If Technology Has Arrived Everywhere, Why has Income Diverged?

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- What **role** does technology play in **income growth dynamics**?

Technology

- Two components

  1. When they arrive to countries

  2. Penetration rate once they are adopted

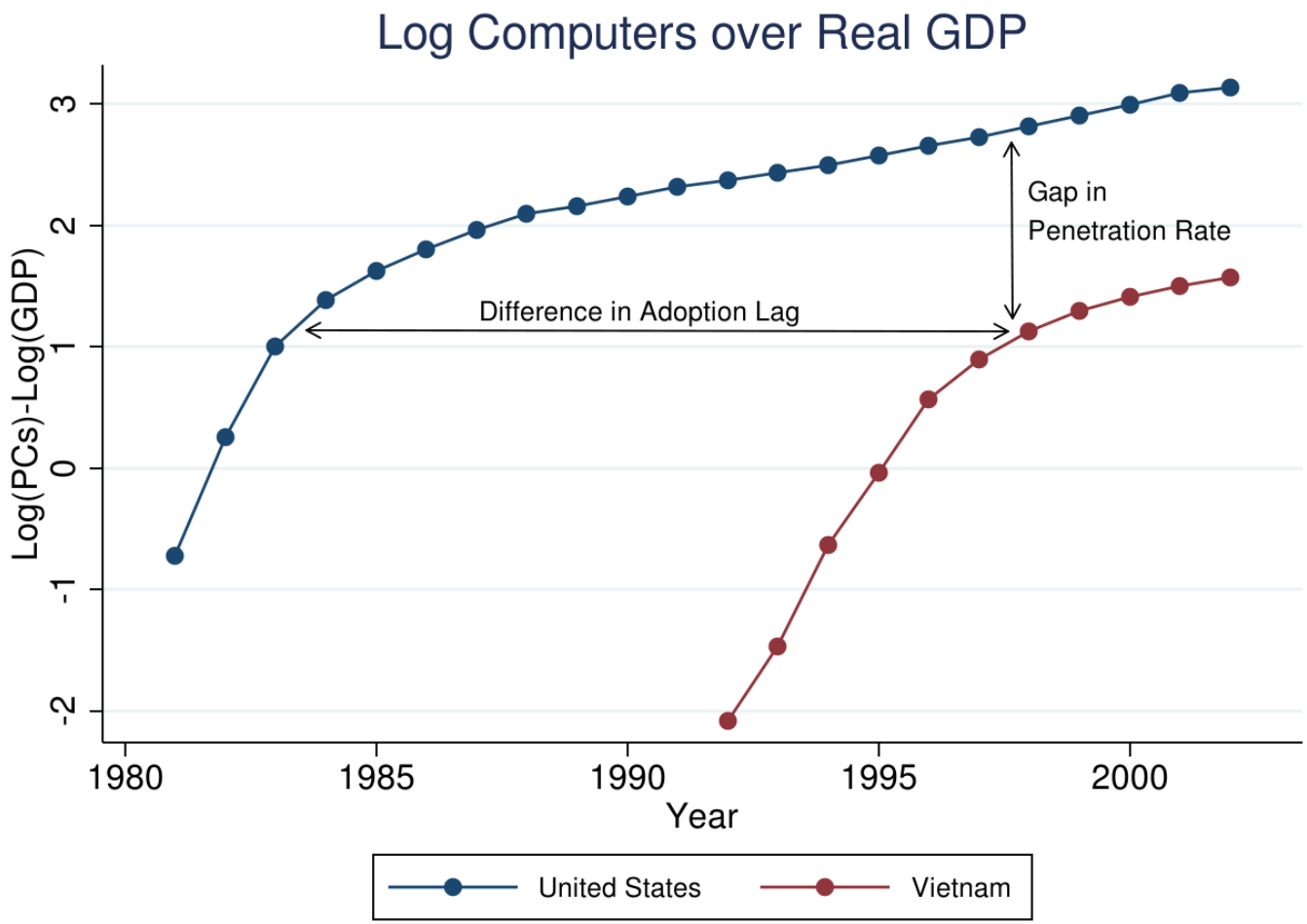
Plan

1. Measure adoption lags and penetration rates for 25 technologies invented over the last 200 years in 150 countries

2. How the diffusion of technology has changed over the last 200 years and how it has differed across countries

3. Compute implications of differences in evolution of technology diffusion for cross-country evolution of productivity **growth**.

Example of our Data and the Two Adoption Margins



Identification

$$y^c_{\tau t} = \beta^c_{\tau 1} + y^c_t + \beta_{\tau 2} t + \beta_{\tau 3} \left((\mu - 1) \ln(t - \beta^c_{\tau 4} - \tau) - (1 - \alpha)(y^c_t - l^c_t) \right)$$

- Adoption lag: curvature at any given moment
- Intensive margin: long-run adoption level relative to income

$$\ln a^c_\tau = \frac{\beta^c_{1,\tau} - \beta^W_{1,\tau}}{\beta_{3,\tau}} + \frac{\gamma}{2}(D^c_\tau - D^W_\tau).$$

- Extensions:
  - Non-homothetic technologies: coefficient different than one in front of y.
  - Model with capital: add euler equation term.

Data

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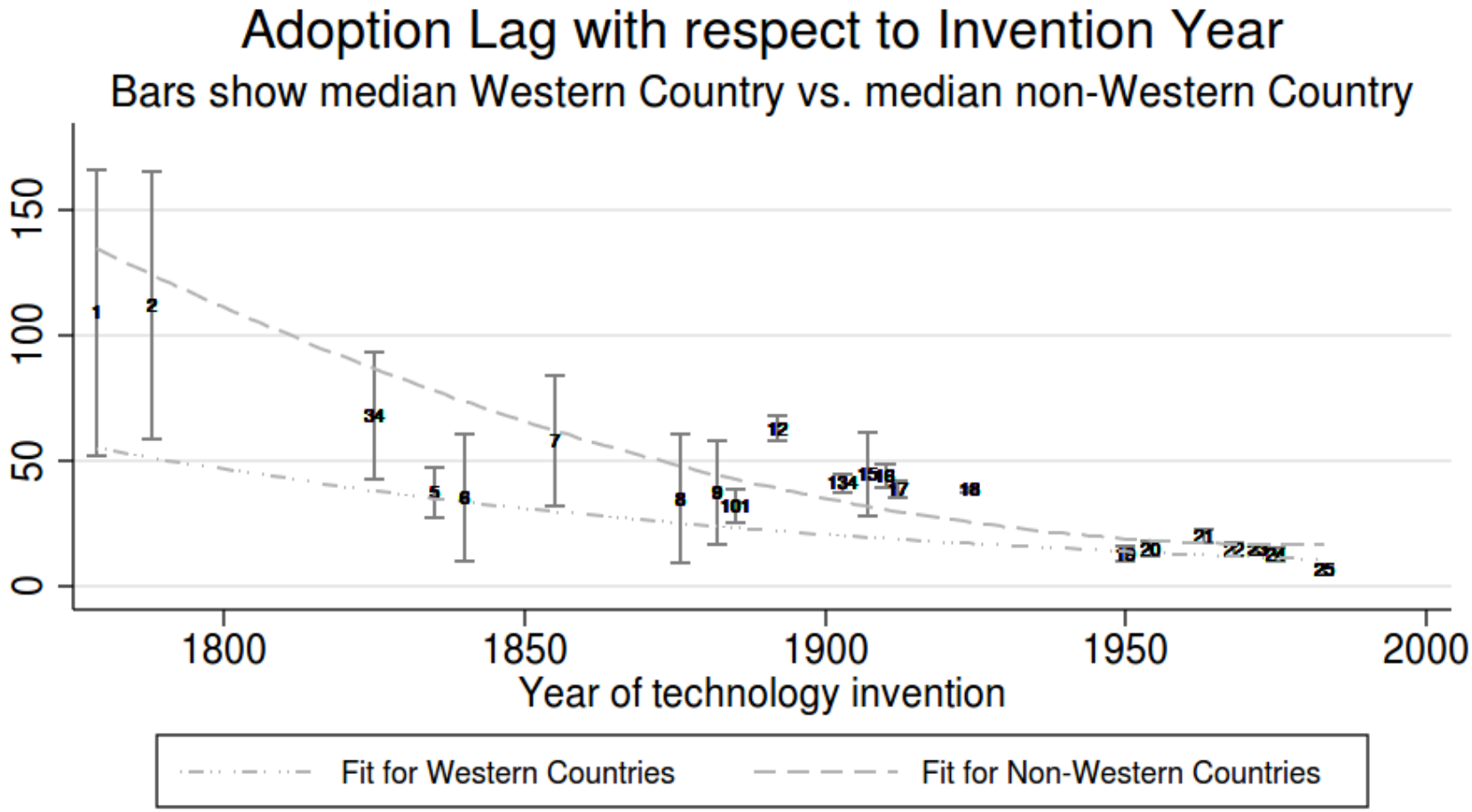
Table: Estimated Adoption Lags

	Invention Year	Obs.	Mean	SD	P10	P50	P90	IQR
Spindles	1779	31	119	48	51	111	171	89
Steam and Motor Ships	1788	45	121	53	50	128	180	104
Railways Freight	1825	46	74	34	31	74	123	50
Railways Passengers	1825	39	72	39	16	70	123	63
Telegraph	1835	43	45	32	10	40	93	43
Mail	1840	47	46	37	8	38	108	62
Steel (Bessemer, Open Hearth)	1855	41	64	34	14	67	105	51
Telephone	1876	55	50	31	8	51	88	51
Electricity	1882	82	48	23	15	53	71	38
Cars	1885	70	39	22	11	34	65	36
Trucks	1885	62	36	22	9	34	62	32
Tractor	1892	88	59	20	18	67	69	12
Aviation Freight	1903	43	40	15	26	42	60	19
Aviation Passengers	1903	44	28	16	9	25	52	18
Electric Arc Furnace	1907	53	50	19	27	55	71	34
Fertilizer	1910	89	46	10	35	48	54	7
Harvester	1912	70	38	18	10	41	54	17
Synthetic Fiber	1924	48	38	5	33	39	41	2
Blast Oxygen Furnace	1950	39	14	8	7	13	26	11
Kidney Transplant	1954	24	13	7	3	13	25	5
Liver Transplant	1963	21	18	6	14	18	24	3
Heart Surgery	1968	18	12	6	8	13	20	4
Cellphones	1973	82	13	5	9	14	17	6
PCs	1973	68	16	3	12	15	19	3
Internet	1983	58	7	4	1	7	11	3
All Technologies		1306	44	35	9	38	86	46



Technologies:
1. Spindles, 2. Ships, 34. Railway Passengers and Freight, 5. Telegraph, 6. Mail,
7. Steel (Bessemer, Open Hearth), 8. Telephone, 9. Electricity, 101. Cars and Trucks, 12. Tractors,
134. Aviation Passengers and Freight, 15. Electric Arc Furnaces, 16. Fertilizer, 17. Harvester,
18. Synthetic Fiber, 19. Blast Oxygen Furnaces, 20. Kidney Transplant, 21. Liver transplant,
22. Heart Surgery, 23. PCs, 24. Cellphones, 25. Internet

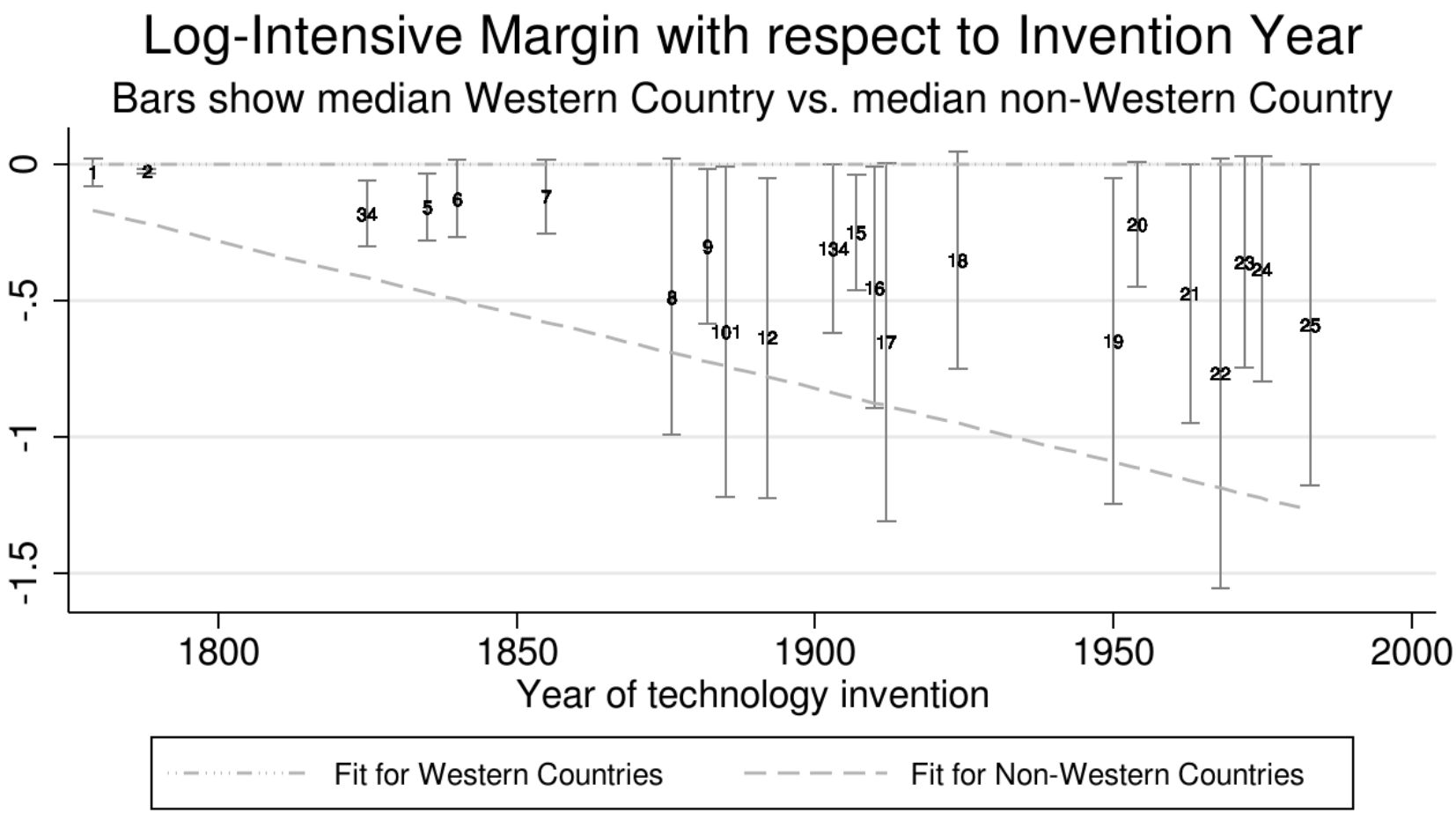
Convergence in Adoption Lags

Dep. Variable:	(1) Log(Lag) World	(2) Log(Lag) Western Countries	(3) Log(Lag) Rest of the World
Year-1820	-0.011**	-0.0081**	-0.0112**
	(0.004)	(0.0004)	(0.0004)
Constant	4.27**	3.67**	4.48**
	(0.07)	(0.07)	(0.05)
Observations	1274	336	938
R-squared	0.45	0.34	0.53

Note: robust standard errors in parentheses,** $p<0.01$. Each observation is re-weighted so that each technology carries equal weight.

Table: Estimated Intensive Margin

	Invention Year	Obs.	Mean	SD	P10	P50	P90	IQR
Spindles	1779	31	-0.02	0.6	-0.8	-0.1	0.8	0.7
Steam and Motor Ships	1788	45	-0.01	0.6	-0.6	0.0	0.7	0.6
Railways Freight	1825	46	-0.17	0.4	-0.6	-0.2	0.4	0.6
Railways Passengers	1825	39	-0.24	0.5	-0.9	-0.2	0.2	0.5
Telegraph	1835	43	-0.26	0.5	-1.0	-0.2	0.3	0.7
Mail	1840	47	-0.19	0.3	-0.6	-0.1	0.1	0.4
Steel (Bessemer, Open Hearth)	1855	41	-0.22	0.4	-0.7	-0.1	0.2	0.6
Telephone	1876	55	-0.91	0.9	-2.2	-0.8	0.1	1.2
Electricity	1882	82	-0.58	0.6	-1.2	-0.5	0.1	0.9
Cars	1885	70	-1.13	1.1	-2.1	-1.1	0.1	1.6
Trucks	1885	62	-0.86	1.0	-1.7	-0.8	0.1	1.1
Tractor	1892	88	-1.02	0.9	-2.3	-0.9	0.1	1.5
Aviation Freight	1903	43	-0.39	0.6	-1.3	-0.2	0.2	0.9
Aviation Passengers	1903	44	-0.45	0.7	-1.3	-0.4	0.2	0.9
Electric Arc Furnace	1907	53	-0.29	0.5	-0.9	-0.2	0.3	0.8
Fertilizer	1910	89	-0.83	0.8	-1.9	-0.7	0.1	1.3
Harvester	1912	70	-1.10	1.0	-2.7	-1.0	0.2	1.5
Synthetic Fiber	1924	48	-0.52	0.7	-1.6	-0.4	0.2	0.9
Blast Oxygen Furnace	1950	39	-0.81	0.9	-2.3	-0.4	0.1	1.8
Kidney Transplant	1954	24	-0.19	0.4	-0.8	-0.1	0.1	0.3
Liver Transplant	1963	21	-0.33	0.7	-1.6	-0.1	0.1	0.5
Heart Surgery	1968	18	-0.44	0.8	-1.7	-0.1	0.2	0.6
Cellphones	1973	82	-0.75	0.7	-1.8	-0.6	0.1	1.2
PCs	1973	68	-0.60	0.6	-1.4	-0.6	0.1	0.9
Internet	1983	58	-0.96	1.1	-2.1	-0.8	0.1	1.5
All Technologies		1306	-0.62	0.8	-1.7	-0.4	0.2	1.0



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Productivity Gap in 1820

- In balanced growth:

$$Y_W / Y_{NW} = e^{(\chi+\gamma)(D_{NW}-D_W)-\ln(a_\tau^{NW})/(1-\alpha)}$$

where $(\chi + \gamma) = 0.2\%$, $\alpha = 1/3$.

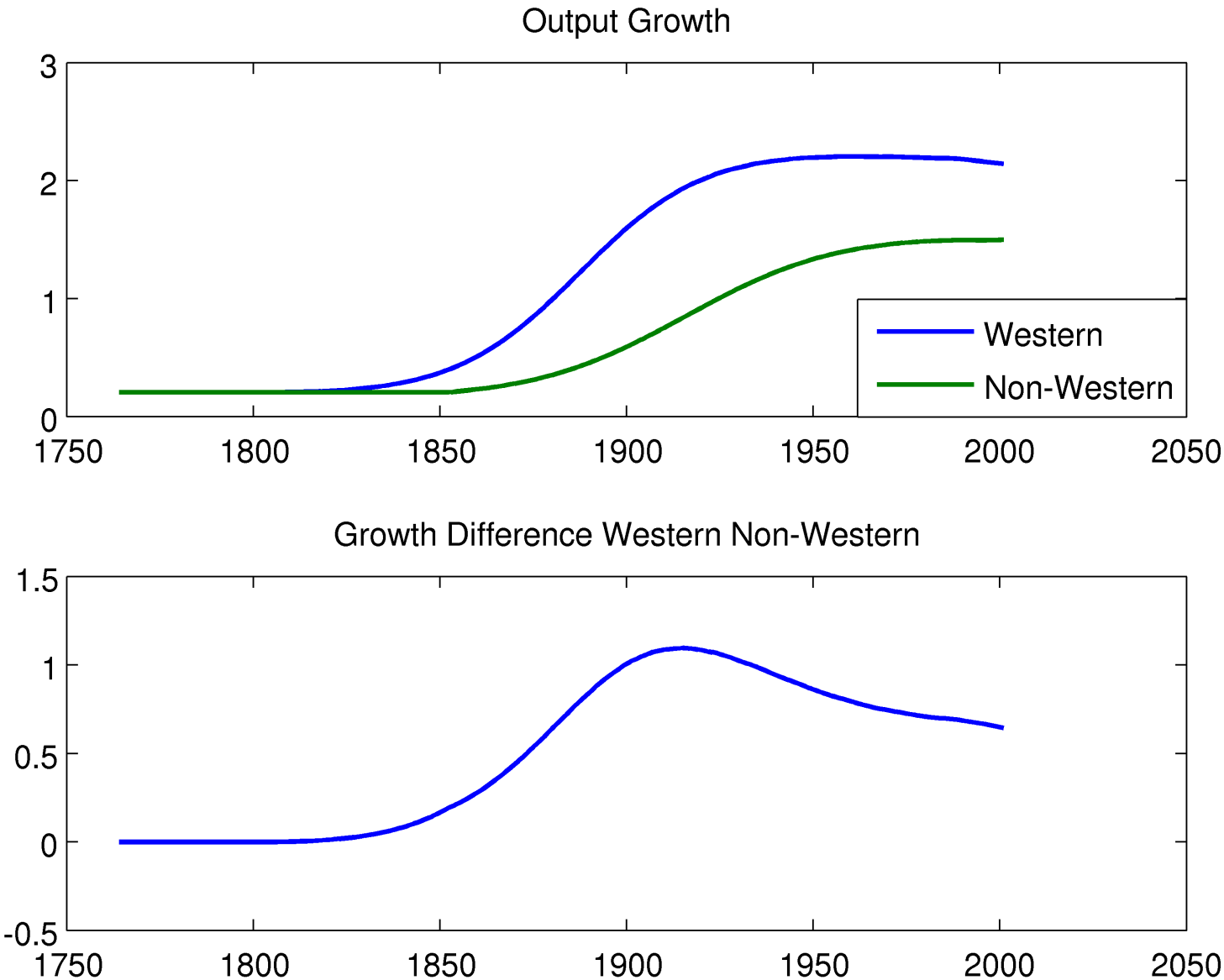
- In 1820:
  - $ln(a_\tau^{NW}) = -0.39$
  - $(D_{NW} - D_W) = 49$
  - Predicted $Y_W / Y_{NW} = 1.9$
  - Maddison $Y_W / Y_{NW} = 1.9$

Transitional Dynamics – After Industrial Revolution

- T=1765, invention of Watt's steam engine as beginning of Industrial Revolution.

- Long-run growth comes evenly from χ and γ
  - Before T, $g_{\text{Old}} = 0.2\%$
  - After T, $\gamma + \chi = 2\%$

Income p.c. growth of Western and Non-Western countries



Growth rates of GDP per capita.

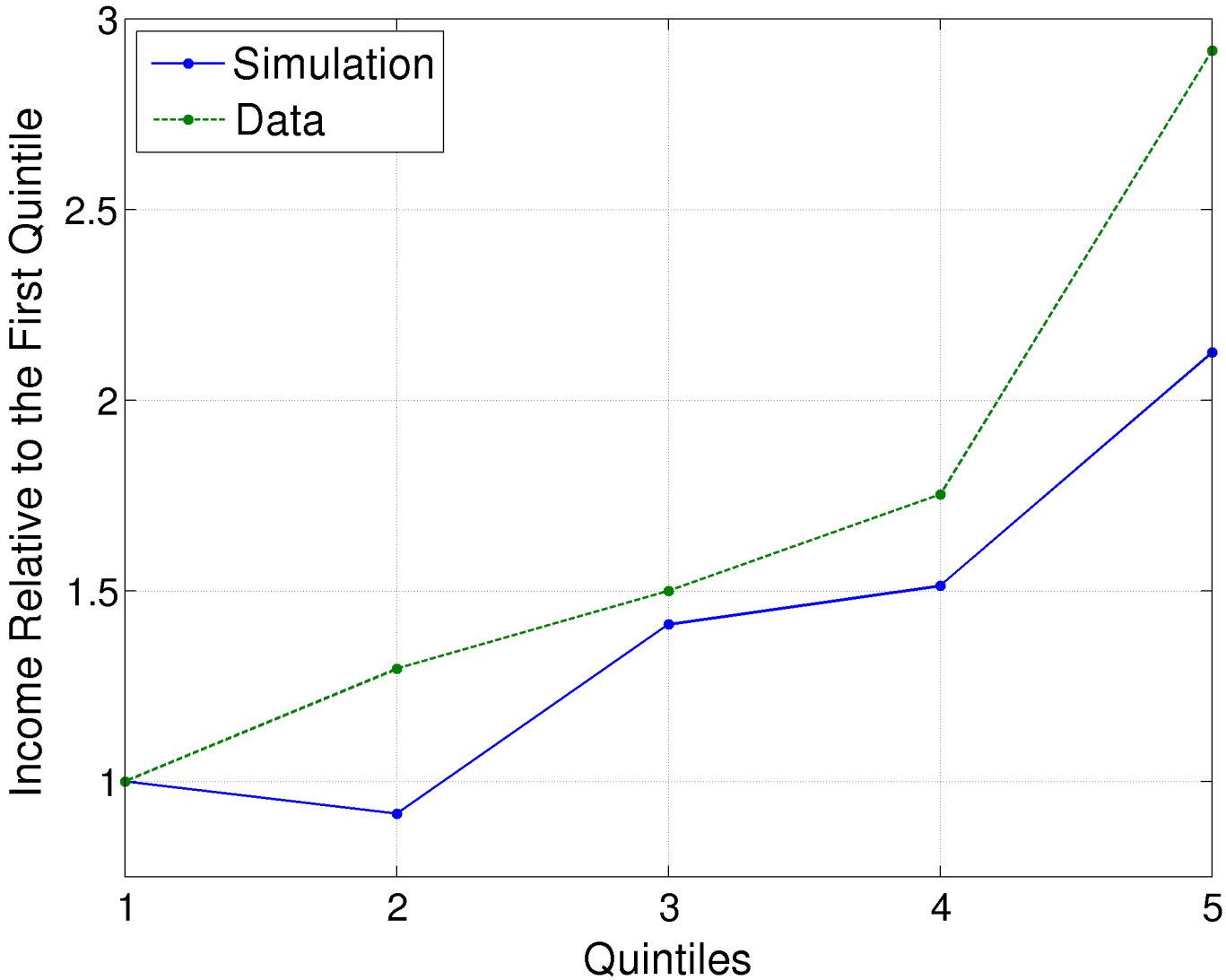
	Sample	
	1820-2000	
	Simulation	Maddison
Western Countries	1.47%	1.61%
Rest of the World	.82%	.86%
Diff. West-Rest	.65%	.75%

- Cumulative gap from 1820-2000 grows by 3.2.

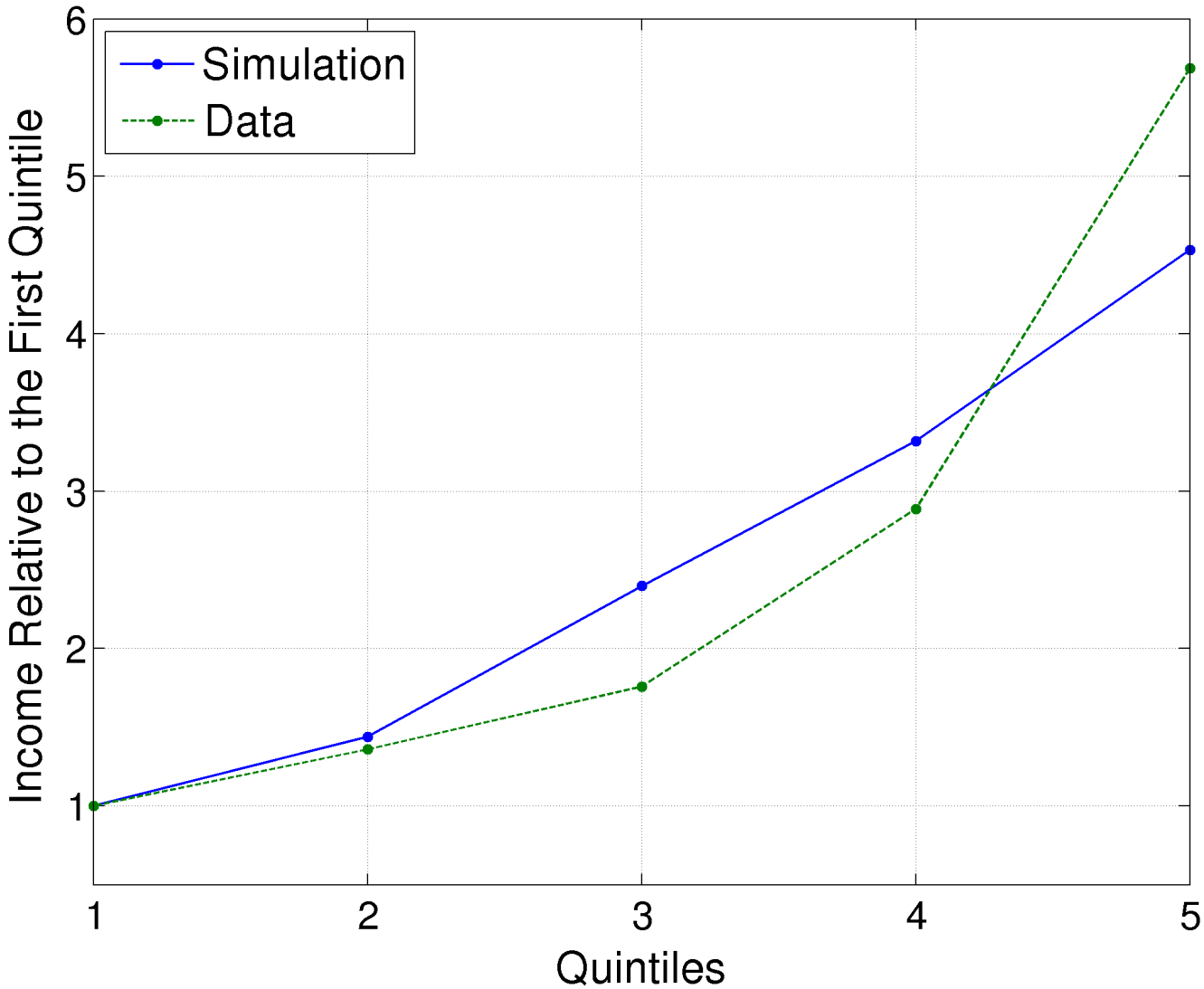
Growth rates of GDP per capita.

	Sample		Subsamples			
	1820-2000		1820-1913		1913-2000	
	Sim.	Madd.	Sim.	Madd.	Sim.	Madd.
Western Countries	1.47%	1.61%	.84%	1.21%	2.15%	1.95%
Rest of the World	.82%	.86%	.35%	.63%	1.31%	1.02%
Diff. West-Rest	.65%	.75%	.49%	.58%	.84%	.93%

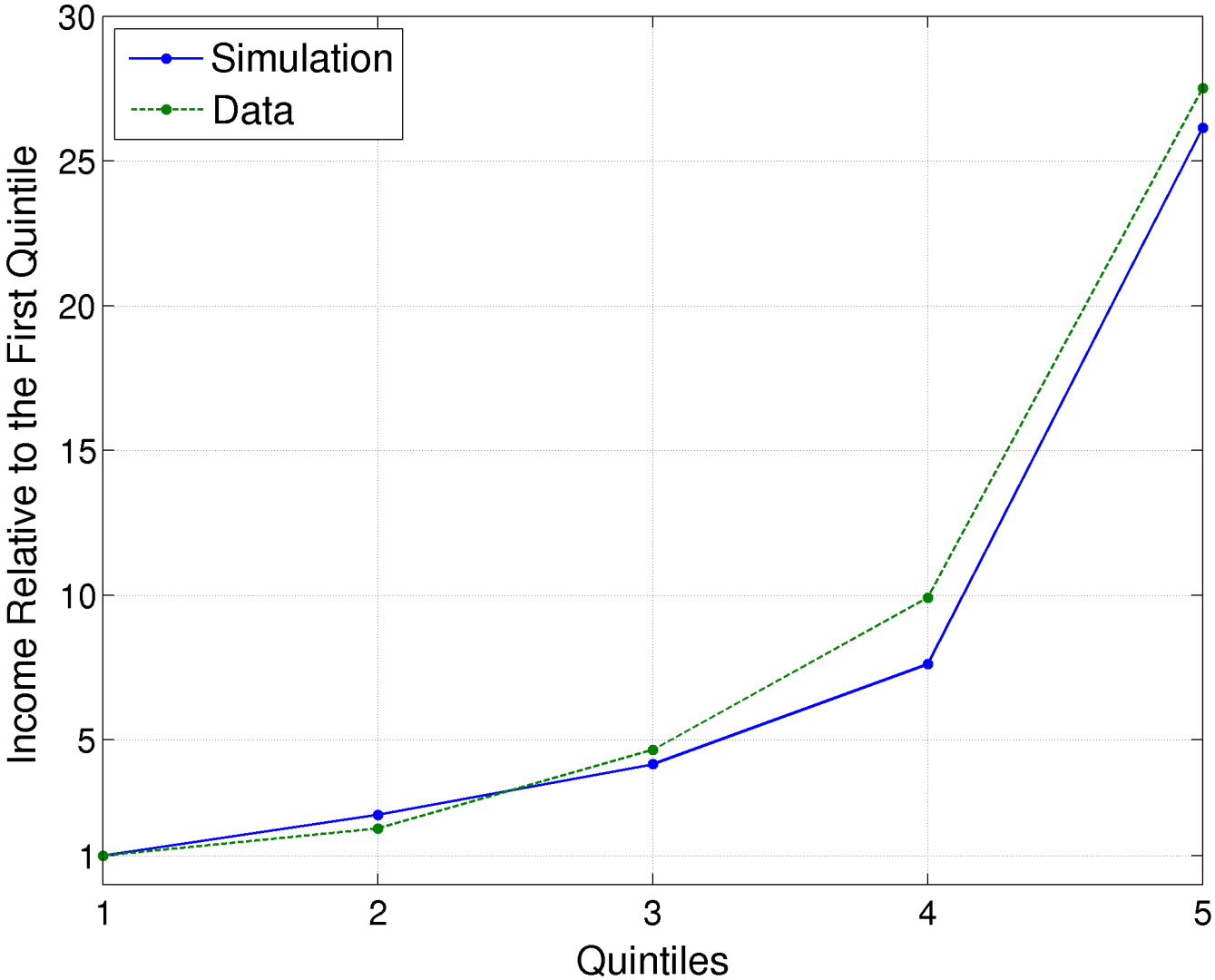
World Income Distribution by Quintiles: 1820



World Income Distribution by Quintiles: 1913



World Income Distribution by Quintiles: 2000



Annual Growth rates of income per capita by regions.

	Simulation		Maddison	
	1820-1913	1913-2000	1820-1913	1913-2000
USA & Canada	.77%	2.05%	1.63%	1.90%
Western Europe	.62%	1.91%	1.04%	2.12%
Africa	.26%	.75%	.36%	.90%
Asia	.34%	1.37%	.49%	1.70%
Latin America	.37%	1.28%	.59%	1.50%

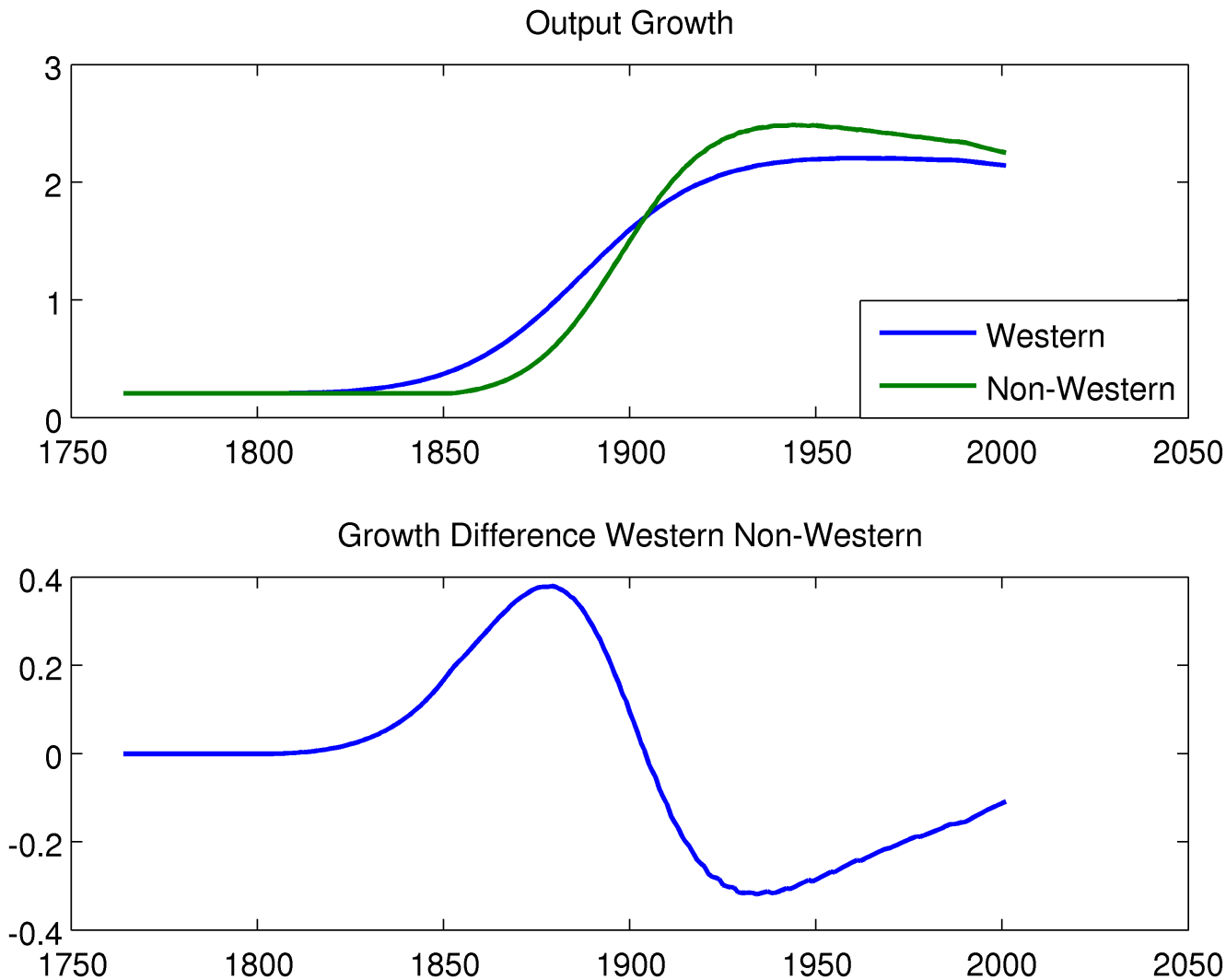
Relative income per capita of Western to Non-Western

Period	Income gap of the West relative to ...	
	Non-Western	
	Maddison	Simulation
Pre 1820	1.9	1.9
1820-2000	3.9	3.2
Cumulative	7.2	6.2

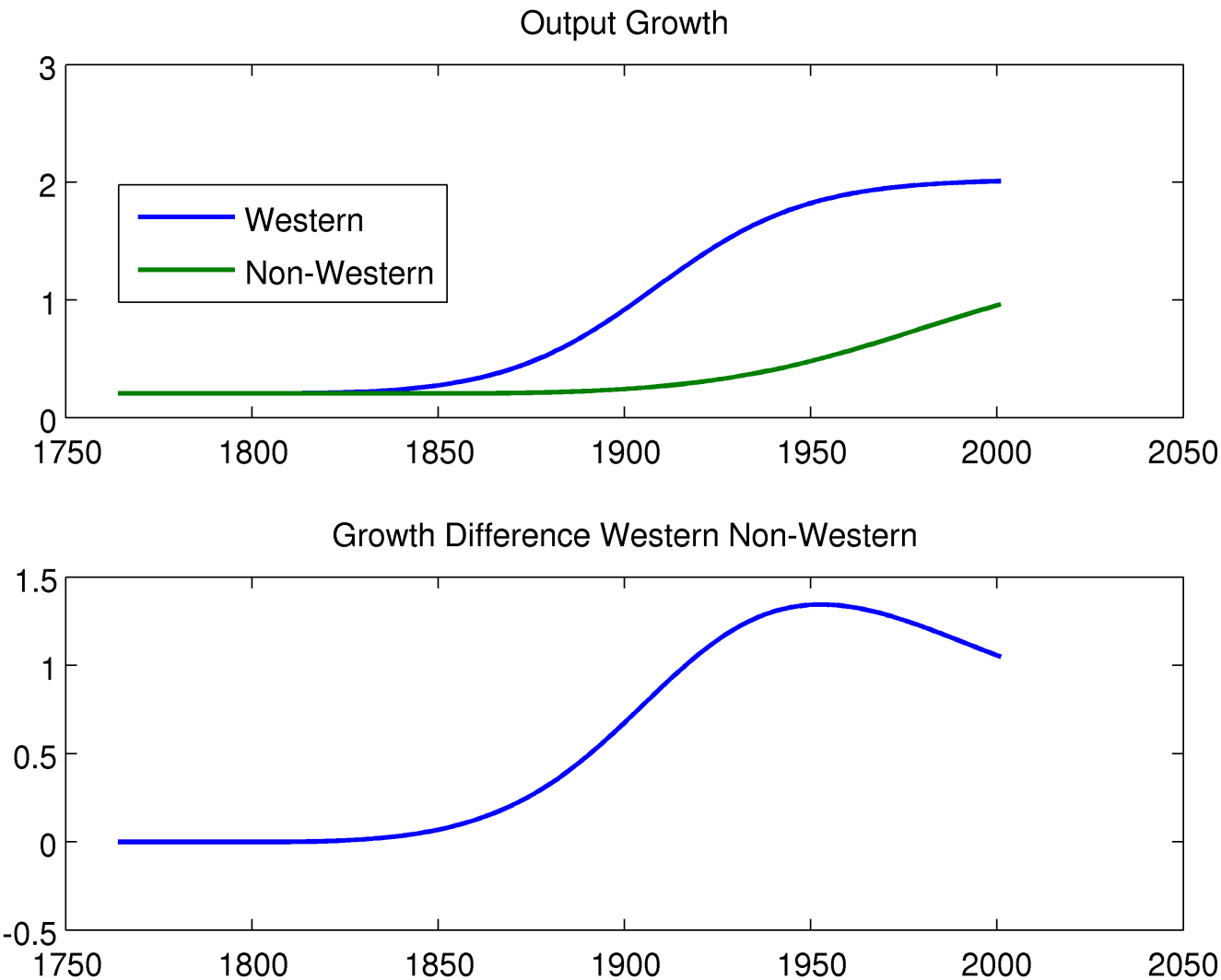
Relative income per capita of Western to other groupings

Period	Income gap of the West relative to ...					
	Non-Western		Bottom 25th		Bottom 10th	
	Maddison	Simulation	Maddison	Simulation	Maddison	Simulation
Pre 1820	1.9	1.9	2	2.3	2.8	2.9
1820-2000	3.9	3.2	5.4	4.5	6.3	5.8
Cumulative	7.2	6.2	10.3	10.3	17.6	17.2

Sources of Growth: Only Lags



Sources of Growth: Only Intensive Margin



Why has the intensive margin diverged?

- Not trivial since most obvious candidates, either not have changed over the last 200 years (e.g., climate, geography) or they have converged (culture, institutions).
- The most natural candidate: Technological Knowledge
- Knowledge about the technology and about how to use it productively

The divergence of technological knowledge

- Knowledge is accumulated by using new technologies but....

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- The industrial revolution brought new opportunities
- In countries that adopted earlier and more intensively industrial technologies, those opportunities grew faster...
- ... leading to a gradual divergence in the intensive margin...
- ...despite the convergence in adoption lags

Summing up

- Great Divergence can be traced back to cross-country technology dynamics
- Over the last 200 years, there has been
  - convergence in adoption lags
  - diverge in long-run penetration rates
- Feed in these dynamics into a model of technology adoption and growth
- Find that consitent with S-shaped and protracted transitional dynamics
- Generates 80% of observed divergence in productivity over the last 200 years