What Was the Industrial Revolution ?

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Conference in Honor of Gary Becker

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The characteristic which distinguishes the modern period in world history from all past periods is the fact of economic growth. It began in western Europe and spread first to the overseas countries settled from Europe....For the first time in human history it was possible to envisage a sustained increase in the volume of goods and services produced per unit of human effort or per unit of accessible resources.

Wherever this enlargement of the productive horizon of the ordinary man appeared it involved a distinctive transformation of the economy concerned. A predominantly agricultural, family-based system of economic organization began to give way to a predominantly industrial system in which representative unit of production was necessarily larger than the family...

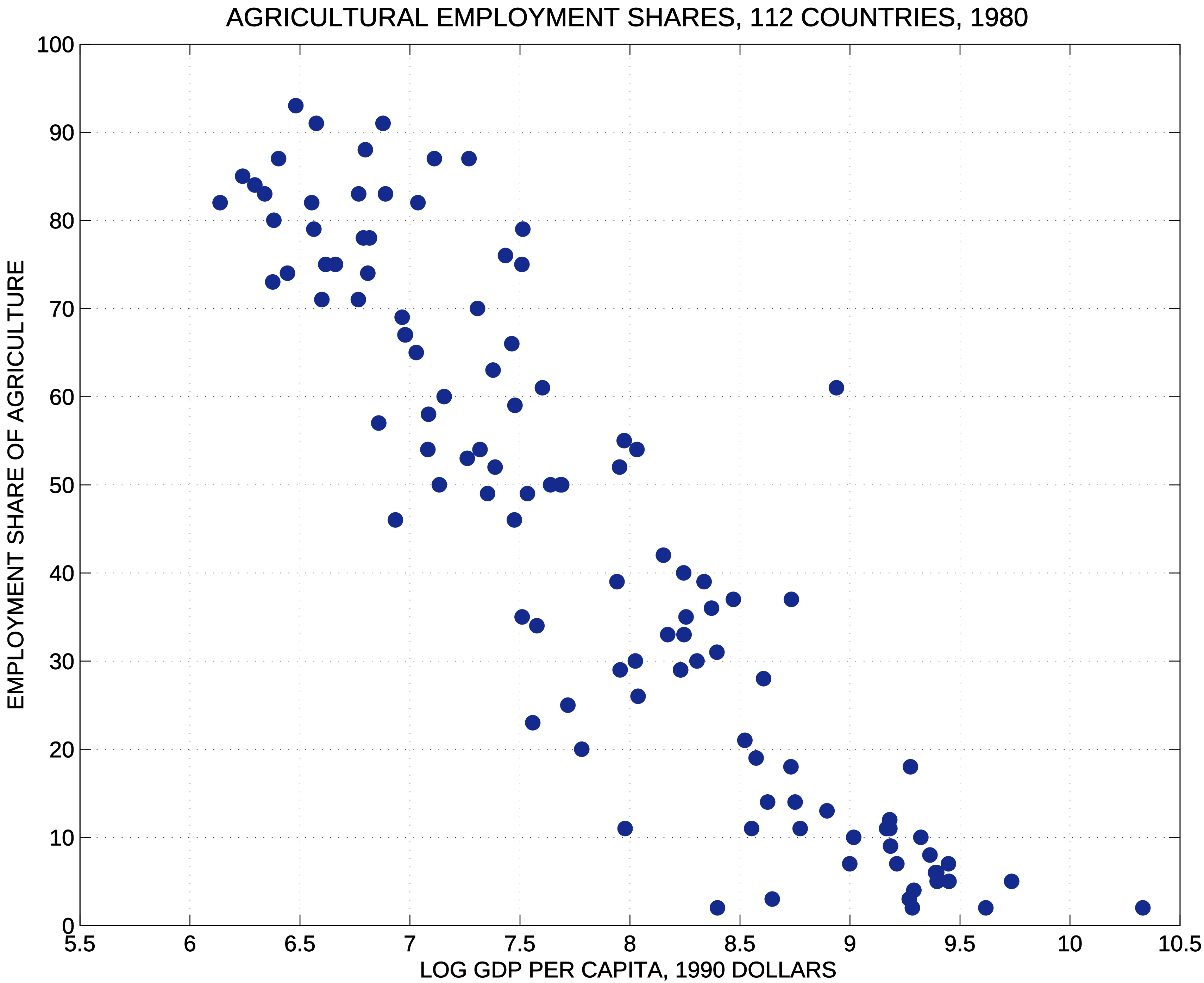
- Taken from: W.A. Cole and Phyllis Deane, 1966 Cambridge Economic History of Europe

- Figure 1: cross-section of 112 countries: plot fraction of labor force engaged in agriculture in against each country's per capita GDP. World Bank numbers for 1980. Income figures in logs: $6 = \$400$ 1990 U.S.; $10 = \$22{,}000$.

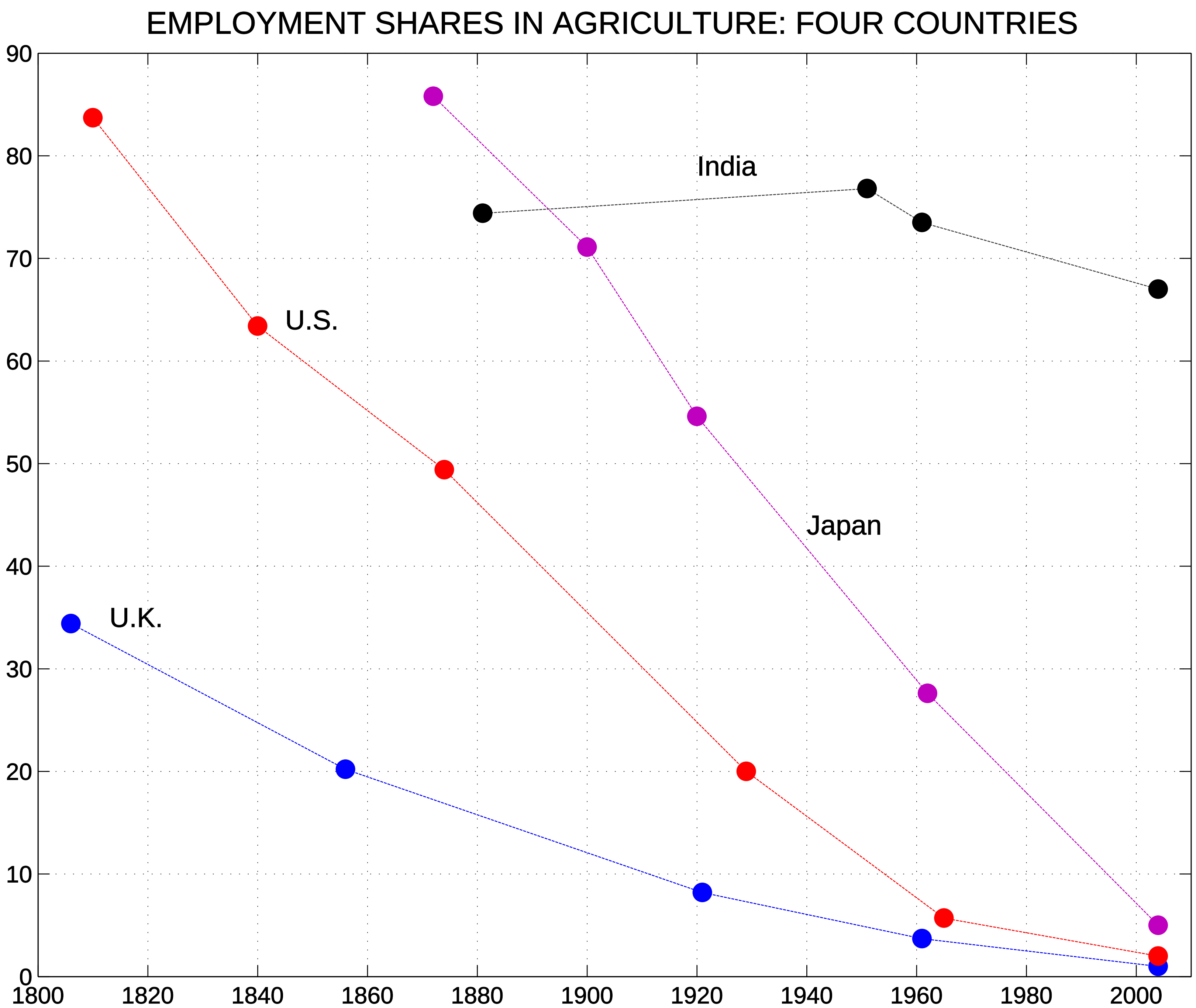
- Figure 2: time series for four countries: plots fraction of workers in agriculture against time. Data from Kuznets (1971), updated to 2004

- Figure 3: Maddison's income data replaces calendar time in 2: figure in the same units as Figure 1

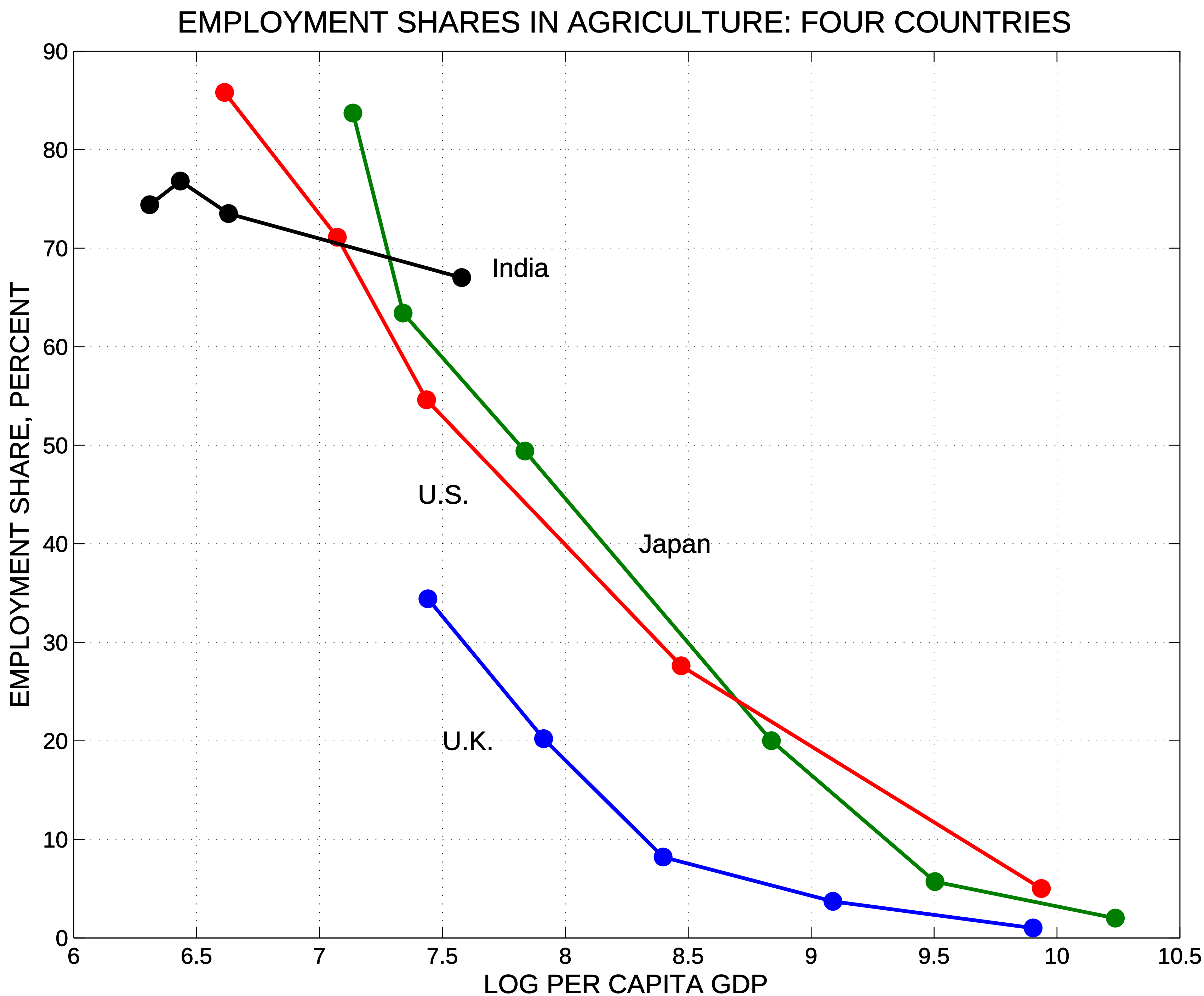
- Figures 4,5: Some curve fitting

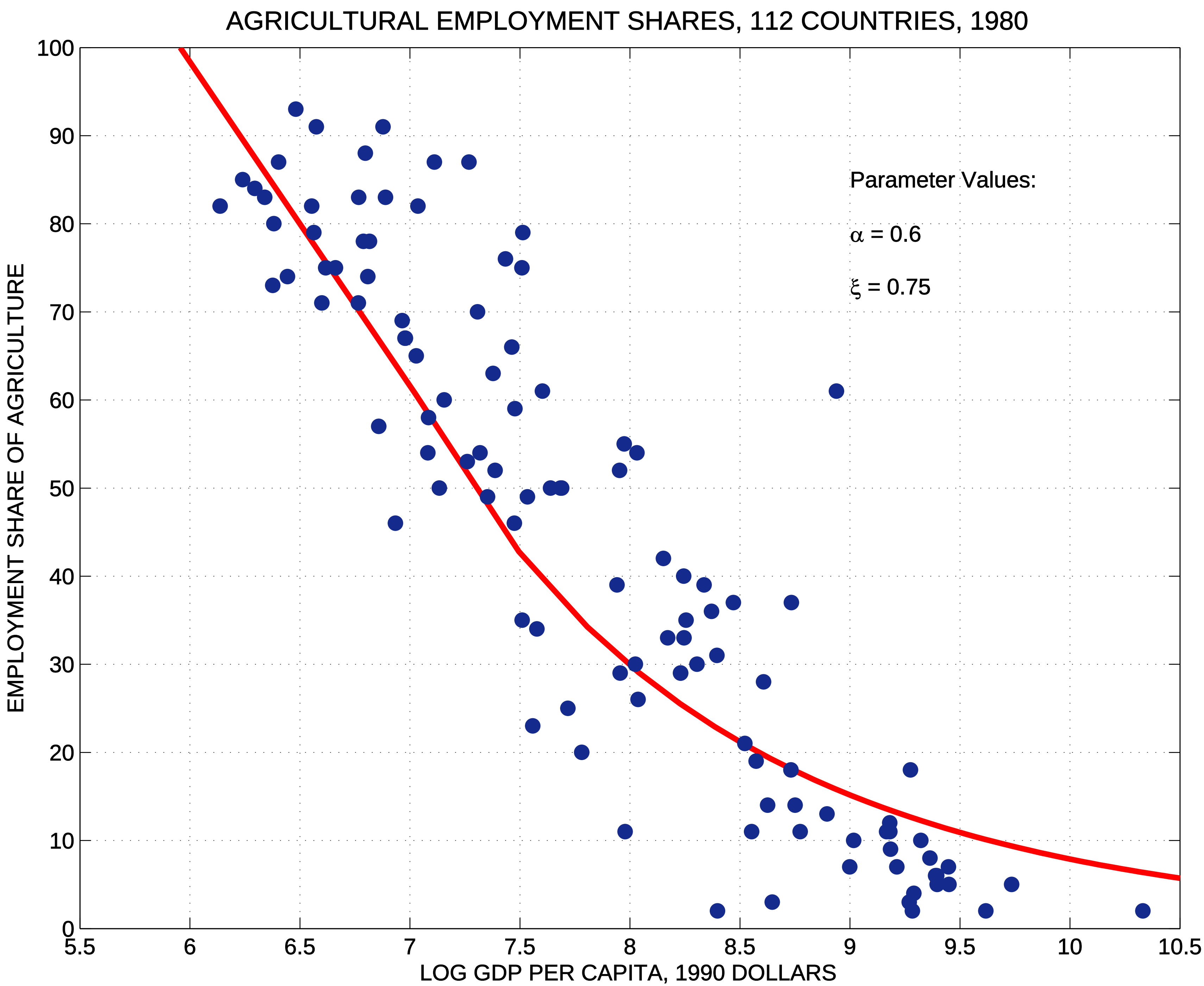


AGRICULTURAL EMPLOYMENT SHARES, 112 COUNTRIES, 1980
EMPLOYMENT SHARE OF AGRICULTURE
LOG GDP PER CAPITA, 1990 DOLLARS
0
10
20
30
40
50
60
70
80
90
100
5.5
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5

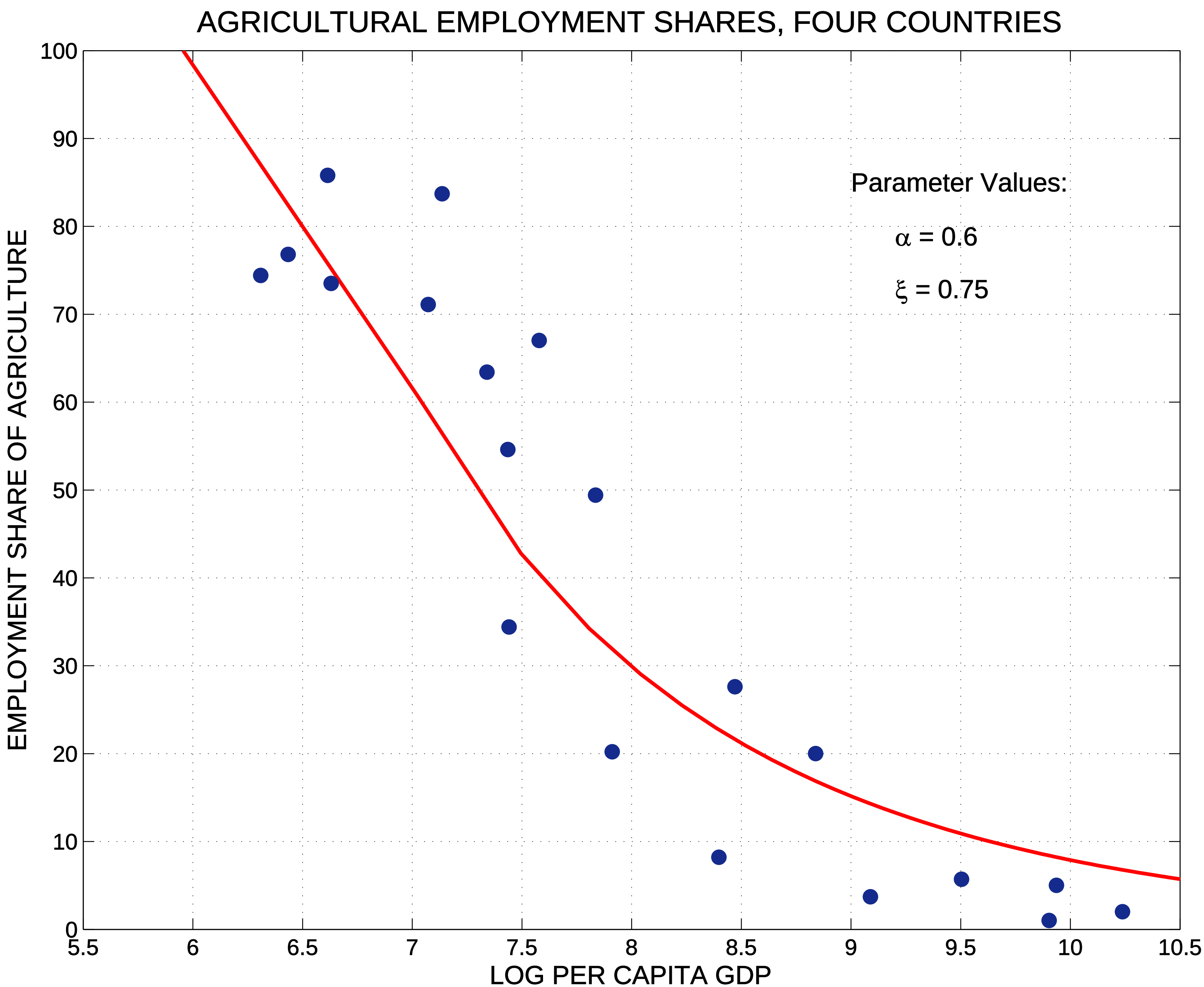


EMPLOYMENT SHARES IN AGRICULTURE: FOUR COUNTRIES
90
80
70
60
50
40
30
20
10
0
1800
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
India
U.S.
Japan
U.K.


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
Parameter Values:
α = 0.6
ξ = 0.75
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



AGRICULTURAL EMPLOYMENT SHARES, FOUR COUNTRIES
Parameter Values:
α = 0.6
ξ = 0.75
EMPLOYMENT SHARE OF AGRICULTURE
LOG PER CAPITA GDP
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

- Note the tight connection between fraction of workforce in agriculture and income levels

- Think of the people in the large agriculture sectors—80 or 90 percent of the work force—as largely illiterate, living on subsistence incomes: "traditional agriculture" (T.W. Schultz)

- Description of working people everywhere before (say) 1750

- Description still accurate for millions of people

- Figures do not show changes in population as the industrial revolution developed, but equally important

- Common pattern in poor, traditional economies is that higher incomes are associated with larger families initially, but then as incomes continue to grow number of children declines. Why?

- Becker (1960) proposed resolution of this puzzle: **quantity/quality trade-off**

- Becker's thinking on this trade-off evolved over the years. Here I rely very closely on his two joint papers with Robert Barro (1988),(1989) and the (1990) paper co-authored with Kevin Murphy and Robert Tamura

- What I will do in this paper is to set out two theoretical models

- One will be a stylized description of a pre-industrial society of traditional farm workers, people in the upper left corner of the slides we have been looking at

- The other will describe a sustained growth economy driven by human capital accumulation

- People in these two economies face quite different opportunities, so their behaviors will be very different

- But my central assumption is that they have exactly the same preferences

1. A Pre-Industrial Economy

- Start with the classical economists—notably Adam Smith and especially David Ricardo

- For them, as for Robert Malthus, fertility decisions and population were central to explaining production and incomes

- My interpretation of Ricardo is based on an adaptation of Becker and Barro's (1988) paper.

- Begin with the fertility decision of a newly-formed farm family, endowed with x units of land and one unit of labor

- Parents value own consumption, the number of children, and the resources they pass on to their children

- Express this as a Bellman equation

$$v(x) = \max_{c,n} W(c, n, v(x/n))$$

- This family values both "quantity" n of children and "quality" x/n per child

- In illustrations below, use the more specific preferences

$$v(x) = \max_{c,n} c^{1-\beta} n^{\eta} v(z/n)^{\beta}$$

- Assume that one unit of labor and x units of land yields $f(x) = Ax^\alpha$ of consumption good

- Divided between adults and children

$$c + kn \leq Ax^\alpha$$

- Land divided equally among children, so each child inherits x/n units of land

- For this specific utility function, value function is $v(x) = Bx^{\xi}$ where

$$\xi = \frac{1-\beta+\eta}{1-\beta+\alpha\beta}\alpha$$

and the optimal number of children is

$$n = \frac{\eta-\alpha\beta}{1-\beta+\eta}\frac{Ax^{\alpha}}{k}$$

provided that $\eta > \alpha\beta$.

- This is situation of individual family with x units of land

- Next consider the economy as a whole

- Let L be total land and N_t be population at date t
- If all families alike then $x_t = L/N_t$. Also have $N_t n_t = N_{t+1}$.
- Then population dynamics are

$$N_{t+1} = N_t n_t = N_t^{1-\alpha} \frac{\eta - \alpha\beta}{1 - \beta + \eta} \frac{A}{k} L^\alpha$$

- Converges to steady-state population N_{ss} with $n = 1$

$$N_{ss} = \left(\frac{\eta - \alpha\beta}{1 - \beta + \eta} \frac{A}{k} \right)^{1/\alpha} L$$

- A classic Malthusian model

- Additional land L, improvements in technologies A have no long run effects except on population

- Example based on egalitarian society of family farms: one form of traditional agriculture

- But easy to modify the model to one where few land owners collect all the land rents and workers—almost all of population—have nothing to pass on to children

- Alters the nature of the quantity/quality tradeoff but maintains Malthusian character

- Malthusian theory is not a model of species breeding itself into starvation or extinction

- Describes a population settling down to a sustainable steady state, determined by available resources and standards of child care

- Model applies to traditional human societies, routinely applied to animal populations

- An empirical success over the centuries prior to IR: explains why pre-industrial societies in the Edens of Java or South China had similar living standards as those on fringes of Sahara or Arctic

2. A Human Capital Economy

- In last models, all production required a given resource—land

- Now consider a labor-only economy, where productivity growth is generated on-the-job by new ideas, higher individual skill levels, diffusion to others

- Distinctive feature of the model is social character of work and creativity: The higher the skill level of the people around you the more you improve your own skills

- Role of schooling in this model is only to prepare for actual work, improving your ability to process, make use of, new ideas

- Economy as a whole described by evolving distribution of productivity levels z .

  $F(z,t) = \text{Pr}\{\text{person of any age at current date } t \text{ has productivity } \le z\}$

- Introduce cohort structure, stratified by age and schooling levels S

$$G(z,s,S,t) = \text{Pr}\{\text{person born at date } t, \text{ of age } s \text{ and}$$

$$\text{with } S \text{ years of schooling has productivity} \le z\}$$

- The cdfs $F(z,t)$ and $G(z,s,S,t)$ (densities f and g) are the "state variables" of this economy

- Age density $\pi(s)$ is constant, with $\pi'(s) \le 0$

- Learning technology is simple: each agent draws from the people around him, drawing people (Platonic forms?) from distribution $F(z,t)$ at given rate $\alpha(S)$

- Require that F have Pareto tail: never run out of ideas

- Have $\alpha'(S) > 0$: role of schooling is to increase ability to learn on the job

- At each draw compare own productivity z to productivity z' of person you meet

- Emerge with $\max(z, z')$

- At later ages s draw from $F(z, t+s)$

- These draws occur continuously, leading to

$$\frac{\partial \log G(z, s, S, t)}{\partial s} = \alpha(S) \log F(z, t+s)$$

- Integrate to get stochastic career of the cohort born in t :

$$\log G(z, s, S, t) = \alpha \int_0^s \log F(z, t+\tau) d\tau$$

- All of this takes as given path of $F(z, t)$

- But all of those who comprise $F(z, t)$ are members of some cohort, as just described

- Close the system by imposing

$$\log F(z,t) = \int_0^\infty \pi(s) \log G(z,s,S,t-s)ds$$

- Combine with

$$\log G(z,s,S,t) = \alpha(S) \int_0^s \log F(z,t+\tau)d\tau$$

  to get

$$\log F(z,t) = \alpha(S) \int_0^\infty \pi(s) \int_0^s \log F(z,t+\tau-s)d\tau ds$$

- Simplify by assuming that all these distributions are Frechet, with cdfs

  $F(z,t) = \text{exp}(-\lambda(t)z^{-1/\theta}) \quad \text{and} \quad G(z,s,S,t) = \text{exp}(-\mu(s,S,t)z^{-1/\theta})$

- Location parameters $\lambda(t)$ and $\mu(s,S,t)$ evolve over time, "shape" or "tail" or "variance" parameter θ is common, constant

- Now have

$$\lambda(t) = \alpha(S)\int_0^{\infty} \pi(s) \int_0^{s} \lambda(t+\tau-s)d\tau ds$$

- Have reduced problem of evolving distributions to one of evolving scalars

- Simplify still more by focusing on balanced growth paths (BGPs)

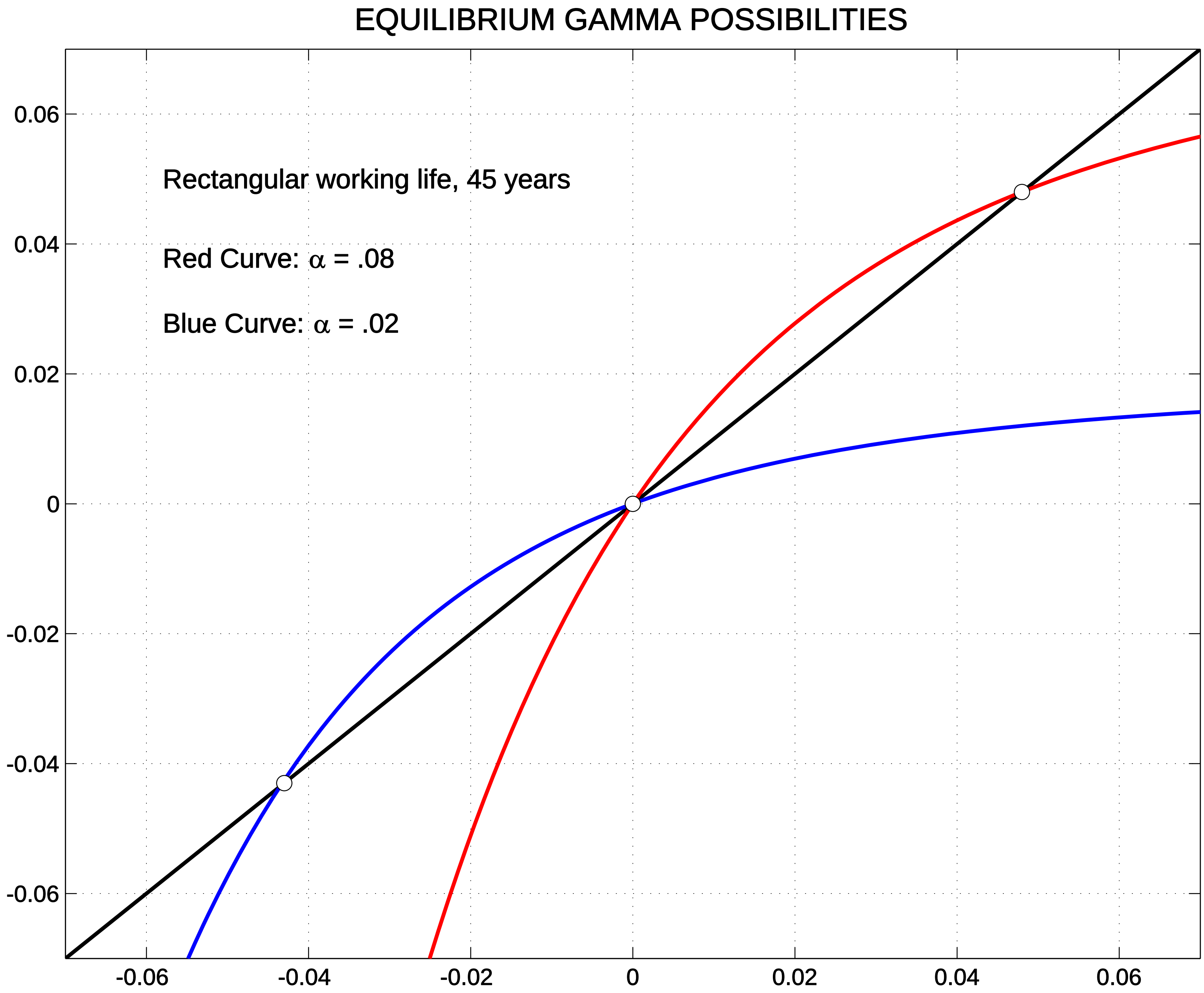
- Assume $\lambda(t) = \lambda_0 e^{\gamma t}$ where γ is a constant yet to be determined

- Then (3) implies

$$\lambda_0 e^{\gamma t} = \alpha(S) \int_0^{\infty} \pi(s) \int_0^{s} \lambda_0 e^{\gamma(t+\tau-s)} d\tau ds$$

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

- The two steady states that might be observed are $\gamma = 0$ and $\gamma > 0$, representing stagnation and sustained growth respectively



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 positive growth need

$$\frac{d\,(rhs)}{d\gamma} = \alpha(S) \int_0^\infty s\pi\,(s)\,ds > 1$$

- Sustained growth requires some combination of schooling and longevity

- This is process of the young learning from their elders. It can be limited by low levels of schooling, resulting in low rates of learning, or by early death or retirement rates that remove good colleagues prematurely

- This possibility of a class of literate merchants, traders, shippers—a "bourgeosie"—co-existing with traditional, Malthisian society is **important**. Human capital, quantity-quality tradeoffs have been around since pre-historic times, long before onset of industrial revolution (cf Doepke (2004), (2005))

- What are the macroeconomic properties of this BGP?

- Treating each worker as solo producer, mean per capita earnings are

$$\begin{aligned} y(t) &= \int_0^\infty z dF(z,t) \\ &= \int_0^\infty z d\, \mathsf{exp}(-\lambda(t) z^{-1/\theta}) \\ &= \lambda(t)^\theta \int_0^\infty (-\,\mathsf{log}(u))^{-\theta}\, du \\ &= A\lambda(0) e^{\theta\gamma t} \end{aligned}$$

- Growth rate determined by individual search efforts γ and richness of environment θ

3. A Schooling Choice Problem

- In the last section, everyone has the same schooling level S, viewed as given parameter

- Maintain the assumption of single schooling level S (easy to modify) but let each person have option to deviate by choosing an S different from others

- In equilibrium, no one wants to deviate.

- Assumed common objective: maximize expected value of earnings stream, discounted back to graduation:

$$V = \int_S^\infty e^{-rs} \Pi(s) W(s, S, t) ds$$

- r is a given interest rate, $\Pi(s) = \int_0^s \pi(\tau) d\tau$, and $W(s, S, t)$ is the expected earnings at t of a person of age s.

- Maintain assumptions of balanced growth and Frechet distributions with parameters $\mu(s, S, t-s)$ and θ

- Calculate mean dollar earnings as follows.

$$
\begin{aligned}
W(s, S, t) &= \int_0^\infty z d \exp(-u) \\
&= \int_0^\infty \left(\frac{u}{\mu(s, S, t-s)} \right)^{-\theta} d \exp(-u) \\
&= \mu(s, S, t-s)^\theta \int_0^\infty u^{-\theta} d \exp(-u) \\
&= A \mu(s, S, t-s)^\theta
\end{aligned}
$$

- Along BGP we see, applying

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

that

$$\mu(s, S, t-s) = \frac{\alpha(S)}{\gamma} \lambda(0) e^{\gamma t} \left(1 - e^{-\gamma(s-S)}\right)$$

- Follows that the EPV of this person's earnings is

$$V = A\lambda(0)^\theta e^{\theta\gamma t} \left(\frac{\alpha(S)}{\gamma}\right)^\theta \int_S^\infty e^{-rs} \Pi(s) \left(1 - e^{-\gamma(s-S)}\right)]^\theta ds$$

- Convenient approximation is to set $\Pi(s) = 1$. Why?

- Schooling comes early in life, death probabilities not be an important factor. Then

$$
\begin{aligned}
V &= A\lambda(0)^{\theta} e^{\theta\gamma t}\left(\frac{\alpha(S)}{\gamma}\right)^{\theta}\int_{S}^{\infty} e^{-rs}\Pi(s)\left(1-e^{-\gamma(s-S)}\right)]^{\theta} ds \\
&= A\lambda(0)^{\theta} e^{\theta\gamma t}\left[\frac{\alpha(S)}{\gamma}\right]^{\theta} e^{-rS}\int_{0}^{\infty} e^{-rv}\left(1-e^{-\gamma v}\right)^{\theta} dv \\
&= B(\gamma,t)\,\alpha(S)^{\theta} e^{-rS}
\end{aligned}
$$

where

$$
B(\gamma,t) = A\lambda(0)^{\theta} e^{\theta\gamma t}\int_{0}^{\infty} e^{-rv}\left(\frac{1-e^{-\gamma v}}{\gamma}\right)^{\theta} dv.
$$

- As above, one BGP possibility is $\gamma = 0$: schooling is of no value

- Other is $\gamma > 0$ and $B(\gamma, t) > 0$. In this case, each agent solves

$$\max_S \left[\theta \log(\alpha(S)) - rS\right]$$

  implying the first order condition

$$\frac{\alpha'(S)}{\alpha(S)} = \frac{r}{\theta}$$

- For example, suppose that $\alpha(S) = KS^{\phi}$, where K and ϕ are known parameters. Then

$$\frac{d \log\left(\alpha(S)^{\theta} e^{-rS}\right)}{dS} = \theta \frac{\phi}{S} - r$$

and optimal schooling is

$$S = \frac{\beta\theta\phi - \eta}{\beta r}.$$

- Higher θ means that a high search intensity is more valuable.

- Higher ϕ means more benefit from schooling on the margin

- Higher r means higher opportunity cost of school

- Formula
$$\gamma = \alpha(S) \int_0^\infty \pi(s) \left(1 - e^{-\gamma s}\right) ds$$
continues to define possible BGPs

- But now schooling level S derived from individual choice problem

- Worth noting that this equilibrium cannot be efficient

- Individual agents concerned only with their own earnings: place no value on the stimulus they provide to others

- Familiar external effect, rationalizes government role in schooling

4. Schooling and the Quantity/Quality Tradeoff

- Solution just described implicitly assumed that everyone simply maximizes EPV earnings—borrowing when young and paying back when old

- No parental support is needed

- Not the way things work!

- Here assume that parental support is essential

- Let S be schooling level attained by parent

- As shown above, this parent has goods production capacity

$$B(\gamma, t)\alpha(S)^{\theta}e^{-rS}$$

- Parent chooses family size n and schooling per child z

- To do this, must use **fraction** δnz of production capacity to ensure that all n children attain schooling level z

- Here δ is given parameter

- (Cf: Becker, Murphy and Tamura (1990), again.)

- Now assume parent's problem is

$$v(S) = \max_{c,n,z}(c^{1-\beta} n^{\eta} v\,(z)^{\beta}).$$

subject to

$$c \leq B(\gamma, t)\alpha(S)^{\theta} e^{-rS}\,(1 - \delta n z)$$

- Bellman equation for this problem can be written

$$v(S) = \max_{c,n,z}(c^{1-\beta} n^{\eta} v\,(z)^{\beta}).$$

$$\log v(S) = (1-\beta)\log(B(\gamma, t)\theta\alpha(S)^{\theta} e^{-rS}).$$

$$+\max_{n,z}\left[(\log(1-\delta n z)) + \eta \log(n) + \beta \log v\,(z)\right]$$

- First order and envelope conditions are

$$\frac{\delta z}{1-\delta n z}=\frac{\eta}{n},$$

$$\frac{\delta n}{1-\delta n z}=\beta\frac{v'(z)}{v(z)}$$

$$\frac{v'(S)}{v(S)}=\frac{d\log\left(B(\gamma,t)\theta\alpha(S)^{\theta}e^{-rS}\right)}{dS}.$$

- Seek a BGP on which $S=z$, S and n are constant, and $c(t)$ grows at a constant rate $\theta\gamma$.

- Normalize by replacing $B(\gamma, t)$ by $B(\gamma, 0)$

- Solve for S and n

$$\frac{\eta}{S} = \beta \frac{d \log \left(\alpha(S)^{\theta} e^{-rS}\right)}{dS} \quad \text{and} \quad \delta n S = \frac{\eta}{1+\eta}$$

- As before use example, $\alpha(S) = KS^{\phi}$, so that optimal schooling is

$$S = \frac{\beta\theta\phi - \eta}{\beta r}.$$

- Implied fertility rate is

$$n = \frac{\eta\beta r}{\delta(1+\eta)(\beta\theta\phi - \eta)}.$$

5. Conclusions?

- Have set out descriptions of two distinct economies
  - Land-based economy, Malthusian, working people at subsistence levels
  - Human capital-based economy, sustained growth potential
- How are the two related?
- Natural idea (cf. Hansen/Prescott (1998), Lucas (2002),(2004)) is to add labor mobility

- Wages in the rural sector when there are $N_a(t)$ workers are

$$w(t) = (1 - \alpha)\, AL^{\alpha} N_a^{-\alpha}(t)$$

- Earnings in the city sector grows like $Ce^{\theta\gamma t}$

- With mobility, we get something like

$$N_a(t) = De^{-(\theta\gamma/\alpha)t}$$

- For given total population the fraction of workers in agriculture shrinks toward zero, just as it does in the data

- But we don't have a given population in this problem: We have a fertility theory

- Have rigged the model so that people in the city are self-sufficient: No matter what others do or when they arrived they follow a path $Ce^{\theta\gamma t}$ and choose fixed schooling levels and fertility rates $n-1$. Let's set $n=1$ permanently for the city.

- Only real actors are those on the farm: to move or to stay? How many children to have?

- Begin with both sectors just maintaining their population numbers.

- Now imagine earnings in city increase. Induces some to move to city. [Why? How?]

- This raises wages on farm, induces higher fertility: population grows in both sectors

- What happens to the fractions?

- Can we find conditions under which fraction in city converges to one?

- Lots of cards left to play: What skills will workers leaving the farm sector take to the urban sector?

- Do they get a z value? Do they get any schooling? How? Do they retain their land wealth or leave it behind?

- Like to see the math?

- Me too!