Why England First?
The End of Resistance and the Start of the Revolution*

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Abstract

This paper puts forth a theory for why the Industrial Revolution happened first in England sometime in the 18th century, which according to Mokyr (2005) coincides with a significant decline in the resistance to the adoption of more productive technology by coalitions of factor suppliers. Our theory attributes the end of this resistance and the start of the revolution to a number of factors, the most important of which include improvements in institutions, more open trade, a more comprehensive system of roads and canals, technological change in agriculture, and even population growth. While diverse, each of these factors in the end affected the size of the markets, and brought about stiffer competition for manufactured goods. As markets grew and competition stiffened, goods became more substitutable, thereby increasing the price elasticity of demand for goods. This was critical for ending resistance, as it meant that adopting firms could more easily compensate workers for any losses they suffered. We illustrate our theory in a model of development and growth whereby resistance to technological change by factor suppliers specialized with respect to the current technology eventually ends, and when it does, an industrial revolution begins. Additionally, we provide empirical support for our theory by comparing market size in England and other countries before and during this time.
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1 Introduction

This paper puts forth a theory for why the Industrial Revolution happened first in England sometime in the 18th century, which according to Mokyr (2005) coincides with a significant decline in the resistance to the adoption of more productive technology by coalitions of factor suppliers. Our theory attributes the end of this resistance and the start of the revolution to a number of factors, the most important of which include improvements in institutions, more open trade, a more comprehensive system of roads and canals, technological change in agriculture, and even population growth. While diverse, each of these factors in the end affected the size of the markets and brought about stiffer competition for manufactured goods. As markets grew and competition stiffened, goods became more substitutable, thereby increasing their price elasticity of demand. This was critical for ending resistance for two reasons. First, a firm that was faced with a more elastic demand experienced a larger percentage increase in its revenues when it lowered its price following the introduction of a more productive technology. Second, a more elastic demand led to larger firms in equilibrium. Both channels allowed a firm to more easily cover the costs of introducing the technology, including the cost associated with compensating specialized groups of factor suppliers to the existing technology who stand to lose from the introduction of the better technology.

We illustrate our theory in a model of development and growth whereby resistance to technological change by factor suppliers specialized with respect to the current technology eventually ends, and when it does, an industrial revolution begins. Additionally, we provide empirical support for our theory by comparing market size in England and other countries before and during this time. The key building block to our model is Lancaster (1979)'s ideal variety preference construct that is in turn based on Hotelling's (1929) model of horizontal differentiation. With Hotelling Lancaster's preferences, each household has an ideal variety that corresponds to his location on the unit circle. As shown by Helpman and Krugman (1985) and later by Hummels and Lugovskky (2005), the price elasticity of demand of each differentiated good increases with the number of people that work in the industrial sector as well as the cost of entering an industry. Desmet and Parente (2007) exploit this feature and show in a one period model how a greater elasticity of demand due to either a larger domestic population or to lower trade costs facilitates innovation.

In this paper, we introduce dynamics into the model of Desmet and Parente (2007) and extend it so as to allow for structural change and resistance by industrial workers. We also extend household preferences over the number of children and in this way allow for population change. Additionally, we introduce a subsistence agriculture constraint as in Galor and Weil (2000). The model generates a pattern of development that accords well with economic history. In particular, it generates an initial period whereby industrial workers resist the adoption of more productive technology and the industrial sector experiences no technological change. As the population increases endogenously, the number of industrial goods, firm size, and the price elasticity of demand of these goods all increase. Eventually, the population reaches a sufficiently large size so that workers allow a better technology to be introduced. This is the start of the Industrial Revolution. Growth during the industrial revolution can be slow on account that the next generation of workers may find it optimal to resist the next better technology that comes along. At some point, the population will increase to a high enough level so that this technology is also introduced. Eventually, the population is sufficiently high that industrial workers in each period never block the introduction of more productive technologies. This corresponds to the modern growth era, with constant and higher growth. The model can also generate a type of demographic transition.

Within this structure we examine the effects of better institutions in the sense of lower entry costs, and higher productivity growth in agriculture for the start of the industrial revolution.[1] We find that better institutions are a good substitute for population size, so that an economy need not have as many people in the economy to industrialize.

[1] We do not explicitly consider the effect of having a more developed transportation system or more open trade because to do so would make the notation unbearable. Lower trade costs, which are analyzed by Desmet and Parente (2007) in the context of a static model of technological change, would similarly hasten the start of the industrial revolution.

Interestingly. we find that a country with better institutions may actually have a smaller total and industrial sector work force over time. We also show that faster agricultural productivity growth hastens the start of the industrial revolution, by facilitating population growth, especially in the urban areas. Moreover, our experiments highlight that agricultural TFP growth is ever the more important in the light of land being a fixed factor of production there. The implication of these findings is that a country with both bad institutions and slow growth in agriculture may never develop.

Clearly, the novelty of our theory is not in the list of factors we identify as being important for the timing and location of the first Industrial Revolution. These factors have been emphasized by various authors before us. Rather, the novelty lies in the mechanism by which each of these factors lead to the end of resistance to technological change by industrial workers, and the introduction of better technology. For instance, one branch of research championed by Douglas North (19XX) and others emphasizes the development of British institutions, with its stronger protection of property rights and enforcement of contracts. Another branch of research championed by Jeffrey Williams and Kevin O'Rourke (2007) emphasizes that fewer international trade barriers as the catalyst for England's Industrial Revolution. Another branch that goes back to Schultz (1953) and more recently emphasized by Diamond (1997) identifies the role of agriculture and the need to generate an agricultural surplus.

Market size has been emphasized as being critical to England's success by other authors as well, but the underlying mechanism is different from ours. Adam Smith (1776) hypothesized that larger markets were important to the Industrial Revolution because it allowed for specialization. Smith's hypothesis has been very recently championed by Szostak (2001), who provides an excellent comparison of transporation systems and travel costs for England and France in the 18th century. Berrill (1960) and Voth (2003) also emphasize market size but they focus on income elasticities of demand rather than price elasticities of demand. More specifically, in their theories market size is not only a function of the number of potential customers, but also of per capita income. Per capita income matters because consumers that are too poor are unable to demand manufactured goods. Manufactured goods, according to Berrill (1960), are critical to the industrialization process because these are the goods that can be mass-produced.

With the exception of Mokyr (1990, 2004, and 2005) and Olsen (1982), none of these other theories emphasizes the role of resistance. Mokyr's theory (2005) for why resistance broke down in the 18th century is very different from ours. His theory is that the English citizenry blocked technological change because they held the erroneous view that technological change was a zero sum game. According to Mokyr, it took a group of "enlightened" individuals to change was this misperception. In contrast, our theory implies that resistance was in the best interest of industrial groups. Olsen's theory (1982) is more similar to ours. He emphasizes the importance of market size increases for the cost of organizing and maintaining interest groups.

Clearly, it is not possible to review all the theories put forth for why the Industrial Revolution first happened in England. Narrative approaches primarily within the field of economic history abound. Pomeranz (2000) emphasizes the role of natural resource, particularly, coal and the American colonies as being critical to breaking from a Malthusian trap. Clark (2007) following the ideas of Galor and Moav (2002) takes an evolutionary approach arguing that the greater fertility among the top parts of the income distribution in England created a society with a conducive attitudes towards literacy, thrift and hard work. Voigtlander and Voth (2006) claim a combination of luck, fertility regimes and capital externalities are all part of the story.Legros, Newman and Proto (2007) emphasize the distribution of wealth. Other works that put forth models that generate a Malthusian period of stagnation, followed by a period of higher and more regular technological change include Goodfriend and McDermott (1995), Galor and Weil (200), Hansen and Prescott (2001), and Lucas (2001).

The paper is organized as follows. Section 2 describes the model and the equilibrium conditions. Section 3 presents the results from a number of numerical exercises. Section 4 then provides empirical support for the theory. In particular, it provides evidence that England's markets were more integrated than any other country in the world at that time. Section 5 concludes the paper.

2 The Model

In this section we describe the underlying structure of our model economy. Time is discrete and infinite. There are three sectors: a household sector, an agricultural sector and an industrial sector. The agricultural sector is competitive and produces a homogenous good using land and labor inputs. Technological change is exogenous there. Agricultural firms are located in the rural regions.

The industrial sector is monopolistically competitive and produces a continuum of differentiated products, each with an address on the unit circle. Production of each differentiated good requires only labor as its input. There is a fixed cost to producing a differentiated product that takes the form of labor. Technological change is not exogenous. Each period, the industrial sector can choose to innovate over the previous period's technology. However, this requires the permission of the households who work in the industrial sector. Industrial firms are located in the urban region.

Each agent lives for two periods. An agent spends the first period of his life as a child, in his parent's care. As a child, the agent makes no decisions. The second period of an agent's life consists of adulthood. At the beginning of his adult life, an agent's residence is determined by the work task of his parent. A child born to an industrial worker begins his adult life in the urban area whereas a child born to an agricultural worker begins his life as a resident of the rural area.

There are two sub-periods to an adult's life. In each sub-period, an adult is endowed with one unit of time.[2] The preference of an adult in each of the sub-periods is defined over consumption of the agricultural good, consumption of the industrial goods, and the number of children. Adults are not allowed to change residence in the first sub-period, but possibly can in the second.

The number of varieties of industrial goods for the economy is determined in the first sub-period. Adults who start out residing in the rural regions make up the supply of agricultural workers whereas adults who start out residing in the city, make up the

[2] The sub-period feature of this model is added in order to define in a meaningful way an equilibrium with process innovation. Additionally, it makes the idea of specialization more natural.

supply of industrial workers. Free entry into the industrial sector determines the number of varieties that are produced.

The second sub-period is when process innovations occur. The number of varieties is determined in the first sub-period, and these firms choose whether to upgrade the technology in their industry. Technological upgrading is costly to the firm in that there is a higher fixed cost to operating the more productive technology. Additionally, the set of workers who worked in a given industry must grant their permission to let their firm upgrade. Workers are not specialized in the new technology, so a firm can hire workers who spent their first sub-period as agricultural workers. To prevent its workers from resisting, a firm can pay a certain fraction of profits from the upgrading to compensate its original workers for any losses in wages. If the initial set of workers chooses resistance, there is no process innovation, and the firm's workforce is the same between sub-periods. If the initial set of workers in a given industry chooses not to resist, then there is process innovation and the firm's workforce consists of the original workers and adults hired from the agricultural sector. In this way, there is migration.

2.1 Household Sector

Individuals

At the beginning of date t there is measure N_t adults alive, with measure N_t^R living in the rural area and measure N_t^U living in the urban area. Each measure is uniformly distributed around the unit circle. There are two sub-periods to each adult's life. We denote the first sub-period of an adult's life by the letter $s = 1, 2$.

Preferences

The preferences of an adult are the same in each sub-period. There is a subsistence level of consumption of the agricultural good. Above this subsistence level, $\bar{a} \geq 0$, the utility of an adult depends on the number of children he has, n_{st}, the quantity of the agricultural good consumed, a_{st}, and the amount and variety of the industrial good consumed, $c_{st}(v)$, where v indexes the variety of the industrial good belonging to the set V. In terms of the industrial goods, each agent has an ideal variety which corresponds to the agent's location on the unit circle. The farther away a particular variety of the industrial good, v, lies from an agent's ideal variety, $\tilde{v}$, the lower the utility derived from a unit of consumption of variety, v. Let $d_{v\tilde{v}}$ denote the shortest arc distance between variety v and the agent's ideal variety $\tilde{v}$. The utility of an adult residing in region $j = R, U$ in sub-period $s = 1, 2$ located at point $\tilde{v}$ on the unit circle for which the subsistence constraint is not binding is

$$Utility = [(a_{st}^j)^{1-\alpha}[g(c_{st}^j(v)|v \in V)]^{\alpha}]^{\gamma}(n_{st}^j)^{1-\gamma} \tag{1}$$

where

$$g(c_{st}^j(v)|v \in V) = \max_{v \in V}[\frac{c_{st}^j(v)}{1 + d_{v,\tilde{v}}^{\beta}}] \tag{2}$$

Endowments

In each sub-period, an adult is endowed with one unit of time. Additionally, each adult is also endowed with an equal claim to profits of the agricultural sector and profits of the industrial sector, should there be any.

Demographics and Mobility

There is a cost of rearing children measured in terms of the agricultural good. This cost differs across regions and possibly across time, but not across sub-periods. Let τ_t^j denote the units of agricultural output needed to raise a child in period t in region $j = U, R$. Children born in the first sub-period are no different from children born in the second sub-period.

In the first sub-period, adults living in the rural area are farm workers, while those living in the urban area are industrial workers. To simplify the analysis, we assume that adults who begin the period in the urban region cannot migrate from the city to the country to become farm workers in the second sub-period. Rural adults may work in the city in the second sub-period depending on whether industry insiders do or do not resist technological change there. In the case some do, they are viewed as temporary or transitional workers, and so their residence does not change. Thus, the rural child rearing cost τ_t^R still applies in the second sub-period of their life.

The measure of adults in period $t+1$ living in the rural area and the urban area depends on the working status of their parents. Children of urban adults start their adult life in the urban sector. Children of adults who worked both sub-periods in the rural sector belong to next period's rural adult population. The children from both sub-periods of a temporary worker, i.e., an adult who in the first sub-period works as a farmer and in the second subperiod works in industry, are assumed to begin their adult life in the urban area. We postpone a statement of the law of motions for N_{t+1}^U and N_{t+1}^R until later in the paper.

2.2 Farming Sector

The farming sector is perfectly competitive. Agricultural goods are produced with a constant returns to scale technology, where labor and land are the inputs. The economy's endowment of land is fixed and normalized to one. For analytical and notational convenience, we assume that farms own the land. Let Q_{st}^f denote the quantity of agricultural output and let L_{st}^f denote the corresponding agricultural labor input in sub-period $s = 1, 2$ of period t. Then

$$Q_{st}^f = A_{st}^f (L_{st}^f)^\theta \tag{3}$$

where A_{st}^f is agricultural TFP, which grows exogenously at $\gamma_a \geq 0$ between periods (but not sub-periods).

2.3 Industrial Sector

In each period and sub-period, each differentiated good can be produced by an increasing returns to scale technology that uses labor as its only input. The increasing returns to scale technology is a consequence of a fixed cost of production, κ, measured in units of labor.

There is a ladder to technologies that can be used to produce any differentiated good. Each ladder differs in the marginal product of labor as well as the fixed cost of production. In the first sub-period, the marginal cost of producing and the fixed cost of producing any differentiated good is just the one that existed in the second sub-period of the previous period. We let κ_{st} denote the fixed labor cost in sub-period $s = 1, 2$ of period t, and we let A^x_{st} denote the marginal product in sub-period $s = 1, 2$ of period t.

In the first sub-period, there is no process innovation, and hence the fixed cost and marginal cost are those that existed in the second sub-period of period $t - 1$. More specifically,

$$A^x_{1t} = A^x_{2t-1} \tag{4}$$

and

$$\kappa_{1t} = \kappa_{2t-1} \tag{5}$$

In the second sub-period, it is possible for any industry that exists in the first period to innovate and go to the next rung on the technology ladder. The factor difference in the marginal product between successive rungs on the technology ladder is $1+\gamma_X$ and the factor difference in the fixed cost between successive rungs on the ladder is $1 + \gamma_\kappa$. Thus,

$$A^x_{2t} = \begin{cases} A^x_{1t} & \text{if no adoption occurs} \\ (1+\gamma_x)A^x_{1t} & \text{if adoption occurs} \end{cases}$$

and

$$\kappa_{2t} = \begin{cases} \kappa_{1t} & \text{if no adoption occurs} \\ (1+\gamma_\kappa)\kappa_{1t} & \text{if adoption occurs} \end{cases}$$

Having introduced this notation, we can specify the production technology for a given differentiated product in sub-period $s = 1, 2$ of period t. More specifically, the output of a given industry $v \in V$ in sub-period $s = 1, 2$ of period t denoted by $Q^x_{st}(v)$ is

$$Q^x_{st}(v) = A^x_{1t}[L^x_{st}(v) - \kappa_{st}] \tag{6}$$

where $L^x_{st}(v)$ is the labor input.

2.4 Household Demand

We start by deriving the individual demand for an agent of type $j \in U, R$ with ideal variety located at point $\tilde{v}$ on the unit circle. To simplify the analysis, we assume that the adult household is myopic with respect to the first-period and second-period. Having a dynamic adult would not change any of the qualitative results. In each sub-period, an adult household has three sources of income: labor income, profits of firms, and land rental income. Let W_{st}^{j} denote the income of a $j = U, R$ type in sub-period $s = 1, 2$. The budget constraint faced by an agent of type i is given by:

$$W_{st}^{j} = a_{st}^{j} + \int_{v \in V} p_{st}(v) c_{st}^{j}(v) dv + n_{st}^{j} \tau_t \tag{7}$$

where the price of agricultural goods has been normalized to 1.

Maximizing (1) subject to (7) gives us:

$$a_{st}^{j} = (1-\alpha)\phi W_{st}^{j} \tag{8}$$

$$\int_{v \in V} p_{st}(v) c_{st}^{j}(v) dv = \alpha\phi W_{t}^{j} \tag{9}$$

$$n_{st}^{j} \tau_t^{j} = (1-\phi) W_{t}^{j} \tag{10}$$

in the case the subsistence constraint is not binding. In the case that the subsistence constraint is binding, then

$$a_{st}^{j} = \bar{a} \tag{11}$$

$$\int_{v \in V} p_{st}(v) c_{st}^{j}(v) dv = \alpha\phi (W_{t}^{j} - \bar{a})/[1-\phi+\alpha\phi] \tag{12}$$

$$n_{st}^{j} \tau_t^{j} = (1-\phi)(W_{t}^{j} - \bar{a})/[1-\phi+\alpha\phi] \tag{13}$$

We make assumptions on the values of TFP in agriculture and industry so as to ensure that $W_{t}^{j} > \bar{a}$ for $j = U, R$ and all $t \geq 0$. The sub-utility function given by equation (2) implies that each individual buys only one differentiated good. As such, the quantity of the variety v' purchased by an agent of type j satisfies

$$c_{st}^{j}(v) = \frac{\alpha\phi W_{t}^{j}}{p_{st}(v)} \tag{14}$$

in the case where the constraint is not binding, and

$$c_{st}^{j}(v) = \frac{\alpha\phi}{1-\phi+\alpha\phi}\frac{W_t{}^{j}-\bar{a}}{p_{st}(v)} \tag{15}$$

in the case it is binding. The variety v' that an agent of type j located at $\tilde{v}$ on the unit circle buys is the one that minimizes the cost of an equivalent unit of the agent's ideal variety, which is $p_{st}(v)(1+d_{v\tilde{v}}^{\beta})$. Thus, the variety v' that the agent of type j located at $\tilde{v}$ on the unit circle buys is

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

In a symmetric equilibrium, aggregate demand is readily determined. Denote by d_{st} the distance between two neighboring varieties in period t, and by $p_{st}(v)$ the price of any variety v. In that case, a fraction d_t of agents consume each variety. Let N_t^R be the mass of rural adults and N_t^U the mass of urban adults. Provided that each measure of each adult type is uniformly distributed around the unit circle and provided that the subsistence constraint is not binding, the aggregate demand for a given variety v is then:

$$Q_{st}^{x}(v) = \frac{d_t\alpha\phi[N_t^R\ W_{st}^R\ + N_t^U\ W_{st}^U\ ]}{p_{st}(v)} \tag{16}$$

2.5 Agricultural supply

If L_{st}^{f} is the labor input in the agricultural sector, then the first order condition of profit maximization implies that the agricultural wage rate is

$$w_{st}^{f} = \theta A_{st}^{f}(L_{st}^{f})^{\theta-1} \tag{17}$$

As farms own the land, the profits of the agricultural sector are

$$\Pi_{st}^{f} = (1-\theta)Q_{st}^{f} \tag{18}$$

Let π_{st}^{f} denote profits of the farming sector per adult in the economy in sub-period s of period t, i.e., $\pi_{st}^{f} = \Pi_{st}^{f}/N_t$.

2.6 Symmetric Equilibrium in Sub-Period 1: Product Innovation

In the first sub-period, firms are not able to adopt the next rung of the technology ladder. The rung is determined in the second sub-period of period $t-1$. In light of this, the decision of a firm in the first sub-period consists of the price to charge, and the quantities of output and labor input. More specifically, an industrial firm's profit maximization problem consists in choosing $p_{st}(v)$, $Q^x_{st}(v)$, and $L^x_{st}(v)$ to maximize

$$p_{st}(v)Q^x_{st}(v) - w^x_{st}L^x_{st}(v)$$

subject to the variety's demand (16) and the production technology (6), where $A^x_{1t} = A^x_{2t-1}$. As in the standard monopoly problem, the profit maximizing price is a mark-up over the marginal unit cost of production w^x_{st}/A^x_{st}, namely

$$p_{1t}(v) = \frac{w^x_{1t}\ \varepsilon_{1t}}{A^x_{1t}(\varepsilon_{1t}-1)} \tag{19}$$

In the above equation, ε_t is the price elasticity of demand for variety v, namely,

$$\varepsilon = -\frac{\partial q_v}{\partial p_v}\frac{p_v}{q_v}$$

Following the same procedure as in Hummels et al., it is easily shown that in a symmetric equilibrium:

$$\varepsilon = 1 + \frac{1}{2\beta}(\frac{2}{d})^{\beta} + \frac{1}{2\beta} \tag{20}$$

Free entry and exit gives us a zero profit condition. A firm's profit can be written as $p_{st}Q_{st} - w^x_t(\kappa_{st} + Q_{st}/A_{st})$. The zero-profit condition is therefore

$$Q^x_{st}(v) = \kappa_{st}A^x_{1t}(\varepsilon_{st}-1) \tag{21}$$

Each firm therefore employs $L^x_{1t} = \kappa_{1t}\varepsilon_{1t}$. The labor market clearing condition in the industrial sector is

$$m_tL^x_{1t} = N^U_t \tag{22}$$

where m_t is the number of firms or varieties and satisfies $d_t = 1/m_t$.

As there are no profits in the industrial sector in the first sub-period, the wealth of each adult is the sum of their wages plus the sum of their rental income. Namely,

$$W_{1t}^U = \pi_{1t}^f + w_{1t}^x \tag{23}$$

and

$$W_{1t}^R = \pi_{1t}^f + w_{1t}^f \tag{24}$$

Total wage payments of industrial workers must be equal to total spending on industrial goods. This gives us:

$$m_t w_{1t}^x L_{1t}^x = \alpha\phi[(w_{1t}^f + \pi_{1t}^f - \bar{a})N_t^R + (w_{1t}^x + \pi_{1t}^f - \bar{a})N_t^U] \tag{25}$$

We are now ready to define the *Symmetric Equilibrium in the product innovation phase.*

Definition 1 *A* Symmetric Equilibrium in the Product innovation phase (sub-period 1) *is a collection of rural and urban household adult choices* $(n_{1t}^i, a_{1t}^i, c_{1t}^i)$*, a vector of wage rates* (w_{1t}^f, w_{1t}^X)*, a vector of agricultural firm choices* $(Q_{1t}^f, L_{1t}^x, \pi_{1t}^f)$*, and a vector of industrial firm choices* $(p_{1t}, \varepsilon_{1t}, Q_{1t}^x, L_{1t}^x)$*, together with a number of industries and distances between industries* (d_t, m_t)*, that satisfies*

1. *(rural household demand for agricultural consumption)*
$$a_{1t}^R = \begin{cases} (1-\alpha)\phi(w_{1t}^f + \pi_{1t}^f) & \textit{else} \\ \bar{a} & \textit{if } \bar{a} > (1-\alpha)\phi(w_{1t}^f + \pi_{1t}^f) \end{cases}$$
2. *(urban household demand for agricultural consumption)*
$$a_{1t}^U = \begin{cases} (1-\alpha)\phi(w_{1t}^x + \pi_{1t}^f) & \textit{else} \\ \bar{a} & \textit{if } \bar{a} > (1-\alpha)\phi(w_{1t}^x + \pi_{1t}^f) \end{cases}$$
3. *(rural household demand for industrial good)*
$$p_{1t}c_{1t}^R = \begin{cases} \alpha\phi(w_{1t}^f + \pi_{1t}^f) & \textit{else} \\ \alpha\phi(w_{1t}^f + \pi_{1t}^f - \bar{a})/[1-\phi+\alpha\phi] & \textit{if } \bar{a} > (1-\alpha)\phi(w_{1t}^f + \pi_{1t}^f) \end{cases}$$
4. *(urban household demand for industrial good)*
$$p_{1t}c_{1t}^U = \begin{cases} \alpha\phi(w_{1t}^x + \pi_{1t}^f) & \textit{else} \\ \alpha\phi(w_{1t}^x + \pi_{1t}^f - \bar{a})/[1-\phi+\alpha\phi] & \textit{if } \bar{a} > (1-\alpha)\phi(w_{1t}^x + \pi_{1t}^f) \end{cases}$$

5. *(rural household demand for children)*

$$n_{st}^R \tau_t^R = \begin{cases} (1-\phi)[\, w_{1t}^f + \pi_{1t}^f] & else \\ (1-\phi)(\, w_{1t}^f + \pi_{1t}^f - \bar{a})/[1-\phi+\alpha\phi] & if\ \bar{a} > (1-\alpha)\phi(\, w_{1t}^f + \pi_{1t}^f) \end{cases}$$

6. *(urban household demand for children)*

$$n_{st}^U \tau_t^U = \begin{cases} (1-\phi)[\, w_{1t}^x + \pi_{1t}^f] & else \\ (1-\phi)(\, w_{1t}^x + \pi_{1t}^f - \bar{a})/[1-\phi+\alpha\phi] & if\ \bar{a} > (1-\alpha)\phi(\, w_{1t}^x + \pi_{1t}^f) \end{cases}$$

7. $N_t^R = L_{1t}^f$ *(Farming labor market clears)*

8. $N_t^U = L_{1t}^x$ *(Industrial labor market clears)*

9. $N_{1t}^R(a_{1t}^R + n_{1t}^R \tau_t^R) + N_{1t}^U(a_{1t}^U + n_{1t}^U \tau_t^U\ ) = Q_{1t}^f$ *(Farming Good market clears)*

10. $w_{1t}^f = \theta A_{1t}^f (L_{1t}^f)^{\theta-1}$ *(profit maximization of farms)*

11. $\pi_{1t}^f = (1-\theta) Q_{1t}^f / N_t$ *(profit of farms)*

12. $\varepsilon_{1t} = 1 + \frac{1}{2\beta}(\frac{2}{d_t})^\beta + \frac{1}{2\beta}$ *(definition of elasticity)*

13. $p_{1t} = \frac{w_{1tt}^x \varepsilon_{at}}{A_{1t}^x(\varepsilon_{1t}-1)}$ *(profit maximization of industrial firm)*

14. $Q_{1t}^x = \kappa_{1t} A_{1t}^x (\varepsilon_{1t} - 1)$ *(zero profit condition)*

15. $Q_{1t}^x = \frac{d_t \alpha\phi[N_t^R\ (w_{st}^f + \pi_{1t}^A)\ + N_t^U\ (w_{st}^x + \pi_{1t}^A)\ ]}{p_{st}}$ *(demand for variety v in the case that the subsistence constraint does not bind for both types)*

16. $Q_{1t}^x = A_{1t}^x (L_{1t}^x - \kappa_{1t})$ *(supply of variety v)*

2.7 Symmetric Equilibrium in Sub-Period 2

In the second sub-period established industries from the first sub-period decide whether to switch to the next rung on the technology frontier. Each industry can do so, but it first needs the permission of the adults who worked in their industry in the first sub-period. Define I_{2t} to be the industry insiders, i.e., number of adults who worked in a particular industry in the first sub-period. Namely,

$$I_{2t} = L_{1t}^x$$

A firm/industry that switches technologies is able to hire workers who previously worked in agriculture. As there is no product innovation in this sub-period, the set of varieties and the distance between firms is fixed. Also, there is the potential for an innovating industry to earn profits. Denote these total industry profits by Π_{2t}^{X} and per capita profits as $\pi_{2t}^{X} = \Pi_{2t}^{X}/N_t$. An industry cannot go to the next technology rung without its insiders' permission. We assume that an innovating industry can use $0 < \lambda < 1$ of its profits from adopting to compensate union members. The remaining fraction $(1 - \lambda)$ of these profits are evenly distributed to the entire adult population.

Two types of symmetric equilibria are possible in the second sub-period. In the first type there is no technological upgrading. In the second, all industries upgrade their technologies by a factor $(1 + \gamma_X)$. We refer to this first type of equilibrium as a *Symmetric Equilibrium without (process) Adoption (SENA)* and the second type as a *Symmetric Equilibrium with Adoption (SEA).* We first study the *Symmetric Equilibrium without Adoption* as it is the simpler of the two to analyze.

2.7.1 Symmetric Equilibrium without Adoption (SENA)

Without innovation, the allocations and prices associated with the *SENA* are exactly the ones that correspond to the first sub-period equilibrium. The conditions in the definition of the symmetric equilibrium for sub-period 1 are thus necessary conditions for the *SENA*. There is one additional condition that the prices and allocations must satisfy, however. Namely, it must be the case that the union of any single industry would not find it optimal to have their industry innovate. Denote with an asterisk the prices and allocations that satisfy equilibrium conditions (1)-(13) above. (These are just the first sub-period symmetric equilibrium allocations and prices.) Then a necessary condition for a given industry not to deviate is that its earnings under innovation are lower than under resistance, namely,

$$w_{2t}^{f*} + \lambda \frac{\Pi_{2t}^{X*}}{I_{2t}} \leq w_{2t}^{x*}$$

Profits of a deviating industry, Π_{2t}^{X*}, are obtained as follows, :

$$\begin{aligned} \arg \max_{d',\varepsilon,p_{st},Q_{st}} \quad & \{p'Q' - w_{2t}^{f*}[Q'/[A_{1t}^{x}(1+\gamma_X)] + \kappa_{1t}(1+\gamma_\kappa)]\} \\ \text{s.t.} \quad & Q' = \frac{2d'\alpha\phi[(w_{2t}^{f*} + \pi_{2t}^{f*})N_t^R + (w_{2t}^{x*} + \pi_{2t}^{f*})N_t^U]}{p\prime} \\ & p_{2t}^*[1 + (d_{2t}^* - d')^\beta] = p'[1 + d'^\beta] \\ & \varepsilon' = 1 + \frac{(1 + d'^\beta)p_v'}{[p_{2t}^*\beta(d_{2t}^* - d')^{\beta-1} + p'\beta d'^{\beta-1}]d'} \end{aligned} \tag{26}$$

The first constraint is just the aggregate demand for the deviating firm's good in the case where the agricultural constraint is not binding for either type of household. In the case that it was binding for the rural household, the term $(w_{2t}^{f*} + \pi_{2t}^{f*})$ is replaced by the expression $(w_{1t}^f + \pi_{1t}^f - \bar{a})/[1 - \phi + \alpha\phi]$, and in the case the subsistence constraint is binding for the urban household the term $(w_{2t}^{x*} + \pi_{2t}^{f*})$ is replaced by the expression $(w_{1t}^s + \pi_{1t}^f - \bar{a})/[1 - \phi + \alpha\phi]$. The second constraint identifies the consumer that is indifferent between buying from the deviating firm at price p' and its nearest competitor located either to its left or right on the unit circle. The last constraint gives the relation between elasticity for the firm's product and its choices of price. It is important to note that d' gives the location of the consumer who is just indifferent between buying the deviating firm's product and its nearest competitor whereas d is the distance between the deviating firm and its nearest competitor. Because firms are evenly spaced, the deviating firm has a competitor to his left and to his right. For this reason, the deviating firm captures $2d'$ of each type of consumers.

2.7.2 Symmetric Equilibrium with Adoption (SEA)

In a *Symmetric Equilibrium with Adoption* all firms in the industrial sector innovate and use the technology that is $(1 + \gamma_X)$ times more productive than the technology used in the first sub-period. Additionally, the technology has a fixed cost that is $(1 + \gamma_\kappa)$ higher than the technology used in the previous period.

Again, since there is no product innovation in the period, there is the possibility of positive profits in the *SEA*. Consistent with the previous section, we assume that each industry's union is entitled to a fraction λ of these profits, the payment for their consent for innovating, and that industries can employ any adult at the competitive wage rate. The remainder of the profits are distributed evenly to every adult agent in the population. Since there are m_t industries, then each individual receives $m_t(1-\lambda)\pi_{2t}^X$ in income from the industrial sector in the symmetric equilibrium.

Because of the assumption that the cost of rearing a child is determined by an adult's residence in the first-sub-period, the wage paid to industrial workers and agricultural workers is the same in such an equilibrium. Hence, the income, fertility choices, and consumption choices are the same for all N_t^R adults and likewise for all N_t^U adults.

An insider's income (who is a $j = U$ adult) in a *SEA* is

$$w_{2t} + \lambda \frac{\Pi_{2t}^X}{I_{2t}} + \pi_{2t}^f + m_t(1-\lambda)\pi_{2t}^X$$

and a non-insider's earnings (who is a $j = R$ adult)

$$w_{2t} + \pi_{2t}^f + m_t(1-\lambda)\pi_{2t}^X$$

Most equilibrium conditions associated with the *SEA* are the same as in the definition of *SENA* except for the superior technology used. The main difference is in the no-deviating condition. In words, the no-deviating condition is that no single group of industry insiders would realize higher earnings by having their firm use the technology from sub-period 1. As only urban adults can work with this technology, a deviating industry must pay a wage rate equal to

$$w' = w_{2t} + \lambda \Pi_{2t}^X / I_{2t}$$

This is the wage rate used to determine the optimal employment and hence its profits. We assume that all the profits of a deviating firm are equally distributed to the workers in the industry, which may be greater than the set of insider from that industry. To simplify the analysis, we assume that the deviating firm must employ all of the insiders. Thus, the employment choice of the deviating industry is constrained to be no less than I_{2t}. Let L_v' denote the employment choice of the deviating industry, then the earnings of an insider are

$$w' + \frac{\Pi'}{L_v'} + \pi_{2t}^f + m_t(1-\lambda)\pi_{2t}^X$$

Profits of a deviating industry are obtained as follows:

$$\begin{aligned}
\arg \max_{d',\varepsilon,p',Q_{st},L'_v} \quad & \{p'Q' - w'L'_v\} \\
\text{s.t.} \quad & Q' = (2d'\alpha\phi[(w^*_{2t} + \pi^{f*}_{2t} + m_t(1-\lambda)\pi^{X*}_{2t})N^R_t + \\
& (w^*_{2t} + \lambda\Pi^{X*}_{2t}/I_{2t} + \pi^{f*}_{2t} + m_t(1-\lambda)\pi^{X*}_{2t})N^U_t])/(p\prime) \\
& p^*_{2t}[1 + (d^*_{2t} - d')^\beta] = p'[1 + d'^\beta] \\
& \varepsilon' = 1 + \frac{(1 + d'^\beta)p'_v}{[p^*_{2t}\beta(d^*_{2t} - d')^{\beta-1} + p'\beta d'^{\beta-1}]d'} \\
& Q' = A^x_{1t}(L'_v - \kappa_{1t}) \\
& L'_v \geq I_{2t}
\end{aligned} \tag{27}$$

Note that in the above problem, the industry's aggregate demand corresponds to the case where the agricultural subsistence constraint does not bind for either houshold. In the case where it did bind for one or both types of households, the income expressions in the demand equation would change accordingly.

Definition 2 *A* Symmetric Equilibrium with Process Adoption *is a collection of rural and urban household adult choices* $(n^i_{2t}, a^i_{2t}, c^i_{2t})$,*a wage rate* $(w_{2t},$ *a vector of agricultural firm choices* $(Q^f_{2t}, L^x_{2t}, \pi^f_{2t})$, *and a vector of industrial firm choices* $(p_{2t}, \varepsilon_{2t}, Q^x_{2t}, L^x_{2t}, \Pi^x_{2t})$ *together with a number of industries and distance between industries* (d_t, m_t) *that satisfies*

1. $a^R_{2t} = (1-\alpha)\phi(w_{2t} + \pi^f_{2t} + m_t(1-\lambda)\pi^X_{2t})$ *(rural household demand for agricultural consumption)*

2. $a^U_{2t} = (1-\alpha)\phi(\, w_{2t} + \lambda\frac{\Pi^X_{2t}}{I_{2t}} + \pi^f_{2t} + m_t(1-\lambda)\pi^X_{2t})$ *(urban household demand for agricultural consumption)*

3. $p_{2t}c^R_{2t} = \alpha\phi(\, w_{2t} + \pi^f_{2t} + m_t(1-\lambda)\pi^X_{2t})$ *(rural household demand for industrial good)*

4. $p_{2t}c^U_{2t} = \alpha\phi(\, w_{2t} + \lambda\frac{\Pi^X_{2t}}{I_{2t}} + \pi^f_{2t} + m_t(1-\lambda)\pi^X_{2t})$ *(urban household demand for industrial good)*

5. $n^R_{2t}\tau^R_t = (1-\phi)[\, w_{2t} + \pi^f_{2t} + m_t(1-\lambda)\pi^X_{2t}]$ *(type i household demand for children)*

6. $n_{2t}^U \tau_t^U = (1-\phi)[w_{2t} + \lambda \frac{\Pi_{2t}^X}{I_{2t}} + \pi_{2t}^f + m_t(1-\lambda)\pi_{2t}^X]$ *(type i household demand for children)*

7. $N_t^R + N_t^U = L_{2t}^f + m_t L_{2t}^x$ *(Farming labor market clears)*

8. $N_t^R(a_{2t}^R + n_{2t}^R \tau_t^R) + N_t^U(a_{2t}^U + n_{2t}^U \tau_t^U) = Q_{2t}^f$ *(Farming Good market clears)*

9. $w_{2t}^f = \theta A_{2t}^f (L_{2t}^f)^{\theta-1}$ *(profit maximization of farms)*

10. $\pi_{2t}^f = (1-\theta) Q_{2t}^f / N_t$ *(profit of farms)*

11. $\varepsilon_{2t} = 1 + \frac{1}{2\beta}(\frac{2}{d_t})^\beta + \frac{1}{2\beta}$ *(definition of elasticity)*

12. $p_{2t} = \frac{w_{2t}\varepsilon_{2t}}{A_{1t}^x(1+\gamma_x)(\varepsilon_{1t}-1)}$ *(profit maximization of industrial firm)*

13. $Q_{2t}^x = \frac{d_t \alpha \phi [N_t^R \ (w_{2t} + \lambda \frac{\Pi_{2t}^X}{I_{2t}} + \pi_{2t}^f + m_t(1-\lambda)\pi_{2t}^X) \ + N_t^U \ \ w_{2t} + \lambda \frac{\Pi_{2t}^X}{I_{2t}} + \pi_{2t}^f + m_t(1-\lambda)\pi_{2t}^X) \ ]}{p_{st}}$ *(demand for variety v)*

14. $Q_{2t}^x = A_{1t}^x(1+\gamma_X)[L_{1t}^x - \kappa_{1t}(1+\gamma_\kappa)]$ *(supply of variety v)*

In addition, the prices and allocations must satisfy the no deviation condition described above.

2.8 Dynamic Symmetric Equilibrium

The dynamic elements of the model economy are the population, the division of this population between the economy's two regions, and the technology used in the industrial sector. These are the only elements that link periods. In the first sub-period of each period, the equilibrium allocation is just the static one with product innovation. In the second sub-period, the equilibrium is either the one with innovation or without innovation. The rural population in period $t+1$ is just the total children born to rural type agents that spend both sub-periods working in the farming sector. The number of such adults is L_{2t}^A. Consequently, the law of motion for the rural population is

$$N_{t+1}^R = L_{2t}^A (n_{1t}^R + n_{2t}^R)$$

The urban population in period $t+1$ is the sum of the children born to urban adults in period t plus the children of the rural adults that work in the industrial sector in the second subperiod, $({N_t}^R - L^A_{2t})$. Thus, the law of motion for the urban population is just

$$N^u_{t+1} = {N_t}^U(n^U_{1t} + n^U_{2t}) + ({N_t}^R - L^A_{2t})(n^R_{1t} + n^R_{2t})$$

The law of motion for the total population is just

$$N_{t+1} = N^U_{t+1} + N^R_{t+1}$$

The existence of multiple equilibria in the second sub-period is possible. In this case, there are dynamic symmetric equilibria. It is entirely possible that neither symmetric equilibrium exists, so that no dynamic symmetric equilibrium exists. In the experiments that follow, we explore the nature of the dynamic equilibria for various parameterizations of the model economy.

3 Numerical Experiments

We now explore the properties of the model. We proceed by assigning the parameters of the model and the initial population as well as its split between the rural and urban regions. We then compute the symmetric equilibrium prices and allocations for the first sub-period of $t = 0$. Next we determine if there exists either the *SENA* and the *SEA* for the second sub-period. In the case that both equilibria exists, we select the *SENA* on the basis that the *SEA* requires some type of coordination across industries. Based on the equilibria values from the first two-subperiods, we determine the urban and regional populations for period as well as the relevant rung of the technology level for industrial firms start with in the first sub-period $t = 1$. We then solve for equilibria in both subperiods of period $t = 1$, and in doing so obtain the urban and regional populations for period $t = 2$. Repeating these steps generates a long equilibrium path. Of course, it is possible that at some point of the path, one may find that no symmetric equilibrium exists in the second sub-period. These paths are not reported here.

The parametrizations do not follow some calibration procedure. Nevertheless, parameter values are restricted so that the economy can meet the subsistence constraint in all periods, and so the wage of industrial workers in the first sub-period equilibrium is always greater than the wage earned by agricultural workers. Additionally, the initial population and splits are set so that there is no large redistribution of population between regions in the first period. The parameters also must give rise to a situation where neither symmetric equilibrium exists.

3.1 Benchmark

We begin with a parameterization that we call the benchmark. The benchmark sets the values of a large number of variables equal to zero so as to simplify the model. As can be seen in the following table, there is no subsistence agricultural consumption, no agricultural TFP growth, no R&D costs, and no diminishing returns to labor in agriculture. By shutting down these features of the model, we hope to develop the intuition for the mechanics of the model.

Table 1: Benchmark Parameter Values

$\gamma_a = 0.0$	$\gamma_x = 0.005$	$\gamma_k = 0.07$	$\theta = 1.0$
$\alpha = 0.20$	$\phi = 0.99$	$\lambda = 0.70$	$\beta = 1.5$
$N_0 = 10$	$N_0^R = 8.3$	$A_0^f = 1.0$	$A_0^x = 2.0$
$\kappa_0 = 0.70$	$\tau_t^R = 0.0173$	$\tau_t^U = 0.0213$	$\bar{a} = 0.00$

Figure 1 shows the technology used at each date in the second sub-period from $t = 0$ until $t = 60$. The important finding is that there is an initial period of no technological adoption; for the first 15 periods, each group of industrial workers finds it optimal to block the adoption of the next technology. At $t = 15$, the *industrial revolution* begins as industrial workers do not block the adoption of the better technology. The main reason why the *industrial revolution* has to wait 15 periods is that the urban population needs time to increase so as to make the price elasticity of demand sufficiently high. The time path of the urban population and the price elasticity of demand are shown in Figures 2 and 3. Relative wage changes have nothing to do with the timing of the *industrial revolution*; the wage of industrial workers in the first subperiod is 1.23 times greater than the wage of agricultural workers in each of the first 14 periods. In each of these periods, industrial workers experience lower total earnings if their industry deviates and adopts the more productive technology.

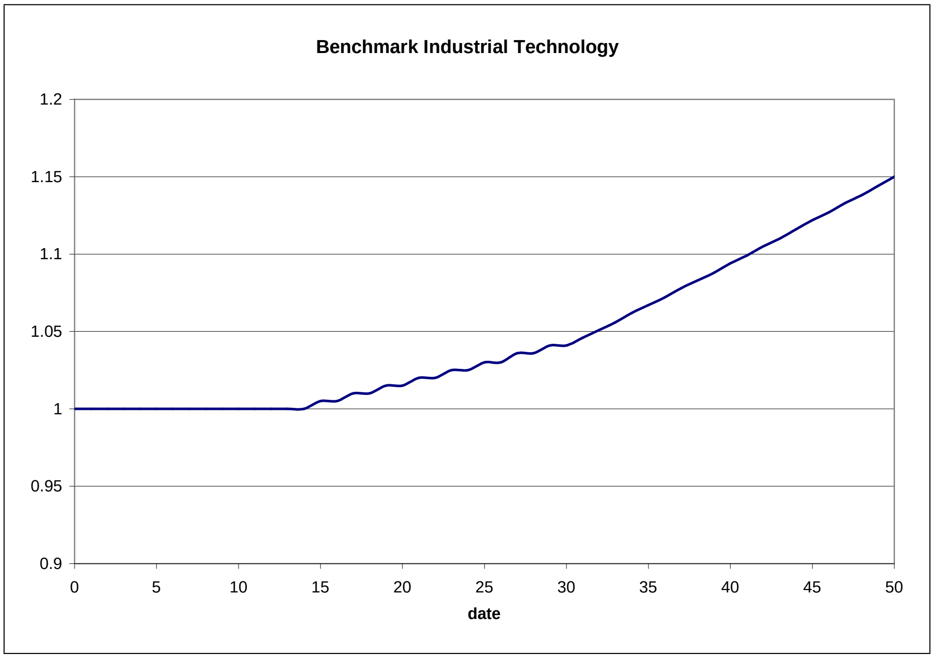

Figure 1: Industrial technology (benchmark case)

The *industrial revolution* lasts a total of 15 periods. In $t = 16$, groups reform and block the adoption of the more productive technology. In $t = 17$, groups do not block the adoption of the technology. This pattern continues until $t = 30$, so that the model generates a period of irregular and modest technological change - *an industrial revolution.* Thereafter, groups never reform and adoption occurs every period. Thus, the model generates a period of technological stagnation, followed by a period of slow and irregular technological change, followed by a period of constant and larger increases in technology.

The result that groups reform and blocking the adoption of the more productive technology for $15 \leq t \leq 30$ requires some additional comment. To understand why groups reform, recall that the income earned by the workers in a deviating industry when all other industries do not adopt is $\lambda \frac{\Pi_{2t}^{X*}}{I_{2t}} + w_{2t}^{f*}$. They key to understanding why groups reform is the first component of this income term, $\lambda \frac{\Pi_{2t}^{X*}}{I_{2t}}$. In $t = 15$, when resistance breaks down,

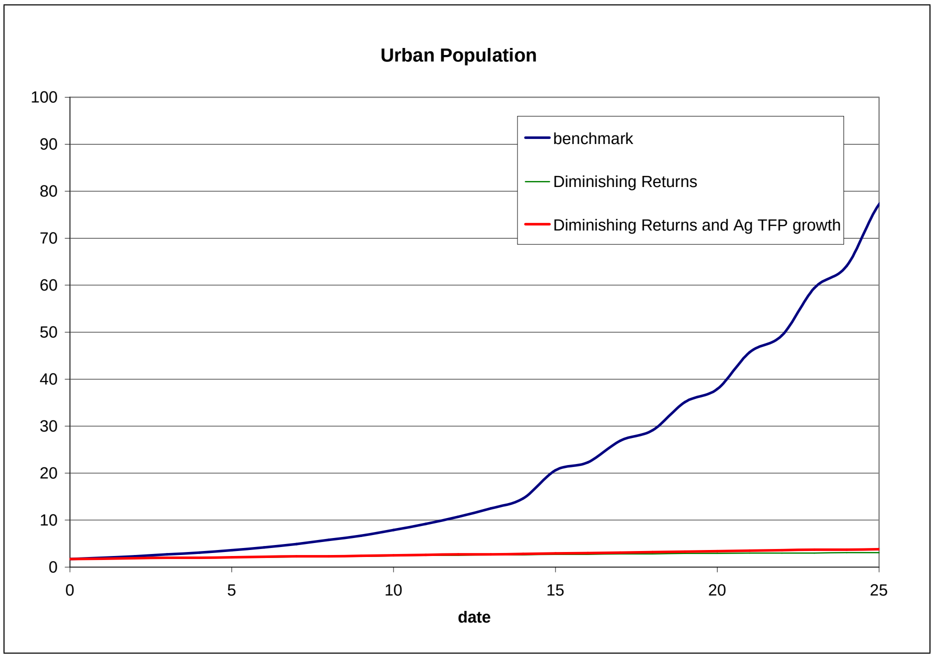

Figure 2: Urban population

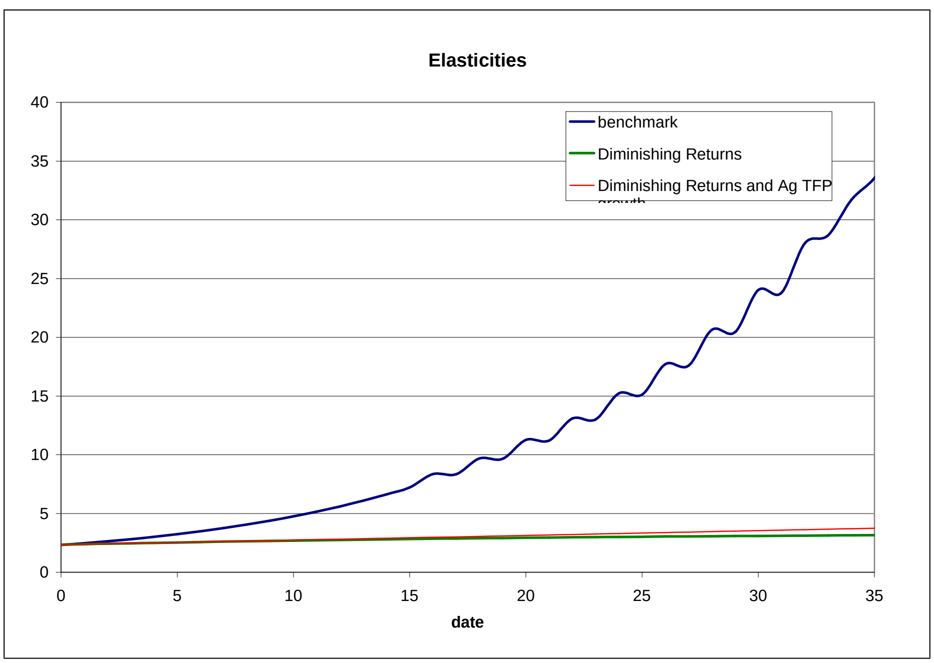

Figure 3: Elasticities

there is a significant migration of workers from the rural region, the effect of which is to bring about a significant people living in the urban region at the start of $t = 16$. This has two countering effects. On the one hand, the large increase in the urban population decreases the relative wage of industrial workers to agricultural workers. As the no-deviation condition is $w_{2t}^{X*} > \lambda \frac{\Pi_{2t}^{X*}}{I_{2t}} + w_{2t}^{f*}$, this makes it less likely that the *SENA* will exist. On the other hand, the large increase in the urban population means a larger union, namely, I_{2t} increases, so that deviating profits are spread among more workers. Until the elasticity increases to a critical level, the profits associated from deviating are not large enough to compensate for the larger union size. In effect, the profits component $\lambda \frac{\Pi_{2t}^{X*}}{I_{2t}}$ of income earned by a deviating industrial worker is so small, that despite the smaller wage differential, the industry finds it optimal to not adopt. This is the reason why the *SENA* exists following a period where no resistance occurred. With population growth and a bigger urban population, the elasticity becomes sufficiently large at $t = 30$ so that the profit component of deviating from the *SENA* is always large enough to ensure that the *SENA* does not exist.

3.2 Agricultural Revolution

We now consider the importance of agricultural factors for the *industrial revolution*. In particular, we seek to examine the relevance of two factors that many researchers have hypothesized are important for understanding the timing of the *Industrial Revolution* in England: land and productivity gains in agriculture. As the classical economists noted, land is a rather unique factor of production in that its supply is fixed. The fixed supply of land meant that population growth could not be sustained absent increases in agricultural productivity. As population growth is essential for initiating the *industrial revolution*, we now explore the consequences of these two factors.

We do this in two steps. First, we change the labor share parameter in the agricultural production function, θ, from 1 in the benchmark to 0.95. No other parameter values are changed. Second, we change the agricultural TFP growth rate parameter, γ_a, from 0.0 in the benchmark to 0.001.

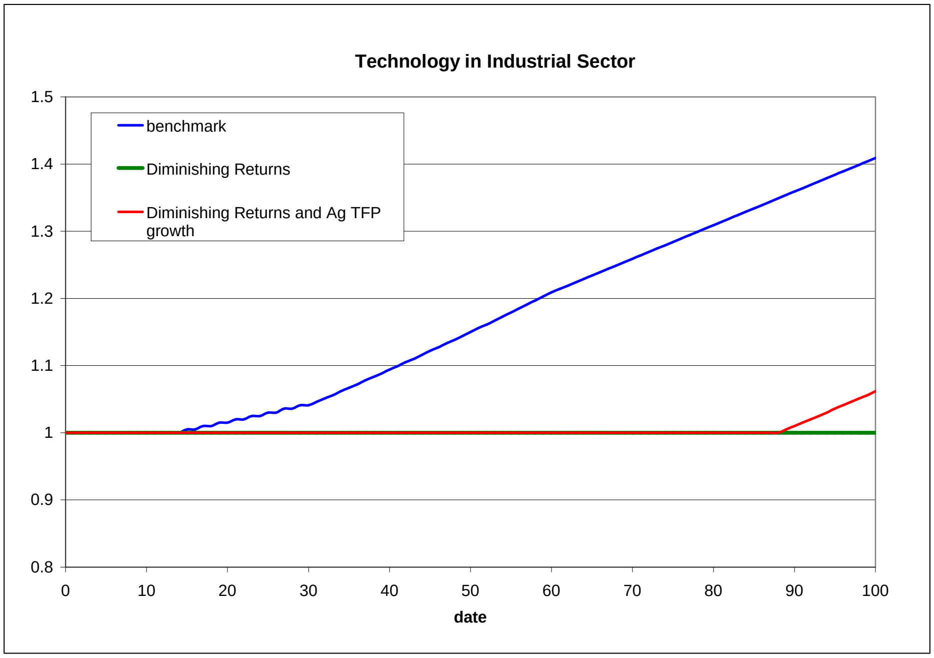

Figure 4: Industrial technology (diminishing returns and TFP growth in agriculture)

Figures 4 depicts the equilibrium paths of the technology used in the industrial sector for the benchmark parametrization, the model with diminishing returns to labor, and the model with both diminishing returns to labor in agriculture, and positive agricultural TFP growth. The findings are striking. In the absence of agricultural TFP growth, the economy does not experience an *industrial revolution* in the first 100 time periods. However, with agricultural TFP growth, the *industrial revolution* begins at $t = 89$. This figure shows that an agricultural revolution is important for the start of an *industrial revolution.*

3.3 Institutions

We next consider the importance of institutions for the start of an *industrial revolution* via two experiments. In the model, better institutions are associated with lower fixed costs to entry. Recall that in each period there are two fixed costs, one associated with using the technology that was used in the previous period, and the other with adopting the next rung on the technology ladder. In the benchmark, we assumed that both costs

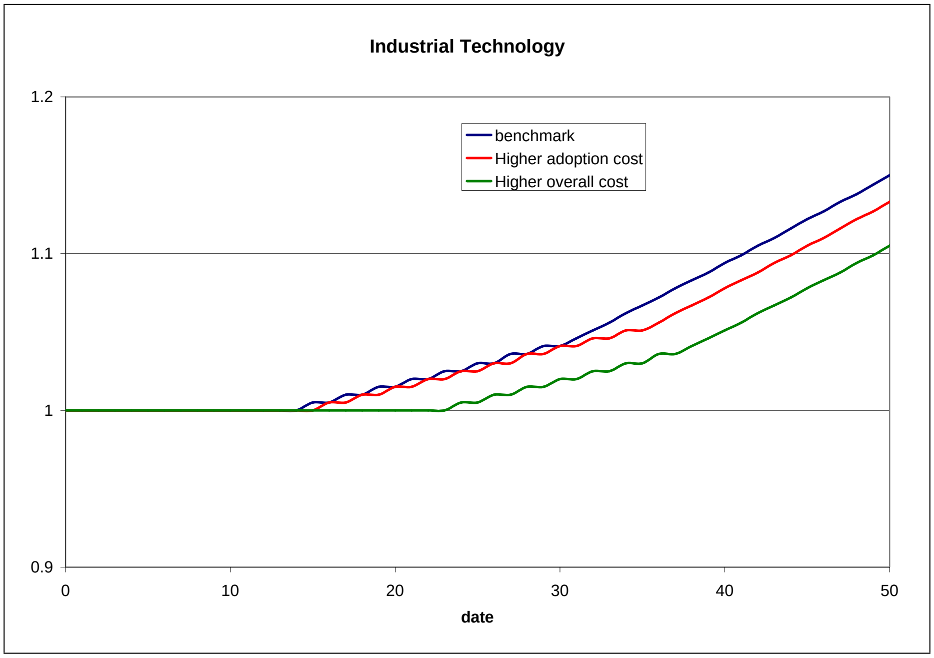

Figure 5: Industrial technology: role of institutions

were the same. In the first experiment, therefore, we deviate from this assumption so that going to the next rung on the technology latter entails an additional fixed labor cost. In particular, we increase γ_κ from it value of 0 in the benchmark to .07.

As can be seen in the Figure 5 depicting the time path of the industrial technology level, a higher fixed cost to adoption delays the start of development, albeit only slightly. The delay is not particularly large but this is not expected given the small increase in γ_κ.[3] In the next expirment, we reset the value of γ_κ to 0.0 so that there is no gap in the fixed cost to using the current rung or the next rung on the technology ladder. Instead, we make it more expensive to use either technology. This we do by increasing the fixed cost of entry, κ_{10} from the benchmark value of 0.70 to a value of 2.70. The effect of this higher fixed cost on the timing of the *industrial revolution* is also shown in Figure 5. As can be seen, the delay in industrialization is much larger; whereas an *industrial revolution* starts at $t = 15$ for the benchmark, it now is delayed for 8 more periods.

[3]The reason that we did not use a larger value for γ_κ is that for such values we found that neither the *SENA* nor *SEA* existed in some period.

The intuition for these results is straightforward. The zero profit condition implies that there are less varieties produced when the fixed cost of entering κ_{10} is higher. With fewer varieties, goods are less substitutable, firms are smaller, and the elasticity of demand is lower. This implies that it is less profitable for any firm to adopt the next rung on the technology level. Hence, in any period, the *SENA* is more likely to exist, and the *SEA* is less likely to exist. This is brought out in Figure 6 that shows the time paths of elasticity.

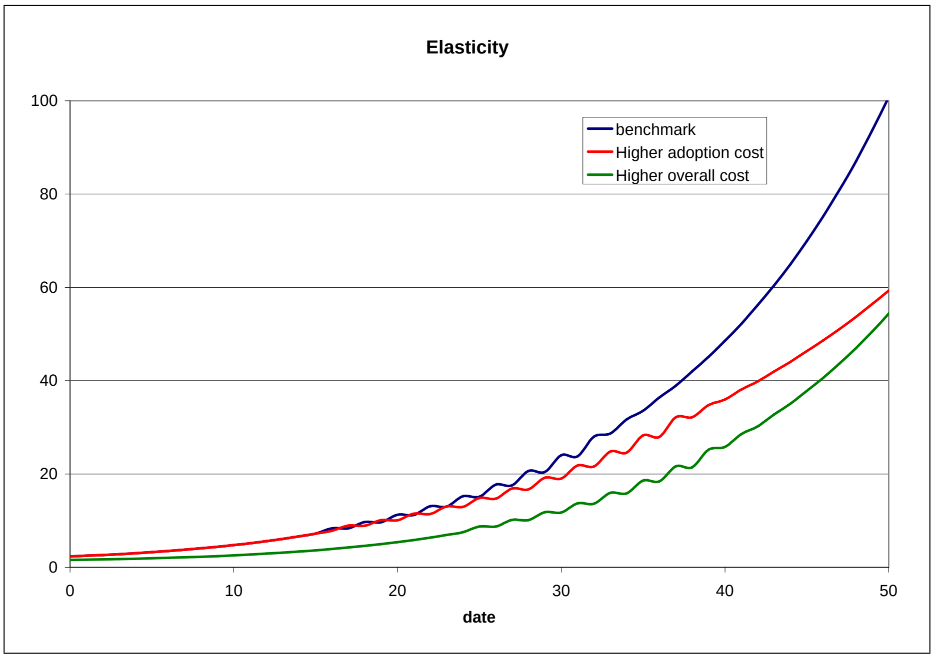

Figure 6: Elasticity: role of institutions

Not surprisingly, better institutions make market size less important in the sense of having a greater urban population. This is apparent from equation (20) using the result that in the first sub-period $L_{1t}^x = \kappa_{1t}\varepsilon_{1t}$ and that the number of varieties is equal to the inverse of the distance between varieties so that $m_t = 1/d_t = N_t{}^U/L_{1t}^x$. Thus, equation (20) reduces to

$$\varepsilon_{1t} = 1 + \frac{1}{2\beta}(\frac{N_t{}^U}{\kappa_{1t}\varepsilon_{1t}})^{\beta} + \frac{1}{2\beta} \qquad (28)$$

More surprising is the relation between institutions and urbanization. As Figure 7 shows, the urban population is higher in the economies with worse institutions, which

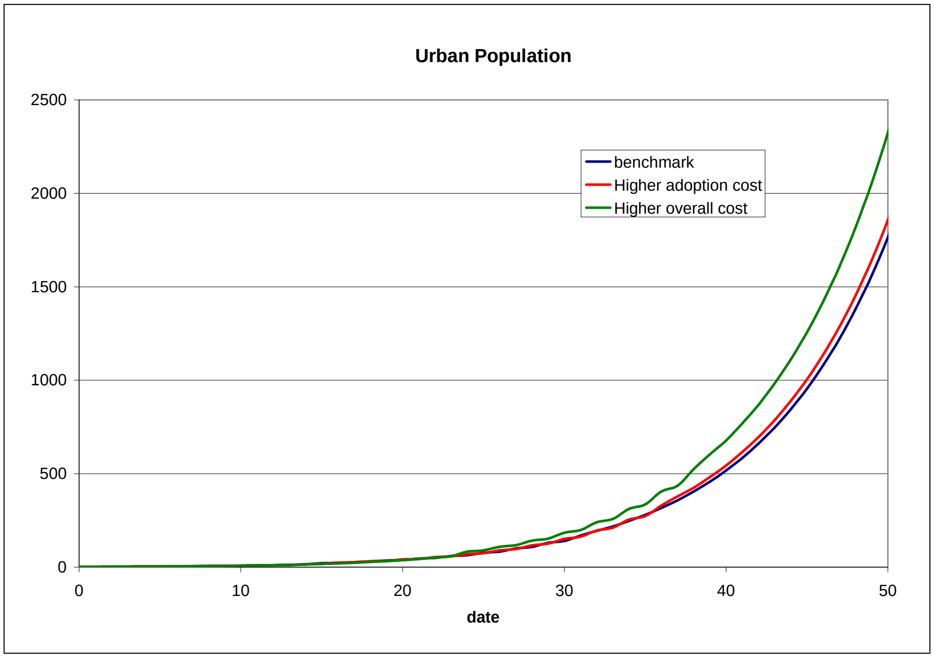

Figure 7: Urban population: role of institutions

are slower to industrialize. This result requires some additional comment. Note that the gaps in disparity in urban populations do not occur until all three economies have industrialized. Hereby, lies the explanation for this surprising result. When the groups no longer resist the adoption of the better technology, migration occurs. The better institutions in the benchmark economy mean that more industrial output is generated with the same amount of industrial workers. Not surprisingly, then, the country with better institutions will optimally allocate more people to the agricultural sector. This explains why there are fewer people living in the urban area in the benchmark economy.

3.4 Demographic Transition

The last set of experiments we perform seek to determine if the model can generate a demographic transition along with an *industrial revolution*. A number of authors, most notably, Galor and Weil (2000) argue that a plausible theory of the industrial revolution must be able to generate a demographic transition of the type we have observed historically. The demographic transition is associated with rising rates of population growth followed by declining rates which eventually level out at a lower growth rate than the one the country starts with. To explore the ability of the model to generate a demographic transition, we proceed in two steps. First, we alter the benchmark so that there is a positive binding subsistence term to agriculture, namely we change the value of $\bar{a}$ from 0.0 to 0.82. In the second experiment, we add agricultural TFP growth. More specifically, we increase the γ_a from 0.0 in the benchmark to 0.0005.

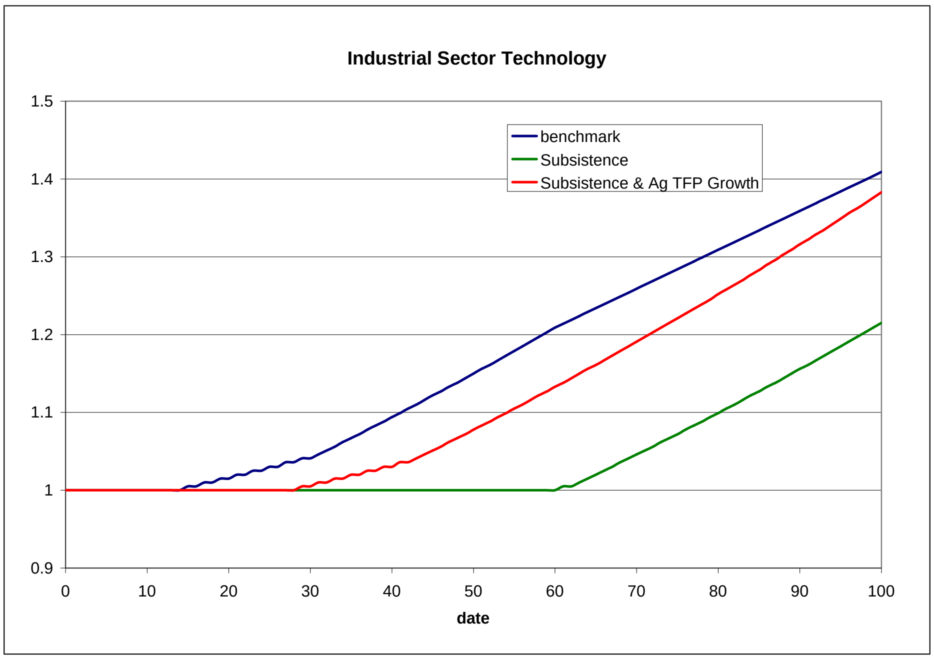

Figure 8: Industrial technology: different scenarios

Figure 8 depicts the time path of industrial level technology for the three experiments; and Figure 9 depicts the population growth rates for the three experiments. As can be seen, the effect of introducing the binding subsistence constraint is to delay the start of the *industrial revolution*. In the experiment with no agricultural TFP growth, the *industrial revolution* is delayed 46 periods whereas in the economy with agricultural TFP growth the start is delayed 14 periods. This result is intuitive as the subsistence term translates into lower populations and hence lower price elasticities of demand. The more interesting comparisons are the population growth rates across the three experiments. Here we see that neither the benchmark nor the the subsistence economy without agricultural TFP growth can generate a demographic transition. In both economies, the population growth never displays an increasing trend over any sub-period. In contrast, the population growth rate for the economy with subsistence agriculture and agricultural TFP growth is characterized by a demographic transition, with at first an increasing rate of growth, followed by a decreasing growth rate that levels off to a lower rate than the initially achieved.

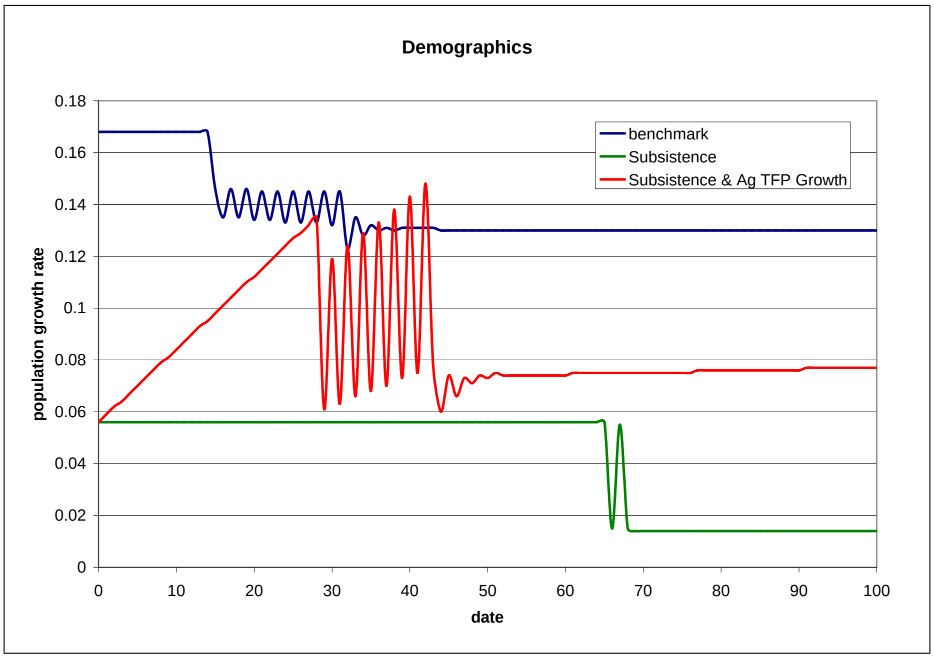

Figure 9: Demographic transition

While the model does generate a demographic transition pattern, it is somewhat off in the timing of things. More specifically, the monotonic increase in the population growth rate occurs before the start of the *industrial revolution*, and during the *revolution* it fluctuates wildly reflecting the fact that industrial groups reform in the period following adoption, only to break up again the next period. Still, given that parents only value the number children they have, the demographic pattern generated is remarkable.

4 Empirical support

To be Added.

5 Conclusion

To be added.

References

[1] Aghion, P. and Howitt, P., 1992. A Model of Growth through Creative Destruction, Econometrica, 60, 323-51.