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Macroeconomic Theory I

Section 3 - Growth (II)

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Section 3 - Growth (II): The Plan

1. Endogenous Growth Theory: key ideas and common themes.
2. EG with a fixed saving rate and share of R&D.
3. Learning-by-doing: The AK model
4. The Romer (1990) model: endogenous R&D investment.
5. Fundamental determinants of growth

New growth theory: key ideas

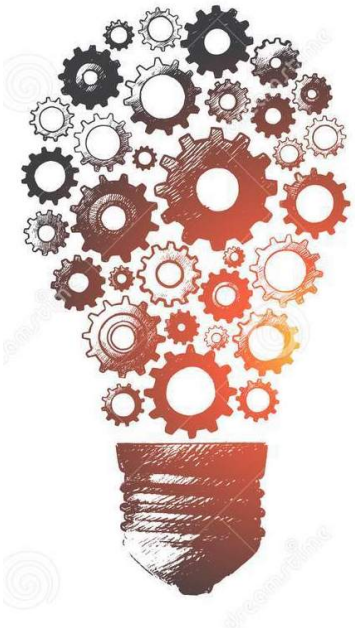
- A production function for innovation

$$\dot{A}(t) = f(A(t), x(t))$$

  x = some measure of R&D efforts.

- A is *non-rival* but potentially *excludable*

- Growth *as a result of market-based incentives* requires that innovators enjoy market power.



Determinants of technological change in the macro literature

1. Public support for basic research (when knowledge not excludable).
2. Private incentives for R&D and innovation (when knowledge somehow excludable)
   - rate of return on R&D vs. rate of return in goods production
3. Alternative opportunities for talented individuals
   - Baumol (1990); Murphy, Shleifer & Vishny (1991)
4. Learning-by-doing: innovation as a side-effect of production
   - AK models

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Endogenous growth with fixed R&D share

Assumptions:

$$Y(t) = A(t)(1 - a_L)L(t); \qquad \dot{A}(t) = B[a_L L(t)]^{\gamma} A(t)^{\theta}; \qquad \dot{L}(t) = nL(t)$$

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Model dynamics:

$$g_A = B a_L^{\gamma} L(t)^{\gamma} A(t)^{\theta - 1}$$

$$\dot{g}_A(t) = \gamma n g_A(t) + (\theta - 1)[g_A(t)]^2$$

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- Value of θ (returns to knowledge in the production of further knowledge) determines the behavior of this model.

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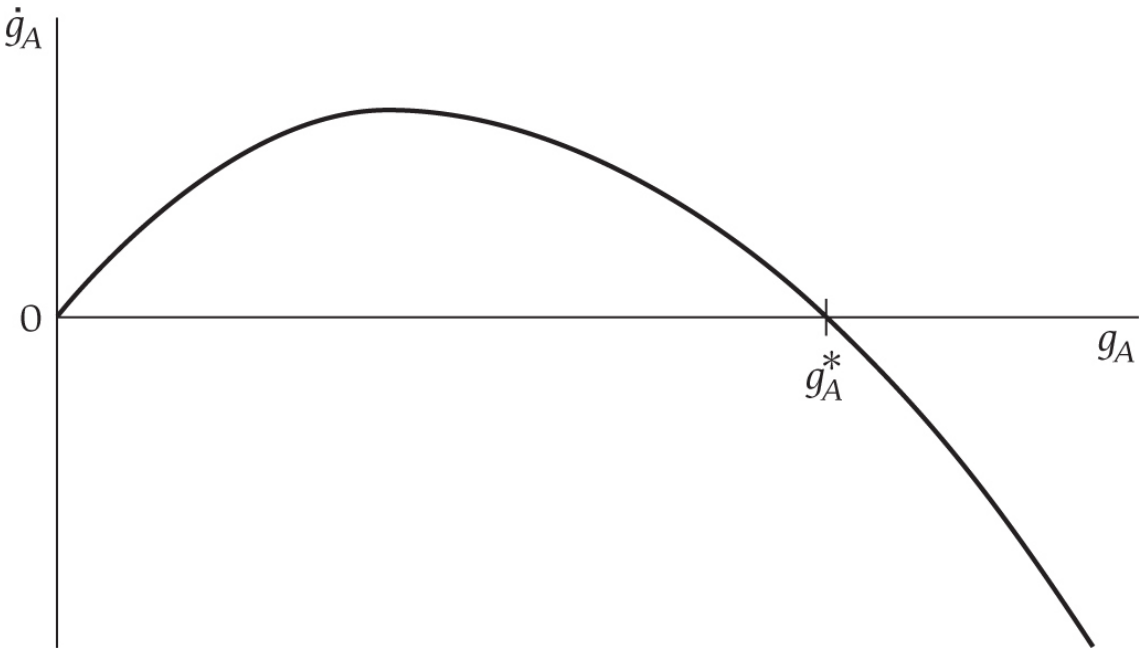
Case (1): decreasing returns to A ($\theta < 1$)



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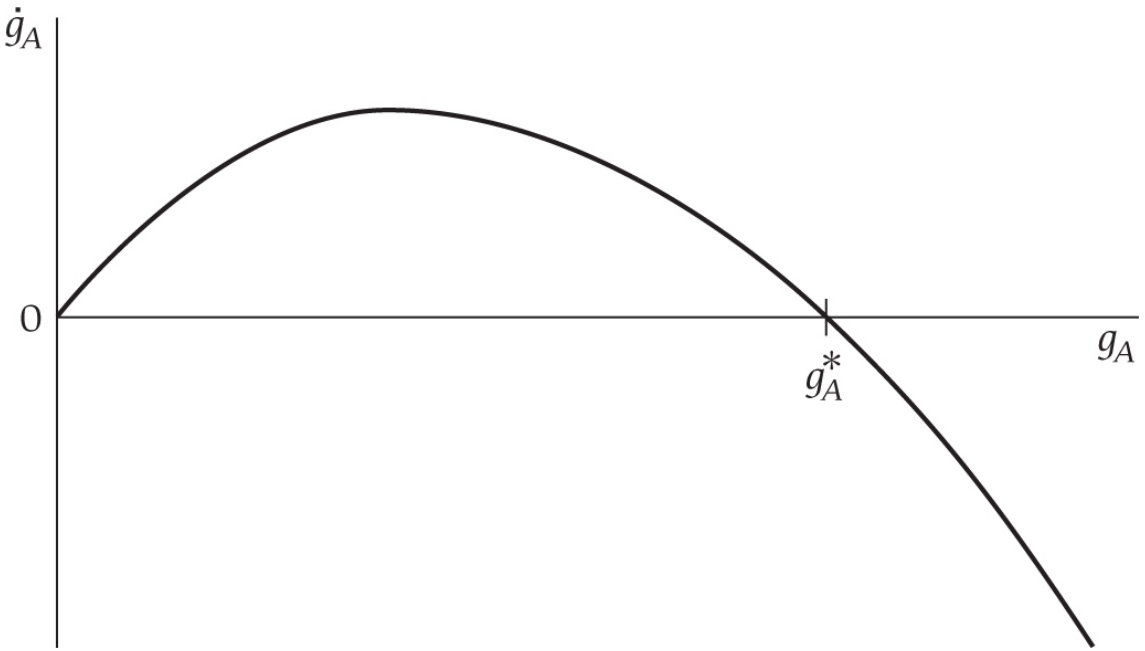

- stable equilibrium
- $g_A^* = \frac{\gamma}{1-\theta} n$;
- no growth effect of a_L and L;
- $g_{Y/L}$ depends (positively) on population growth;
- *semi-endogenous growth*.

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Effect of a increase in a_L or L with decreasing returns to A ($\theta < 1$)

$$g_A(t) = B a_L{}^{\gamma} L(t)^{\gamma} A(t)^{\theta-1}$$

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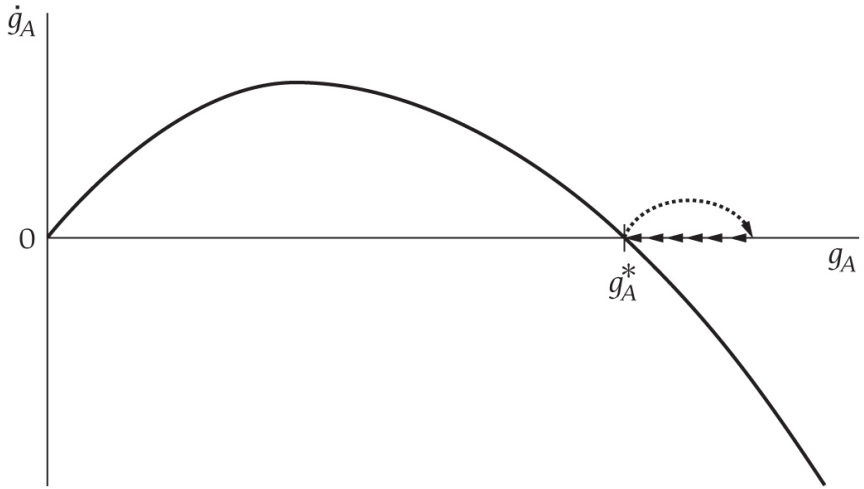

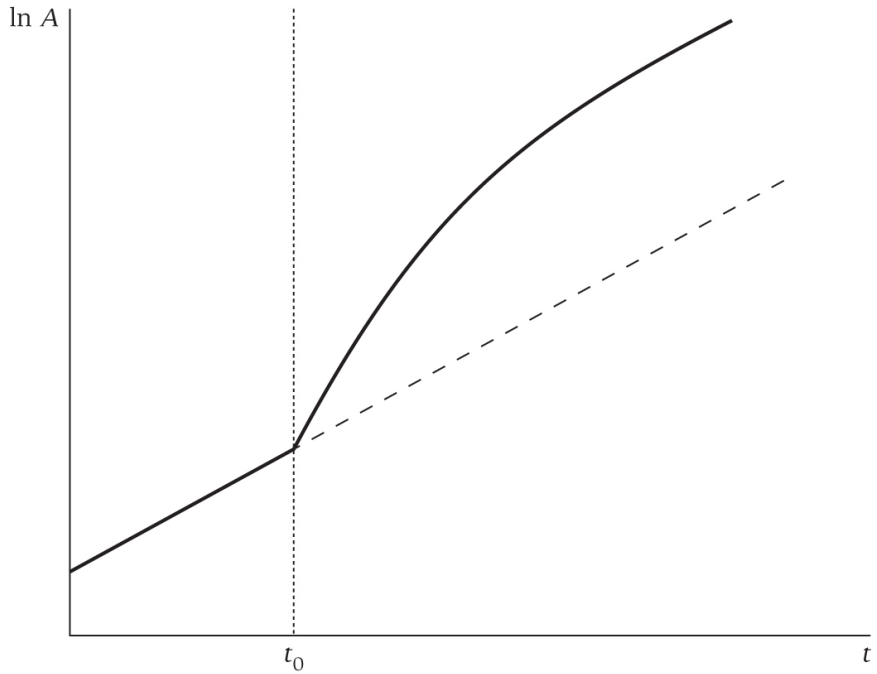

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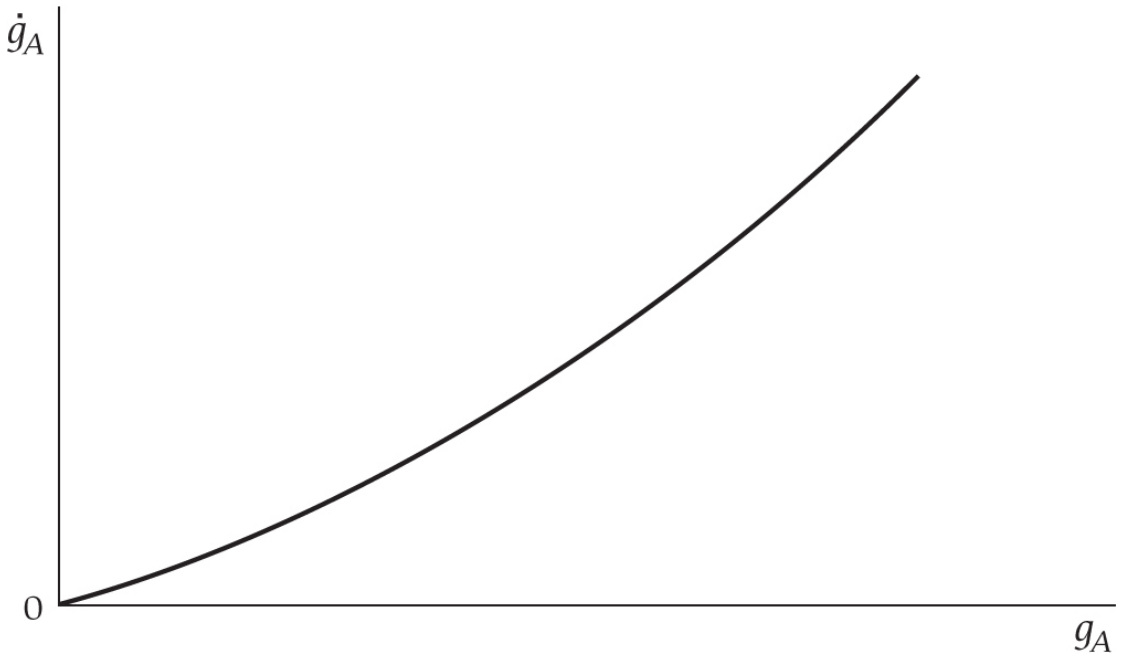
$$\dot{g}_A(t) = \gamma n g_A(t) + (\theta - 1)[g_A(t)]^2$$

Case (2): increasing returns to A ($\theta > 1$)



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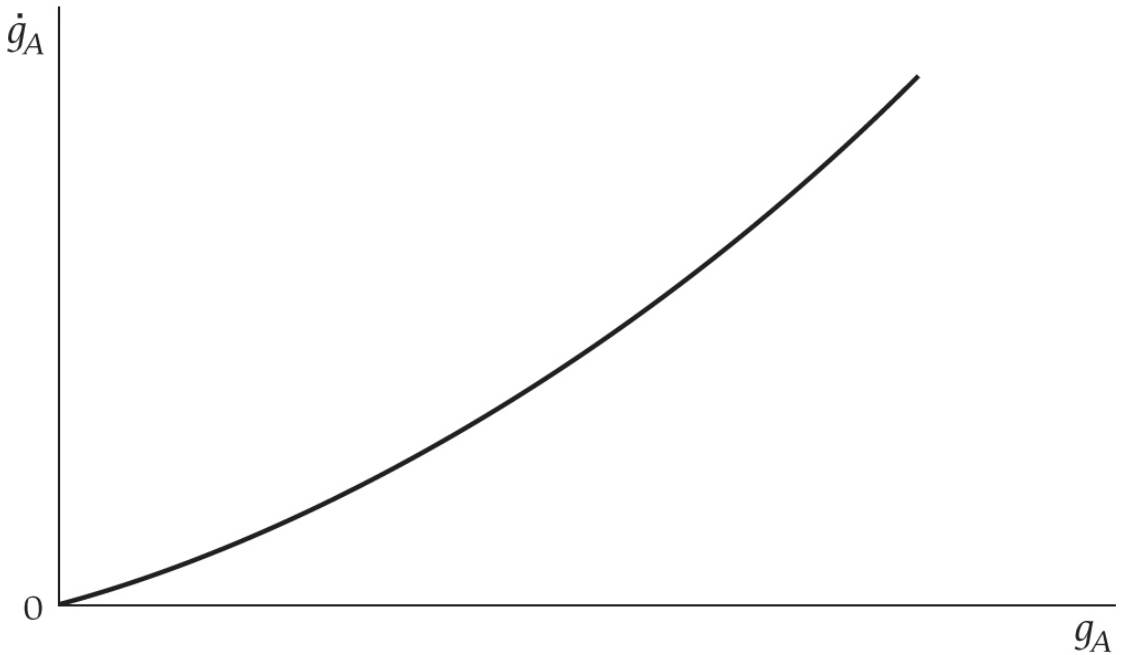

- no equilibrium;
- ever-increasing ('explosive') growth;
- intuition: every marginal addition to A results in a bigger increase in A.

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Case (3): constant returns to A ($\theta = 1$)

$$g_A(t) = Ba_L^{\gamma} L(t)^{\gamma}$$
$$\dot{g_A}(t) = \gamma n g_A(t)$$

- if $n > 0$, g_A is ever-increasing ('explosive' growth);
- If $n = 0$, g_A fixed (no transitions, always in equilibrium).
  - endogenous growth: growth depends on a_L (which *can* be affected by policy);
  - example of a *linear growth model*.

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Learning-by-doing: The AK model

Assumptions:

$$Y(t) = K(t)^{\alpha}[A(t)L(t)]^{1-\alpha}; \qquad A(t) = BK(t);$$

$$\dot{K}(t) = sY(t); \qquad L(t) = \bar{L}.$$

Kenneth Arrow

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Dynamics of the model:

$$Y(t) = bK(t) \quad \text{with } b = (B\bar{L})^{1-\alpha}$$

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$$\dot{K}(t) = sbK(t) \Rightarrow g_k = sb$$

PS: where have you seen $Y = bK$ and $g_k = sb$ before??

New growth theory and the *linearity* assumption

- *AK model*: A linear in K ($\phi = 1$).
  - g_Y depends on s.
- *EGT with fixed R&D share*: $\dot{A}$ linear in A ($\theta = 1$)
  - g_Y depends on R&D share (a_L) and population *size* (L).
- *Romer (1990)* is also a linear growth model
  - $\dot{A}$ linear in $A(t) \rightarrow g_Y$ depends on L.
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  - more people $\rightarrow$ more ideas $\rightarrow$ more growth
- *Linear growth models*: linearity allows to get stable endogenous growth.
- *The 'trick' of EGT*: if $\dot{A}$ is linear in A, it means that the other factors that multiply A in the knowledge-production function affect the rate of growth of technology (so they will affect growth).

The Romer model

(a simplified version)

Assumptions about production

- Ethier production function:

$$Y = \left[\int_{i=0}^{A} L(i)^{\phi} di \right]^{1/\phi}, \quad 0 < \phi < 1$$

  - $L(i)$ = quantity of input i = labor employed in producing i;
  - A = number of different input *types* employed.

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- When all existing inputs are produced in equal quantities:

$$Y = \left[A \left(\frac{L_Y}{A} \right)^{\phi} \right]^{1/\phi} = A^{\frac{1-\phi}{\phi}} L_Y$$

  - L_Y= workers in inputs production = tot. amount of inputs

Demand for inputs

- Patent-holder hires workers to produce the input associated with her idea;
- inputs then sold to (competitive) final output producers;
- Downward-sloping demand curve for input i:

$$L(i) = \left[\frac{\lambda}{p(i)} \right]^{\frac{1}{1-\phi}}$$

$p(i)$ = price of input i.

Other key assumptions

- Full-employment assumption:

$$L_A(t) + L_Y(t) = \bar{L}$$

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- Euler equation (from log utility & budget constraint):

$$g_C = \dot{C}(t)/C(t) = r(t) - \rho$$

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- Free-entry condition in the R&D sector:

$$\int_{\tau=t}^{\infty} e^{-r(\tau-t)}\pi(i,\tau)d\tau = \frac{w(t)}{BA(t)}$$

PV of profits from an idea = production cost

The logic of the model

Discount rate (ρ)

↓

Interest rate (r)

↘

Market power of innovators $\left(\frac{1-\phi}{\phi}\right)$

↙

Discounted returns from R&D activity (R)

↘

← **Population** ($\bar{L}$)

↙

Number of workers in R&D (L_A)

↓

growth rate of technical knowledge (g_A)

↓

Growth rate of the economy (g_Y)

Solving the model

- $g_Y = \frac{1-\phi}{\phi} g_A + g_{L_Y} = \frac{1-\phi}{\phi} B L_A + g_{(\bar{L}-L_A)}$.
- Steady state $\rightarrow$ constant L_A.
- Use R&D free-entry condition to infer $L_A^\star$ and thus $g_Y^\star$.

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- Steps:

1. Calculate $\pi(t)$ and $g_\pi = g_\pi(g_W)$
2. Figure out r and g_W
3. Calculate PV of profits from a new idea $R(t)$ using $R(t) = \frac{\pi(t)}{r-g_\pi}$
4. Set PV of profits from idea = production cost, to obtain L_A^* & g_Y^*.

Step 1: find $\pi(t)$ and g_π

- Monopolist patent-holder sets

$$p(i,t) = \frac{\eta}{\eta - 1} w(t)$$

- From demand curve we have:

$$\eta = -\frac{\partial L(i)}{\partial p(i)} \frac{p(i)}{L(i)} = \frac{1}{\phi - 1} \quad \rightarrow \quad p(i,t) = \frac{w(t)}{\phi}$$

- Profits at each point in time:

$$\pi(t) = \frac{\bar{L} - L_A}{A(t)} \left[\frac{w(t)}{\phi} - w(t) \right] = \frac{1-\phi}{\phi} \frac{\bar{L} - L_A}{A(t)} w(t)$$

- Growth rate of profits:

$$g_\pi = g_W - g_A$$

Step 2: find r and g_W

- All output is consumed and we are assuming constant L_A, so

$$g_C = g_Y = \frac{1-\phi}{\phi} BL_A$$

- Having g_C, we can derive interest rate $r(t)$ from Euler equation:

$$r(t) = \rho + \frac{\dot{C}(t)}{C(t)} = \rho + \frac{1-\phi}{\phi} BL_A$$

- Constant monopoly mark-up implies constant wage share, so

$$g_W = g_Y = \frac{1-\phi}{\phi} BL_A \quad \rightarrow \quad g_\pi = g_w - g_A = \frac{1-\phi}{\phi} BL_A - BL_A$$

Step 3 - Figure out the PV of profits from a new idea

- PV of profits from a new idea:

$$R(t) = \frac{\pi(t)}{r - g_\pi}$$

- From previous steps:

$$\pi(t) = \frac{1-\phi}{\phi}\frac{\bar{L} - L_A}{A(t)}w(t); \quad r = \rho + \frac{1-\phi}{\phi}BL_A; \quad g_\pi = \frac{1-\phi}{\phi}BL_A - BL$$

- Plugging-in:

$$R(t) = \frac{\pi(t)}{r - g_\pi} = \frac{\frac{1-\phi}{\phi}\frac{\bar{L} - L_A}{A(t)}w(t)}{\rho + BL_A} = \frac{1-\phi}{\phi}\frac{\bar{L} - L_A}{\rho + BL_A}\frac{w(t)}{A(t)}$$

Step 4 - Set R(t) = production cost and infer L_A^*

$$\frac{1-\phi}{\phi}\frac{\bar{L}-L_A}{\rho+BL_A}\frac{w(t)}{A(t)} = \frac{w(t)}{BA(t)} \quad \rightarrow \quad L_A^\star = (1-\phi)\bar{L} - \frac{\phi\rho}{B}$$

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$$\Downarrow$$

$$L_A^{*}=\max\{(1-\phi)\bar{L}-\frac{\phi\rho}{B},0\}$$

$$\Downarrow$$

$$g_Y^{*}=\max\{\frac{(1-\phi)^2}{\phi}B\bar{L}-(1-\phi)\rho,0\}$$

(note: economy always on equilibrium path–no transition dynamics)

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(A second look at) The logic of the model

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Welfare: optimal vs. actual growth

1. *Find the PV of lifetime utility*

$$U = \int_{t=0}^{\infty} e^{-\rho t} \ln C(t) dt \quad \Rightarrow \quad U = \int_{t=0}^{\infty} e^{-\rho t} ln\left[C(0)e^{g_C}\right] dt$$

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$$U = \frac{1}{\rho}\left(ln\frac{\bar{L} - L_A}{\bar{L}} + \frac{1-\phi}{\phi} lnA(0) + \frac{1-\phi}{\phi}\frac{BL_A}{\rho}\right)$$

Welfare: optimal vs. actual growth

2. *Maximize PV lifetime utility w.r.t. L_A*

$$\max_{L_A} U = \frac{1}{\rho}\left(ln\frac{\bar{L}-L_A}{\bar{L}} + \frac{1-\phi}{\phi} lnA(0) + \frac{1-\phi}{\phi}\frac{BL_A}{\rho} \right)$$

$$\downarrow$$

$$L_A^{OPT} = \max\{\bar{L} - \frac{\phi}{1-\phi}\frac{\rho}{B}, 0\}$$

3. *Compare L_A^{OPT} with $L_A^{\star}$*

$$L_A^{\star} = (1-\phi)L_A^{OPT}$$

Takeaway: Too little resources devoted to R&D; more market power for innovators (lower input substitutability, ϕ) is better for society.

Extensions

- Fixed K in the production function for Y but not $\dot{A}$ –> s has a level effect (Romer, 1990);
- but if K enters the production of $\dot{A}$, s likely to have growth effects;
- decreasing returns to A in the production of $\dot{A}$ –> semi-endogenous growth (Jones, 1995)
  - long-run growth depends only on n, while forces affecting L_A have only level effects;
- quality-ladder models: innovation as improvement of existing inputs (Grossman & Helpman, 1991; Aghion & Howitt, 1992).

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- ...but Romer-type models may explain growth at a worldwide scale in the very long-run (Kremer, 1993).
- P.Krugman: *"too much of [EGT] involves making assumptions about how unmeasurable things affect other unmeasurable things."*

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"The factors we have listed (innovation, economies of scale, education, capital accumulation, etc.) are not causes of growth: they *are* growth"

(North and Thomas, 1973, p.2)

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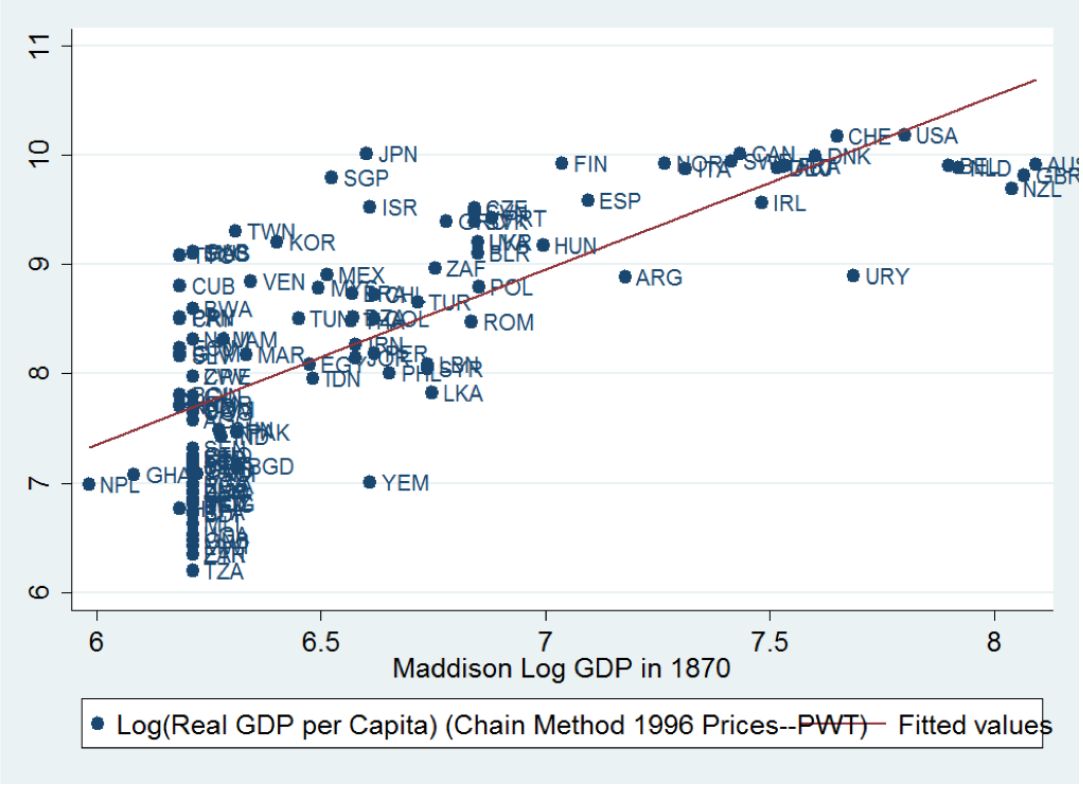
Exhibit A: GDP per capita is horribly persistent

- most countries that are poor (rich) today were poor (rich) in 1870.



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Fundamental causes: the main candidates

- Historical accidents (‘luck’);
- Geography;
- Culture;
- Institutions;
- Their historical interactions.

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Institutions and economic outcomes

"Institutions are the rules of the game in a society (...) the humanly devised constraints that shape human interaction"

- They determine payoff-matrix & strategy set in a game;
- but at the same time are equilibrium outcomes of a (prior) game.
- Laws, organizations, social norms, conventions.
  - 'old-school' Marxian view: institutions=relations of production;
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- Institutions determine the organization of production, the distribution of wealth & power, and the structure of incentives for investment;

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How do we know that institutions matter?

- Institutions are endogenous and evolve slowly;
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How do we know that institutions matter?

- Institutions are endogenous and evolve slowly;
- randomized experiments are usually impossible;
- evidence from *natural experiments*
  - Colonial settlers making arbitrary decisions about the institutions to be imposed.
  - Geography-driven variation in important institutional factors.
  - Political events that suddenly impose starkly different institutions to contiguous and previously similar areas
    - North vs. South Korea;
    - West vs. East Germany.

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The Korean War as a natural experiment

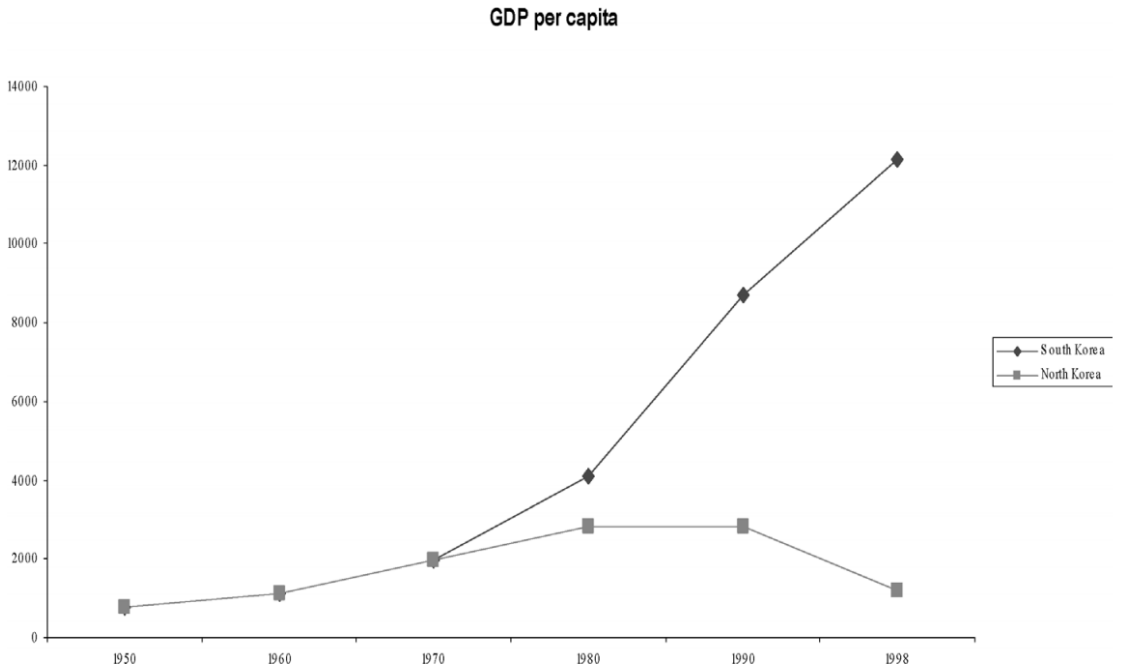

Figure 3. GDP per capita in North and South Korea, 1950–98.

- Similar economy, same culture and common government until 1950;
- then North 'treated' with authoritarian communist central planning and South with export-oriented capitalism.

(can you find any potential problem with this natural experiment?)

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Math, Girls & Socialism

- Math skills basic ingredient for growth;
- Math gender gap: biology or institutions?
- 1945 division of Germany –> sudden institutional divergence;
- Lippman & Senik (2018): Math gender gaps diverge as a result, even well after unification.

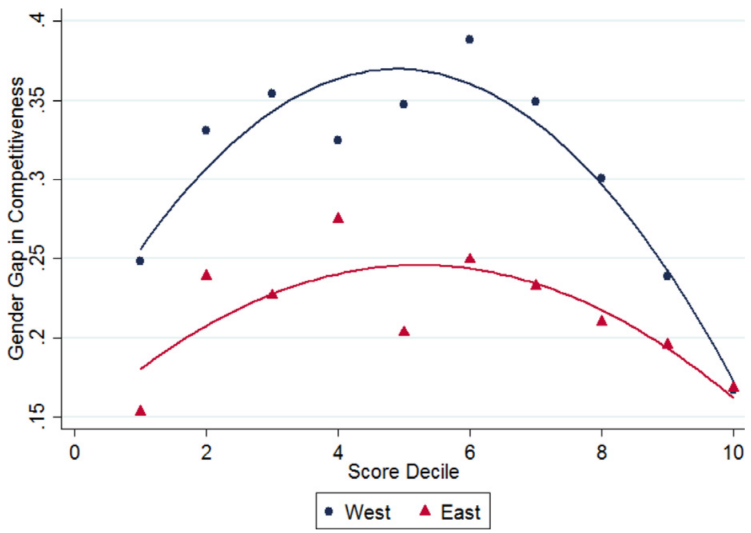

Fig. 1. Competitive attitudes in math by deciles – PISA-E 2003 Germany. Notes: The data comes from the German National Evaluation of Pisa. The sample is restricted to individuals who were born in Germany. Competitive attitudes in mathematics by deciles (computed on the basis of PISA

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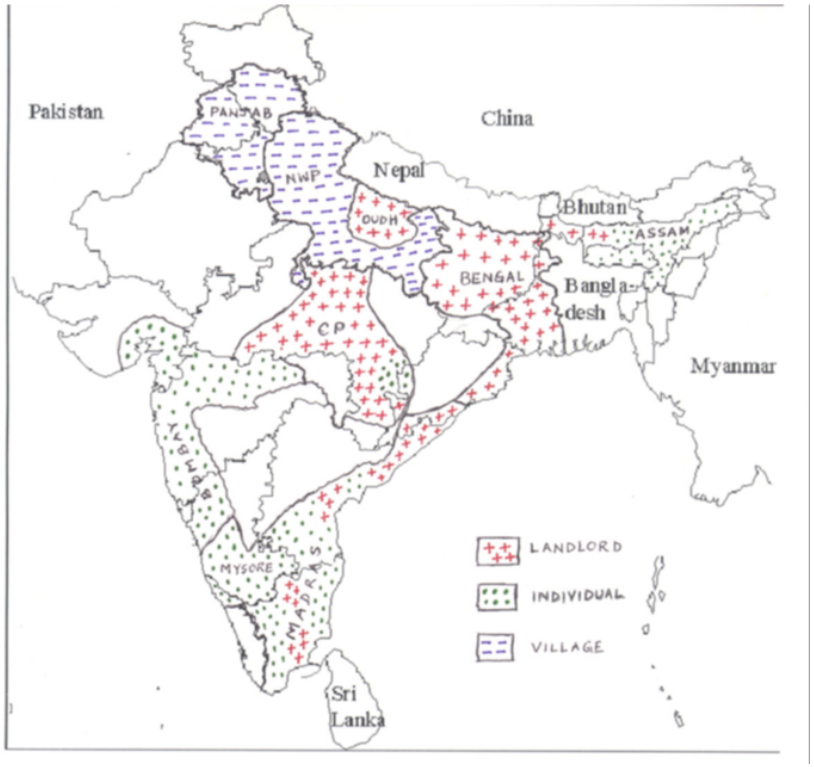
The development legacy of colonialism in India

- 1750-1860: The British colonize India in bits.
- In some places they give the local elite ownership rights over the land. (Zamindari)
- Elsewhere they give the farmers property rights to the land. (Ryotwari)



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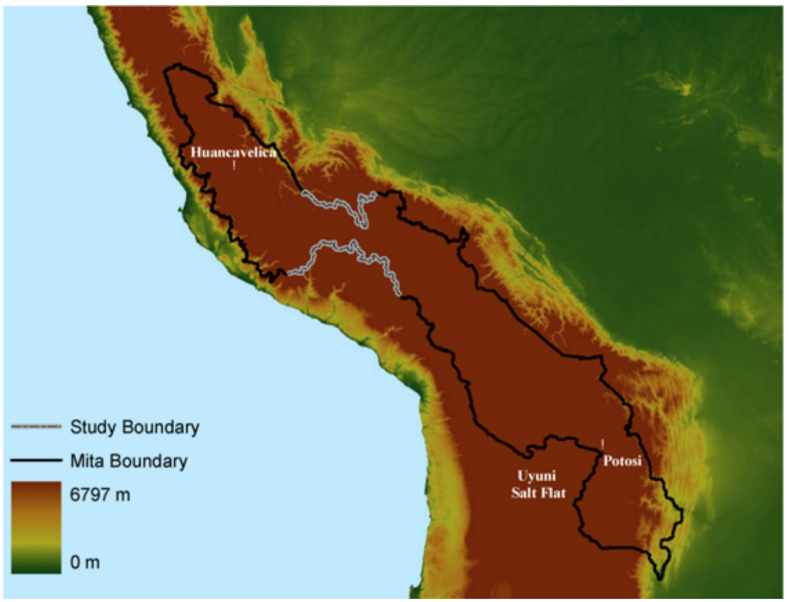
The development legacy of colonialism in India

- Landlords-controlled districts fell behind in agricultural productivity, health and education;
- they still display worse social and economic indicators today;
- main channel seem to be investment in public goods;
- the authors attribute this to less willingness of peasants to support development expenditure because of mistrust of landlords.
- (Banerjee and Iyer, 2004)

UMASS AMHERST

Natural experiments: colonialism and forced labor in Peru

- Peru (and Bolivia)'s indigenous people forced to work on silver and mercury mines in Potosi from 1573-1812;
- Potosi area (the *mining mita*) delineated by Spanish in 1573;
- Regression-discontinuity: compare people living today very near the border but on different sides;



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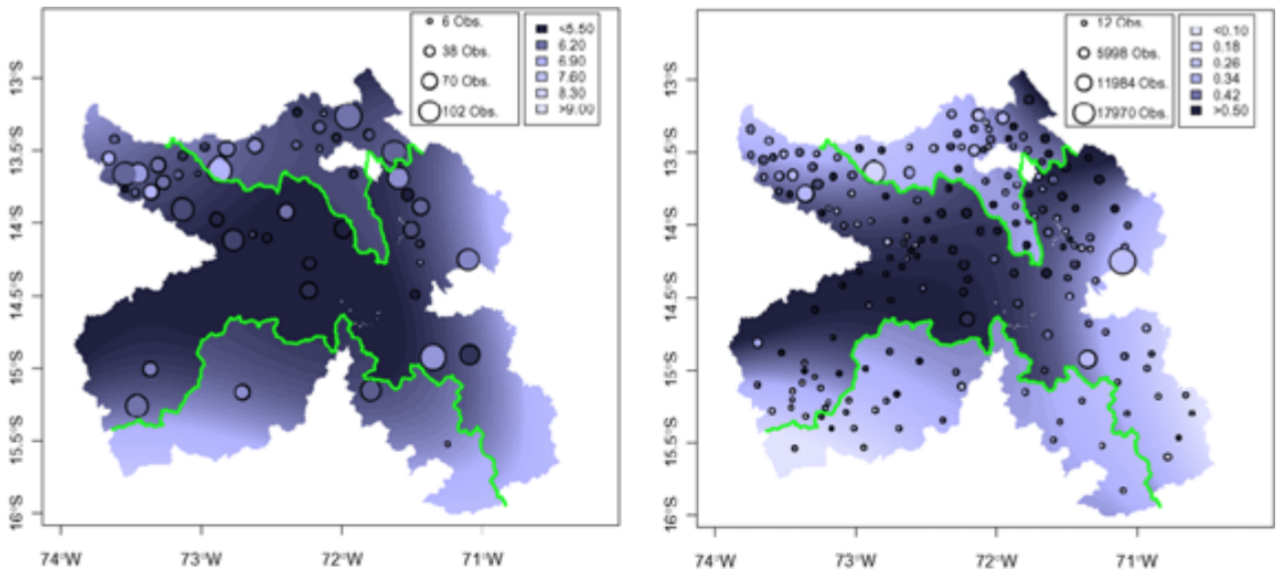
Colonialism and forced labor in Peru



(a) Consumption (2001) (b) Stunting (2005)

- Today households inside the Mita have ≈ 25% lower consumption, worse health outcomes, participate less in markets;

Colonialism and forced labor in Peru

- What accounts for the large *Mita* effect?
- Melissa Dell (author) argues that channel is land tenure system, but in a way different from Indian case:
- to minimize competition in exploiting labor, the Spanish restricted the formation of haciendas in mita districts;
- no well-defined property rights over land inside Mita for long time;
- outside the Mita, many powerful haciendas formed a lobby that was able to get roads built, improving market access;
- as a result areas inside the Mita have less public goods and infrastructure, and less access to road networks;

UMASS AMHERST

...OK, but what causes institutions?

- *"While we have good reason to believe that economic institutions matter for economic growth, we lack the crucial comparative static results which will allow us to explain why equilibrium economic institutions differ."* (Acemoglu, 2005, p.389)
- Why Europe (and not Africa or America) first developed the complex capitalist institutions that lead to the industrial revolution?
- We don't know a whole lot about causes of institutional variation...
- ... but we can get substantial insights after introducing the role of *geography*.

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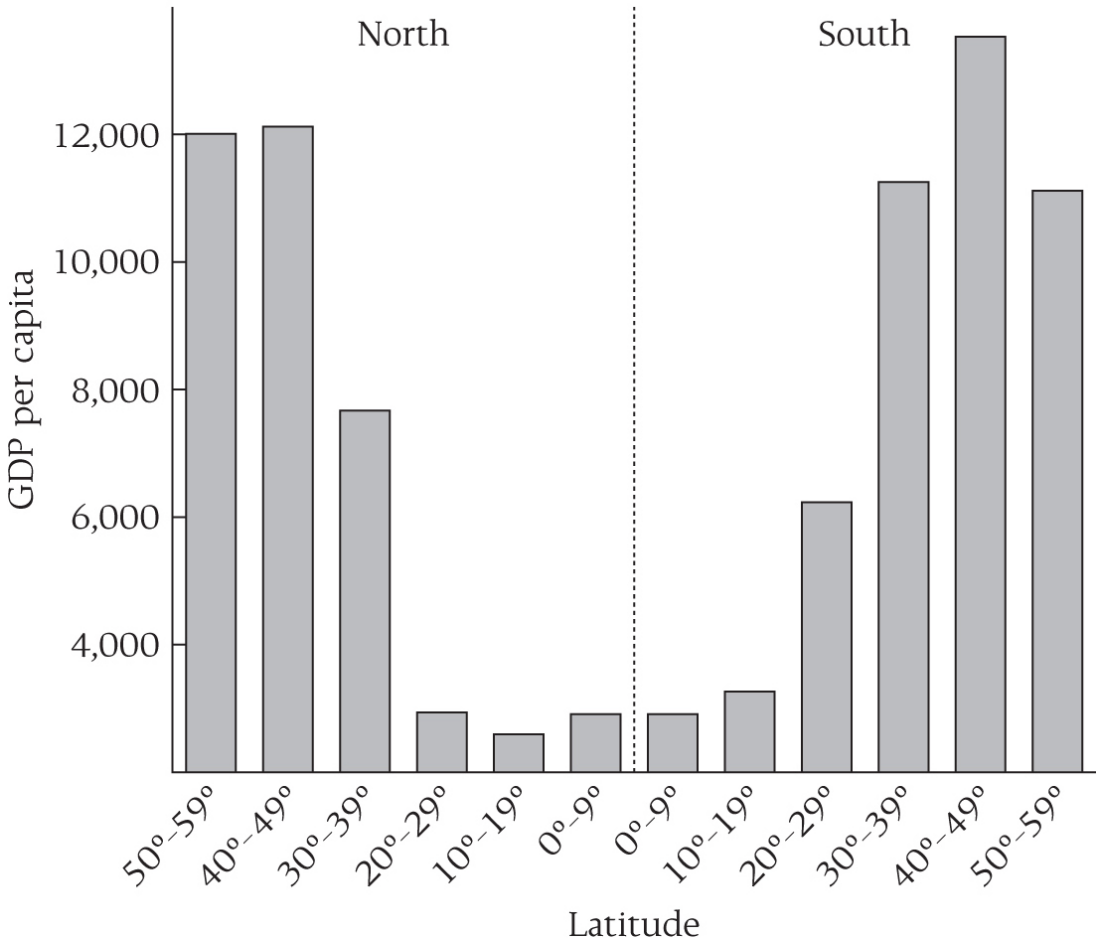
Latitude and income per capita



- A lot of stuff correlates spuriously with GDP;
- what's special about latitude? *exogeneity*;
- latitude is not caused by income, nor by third factors affecting income;
- suggests that geography must somehow *be part* of the story;

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Geography and long-run growth

- How to think of the role of geography?
- direct effects: land, labor productivity, natural resources, culture...
- but the most important way geography matters might be by influencing the historical evolution of institutions;

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Geography and long-run growth

- How to think of the role of geography?
- direct effects: land, labor productivity, natural resources, culture...
- but the most important way geography matters might be by influencing the historical evolution of institutions;
- large-scale institutional explanations of development trajectories typically rely on geography
  - Sokoloff and Engerman on paths of development in the New World;
  - Acemoglu-Robinson on disease incidence & colonization strategies;
  - Locally, also the mining mita's boundaries were dictated by geography;
- (of course institutions can *also* evolve independently of geography and thus exert an independent effect without geography playing any role, like in S. vs N. Korea; E. vs W. Germany; 1970s Chile; etc..)

UMASS AMHERST

Guns, Germs and Steel

- Jared Diamond (1997);
- ‘Guns, germs & steel’ allowed Europeans to expand and colonize;
- Why was it Eurasians to develop the ingredients of power?
- Eurasia had a head start (1000s of years) in agriculture;
- Agriculture → Sedentary societies w/ storable food surpluses → complex States & markets → technology and military power;

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Guns, Germs and Steel

- Ok, but why Eurasia?
- Eurasia was better endowed with wild plants and animals suitable for domestication...
  - of the world's 14 species of valuable domestic mammals, 13 were Eurasian, only one American, and none Australian.
  - of the world 56 largest-seeded grass species, 33 are originally from Eurasia.
- ..and its east/west axis facilitated the spread of these domesticates throughout the continent.

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Fertile Crescent: the earliest 'cradle of civilization'

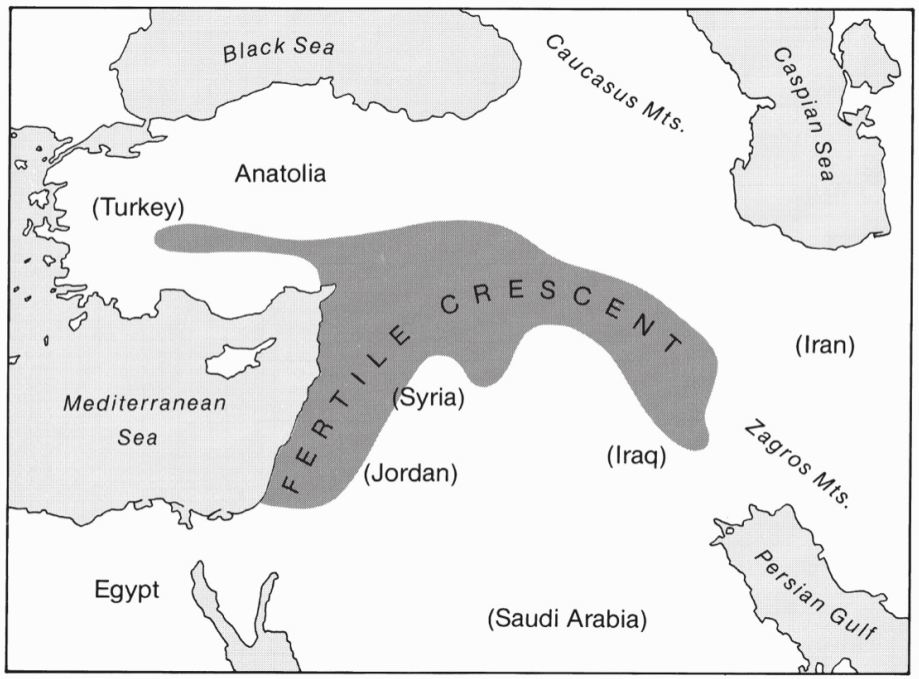

Figure 8.1. The Fertile Crescent, encompassing sites of food production before 7000 B.C.

- Other cradles of civilization in the rest of the world?
- Yes, but: much later, with less productive species available, and with less margin for east-west spread.

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Guns, Germs and Steel

- Two crucial determinants of development: geography & institutions;
- But only geography is exogenous;
- The most important determinant of institutions is 'length of exposure to sedentary agriculture'.
- Historical exposure to agriculture → historical evolution of institutions → institutions today;
- Social choices that can reform institutions *do* matter, but they are constrained by geography and history.
- This theory explains broad patterns, but not why (for example) the industrial revolution happened in Britain rather than (say) Italy.

Olsson & Hibbes (2005) Biogeography and long-run development

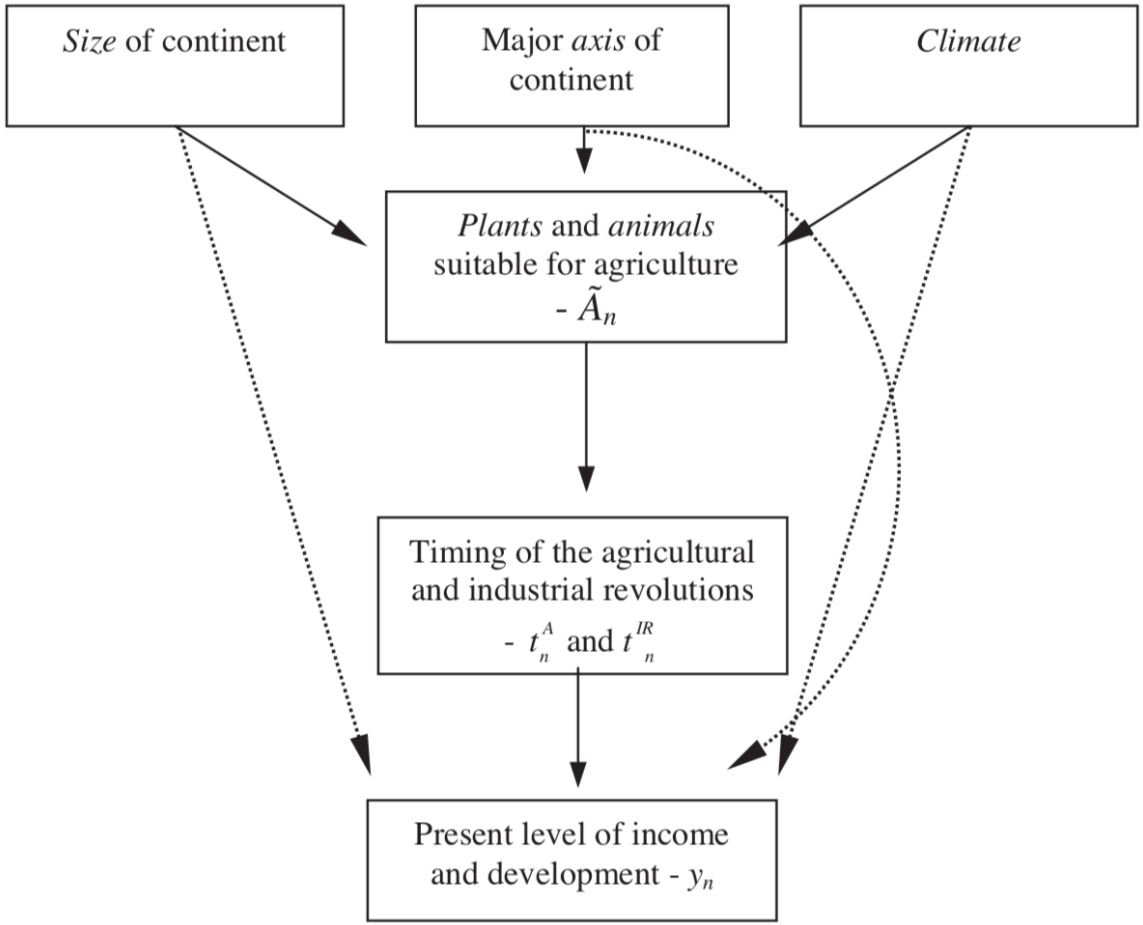

Fig. 1. Biography and long-run economic development.

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‘State antiquity’ predicts modern economic growth

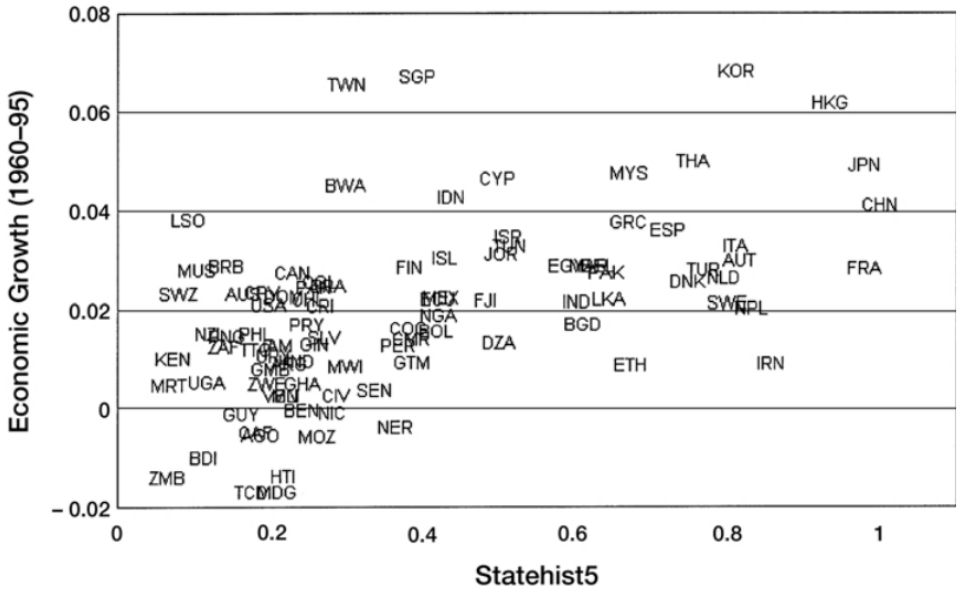

Figure 1. State history and economic growth.

- from Bockstette at al. ‘The advantage of an early start’ (2002, JEG);
- consistent with J.Diamond’s hypothesized channel for indirect effect of geography through institutions;
- far from conclusive and to be treated with caution of course: there may be confounding factors