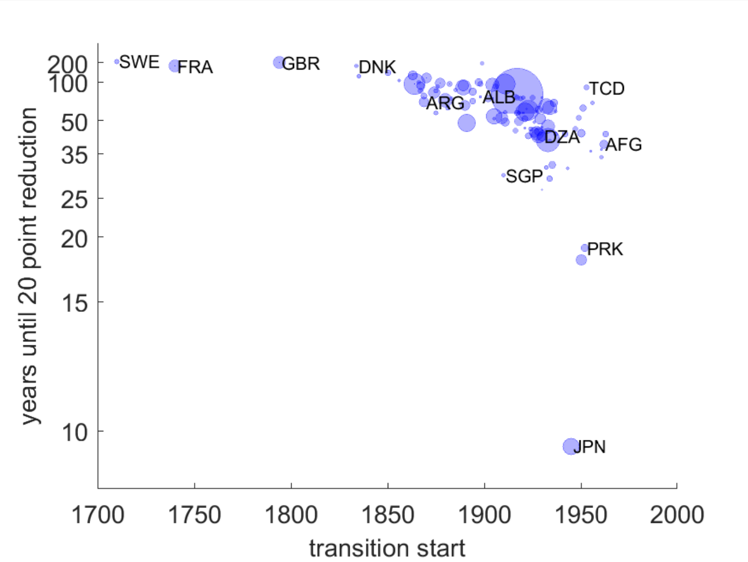


Countries entering transitions over time

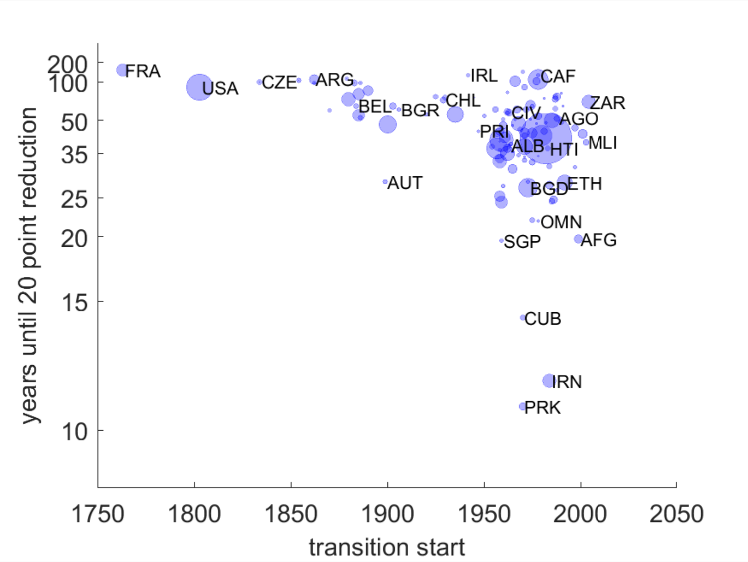
	before 1870	1870-1900	1900-1930	1930-1960	1960-1990	after 1990	All
mean initial lnGDPpc	7.72	7.85	7.55	7.42	7.32	6.55	7.55
mean initial CDR	26.67	26.30	23.88	27.06	26.12	22.28	25.57
mean slope CDR	-0.19	-0.25	-0.38	-0.59	-0.79	-0.93	-0.44
N	11	18	43	31	9	1	113

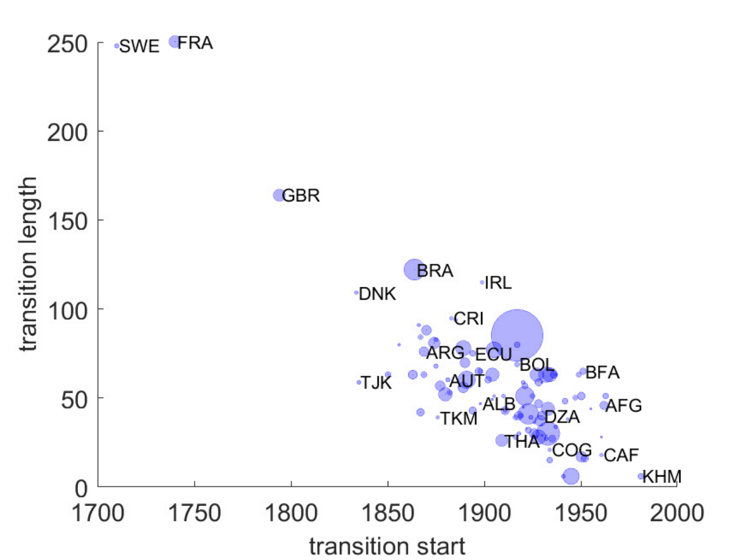
	before 1870	1870-1900	1900-1930	1930-1960	1960-1990	after 1990	All
mean initial lnGDPpc	7.46	8.39	7.92	7.93	8.03	7.19	7.96
mean initial CBR	38.74	36.02	39.70	39.82	44.21	46.70	42.51
mean slope CBR	-0.19	-0.32	-0.33	-0.51	-0.58	-0.50	-0.51
N	4	11	6	20	70	9	120

Transitions are getting faster, CDR (I)

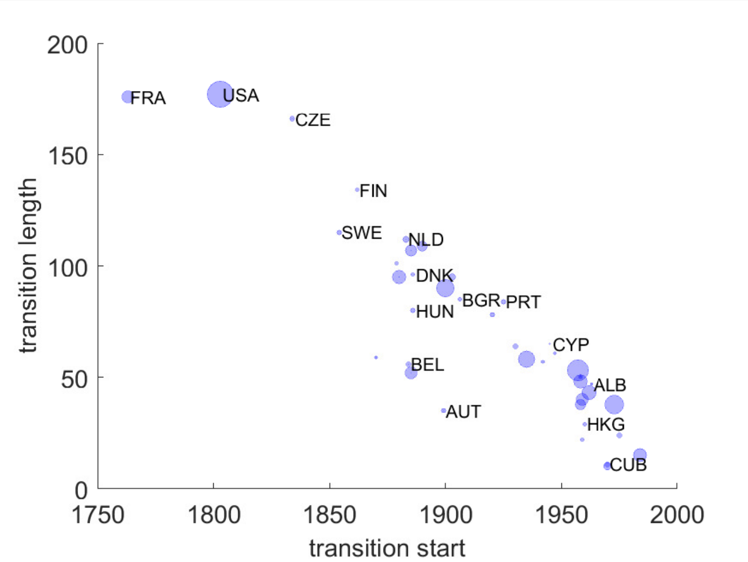


Transitions are getting faster, CBR (II)

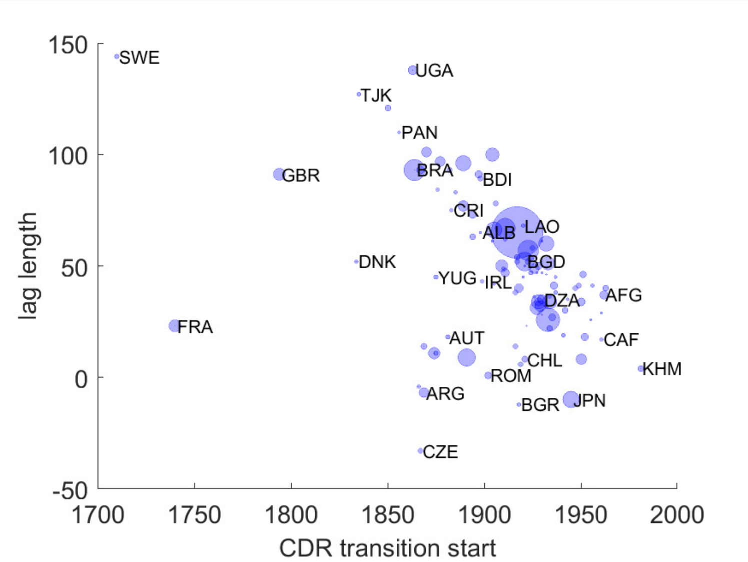



transition length
transition start
250
200
150
100
50
0
1700
1750
1800
1850
1900
1950
2000
SWE
FRA
GBR
BRA
DNK
IRL
CRI
ARG
ECU
BOL
BFA
TJK
AUT
AFG
ALB
TKM
DZA
THA
COG
CAF
KHM

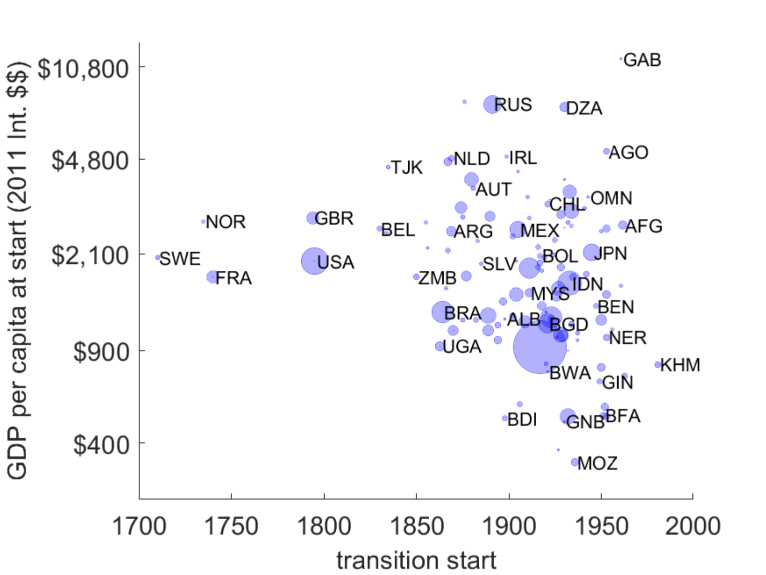
Transitions are getting faster, CBR (IV)



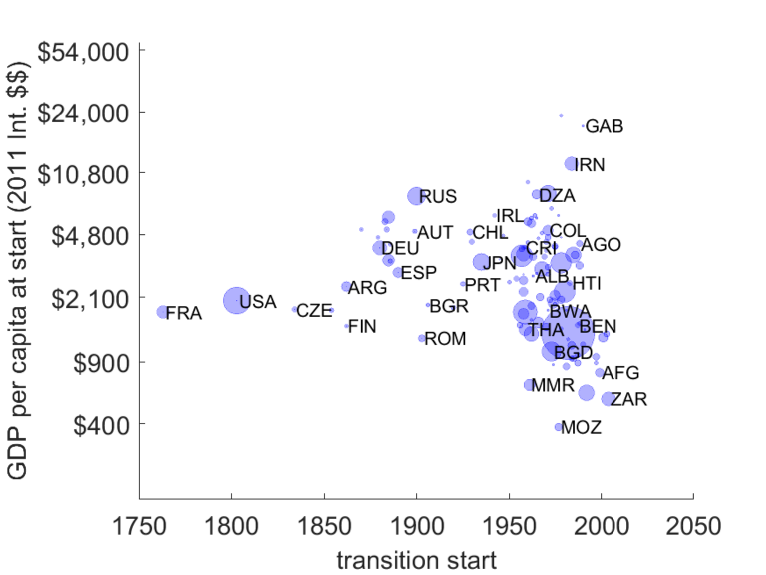
Time gap between the CDR and the CBR transitions



Income at the start of the CDR transitions



Income at the start of the CBR transitions



An empirical model of transitions

- Let T be the date at which a transition (mortality or fertility) starts.
- Let the probability of transition starting at time t conditional on not having occurred before be given by

$$\Pr(T^i = t | T^i \geq t) = G\left(\sum_{l=0}^{k-1} x_{l,it}\beta_l\right) \tag{1}$$

where G is the Logistic function and x_i is a set of controls:

- Let us start first just with $\ln(GDPpc)$ and $\ln(GDPpc)^2$.

Distribution of log GDPpc at the start of the CBR transitions

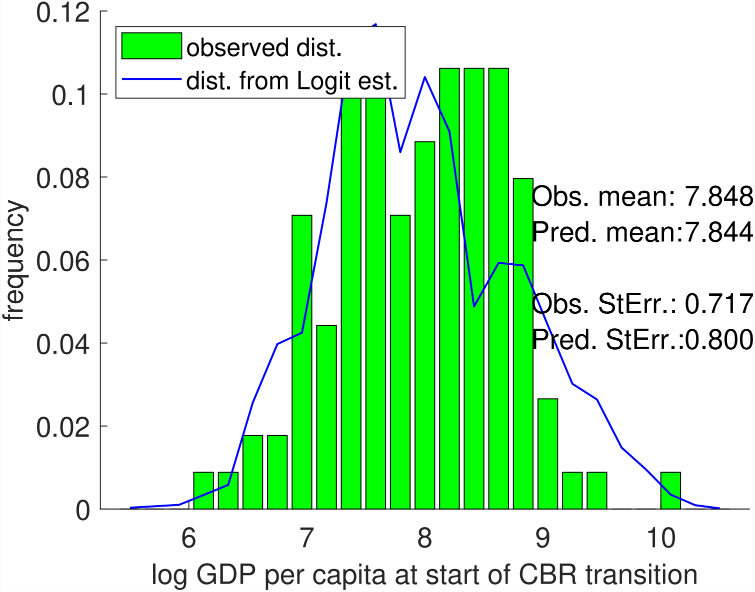


Figure 1: Within Sample Predictions

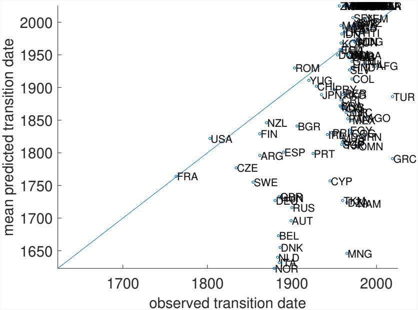
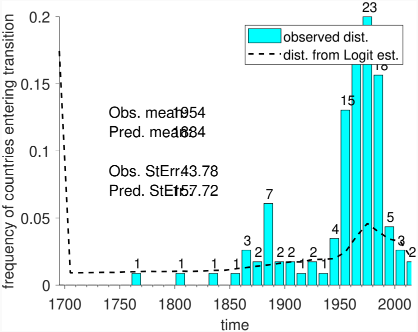


Figure 2: Distribution of Transition Dates



Do neighbors matter?

- We clearly need additional info in the Logit.
- We extend the analysis by including network effect.
- We estimate

$$\Pr(T^i = t | T^i \geq t) = G\left(\sum_{l=0}^{k-1} x_{l,it}\beta_l + \beta_k \mathcal{A}_{it}\right)$$

given:

$$\mathcal{A}_{it} \equiv \left[\sum_{j=1}^{N} g_{ij}\mathcal{I}_{j,t-1}\right]^{\psi}$$

where $\mathcal{I}_{j,t} = 1$ if the transition has already started in country j and g_{ij} measures the inverse of *the distance* between country i and country j.

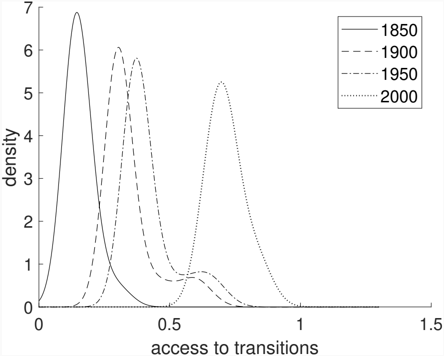
- We follow Melitz and Toubal (2013) by borrowing their data on bilateral geographic, linguistic, religious, and legal distances.
- Strong evidence of network effects for CBR. Weaker for the CDR.

Estimates, CBR

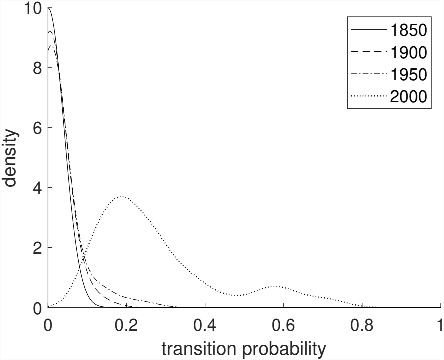
cons	-21.06	-36.78	-31.65	-33.57	-32.75	-27.47	-28.66	-27.06
	(7.37)	(8.78)	(9.10)	(8.60)	(8.86)	(8.86)	(9.05)	(8.99)
lnGDPPC	2.07	6.22	4.65	6.05	5.20	3.69	3.91	3.56
	(1.85)	(2.21)	(2.29)	(2.16)	(2.21)	(2.23)	(2.29)	(2.27)
lnGDPPC ^{2}	-0.01	-0.33	-0.24	-0.32	-0.27	-0.19	-0.19	-0.18
	(0.12)	(0.14)	(0.14)	(0.13)	(0.14)	(0.14)	(0.14)	(0.14)
access		0.79	9.86	0.86	0.91	13.79	9.72	12.23
		(0.34)	(0.96)	(0.15)	(0.13)	(1.36)	(0.98)	(1.24)
$<$ 500km			2.68			2.61	2.44	2.49
			(0.31)			(0.43)	(0.33)	(0.42)
500-1000km			1.62			1.38	1.49	1.41
			(0.34)			(0.52)	(0.35)	(0.48)
1000-2000km			0.83			0.78	0.90	0.84
			(0.32)			(0.42)	(0.31)	(0.39)
ling. dist				1.02		1.21		0.77
				(0.00)		(0.89)		(0.87)
legal dist					0.31		0.25	0.16
					(0.06)		(0.27)	(0.32)
ψ, curv.		0.48	0.38	0.46	0.48	0.39	0.39	0.40
		(0.06)	(0.11)	(0.00)	(0.02)	(0.08)	(0.13)	(0.09)
LLn	-661.3	-480.5	-456.7	-479.6	-478.1	-455.0	-455.0	-454.5
Pseudo-R^2	0.132	0.369	0.401	0.370	0.372	0.403	0.403	0.403
N. Obs.	48712	48712	48712	48712	48712	48712	48712	48712

Counterfactuals CBR, I

“Access to transitions” variable

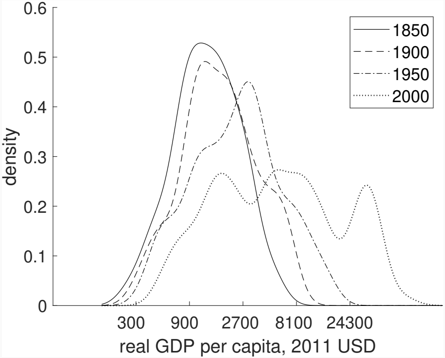


Transition prob., given observed access and GDPpc = $2000

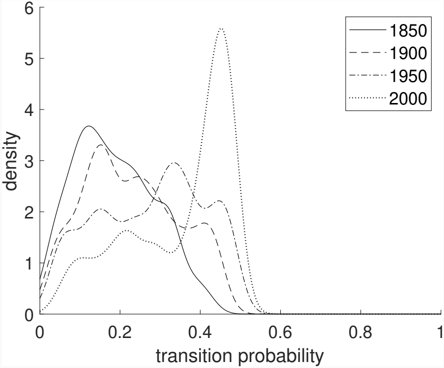


Counterfactuals CBR, II

Distribution of log GDPpc



Trans. prob. given log GDPpc, with access set to year 2000 mean



Model

- Consider a world that consists of different locations.
- Consumers in each location i live for two periods, one as children and one as adults.
- As adults, they work, consume, choose how many children to have, n_{it}, and how much education, e_{it}, to provide for each of them.
- Each child requires a time commitment of τ_1.
- Educating children is also time-consuming, to obtain e_{it} for each child, parents must pay a total time cost of $n_{it} e_{it} \tau_2$.
- With an exogenous probability s_{it} a child survives and moves to adulthood.

Human capital

- Adults have a total time endowment of 1.

- They do not value leisure, and so supply $1 - \tau_1 n_{it} - \tau_2 n_{it} e_{it}$ units of time to the labor market.

- The income that parents receive per unit of labor depends on the equilibrium unskilled and skilled wages, w_{it}^U and w_{it}^S, and their level of human capital, h_{it}.

- For each unit of labor supplied, adults receive income $y_{it} \equiv w_{it}^U + h_{it} w_{it}^S$.

- The level of education that children receive determines their level of human capital when they are adults:

$$h_{it+1} = e_{it}$$

Adults' problem

- Parents choose c_{it}, e_{it}, and n_{it} to maximize

$$\log(c_{it} - \overline{c}_i) + \log(s_{it} n_{it}) + \beta \log y_{i,t+1},$$

subject to

$$c_{it} = (1 - n_{it}(\tau_1 + \tau_2 e_{it}))y_{it},$$

and

$$y_{it+1} \equiv w^U_{it+1} + h_{it+1} w^S_{it+1}$$

with $h_{it+1} = e_{it}$.

Decisions

- The optimal decisions for e_{it} and n_{it} are given by

$$e_{it} = \frac{\beta \frac{\tau_1}{\tau_2} - \frac{1}{\phi_{i,t+1}}}{1-\beta},$$

and

$$n_{it} = \frac{1}{2}\left(1 - \frac{\overline{c}_i}{y_{it}}\right)\frac{1}{\tau_1 + \tau_2 e_{it}}.$$

where:

$$\phi_{it} = \frac{w_{it}^S}{w_{it}^U}$$

is the skill premium.

- e_{it} is increasing in $\phi_{i,t+1}$ (the skill premium) and in τ_1 and decreasing in τ_2.
- n_{it} is decreasing in τ_1, τ_2 and e_{it} and decreasing in $\overline{c}_i$.

Production and the skill premium

- Time-t output for country i, Y_{it}, be given by

$$Y_{it} = [(A_{it}S_{it})^{\rho} + (B_{it}[aL_{it}^{\omega} + (1-a)U_{it}^{\omega}]^{\frac{1}{\omega}})^{\rho}]^{\frac{1}{\rho}},$$

- Given this production technology, the skill premium is given by

$$\phi_{it} = \frac{w_{it}^{S}}{w_{it}^{U}} = \left(\frac{A_{it}}{B_{it}}\right)^{\rho} \frac{S_{it}^{\rho}}{[aL_{it}^{\omega} + (1-a)U_{it}^{\omega}]^{\frac{\rho}{\omega}-1}(1-a)U_{it}^{\omega-1}}$$

Technology diffusion I

- World is composed of 1 frontier country (country 0) and n followers, $N = \{1, .., n\}$.

- Distance of each follower from the frontier is given by

$$d_{it} = \phi_{oi}(t) + \phi_1(t) d_i^g + \phi_2(t) d_i^c$$

  where

  - $\phi_{oi}(t)$ time-varying idiosyncratic barriers.
  - d_i^g is geographic distance.
  - d_i^c is linguistic/cultural differences.
  - $\phi_j(t)$ for $j \in \{1, 2\}$ is the same across countries and declining at a constant rate:

$$\phi_j(t+1) = \phi_j(t)(1 - g_{\phi_j}) \text{ for } j \in \{1, 2\}$$

Technology diffusion II

- Let $\overline{A}_t$ and $\overline{B}_t$ be the frontier level of technology.
- For $t \in \{..., -3, -2, -1, 0\}$, $A_t = \overline{A}_0$ and $B_t = \overline{B}_0$.
- At time 1, frontier skilled labor productivity makes an unanticipated jump $\overline{A}_1 > \overline{A}_0$ while $\overline{B}_1 = \overline{B}_0$.
- For $t \in \{2, 3, 4, ...\}$

$$\overline{A}_t = (1+g)\overline{A}_{t-1}$$

and

$$\overline{B}_t = (1+g)\overline{B}_{t-1}$$

Technology diffusion III

- In the long run, all countries will achieve an overall TFP proportional to whatever part of their barriers to the frontier, if any, does not vanish with the decreasing importance of distance.

- The level of technology in a non-frontier country depends on its distance from the frontier:

$$A_{i,t+1} = A_{it}\left(1 + ge^{-\zeta_A d_{it}}\frac{\overline{A}_t}{A_{it}}\right)^{\theta_1}$$

  and

$$B_{i,t+1} = B_{it}\left(1 + ge^{-\zeta_A d_{it}}\frac{\overline{B}_t}{B_{it}}\right)^{\theta_2}$$

- Similar to Lucas (2009, AEJ-Macro).

- Finally, we assume that the survival probability depends on technology as:

$$s_{it} = 1 - \frac{1 - s_i^0}{(A_{it} + B_{it})^{\zeta_s}}$$

Vital statistics

- The CBR:

$$B_{it} = \frac{U_{it} n_{it}}{U_{it} + U_{it} s_{it} n_{it}} = \frac{n_{it}}{1 + s_{it} n_{it}}$$

- The CDR:

$$D_{it} = \frac{U_{it} + U_{it} n_{it}(1 - s_{it})}{U_{it} + U_{it} s_{it} n_{it}} = \frac{1 + n_{it}(1 - s_{it})}{1 + s_{it} n_{it}}$$

- Rate of population growth:

$$B_{it} - D_{it} = \frac{n_{it} s_{it} - 1}{1 + s_{it} n_{it}}$$

Quantitative exercise

- Suppose we are in a world in which period 0 is 1775, and a model period lasts 25 years.
- Distances d_{it} are a function of physical distance only:

$$d_{it} = \phi_t d_i^g$$

- A frontier country (UK), assumed to be on average effectively 50 kilometers from the notional "frontier."
- Seven followers: 312.5 km., away (e.g. Paris), 625 km. away (e.g. Geneva), 1250 km. away (e.g. Vienna), 2500 km. away (e.g. Moscow), 5000 km. away (e.g. Baghdad), and 10000 km. away (e.g. Manila).
- All of these countries are initially identical except for their distance from the frontier. Also, all in a population steady state in which total births equal total deaths.
- In period 0, frontier technology starts growing and the importance of distance for diffusion starts falling.

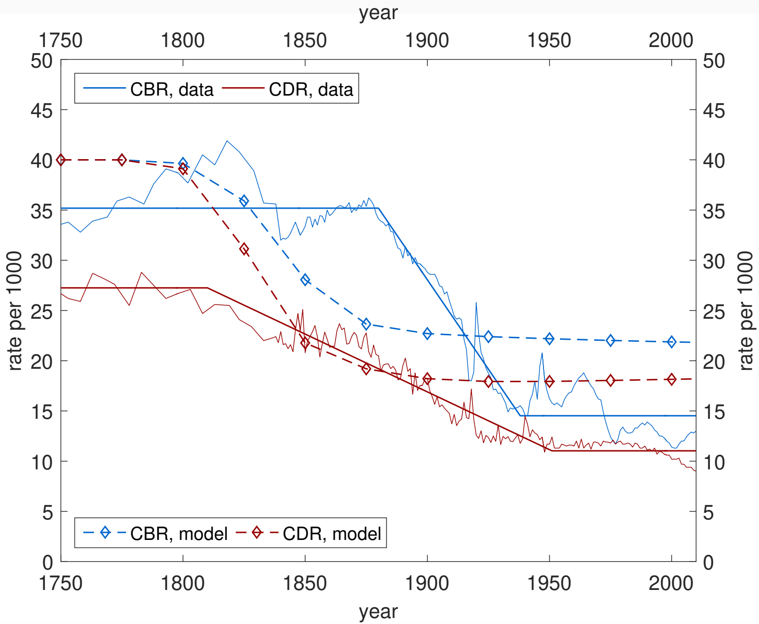
Calibration I

Parameter	Description	Value
	Preferences	
β	altruism	0.8
$\bar{c}$	minimum consumption	2
τ_1	time cost of fertility	0.133
τ_2	time cost of education	0.05
	Technology	
ρ	substitutability between skilled, unskilled labor	0.8
ω	substitutability between land, unskilled labor	0.1
$\frac{\bar{A}_0}{\bar{B}_0}$	initial ratio between skilled and unskilled TFP	0.2
$\frac{\bar{A}_1}{\bar{B}_0}$	long-run ratio between skilled and unskilled TFP	0.5
s_0	initial infant mortality rate	0.5

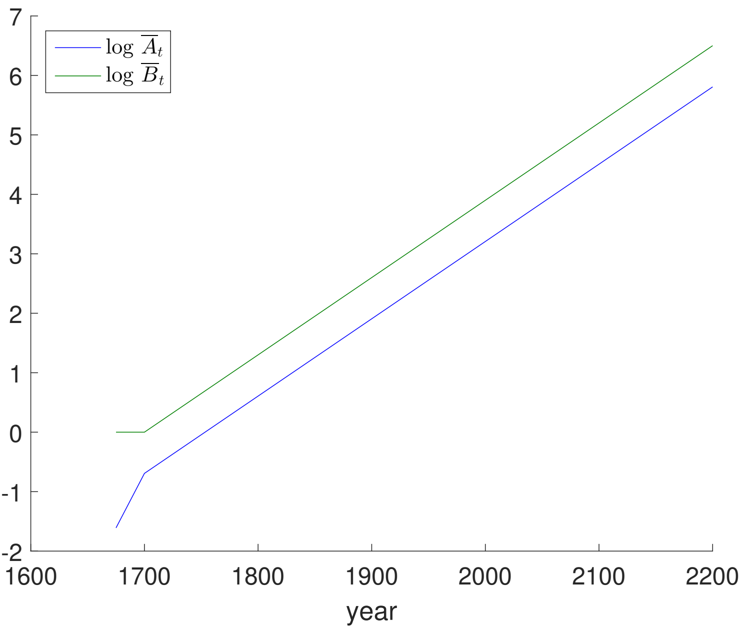
Calibration II

Parameter	Description	Value
	Growth and Diffusion	
ϕ_0	initial cost of distance	3.7
g_ϕ	rate of decline in cost of distance	0.4895
g	rate of technology growth	0.325
ζ	elasticity of mortality to technology	2
θ	elasticity of unskilled TFP growth to gap with frontier	.25

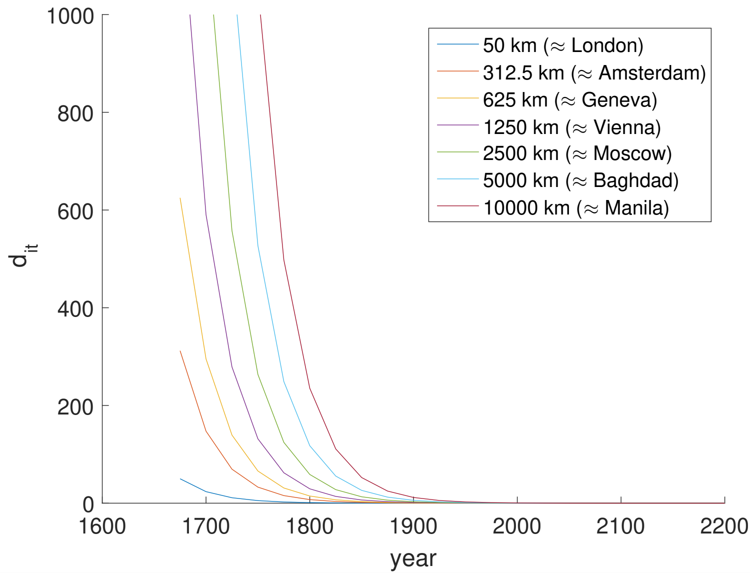
Demographic transition in Great Britain/UK



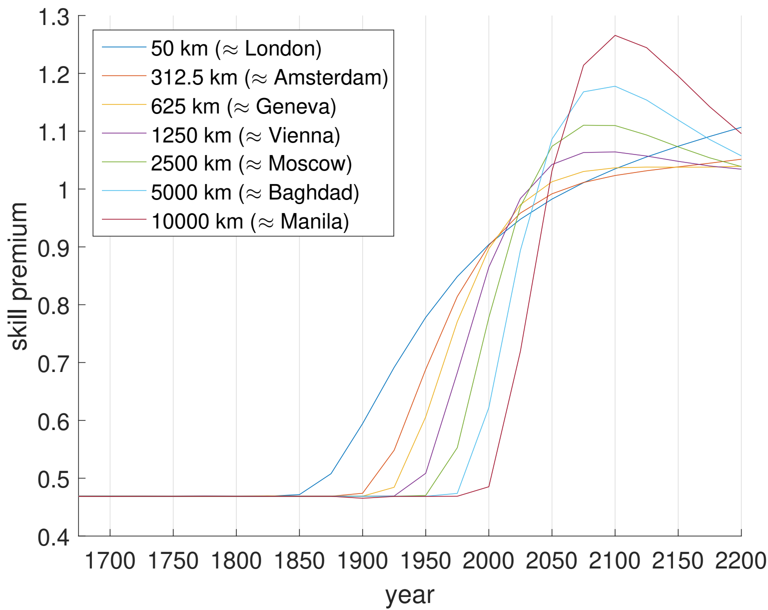
Technology at the frontier



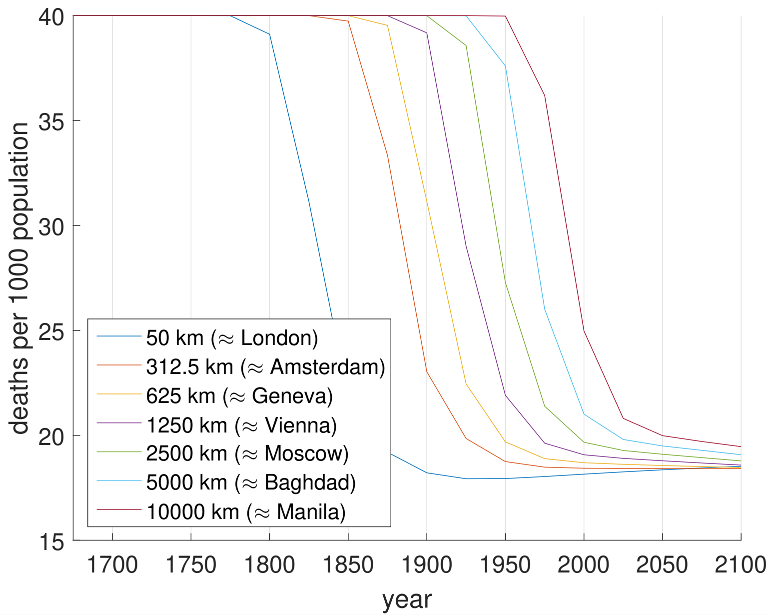
Effective distance from frontier



Skill premium

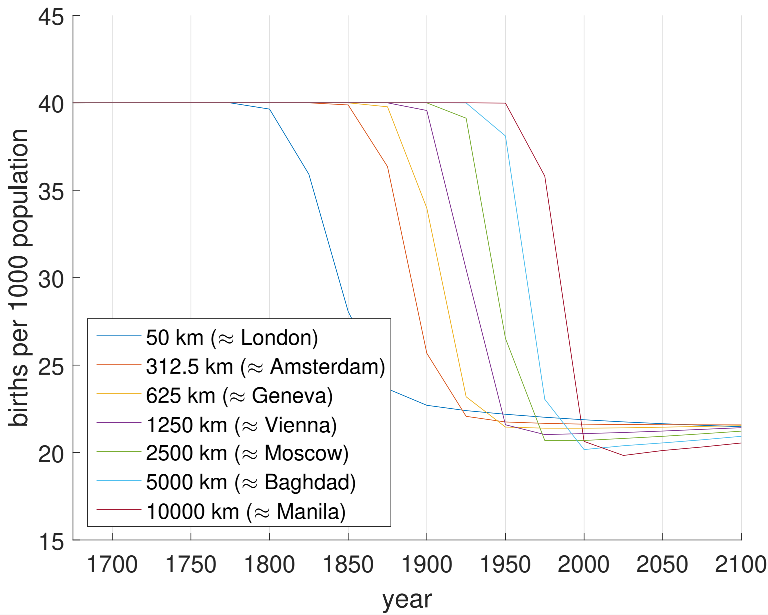


CDR



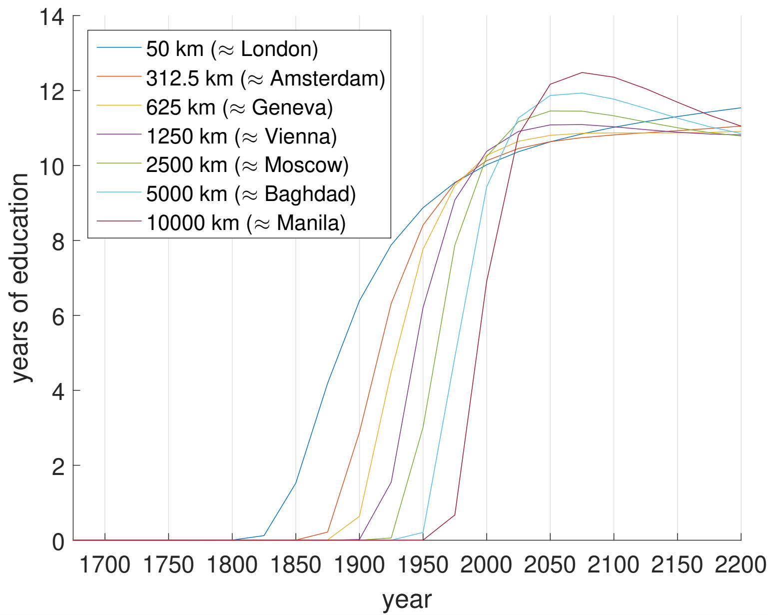
40
35
30
25
20
15
deaths per 1000 population
1700
1750
1800
1850
1900
1950
2000
2050
2100
year
50 km (≈ London)
312.5 km (≈ Amsterdam)
625 km (≈ Geneva)
1250 km (≈ Vienna)
2500 km (≈ Moscow)
5000 km (≈ Baghdad)
10000 km (≈ Manila)

CBR



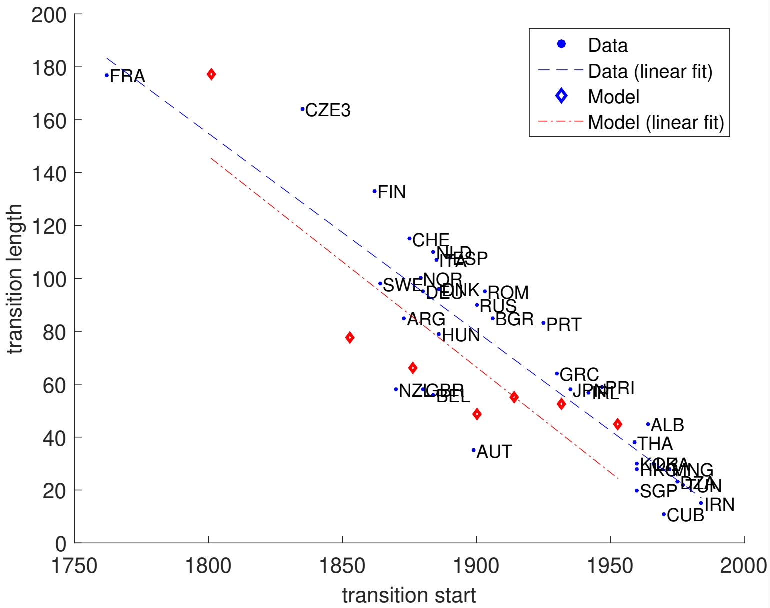
45
40
35
30
25
20
15
births per 1000 population
1700
1750
1800
1850
1900
1950
2000
2050
2100
year
50 km (≈ London)
312.5 km (≈ Amsterdam)
625 km (≈ Geneva)
1250 km (≈ Vienna)
2500 km (≈ Moscow)
5000 km (≈ Baghdad)
10000 km (≈ Manila)

Education

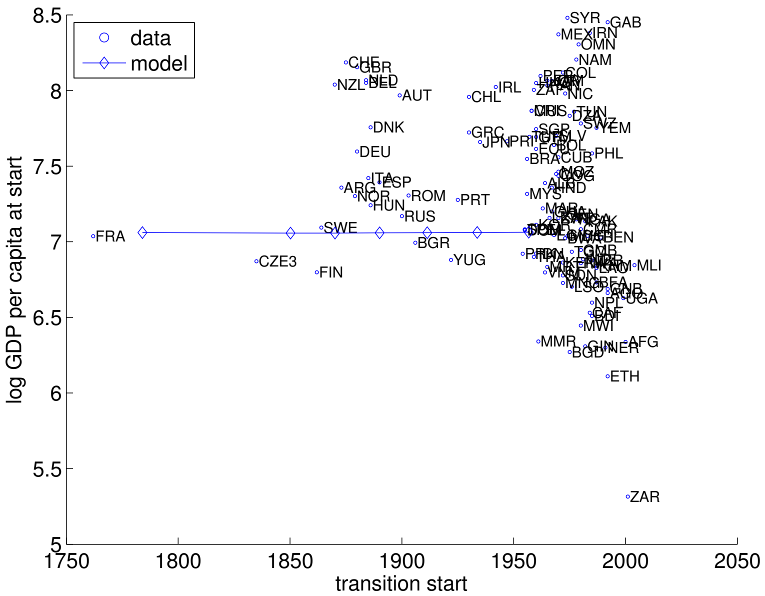


50 km (≈ London)
312.5 km (≈ Amsterdam)
625 km (≈ Geneva)
1250 km (≈ Vienna)
2500 km (≈ Moscow)
5000 km (≈ Baghdad)
10000 km (≈ Manila)
years of education
14
12
10
8
6
4
2
0
1700 1750 1800 1850 1900 1950 2000 2050 2100 2150 2200
year

Transition length: data vs. model



GDP per capita at the start of fertility transition



Conclusions

- Construct a data set on demographic transitions for 188 countries over the last 250 years.
    1. Transitions are becoming faster.
    2. GDP per capita at the start of a transition is roughly constant.
    3. For a country, an key correlate of the start of a fertility transition is the number of neighbors who has already started their transitions.
- Build a simple model of demographic transition that has the *potential* to account for these facts.
- The model economy has two key features:
    1. households deciding how many children to have and how much to invest in their human capital.
    2. diffusion of technology from a frontier country to the rest of the world.