

# The Evolution of Markets and the Revolution of Industry: A Unified Theory of Growth

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- What explains the transition from Malthusian growth to modern growth, and the associated structural transformation and demographic transition?
- What is the mechanism that gave rise to the Industrial Revolution?

# Consumer Revolution and Industrial Revolution

- Previous models focus almost exclusively on the more efficient use of resources in production (*process innovation*).
- However, during the 17th and 18th century England experienced, in addition to technological innovation, a rapid expansion in the varieties of consumer commodities (*product innovation*).
- This phenomenon has been referred to as the *Consumer Revolution*.
- This suggests that the Industrial Revolution was as much about *product innovation* as *process innovation*.

# Our paper proposes novel mechanism

- The list of possible factors leading to the Industrial Revolution is well known: population size (Smith, 1776), openness to trade (Findlay and O'Rourke, 2007), transportation costs (Szostak, 1991), institutions (North and Thomas, 1973), agricultural revolution (Schultz, 1961).
- We do not add to this list of factors. In fact, an advantage of our theory is that it will be consistent with these factors.
- Instead, we propose a novel mechanism through which these factors led to the transition from Malthusian to modern growth.
- Consistent with the historical record, both product and process innovation will be important.
- In particular, product innovation will be essential to set in motion the mechanism that leads to process innovation.

## Larger markets

- More varieties (*product innovation*).
- Greater competition, more elastic demand and smaller markups.
- Firms need to be larger to break even.
- Firms better able to cover innovation costs (*process innovation*).

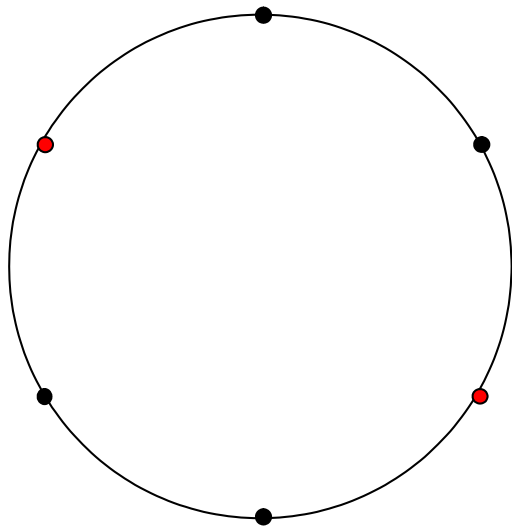
# Mechanism: based on Hotelling-Lancaster preferences

Hotelling-Lancaster (instead of Spence-Dixit-Stiglitz) preferences

- Product space is bounded, and each product has a specific address on the unit circle.
- As the market becomes larger, and the number of varieties increases, the product space becomes more crowded, and competition toughens.
- Markups fall, so firms must be larger to break even.

Difference with Spence-Dixit-Stiglitz: doubling the population increases the number of varieties, but *less* than proportionally, so firms become larger.





# Product and process innovation in growth theory

- Models are generally based on Spence-Dixit-Stiglitz.
- First generation endogenous growth models (e.g., Grossman and Helpman, 1991).
  - Switch off product innovation, keeping (by assumption) number of varieties constant.
  - Larger markets lead to larger firms, and thus to more process innovation.
- Second generation endogenous growth models (e.g., Young, 1998).
  - Endogenize number of varieties. Allow for product innovation.
  - Market size no longer affects firm size, and thus does no effect on process innovation.
- Conclusion: unable to generate the co-existence of product and process innovation.

## ● Positive relation between market size and price elasticity

- U.S. gasoline markets in Southern California (Barron et al., 2008).
- Responsiveness of imports to lowering of trade costs greater in larger markets (Hummels and Lugovskyy, 2006).

## ● Negative relation between market size and mark-ups

- Mark-ups dropped by 67 percent between 1870 and 2003 in the UK (Ellis, 2006).
- Mark-ups fall with import competition (Tybout, 2003).

## ● Positive relation between market size and firm size

- Before Industrial Revolution: importance of putting-out system as transition from cottage industry to factory system.
- During Industrial Revolution: cotton industry in Manchester (Lloyd-Jones and Le Roux, 1980), US manufacturing (Sokoloff, 1984).
- Recent evidence on U.S. (Campbell and Hopenhayn, 2005).

# Empirical evidence on product and process innovation

- Product innovation before and during the Industrial Revolution.
  - Berg (2002) analyzes British patents between 1627 and 1825. Over one-quarter specified new products or new varieties of existing ones.
  - Griffiths et al. (1992) document that about half of 166 patented and non-patented improvements in the textile industry between 1715 and 1800 concerned product innovation.
  - De Vries (1993) documents increasing variety in household durables during the 18th century.
  - The creation of new consumer goods was well underway before the start of the Industrial Revolution (Styles, 2000).
- Larger firms are engaged in more process innovation.
  - In 19th century larger firms were more likely to use steam power (Atack, 2008).
  - In 1970s larger banks were more likely to adopt ATMs (McDowell, 1984).

- Galor and Weil (2000): link between technological progress and human capital returns.
- Hanson and Prescott (2002): switch from Malthus to Solow, based on exogenous TFP growth.
- Goodfriend and McDermott (1995): increasing returns to specialization.

- **Household sector:**  $N_t^f$  households employed in agriculture (farm),  $N_t^x$  households employed in industry (city).
- **Industrial sector:** monopolistically competitive
  - Each firm produces a unique variety, located on the unit circle.
  - Product and process innovation.
- **Agricultural sector:** perfectly competitive, uses labor and industrial intermediate goods.

# Household endowments

- At beginning of period  $t$  there is a measure  $N_t$  of households, uniformly distributed around unit circle.
- Each household is endowed with one unit of time, which it uses to rear children or work.
- Households are free to work in either sector.

$$N_t = N_t^f + N_t^x$$

where both  $N_t^f$  and  $N_t^x$  are uniformly distributed around unit circle.

# Household preferences

- Households derive utility from the number of children,  $n_t$ , agricultural consumption,  $c_{at}$ , and industrial consumption of variety  $v$ ,  $c_{vt}$ .

$$U = [(c_{at} - c_{\bar{a}})^{1-\alpha} [g(c_{vt} | v \in V_t)]^\alpha]^\mu (n_t)^{1-\mu}$$

- Agricultural subsistence constraint:  $c_{\bar{a}}$ .
- Each household has an ideal industrial variety given by its location on the unit circle.
- The subutility function  $g(c_{vt} | v \in V)$  of a household with ideal variety  $\tilde{v}$  is

$$g(c_{vt} | v \in V) = \max_{v \in V_t} \left[ \frac{c_{vt}}{1 + d_{v, \tilde{v}}^\beta} \right]$$

- Households live for one period.
- Time cost of rearing children is higher in the city than on the farm:

$$\tau^x > \tau^f$$

- Law of motion of population.

$$N_{t+1} = n_t^f N_t^f + n_t^x N_t^x$$

where  $n_t^i$  is the number of children, with  $i \in \{f, x\}$ .

# Utility maximization

Budget constraint:

$$y_t^i(1 - \tau^i n_t^i) = c_{at}^i + \sum_{v \in V} p_{vt} c_{vt}^i$$

First order necessary conditions:

$$\begin{aligned} c_{at}^i &= \mu(1 - \alpha)(y_t^i - c_{\bar{a}}) + c_{\bar{a}} \\ \sum_{v \in V_t} p_{vt} c_{vt}^i &= \mu\alpha(y_t^i - c_{\bar{a}}) \\ \tau^i n_t^i &= (1 - \mu)\left(1 - \frac{c_{\bar{a}}}{y_t^i}\right) \end{aligned}$$

Each agent consumes a single industrial variety. An agent located at  $\tilde{v}$  buys the variety  $v'$  that minimizes the cost of an equivalent unit of its ideal variety, so that

$$v' = \operatorname{argmin}[p_{vt}(1 + d_{v,\tilde{v}}^\beta) | v \in V]$$

- Monopolistically competitive. Labor only input.
- Fixed cost (two components — operating and R&D): increasing returns.
- Free entry and exit of firms.
- Technology:

$$Q_{vt} = A_{xt}(1 + g_{vt})[L_{vt} - \kappa_{vt}]$$

- $A_{xt}$  is average industry technology used in period  $t - 1$ . Default in period  $t$ .
- $\kappa_{vt}$  is a fixed labor cost.

The fixed labor cost

$$\kappa_{vt} = \kappa e^{\phi g_{vt}}$$

has two components

- An operating component,  $\kappa$ .
- An R&D component, which depends on the improvement in the technology,  $g_{vt}$ .

# Profit maximization of industrial firms

- Firm chooses  $p_{vt}$  and  $g_{vt}$ ) that maximize

$$\Pi_{vt} = p_{vt}Q_{vt} - w_{xt}\left[\kappa e^{\phi g_{vt}} + \frac{Q_{vt}}{A_{xt}(1 + g_{vt})}\right]$$

taking aggregate variables and other firms' variables as given.

- The first order condition with respect to price is

$$p_{vt} = \frac{w_{xt}}{A_{xt}(1 + g_{vt})} \frac{\varepsilon_{vt}}{\varepsilon_{vt} - 1}$$

where  $\varepsilon_{vt}$  is the price elasticity of demand for variety  $v$ .

- The first order necessary with respect to technology is

$$-\phi \kappa e^{\phi g_{vt}} + \frac{Q_{vt}}{A_{xt}(1 + g_{vt})^2} \leq 0$$

- Income of households in the industrial sector per unit of time worked:

$$y_t^x = w_{xt}.$$

- Perfectly competitive.
- Inputs: labor, land, and intermediate industrial inputs.
- Farms are owned by absentee landlords, distributed uniformly around the unit circle, each owning one unit of land. A landlord's location on the unit circle corresponds to his ideal variety of the industrial intermediate input.
- Technology:

$$Q_{at} = A_{at} [\theta L_{at}^{\sigma} + (1 - \theta) (\sum_{v \in V_t} k_{vt})^{\sigma}]^{\frac{\rho}{\sigma}}$$

where  $0 < \theta \leq 1$ ,  $1 > \sigma \geq 0$  and  $0 < \rho \leq 1$ .

- Agricultural TFP,  $A_{at}$ , grows at an exogenous rate:

$$A_{at+1} = A_{at}(1 + g_{at}).$$

# Profit maximization of farms

- The profits of a farm are

$$\Pi_{at} = A_{at}[\theta L_{at}^\sigma + (1 - \theta)(\sum_{v \in V_t} k_{vt})^\sigma]^\frac{\rho}{\sigma} - w_{at}L_{at} - \sum_{v \in V_t} p_{vt}k_{vt}$$

- The standard first order conditions are

$$w_{at} = \rho\theta A_{at}[\theta L_{at}^\sigma + (1 - \theta)(\sum_{v \in V_t} k_{vt})^\sigma]^\frac{\rho}{\sigma}-1 (L_{at})^{\sigma-1} = \rho\theta Q_{at}^{1-\frac{\sigma}{\rho}} A_{at}^\frac{\sigma}{\rho} L_{at}^{\sigma-1}$$

$$p_{vt} = \rho(1 - \theta)A_{at}[\theta L_{at}^\sigma + (1 - \theta)(\sum_{v \in V_t} k_{vt})^\sigma]^\frac{\rho}{\sigma}-1 (\sum_{v \in V_t} k_{vt})^{\sigma-1}$$

- Profits per unit of time worked,  $\pi_{at}$ , are

$$\pi_{at} = (1 - \rho)\frac{Q_{at}}{L_{at}}$$

- Farm profits are taxed away and rebated to the farm households.
- Income per unit of time work is sum of wages per unit of time worked and profits per unit of time worked:

$$y_t^f = w_{at} + \pi_{at}$$

- The variety  $v'$  a landlord located at  $\tilde{v}$  uses is

$$v' = \operatorname{argmin}[p_{vt}(1 + d_{v,\tilde{v}}^\beta) | v \in V_t]$$

# Symmetric equilibrium

- As is standard in this literature, we only focus on symmetric Nash equilibria.
- In such an equilibrium, all firms use the same technology, charge the same price, and all industrial goods are equally spaced along the unit circle.

# Aggregate industrial demand in a symmetric equilibrium

- The distance between two neighboring varieties is  $d_t$ .
- Take a variety  $v$ . Denote by  $v_c$  the nearest competitors to the right and to the left.
- The household who is indifferent between buying varieties  $v$  and  $v_c$  is the one located at distance  $d_{vt}$  from  $v$ , where

$$p_{ct}[1 + (d_t - d_{vt})^\beta] = p_{vt}[1 + d_{vt}^\beta]$$

- Aggregate demand for variety  $v$  coming from households is

$$C_{vt}^f + C_{vt}^x = \frac{d_t \mu \alpha (y_t^f N_t^f + y_t^x N_t^x - N_t c_{\bar{a}})}{p_{vt}}$$

where  $d_t = 2d_{vt}$ .

# Aggregate industrial demand in a symmetric equilibrium

- Aggregate demand for variety  $v$  coming from farms:

$$K_{vt} = \frac{2d_{vt}(\rho(1-\theta))^{\frac{1}{1-\sigma}} [\mu(1-\alpha)(y_t^f N_t^f + y_t^x N_t^x - N_t c_{\bar{a}}) + N_t c_{\bar{a}}]^{\frac{\rho-\sigma}{\rho(1-\sigma)}} A^{\frac{\sigma}{\rho(1-\sigma)}}}{p_{vt}^{\frac{1}{1-\sigma}}}$$

- Aggregate demand for variety  $v$  is then the sum of  $C_{vt}^f$ ,  $C_{vt}^x$  and  $K_{vt}$ .
- The price elasticity of demand for variety  $v$  is:

$$\begin{aligned}\varepsilon_{vt} &= \frac{C_{vt}^f + C_{vt}^x + \frac{1}{1-\sigma} K_{vt}}{C_{vt}^f + C_{vt}^x + K_{vt}} - \frac{\partial d_{vt}}{\partial p_{vt}} \frac{p_{vt}}{d_{vt}} \\ &= \frac{C_{vt}^f + C_{vt}^x + \frac{1}{1-\sigma} K_{vt}}{C_{vt}^f + C_{vt}^x + K_{vt}} + \frac{1}{2\beta} \left(\frac{2}{d_t}\right)^\beta + \frac{1}{2\beta}\end{aligned}$$

# Symmetric static equilibrium

- Utility maximization of each household.
- Profit maximization of agricultural firms
- Profit maximization of industrial firms
- Market clearing: agricultural market, industrial goods markets, labor markets
- Zero profits of industrial firms: determines the number of industrial goods produced
- Utility equalization across sectors.

# Symmetric static equilibrium

- Price elasticity of demand depends positively on employment in the industrial sector. For  $\sigma = 0$ ,

$$\frac{\partial \varepsilon}{\partial N^x} = \frac{(2\mu/\kappa e^{\phi g_v})^\beta \beta (N^x)^{\beta-1}}{2\beta(\beta+1)\varepsilon^\beta - (2\beta+1)\beta\varepsilon^{\beta-1}} > 0$$

- Intuition: a larger industrial sector implies a greater number of varieties being produced. It is easy to see that this leads to a higher price elasticity of demand.
- Technological progress is a positive function of the price elasticity of demand. Combining the FONC for technology and the zero profit condition allows us to write:

$$g_{vt} = \frac{\varepsilon_{vt} - 1}{\phi} - 1$$

- Therefore, technological progress depends positively on the size of the industrial sector.

# Symmetric dynamic equilibrium

- Dynamic equilibrium is sequence of static equilibria.
- Periods are linked through:
  - Industrial technology at the end of period  $t$  becomes default industrial technology in period  $t + 1$ .
  - Agricultural TFP growth.
  - Demographics.

$$N_{t+1} = n_t^f N_t^f + n_t^x N_t^x$$

**Proposition 1.** *The economy converges to a balanced growth path with constant technological progress in industry provided that (i)*

*(ii)  $\frac{1-\mu}{\tau^f} - 1) \frac{(1-\alpha)(1-\gamma)}{\alpha+\gamma(1-\alpha)} \left(\frac{\tau^x}{\tau^f}\right)^{\frac{1-\mu}{\mu}} + \left(\frac{1-\mu}{\tau^x} - 1\right) = 0$ , (ii)  $g_{at} > 0$  for all  $t$ , and (iii)  $\theta$  is sufficiently close to 1,  $\rho$  is sufficiently close to 1, and  $\sigma = 0$ .*

**Proposition 2.** *Assuming  $\sigma = 0$ , technological progress in the balanced growth path is a positive function of population,  $N$ , and a negative function of the cost parameter of innovation,  $\phi$ .*

- Parameterize model and solve for dynamic equilibrium
- Calibrate to the experience of England between 1300 and 2000.
- Key observations of the Malthusian era targeted: (i) a more or less constant living standard, (ii) a constant population growth rate, and (iii) a huge share of agricultural employment in the economy.
- Key observations of the modern growth era targeted are: (i) a constant positive rate of growth of per capita GDP, and (ii) a tiny and constant agricultural share of employment.
- One period: 25 years (corresponding to adult life).

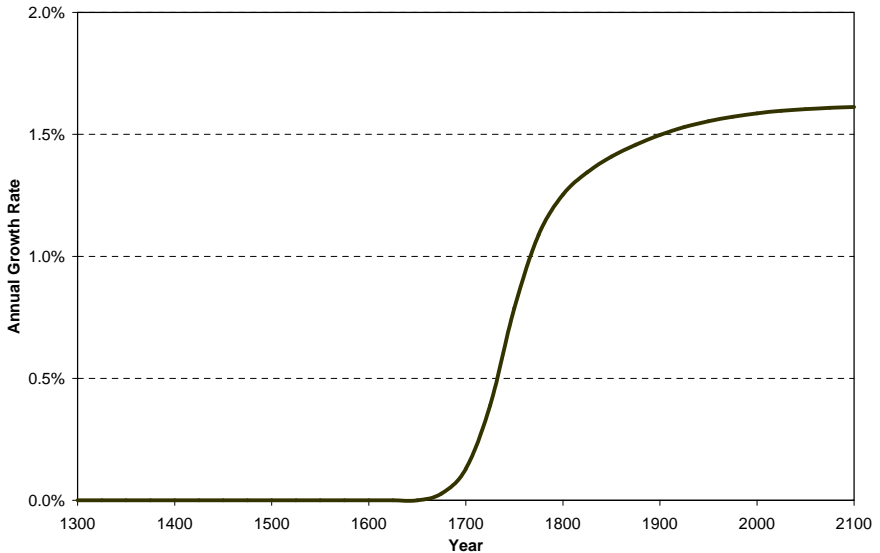
# Parameter values

1. Population	
$N_0 = 120$	start of industrial revolution in 1750
2. Industrial technology parameters	
$A_{x0} = 1$	normalization
$\kappa = 5.75$	20% of total labor input are non-production workers in limit
$\phi = 3.25$	limiting growth of per capita GDP equal to 1.5-2% per year
3. Agricultural technology parameters	
$A_{a0} = 2.91$	constant agriculture living standard in pre-1500 era
$\gamma_a = 0.005$	pre-1500 population growth rate of .025% per year
$\theta = 0.5$	intermediate good share in agriculture in 1750
$\rho = 0.8$	land share of agricultural output 20 percent
$\sigma = 0.82$	rapid structural transformation of English economy starting in 1750.
4. Preference parameters	
$c_{\bar{a}} = 0.5$	1250 agricultural share of employment of .80 as reported by Allen (2004)
$\alpha = 0.9$	2% share of agricultural employment in the limit (Mitchell, 1995)
$\mu = 0.92$	number of urban children close to 1 in limit
$\beta = 0.8$	between 15 and 25 percent mark-up in the limit
5. Child rearing parameters	
$\tau^f = 0.011$	zero population growth in the limit
$\tau^x = 0.946$	estimates between 7.5% and 15% per household (de la Croix et al., 2004)

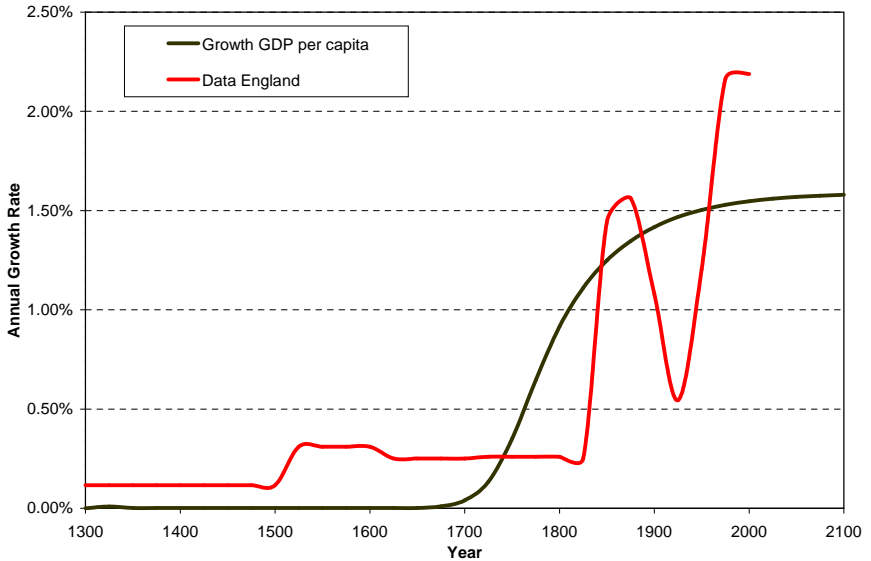
- **Malthusian era** with almost no growth. No endogenous technological change in industry. Slow population growth.
- **Industrial revolution** with accelerating growth. Sets into motion when industrial market becomes large enough, and elasticity big enough. Population growth leads to higher technological progress.
- **Modern economic growth** with growth rate leveling off as population growth converges to zero.

In addition: **structural transformation** and **demographic transition**

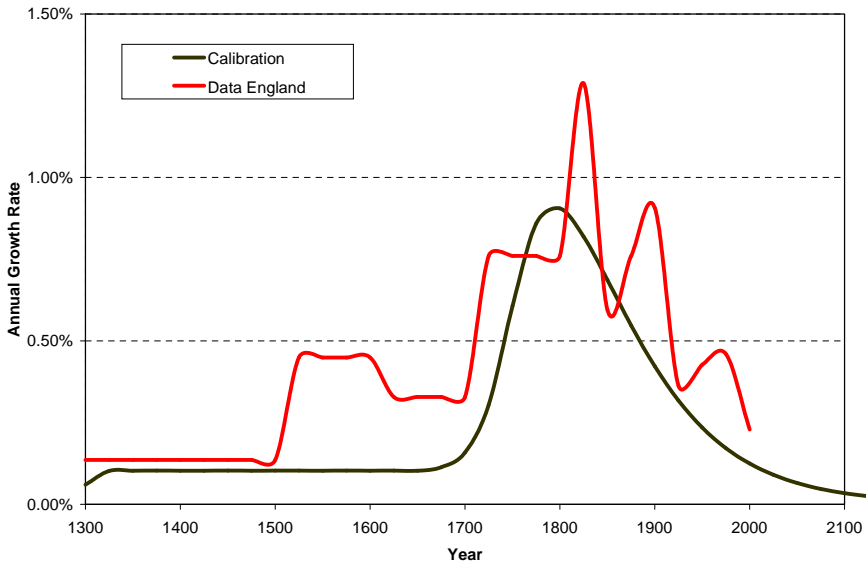
## Technological Progress Industry



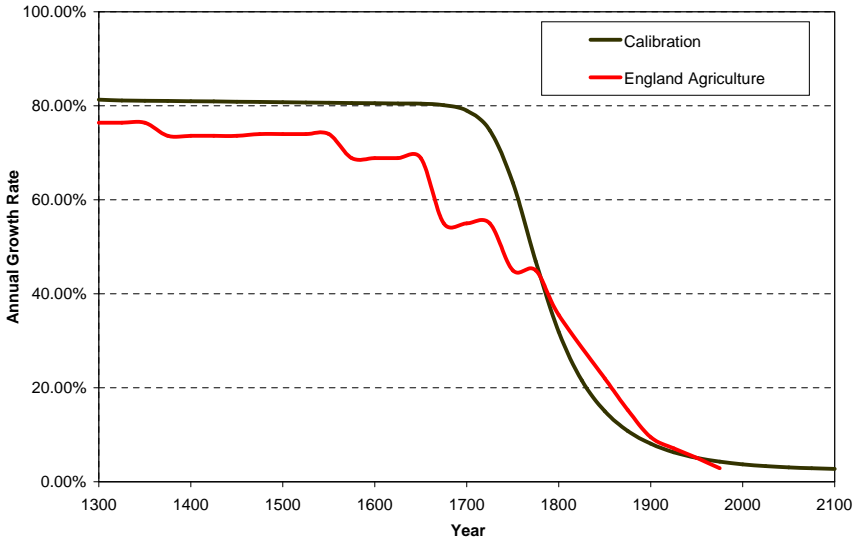
## Growth GDP per capita



# Population Growth



## Agricultural share



## Growth pattern: Malthusian phase

- Market is too small and elasticity too low for innovation to take off endogenously.
- However, there is some TFP growth in agriculture, and some population growth.

## Growth pattern: industrial revolution

- Once the market is large enough, and elasticity big enough, innovation takes off.
- Innovation leads to higher income.
- This, in turn, leads to higher population growth and an increasing share of the labor force employed in industry.
- As a result, the expansion of the industrial sector accelerates, and innovation speeds up.

## Growth pattern: modern growth

- Innovation and growth in GDP per capita levels off.
- Population growth converges to zero.

- **Structural transformation:** subsistence constraint.
- **Demographic transition:** composition effect because of differential fertility on the farm and in the city.

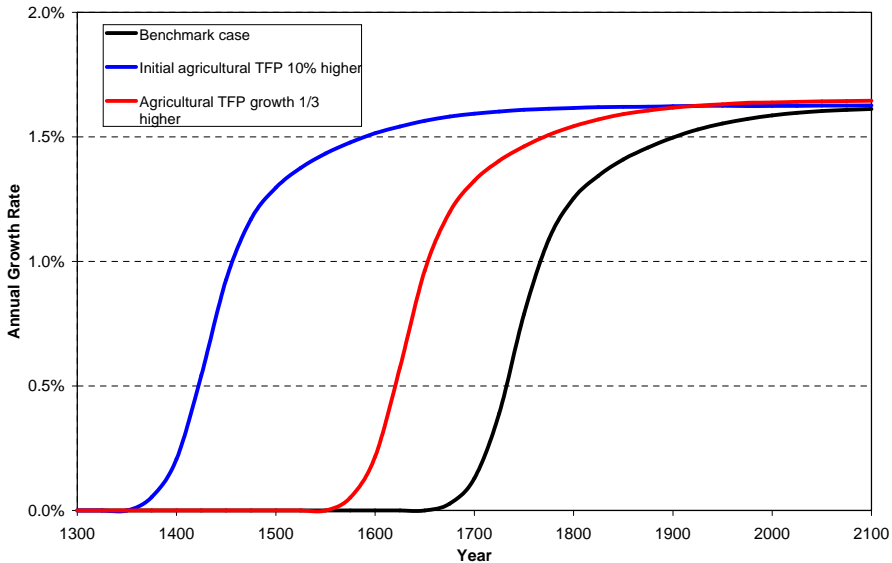
# Timing of industrial revolution

How does the timing of the industrial revolution depend on

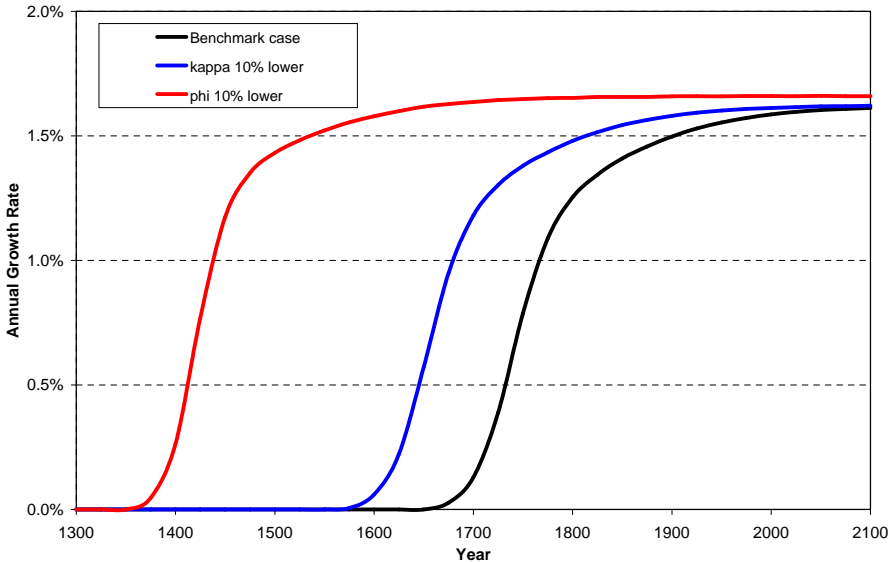
- Agricultural productivity?
- Population size?
- Institutions?

Greater population, higher agricultural productivity, and better institutions all HASTEN the industrial revolution. Each of these factors increases the elasticity of demand, and thus competition and innovation.

## Technological Progress Industry



## Technological Progress Industry



- This paper has put forth a simple model of the transition of an economy from a Malthusian era of roughly constant living standards to a modern growth era.
- The key for the start of an industrial revolution is the increase in market size that occurs in the Malthusian phase from rising population.
- Novelty is the mechanism (link between market size, elasticity of demand, and innovation), and not the list of factors that affect the timing.