# Human Capital and Growth

Robert E. Lucas, Jr.

IIES, Stockholm

September 4, 2012

- Theme of this talk is that rates of learning—in school, on the job, anywhere—depend not just on our own efforts but also, crucially, on the people we interact with

- This social character of knowledge creation is familiar to us from our own careers

- Histories of innovation in arts, science, business, athletics all deal with influences and cross fertilization among members of specialized cultures

- These features possibly implicit in Arrow, *REStud* (1962), Romer, *JPE* (1986), Lucas, *JME* (1988), Stokey, *JPE* (1988). Arrow and Stokey in particular explicitly emphasize someone's innovation (in capital goods, new products) stimulating or enabling innovations by others

- Propose here to begin with another description of a learning technology that has specific, distinct roles for the learner/innovator and his intellectual environment

- Believe that failure to do this has led growth theorists to understate the role of human capital accumulation very seriously

- Cost of this omission is that we assign much too large a role to "exogenous" technological change, and so underestimate ability of policies to affect growth

- Try to explain the nature of this mistake, propose alternative strategy

# PLAN OF TALK

1. U.S. census evidence on individual earnings
2. An endogenous growth model with social learning
3. Version with a cohort structure
4. Calibration to census age-earnings profiles
5. Related work, open questions, conclusions
6. A model of development?

# 1 Census evidence

- U.S. census earnings data introduced in 1940, repeated every decade since, stratified by age, gender, race, level of schooling

- Attempt to describe evidence with few parameters led Mincer, Schultz, Becker, Ben Porath to develop models of human capital accumulation in 1950s, 60s

- Focus here on interpretations of this body of evidence

- Next slides: age-earnings profiles from large sub-sample of 1990 U.S. census

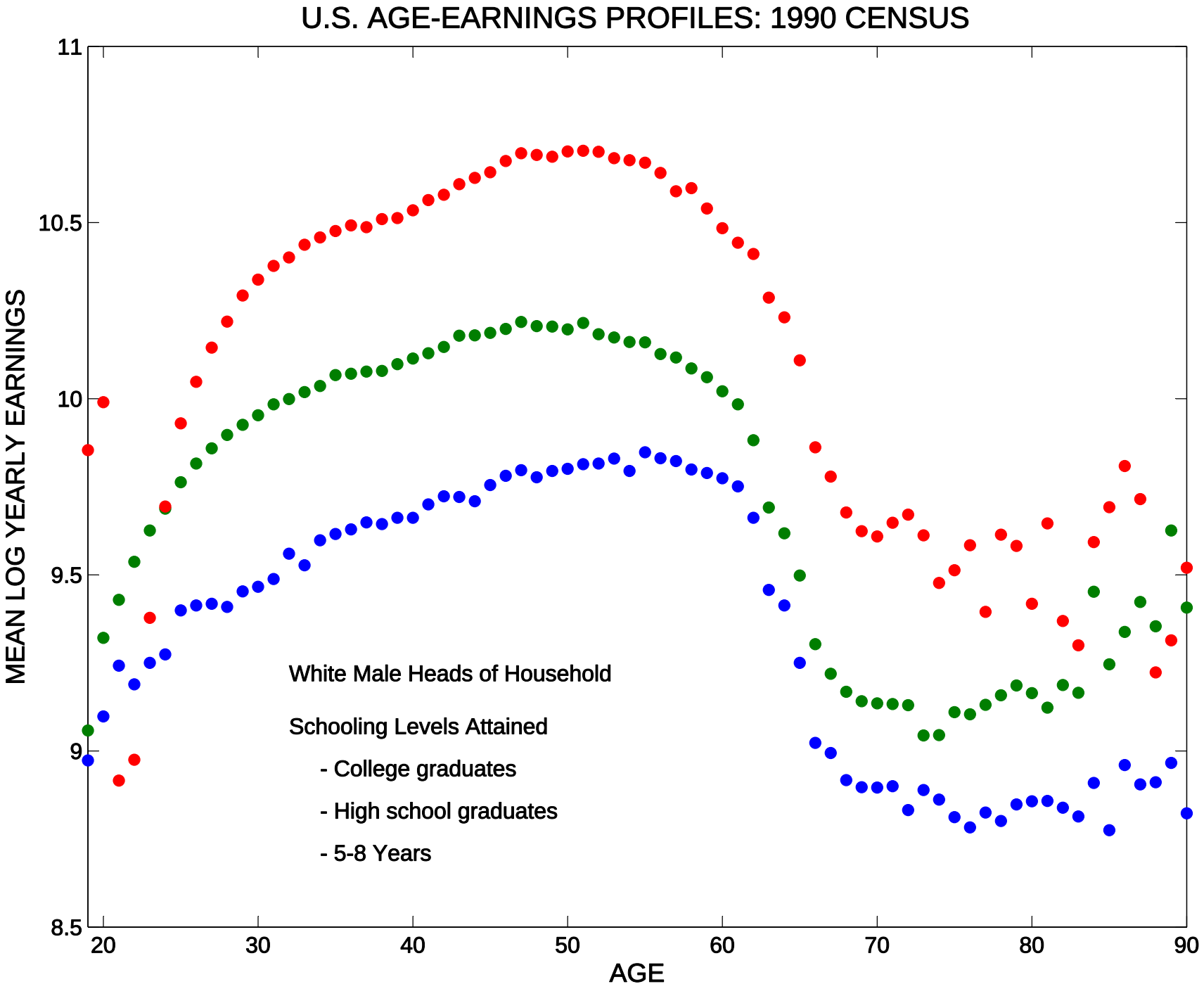
- White male heads of household (others not shown)

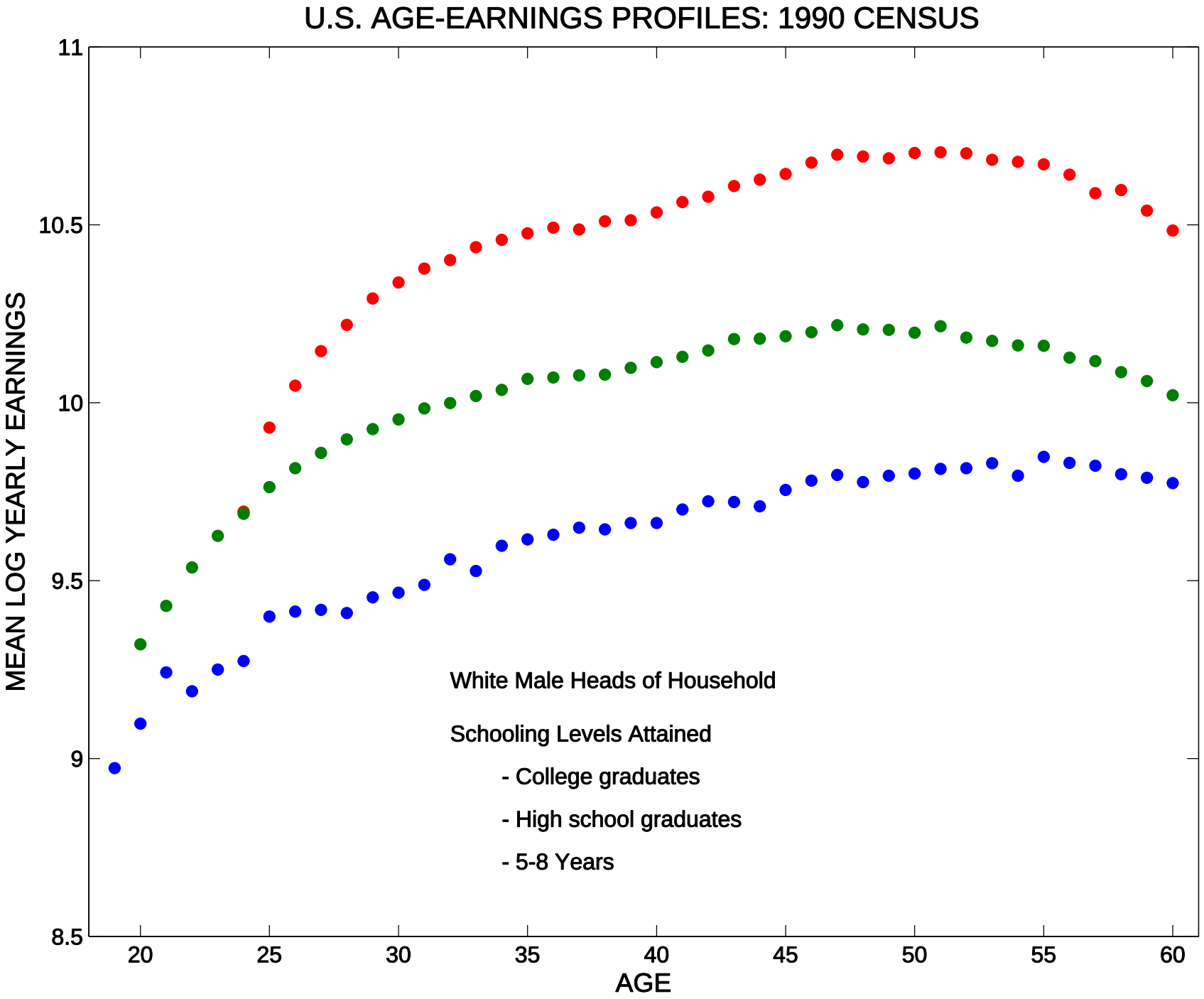
(Better for my purposes to synthesize a "representative" earner. Have not done so.)

- Three schooling levels (out of many more)

- Plots of mean log(earnings) in each cell

- Other census years very similar


U.S. AGE-EARNINGS PROFILES: 1990 CENSUS
MEAN LOG YEARLY EARNINGS
AGE
11
10.5
10
9.5
9
8.5
20
30
40
50
60
70
80
90
White Male Heads of Household
Schooling Levels Attained
- College graduates
- High school graduates
- 5-8 Years


U.S. AGE-EARNINGS PROFILES: 1990 CENSUS
MEAN LOG YEARLY EARNINGS
AGE
11
10.5
10
9.5
9
8.5
20
25
30
35
40
45
50
55
60
White Male Heads of Household
Schooling Levels Attained
- College graduates
- High school graduates
- 5-8 Years

- Applications to aggregate growth: use U.S. earnings evidence to estimate level, growth of "quality corrected" labor force

  - Solow, *REStat* (1957), Denison, monograph (1962) — growth accounting, U.S. time series

  - Krueger, *EconJ* (1968), Hall and Jones, *QJE* (1999) — growth accounting applied to cross-section of countries

- These authors interpret age-earnings profiles in cross-sections as reflecting age effects: 50 year olds just more productive than 30 year olds. (Same interpretations for gender, race? Don't go there!)

- Findings: negligible aggregative contribution of on-the-job learning (age-distributions don't differ enough over time or location)

- For schooling/earnings estimate cause/effect relation.

- "Amount" measured in years of schooling, independent of location, date

- Findings: substantial effects of years of schooling—but far short of explaining Solow residuals

- Many view this as evidence that human capital (especially on-the-job learning) a minor factor in explaining productivity differences over time and space.

- Observed productivity growth must be due to something else—new technology, increases in knowledge capital, innovation, ....

- See this as a completely inadequate response

- Earlier sceptics include Weiss and Lillard, *JPE* (1978), Manuelli and Seshadri, *UWwp* (2005), Heckman, Lochner, Todd, *HBKch*. (2006), Bowlus and Robinson, *UWOwp* (2008)

# 2 A Model of Social Learning

- Want to take a different approach to on-the-job learning
- Idea is to view age-related earnings differences as due to longer exposure to ideas of others—co-workers, supervisors, competitors, movie stars,...
- The higher the productivity of people you deal with, the more you gain from this exposure
- Rest of talk is working out of a model that captures this idea in tractable way, has predictions that accord with evidence just reviewed

- Use an endogenous growth model based on ideas of Kortum, *Ecma* (1997), Eaton and Kortum, *IER* (1999), Alvarez, Buera, Lucas, *NBERwp* (2009), Lucas, *Eca* (2008)

- Closed economy consists of large group of people, each completely described by his productivity level (his earnings), a random variable $\tilde{x}$.

- Describe the knowledge of the group as a probability measure, with cdf $F(x,t)$, density $f$

$$F(x,t) = \text{Pr}\{\tilde{x} \text{ chosen at random at } t \text{ is } \leq x\}$$

- Everyone works full-time, so a person's $\tilde{x}$ is his contribution to gdp

- Adding up, GDP per person is

$$y(t) = \int_0^\infty x f(x,t) dx$$

- Agents also search for new ideas, stimulated by meeting others, at a given rate $\alpha$ per unit of time

- These meetings take the form of continuous draws from the common environment $F(x,t)$

- If you bring $\tilde{x}$ to a meeting and match up with $\tilde{y}$ you emerge with $\tilde{z} = \max(\tilde{x}, \tilde{y})$

- The cdf $F(x,t)$ then has the property

$$F(x,t+h) - F(x,t) = F(x,t)F(x,t)^{\alpha h} - F(x,t)$$

- Dividing by $h$ and letting $h \longrightarrow 0$ yields the law of motion

$$\frac{\partial \log\left(F(x,t)\right)}{\partial t} = \alpha \log\left(F(x,t)\right)$$

- The solution is

$$\log\left(F(x,t)\right) = \log\left(F(x,0)\right) e^{\alpha t}$$

- And that's it? Yes, for now. I'll complicate it later

- Is this a formalism limited to "imitation" or "replication"? Of course not.

- It means that...an article by A that you read, a television program of B's that you watched, a conversation you had with C, something you bought from D,... helped you to solve a problem you were working on, maybe even to discover something new to the world

- Would it help to add multiple dimensions of knowledge and do all of this in $\mathbf{R}^n$?

- Will seek a very specific equilibrium path for the evolving knowledge distribution $F(x,t)$

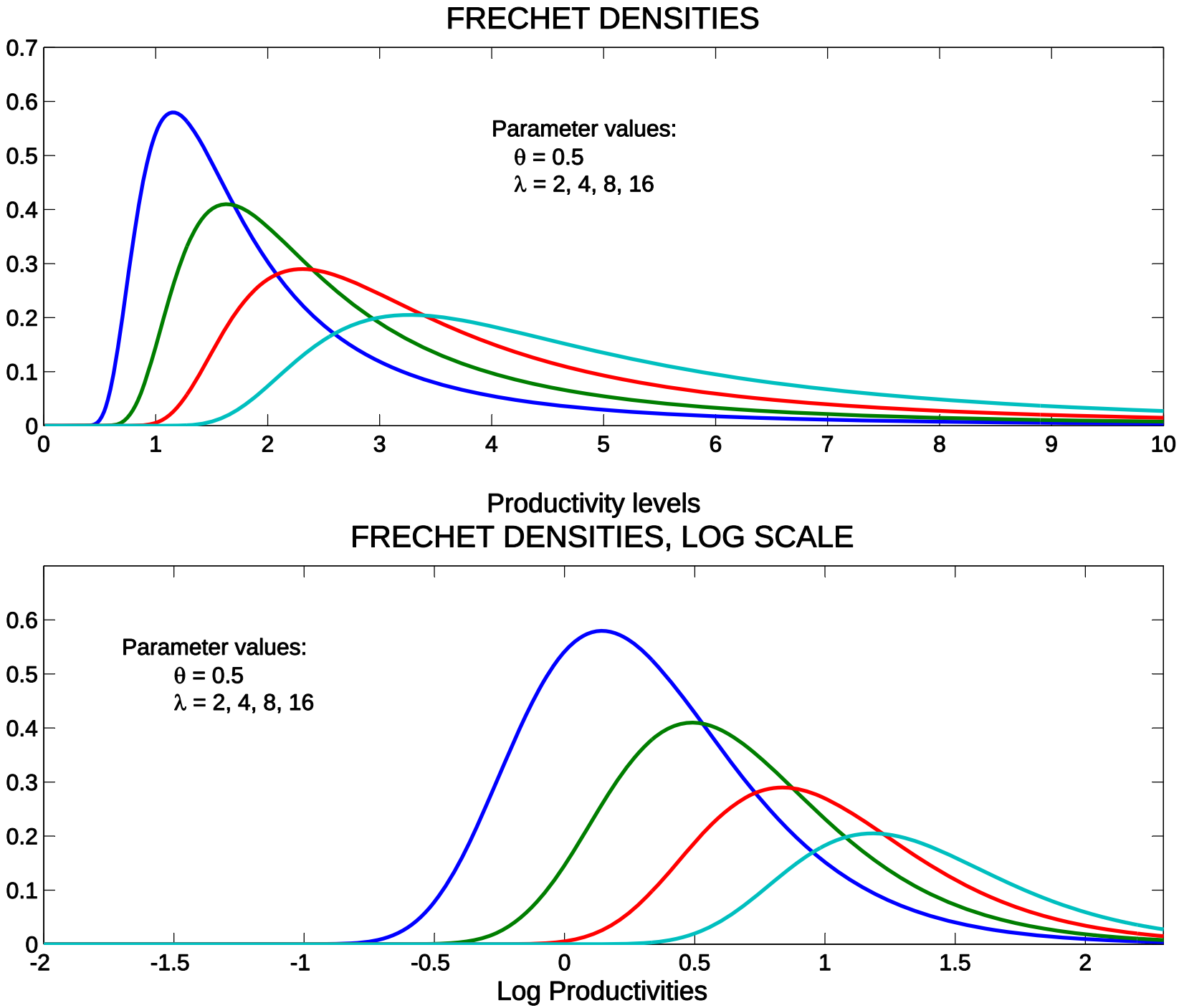
- Assume that $F(x,0)$ is a Frechet distribution with parameters $(\lambda(0),\theta)$ [If a RV $\tilde{z}$ is exponentially distributed with parameter $\lambda$ and $\theta \in (0,1)$ then $\tilde{x} = \tilde{z}^{-\theta}$ is Frechet $(\lambda,\theta)$]

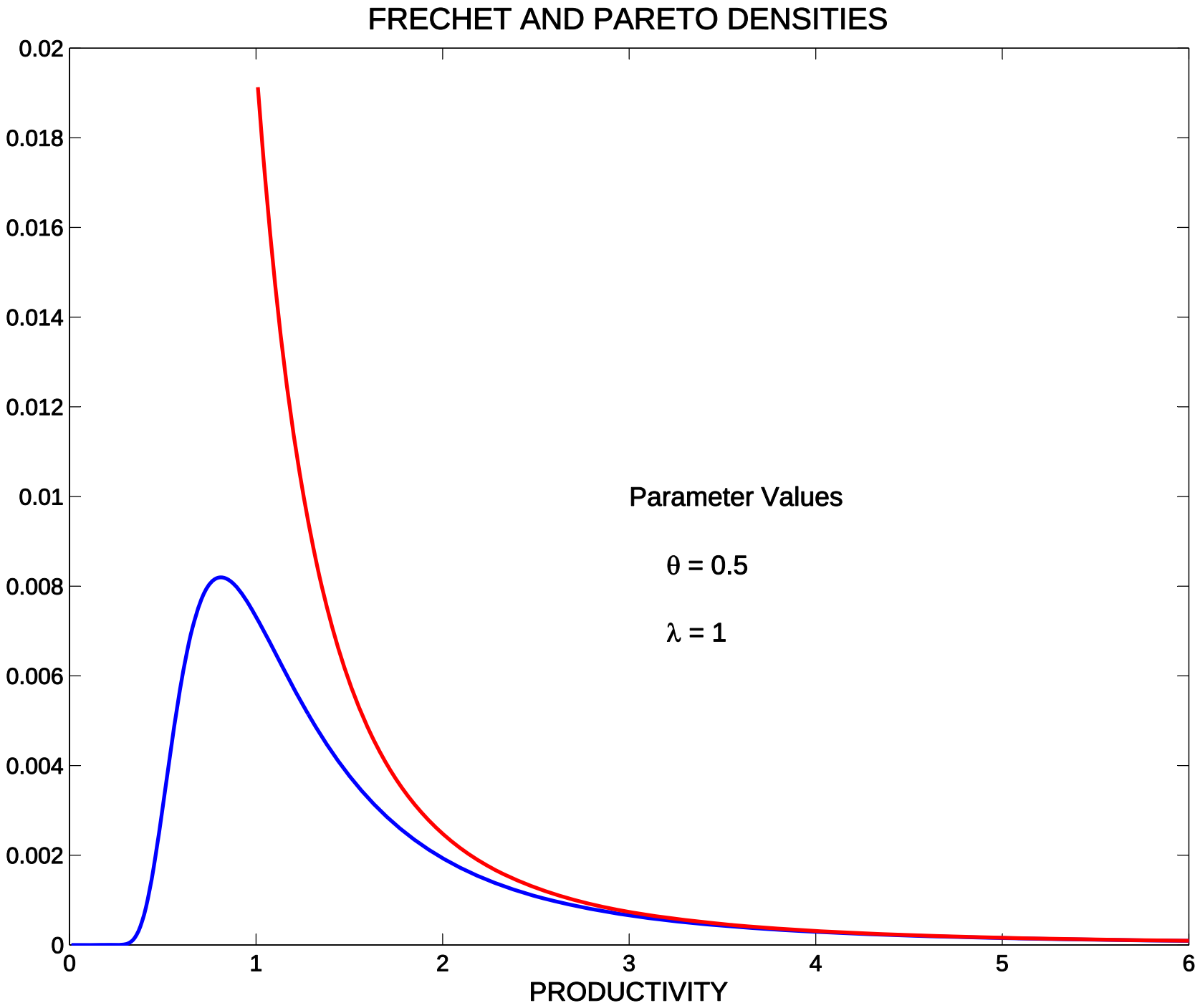
- Can show that in this case $F(x,t)$ is a Frechet distribution with parameters $(\lambda(t),\theta)$, where

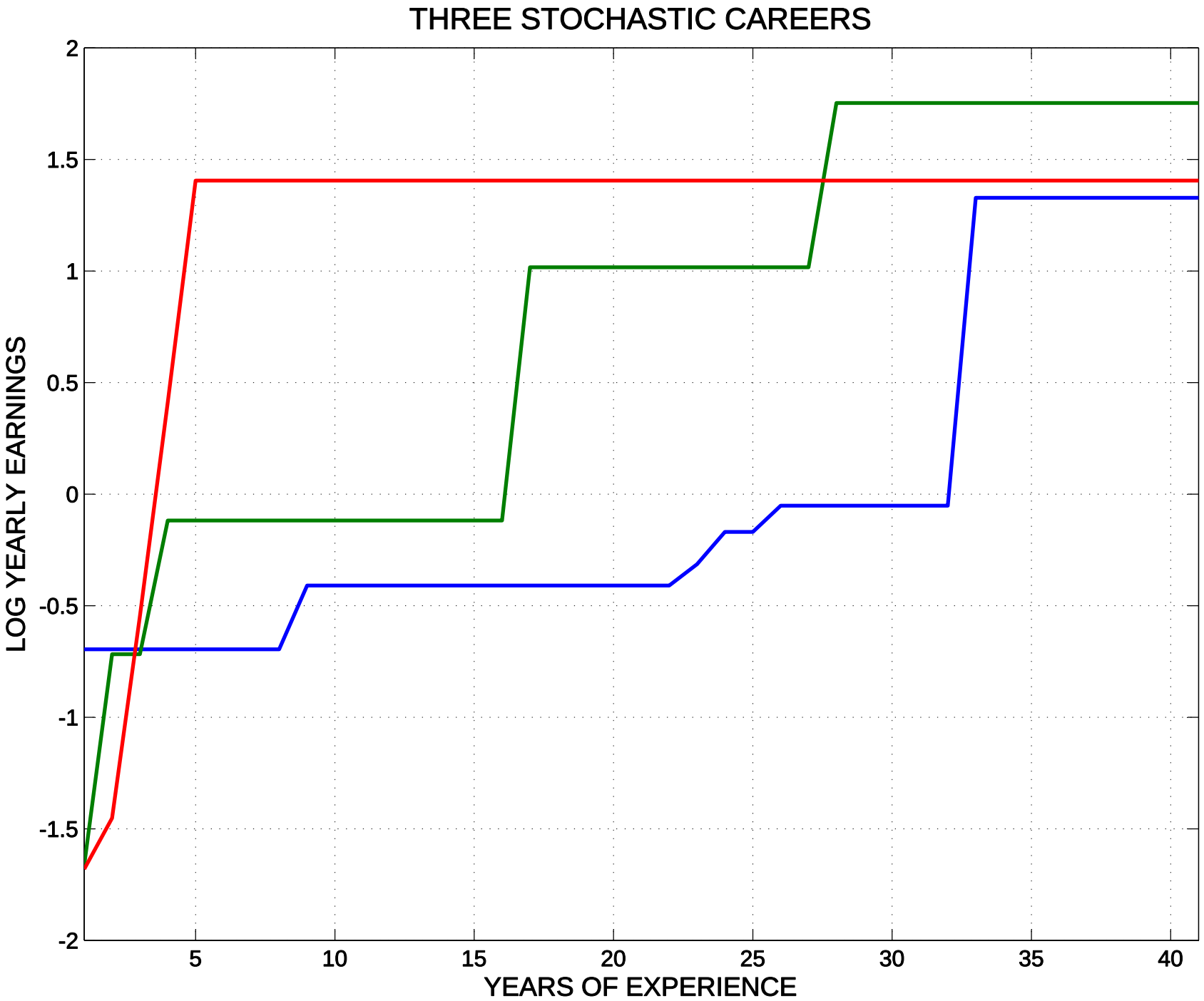
$$\lambda(t) = \lambda(0)e^{\alpha t}$$

- Then GDP grows according to

$$y(t) = \int_0^\infty xf(x,t)dx = Ke^{\alpha\theta t}$$


FRECHET DENSITIES
Parameter values:
θ = 0.5
λ = 2, 4, 8, 16
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0 1 2 3 4 5 6 7 8 9 10
Productivity levels
FRECHET DENSITIES, LOG SCALE
Parameter values:
θ = 0.5
λ = 2, 4, 8, 16
0.6
0.5
0.4
0.3
0.2
0.1
0
-2 -1.5 -1 -0.5 0 0.5 1 1.5 2
Log Productivities


FRECHET AND PARETO DENSITIES
0.02
0.018
0.016
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
0
1
2
3
4
5
6
PRODUCTIVITY
Parameter Values
θ = 0.5
λ = 1


THREE STOCHASTIC CAREERS
LOG YEARLY EARNINGS
YEARS OF EXPERIENCE
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
5
10
15
20
25
30
35
40

- The assumed Frechet $(\lambda(0), \theta)$ "works" in the sense of delivering sustained growth at rate $\alpha\theta > 0$ because it is "fat tailed", like a Pareto. Parameter $\theta$ a measure of the fatness

- Fat tail ensures that the economy will never exhaust its stocks of new ideas

- Growing literature of related work on economic applications of these distributions: Gabaix, *QJE* (2009), *Ann Rev* (2009), *Ecma* (2011), Luttmer, *QJE* (2007), Rossi-Hansberg/Wright, *AER* (2007, Lucas/Moll, *NBERwp* (2012), Perla/Tonetti, *NYUwp* (2012), Alvarez/Buera/Lucas (in progress) (2012)

# 3 Social Learning with a Cohort Structure

- To interpet census evidence need a version with a cohort structure: people who attend school, have careers, age, retire.

- Demography given, constant: age density $\pi(s)$, cdf $\Pi(s)$

- For now, set schooling aside.

- Assume everyone goes to work at age $s = 0$

- Keeps going, and meeting people at rate $\alpha$, until retirement

- Central assumption, as in last section, is that economy is on a BGP
- Common Frechet environment $(\lambda(t), \theta)$ , $\lambda(t) = \lambda(0)e^{\gamma t}$
- Want to consider person born in year $t - s$, now of age $s$: a member of cell $s$ in the census year $t$
- For the all the years $v \in [t - s, t]$ he has drawn from Frechet distributions $(\lambda(v), \theta)$ at the rate $\alpha$
- By date $t$. his productivity is the largest of all the draws he has taken over this period

- Turns out that productivity distribution for the cell $s$ at date $t$ is equivalent to a single draw from a Frechet distribution with tail parameter $\theta$ and location parameter $\mu(s,t)$ where

$$\mu(s,t) = \alpha \int_{t-s}^{t} \lambda(v)dv$$

- Also have companion equation

$$\lambda(t) = \int_{0}^{\infty} \mu(s,t)\pi(s)ds$$

- Combine to get

$$\lambda(t) = \alpha \int_{0}^{\infty} \int_{t-s}^{t} \lambda(v)dv\pi(s)ds$$

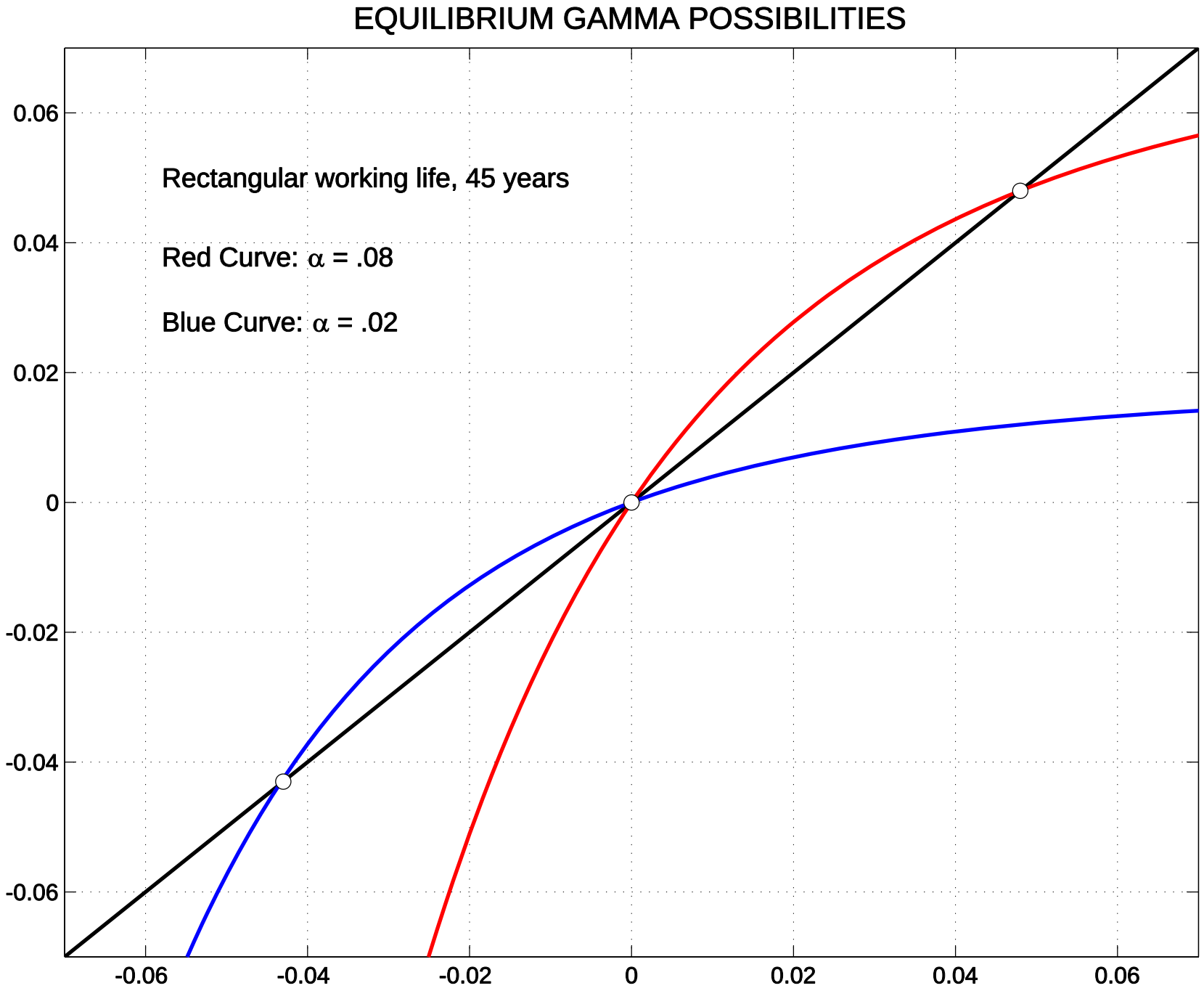
- Focus on behavior along a BGP, $\lambda(t) = Be^{\gamma t}$ for some $B$ and $\gamma$.

- Then

$$Be^{\gamma t} = \int_0^\infty B\frac{\alpha}{\gamma}e^{\gamma t}\left(1 - e^{-\gamma s}\right)\pi(s)ds$$

$$\gamma = \alpha\int_0^\infty \left(1 - e^{-\gamma s}\right)\pi(s)ds \qquad (*)$$

- Solve for $\gamma$. GDP growth rate is $\gamma\theta$.


EQUILIBRIUM GAMMA POSSIBILITIES
Rectangular working life, 45 years
Red Curve: α = .08
Blue Curve: α = .02
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.06
-0.04
-0.02
0
0.02
0.04
0.06

- For any age distribution, then, there will be a diffusion rate $\alpha > 0$ below which growth cannot be sustained. Age-earnings profiles will have same increasing, concave shape but for small $\alpha$ all this learning will be replacement investment only

- Identify low $\alpha$ with traditional agricultural societies—economics of Malthus/Ricardo (?)

- Identify high $\alpha$ with urban, "bourgeois" societies (?)

- Come back to this

# 4 Calibration and Testing

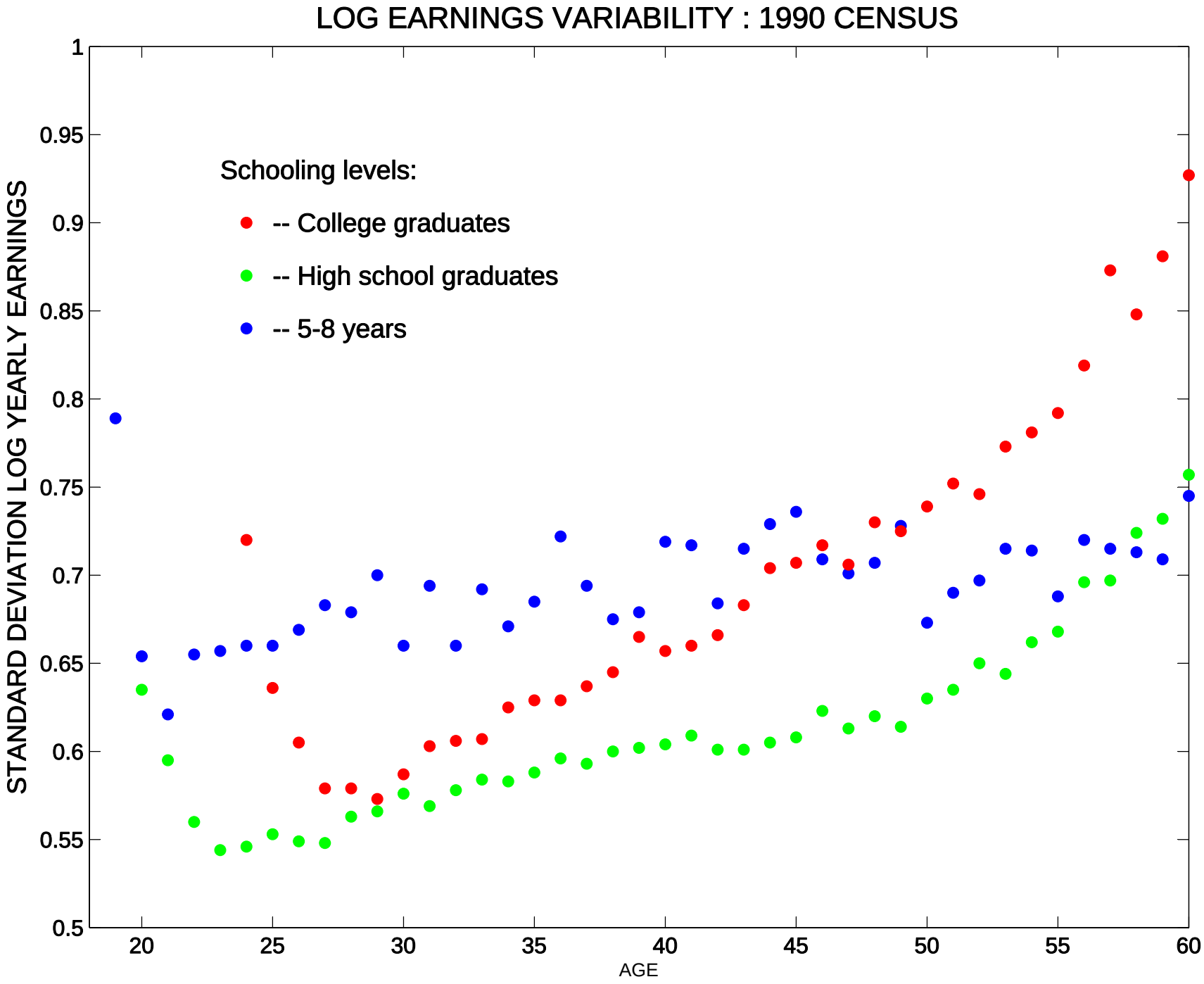
- BGP, Frechet model makes exact predictions about within-cell earnings distributions. Look at mean,.variance of log earnings in cell $(s, t)$

$$w(s,t) = K + \theta\gamma t + \theta \log(1 - e^{-\gamma s})$$

$$\text{Var}(\log(\text{earnings})) = \theta^2 \frac{\pi^2}{6}$$

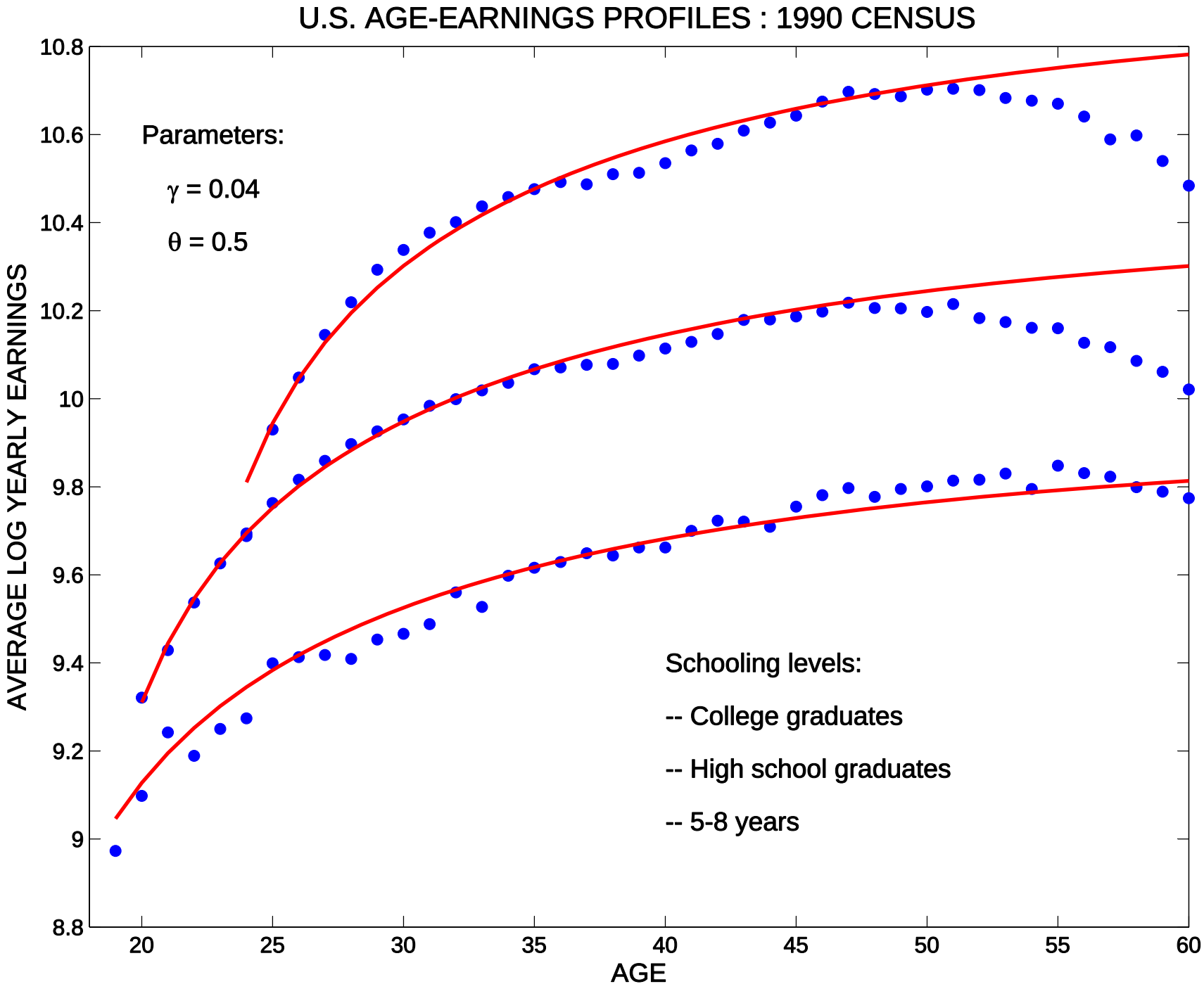
- Growth rate of per capita GDP along BGP in the model is $\gamma\theta$, about 0.02 in U.S.

- Use observed variance to estimate $\theta$, and then $\gamma = (.02)/\theta$


LOG EARNINGS VARIABILITY : 1990 CENSUS
STANDARD DEVIATION LOG YEARLY EARNINGS
AGE
Schooling levels:
-- College graduates
-- High school graduates
-- 5-8 years
1
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
20
25
30
35
40
45
50
55
60

- Variance high for new graduates (why?)...
- ... and rises gradually after age 23 (cf Deaton and Paxson (1994)) – why?
- A real problem with the model: variable $\theta$ would require very different analysis. But must press on...
- Estimate S.D. at 0.6, implying $\theta = 0.5$, and $\theta\gamma = .02$, $\gamma = .04$
- Implied age earnings profile is then

$$K' + \theta \log(1 - e^{-\gamma s})$$


U.S. AGE-EARNINGS PROFILES : 1990 CENSUS
AVERAGE LOG YEARLY EARNINGS
AGE
10.8
10.6
10.4
10.2
10
9.8
9.6
9.4
9.2
9
8.8
20
25
30
35
40
45
50
55
60
Parameters:
γ = 0.04
θ = 0.5
Schooling levels:
-- College graduates
-- High school graduates
-- 5-8 years

- Last slide illustrates well-known relation between earnings and schooling

- What about external effects here? How estimate them?

- Clear that need multiple "types" to pursue this: people make different schooling choices, or have different options, or mix of these.

- Take economy's school/type distribution to have given density $\phi(S)$

- Assume that draw from cell $(s, S)$ at date $t$ is Frechet RV with parameters $\mu(s, S, t)$ and $\theta$

- Let $\Gamma(S)$, $\Gamma'(S) > 0$, be schooling effects on productivity:

$$\mu(s, S, t) = \alpha \int_{t-s+S}^{t} \Gamma(S)\lambda(v)dv$$

$$\lambda(t) = \int_{s \geq S} \mu(s, S, t)\pi(s)\phi(S)dsdS$$

- Again seek BGP

$$\gamma = \alpha \int_{s,S} \left(1 - e^{-\gamma(s-S)}\right) \Gamma(S)\pi(s)\phi(S)dsdS$$

- Positive gdp level effect from increased schooling (not visible on BGP) and also (above) a predicted growth rate effect—increase in $\gamma$

# 5 Open Questions, Related Work, Conclusions

- So what have we got?
- A model that generates sustained growth based **only** on human capital accumulation
- Findings of growth accountants **assume** equality of private and social returns
- Can't then be used as proof of equality
- Both models fit census evidence reviewed here equally well

5.1 Model developed here is pure technology: Agents are given no decisions to make!

- Lucas and Moll, NBER (2012), Perla and Tonetti (2012) study different versions where agents must choose between producing with the knowledge thay have and searching for more. In both. choice of $\alpha$ is a continuous control problem.

- Could also analyze choice among different environments $\lambda(t)$ : Where to go to school? Where to live and work.

- Matsuyama, *JET* (1992), Lucas, *JPE* (2004)

5.2 Know that firms can (partially) internalize learning externalities and complementarities among workers of different ages

- Reluctant to discuss "knowledge" of a firm: What does it mean?
- But interesting work by Prescott/Visscher, *JPE* (1980), Prescott/Boyd, AER (1987)
- Age-related models in Chari and Hopenhayn, *JPE* (1991), Ki Seong Park, *IER* (1997), Jovanovic (in progress)
- Empirical approach in McGrattan/Prescott, AER (2007), JET (2009)

5.3 Much evidence of effects of trade on technology diffusion, over and above classical gains

- See Klenow/Rodriguez-Clare, *NBERwp* (2004).

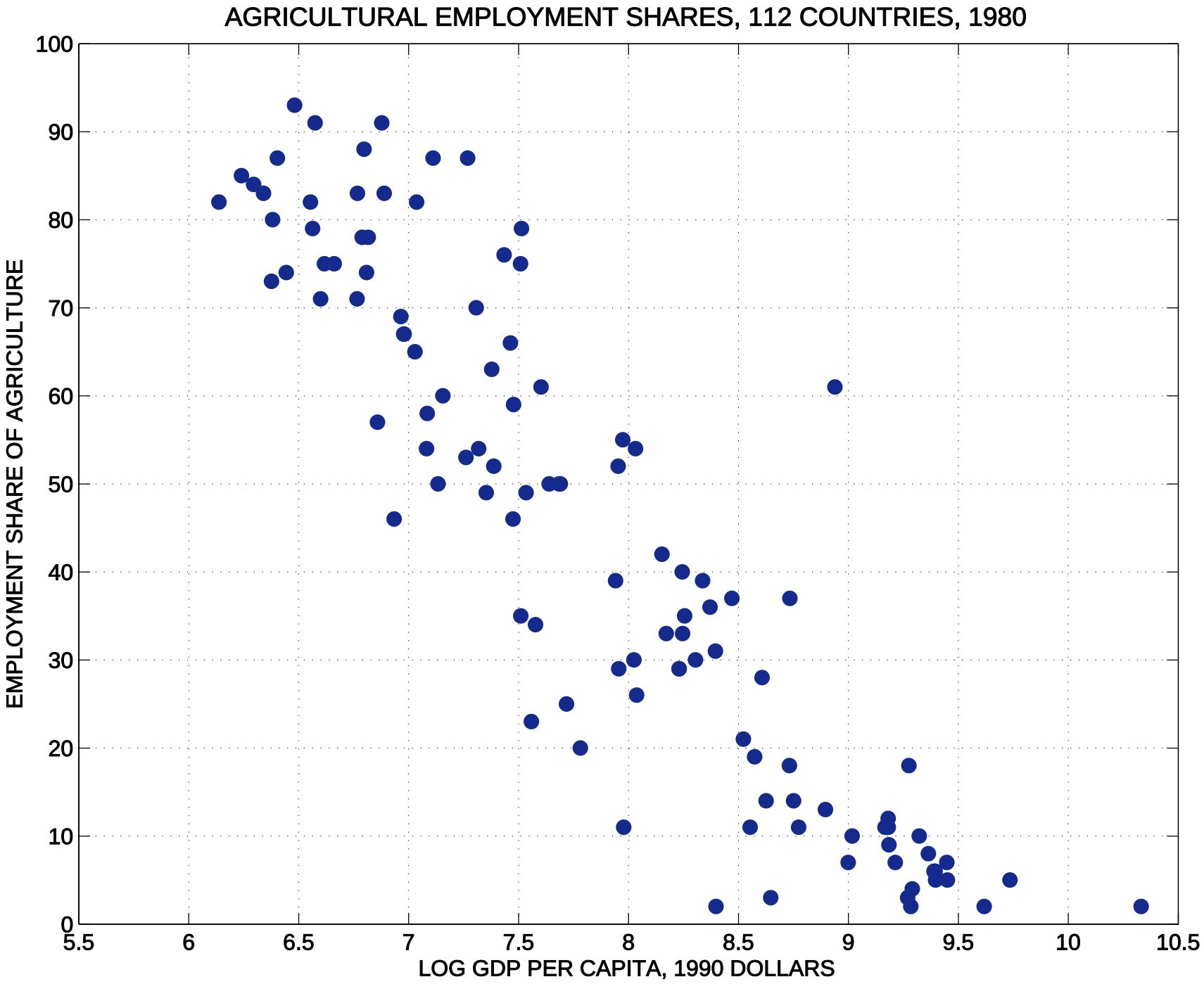
- In Alvarez/Buera/Lucas (in progress) international trade alters the learning environment $G_i(x,t)$ in country $i$ that dominates the autarchy environment $F_i(x,t)$

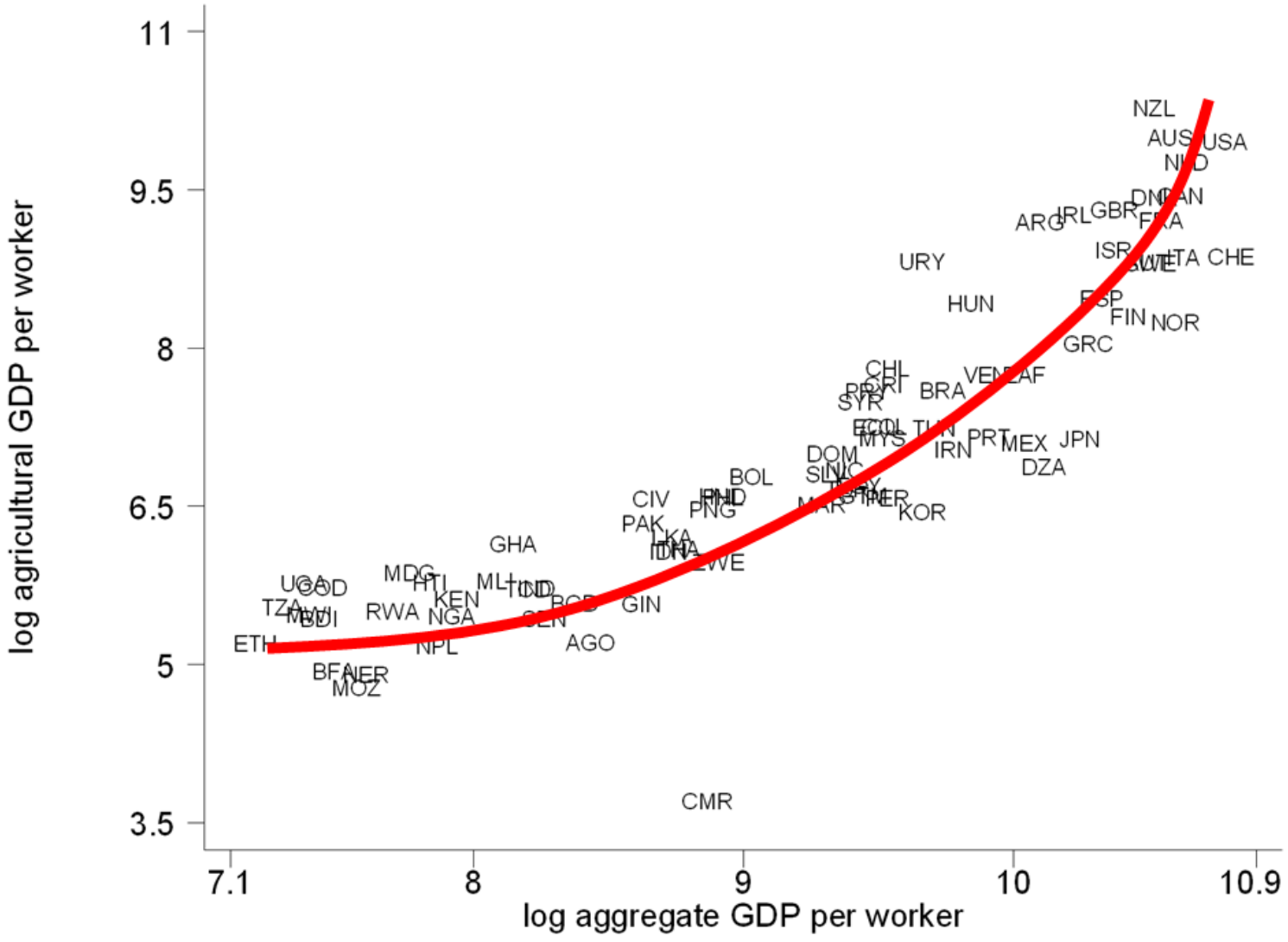
- Selection effect of trade: low productivity domestic producers replaced by high productivity foreigners

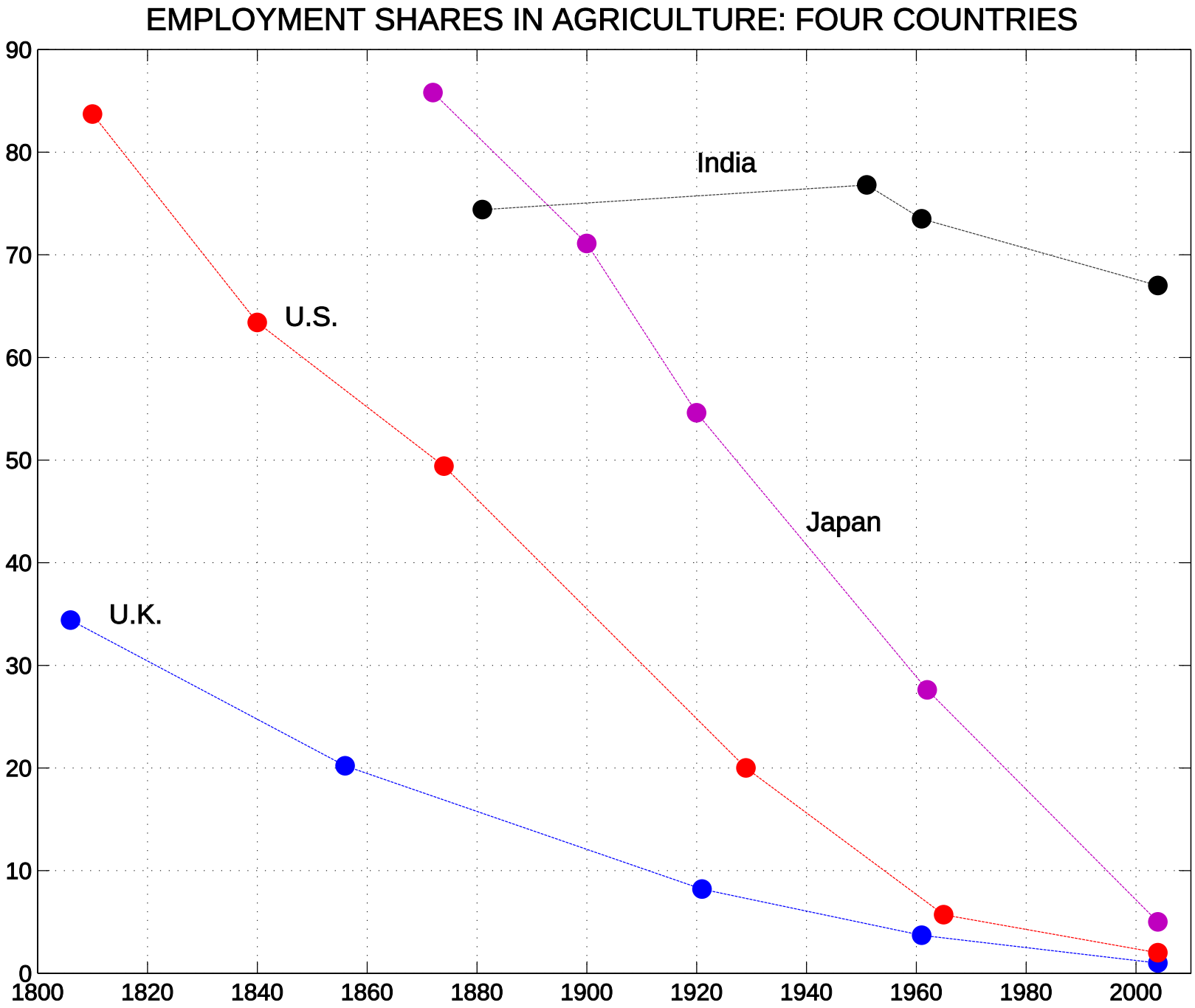
- Trade can improve learning environment for both parties

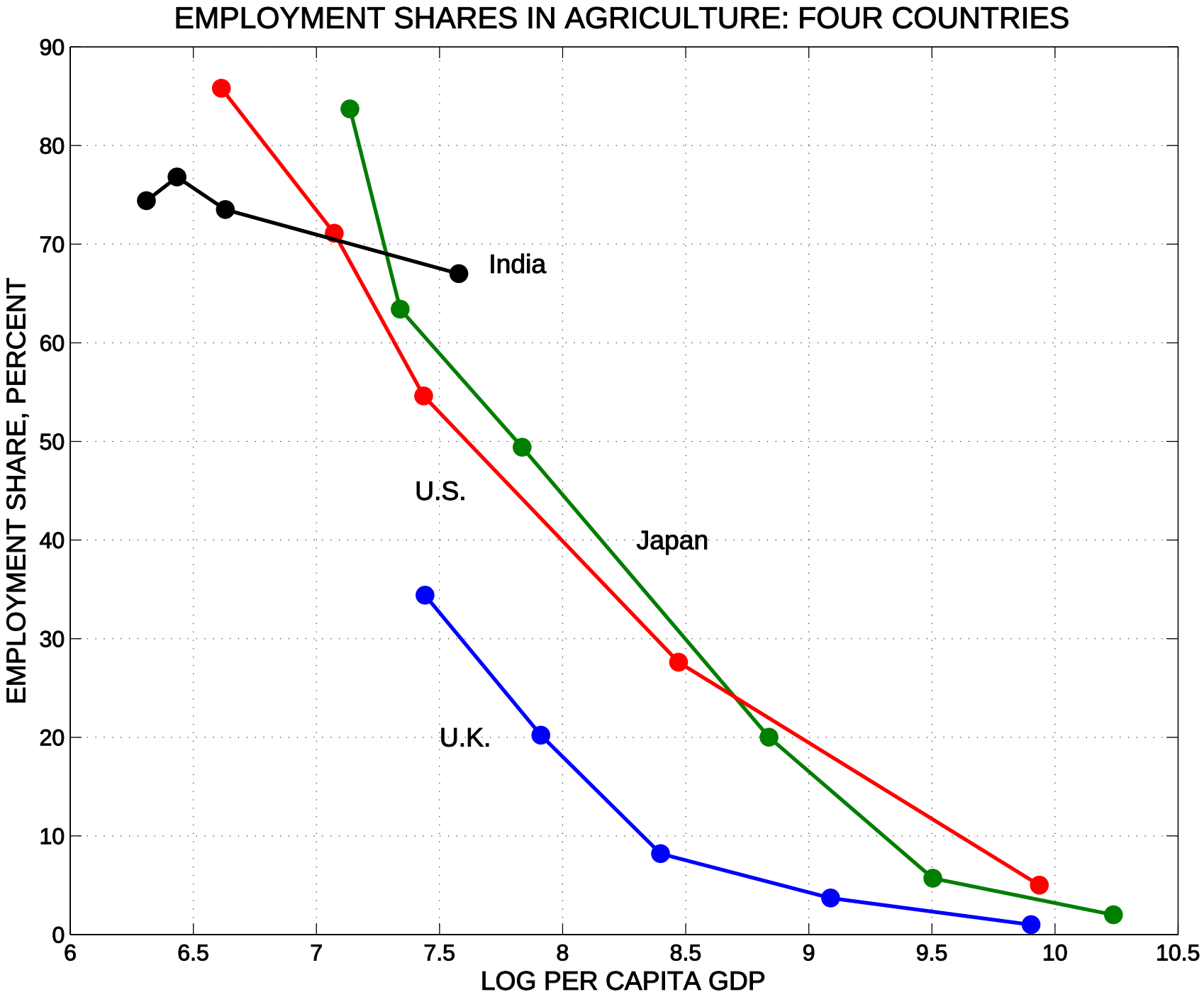
# 6. A Model of Development?

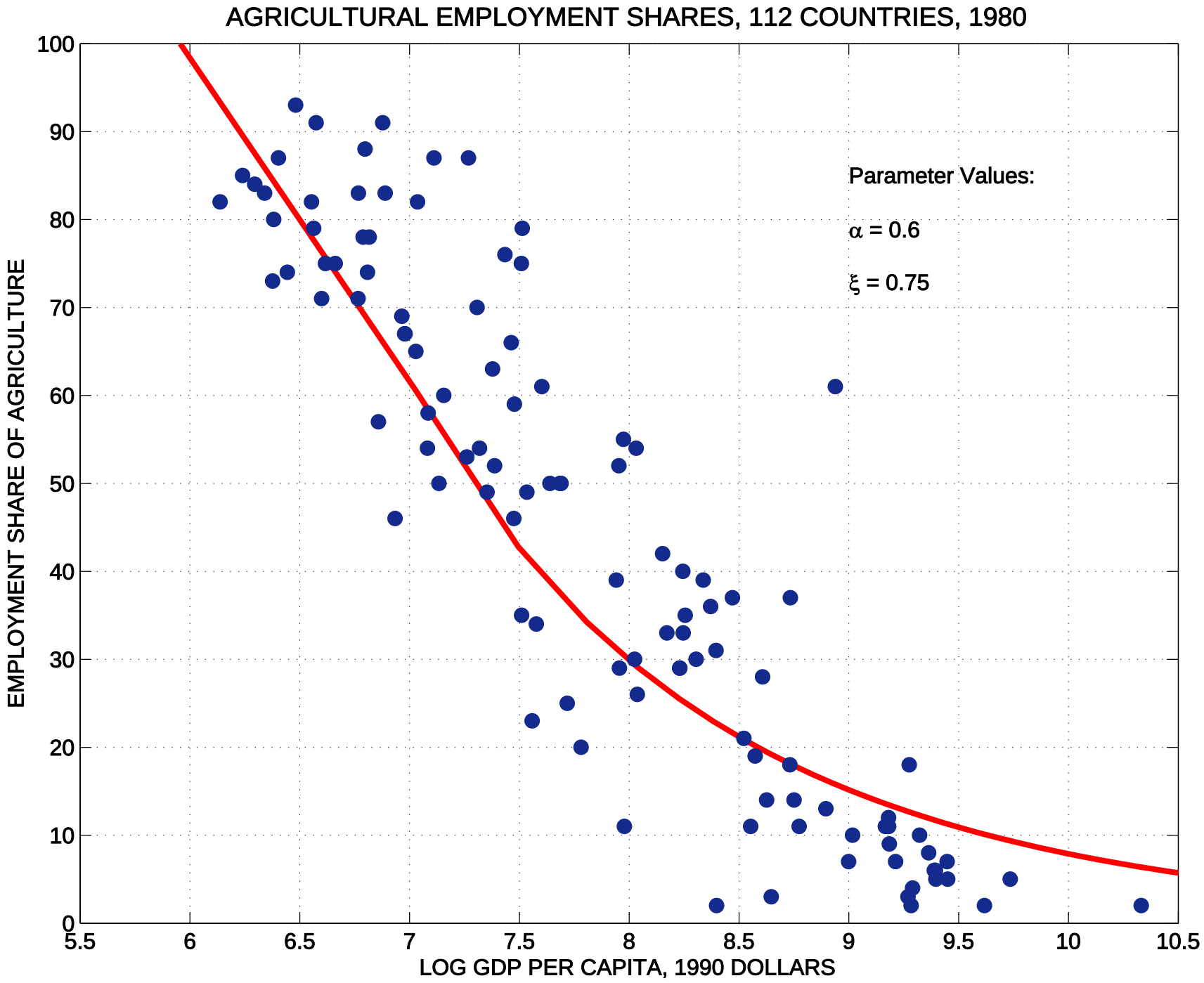
- However fitted out, model sketched above treats "bourgeosie" as entire economy.
- Not a bad assumption for wealthy economies today.
- No good at all for pre-industrial economies or poor economies today
- Some kind of dual economy model essential to interpret evidence on gdp growth and income levels

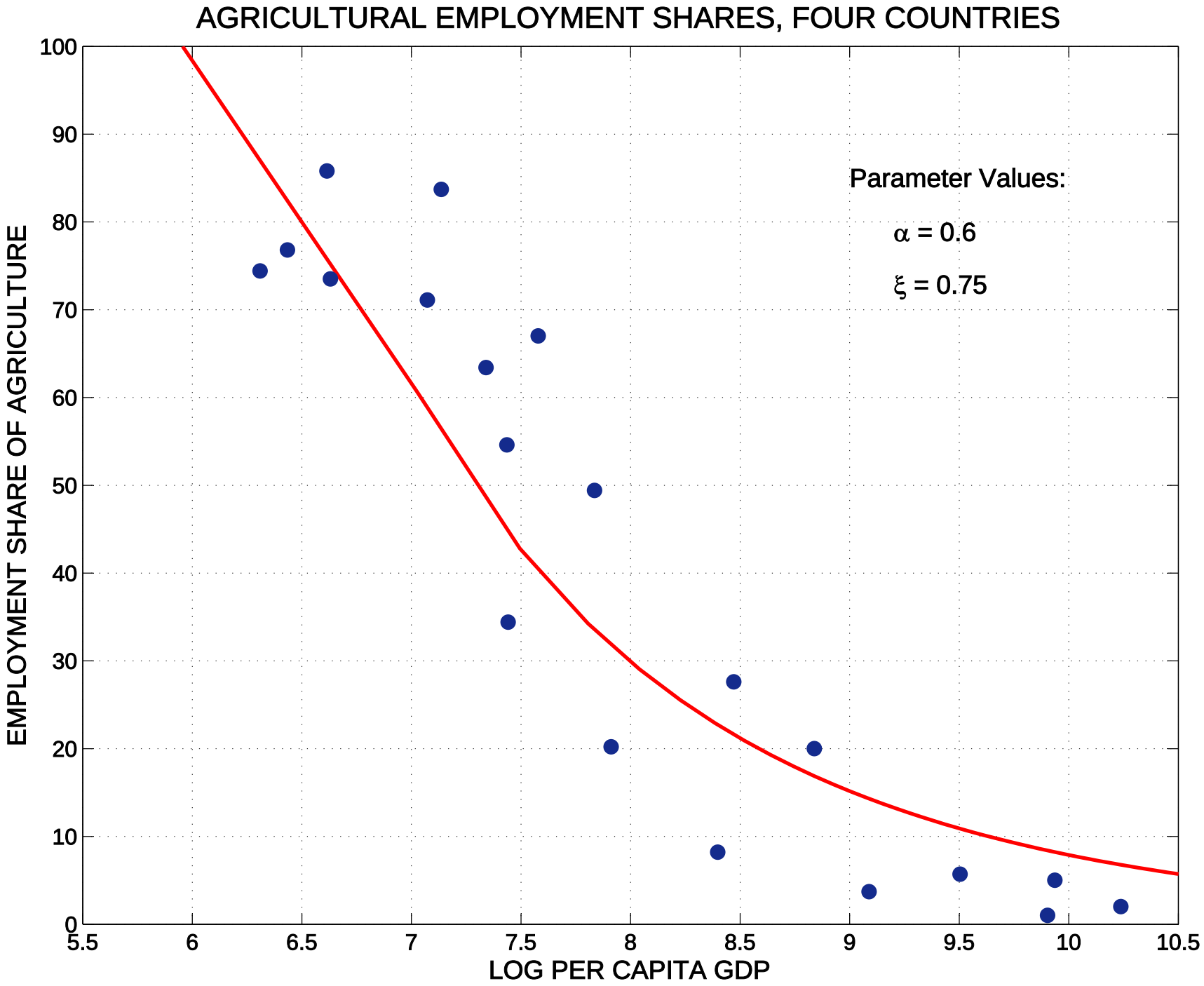

AGRICULTURAL EMPLOYMENT SHARES, 112 COUNTRIES, 1980
EMPLOYMENT SHARE OF AGRICULTURE
LOG GDP PER CAPITA, 1990 DOLLARS
0
10
20
30
40
50
60
70
80
90
100
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5


log agricultural GDP per worker
11
9.5
8
6.5
5
3.5
7.1
8
9
10
10.9
log aggregate GDP per worker
NZL
AUS
USA
NLD
DNK
CAN
ARG
IRL
GBR
FRA
ISR
SWE
CHE
URY
HUN
ESP
FIN
NOR
GRC
CHL
VEN
ZAF
BRA
SYR
MYS
IRN
PRT
MEX
JPN
DZA
DOM
BOL
CIV
PAK
PNG
KOR
GHA
MDG
HTI
KEN
RWA
NGA
GIN
AGO
NPL
ETH
MOZ
CMR


EMPLOYMENT SHARES IN AGRICULTURE: FOUR COUNTRIES
90
80
70
60
50
40
30
20
10
0
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
India
U.S.
Japan
U.K.


EMPLOYMENT SHARES IN AGRICULTURE: FOUR COUNTRIES
EMPLOYMENT SHARE, PERCENT
LOG PER CAPITA GDP
0
10
20
30
40
50
60
70
80
90
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
India
U.S.
Japan
U.K.


AGRICULTURAL EMPLOYMENT SHARES, 112 COUNTRIES, 1980
EMPLOYMENT SHARE OF AGRICULTURE
LOG GDP PER CAPITA, 1990 DOLLARS
Parameter Values:
α = 0.6
ξ = 0.75
0
10
20
30
40
50
60
70
80
90
100
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5


AGRICULTURAL EMPLOYMENT SHARES, FOUR COUNTRIES
EMPLOYMENT SHARE OF AGRICULTURE
LOG PER CAPITA GDP
Parameter Values:
α = 0.6
ξ = 0.75
100
90
80
70
60
50
40
30
20
10
0
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5

- See economic development as defined by this universal moving along these curves, this emptying-out the traditional sector of all economies

- Active role played by the problem-solving, idea-generating class I have focused on here

- Ongoing improvements in living standards of this class continues to attract immigration from the traditional sectors

- Agriculture, other functions, absorbed by this class, transformed into something else