The Quest for Productivity Growth in Agriculture and Manufacturing

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March 2006
This is a preliminary and incomplete draft

Abstract

We develop a theory to explain the transition from stagnation to modern growth. We focus on the forces that shaped the evolution of total factor productivity in agriculture and manufacturing across history. More specifically, we build a multisector model of endogenous technical-change and economic growth. We consider an expanding-variety setup with rising labor specialization and two different R&D technologies, one for agriculture and another for manufacturing. As a consequence, total factor productivity in the model can increase via two different channels. First, population growth allows larger levels of specialization of land and labor in the economy that bring efficiency gains. This type of productivity improvement is capital saving, but can not generate sustained growth. Technical change is also possible by investing in R&D. Unlike specialization, new technologies generated in this way are land and labor augmenting, and are the key to modern growth.

In the model, the economy has not incentives to invest in R&D until a minimum knowledge base is available to researchers. This is in line with ideas contained in Mokyr (2005). To make possible the accumulation of this minimum knowledge base, we assume that learning-by-doing is the implicit underlying force that leads to specialization. However, land and labor specialization is based on knowledge whose nature differs in agriculture and in manufacturing. More specifically, whereas this knowledge is *farm-specific* in agriculture, mainly concern with the acquisition of uncodified information about local conditions of soil and whether, specialization in manufacturing is the result of *general* knowledge, mainly codified, that contributes at a larger extent to the knowledge base.

JEL Classification: O13, O14, O41.
Key words: stagnation, modern growth, specialization, learning-by-doing, R&D, Knowledge base.

1 Introduction

Recent papers such as Galor (2005), Gollin *et al.* (2005), and Parente and Prescott (2005), among others, provide theories that try to capture the evolution of income per capita over the course of human history. Differences in total factor productivity (TFP) has been proposed by some of these papers as a main explanation of the transition from pre-industrial-revolution stagnation to modern growth and cross-country income disparities. However, with the exception of Parente and Prescott (2005), previous literature has taken differences in TFP as exogenous. The goal of our paper is breaking apart from the exogenous-TFP assumption to develop a theory that can help explain the evolution of productivity in agriculture and manufacturing, as well as the one of income, across history and nations.

There are several important reasons to pursue this goal. First of all, As Galor (2005) writes, "[Identifying] the underlying forces that triggered the transition from stagnation to growth and ... the great divergence in income per capita across countries ... [is] one of the most significant challenges facing researches in the field of growth and development". Second of all, the exogenous-TFP assumption is widely viewed as a main problem to develop growth theories that can offer policy guidance (e.g., see Parente and Prescott (2004)). Third, authors such as Gollin *et al.* (2000, 2005), Restuccia *et al.* (2004), and Ripoll and Cordoba (2005), among others, conclude that a greater understanding of the determinants of agricultural productivity is key to building models that can better confront the issues facing many of today's development nations. Last but not least, the notion of a relatively slow productivity growth in agriculture that has been, since Adam Smith, central to many theories of economic growth and development does not hold in the recent data analyzed by, for example, Bernard and Jones (1996) and Martin and Mitra (1999).

In this paper, we build a multisector overlapping-generations model of endogenous technical-change and economic growth. We consider an expanding-variety setup with rising labor specialization and two different R&D technologies, one for agriculture and another for manufacturing. As a consequence, total factor productivity in the model can increase via two different channels. First, as in Goodfriend and McDermott (1995), population growth allows larger levels of specialization of land and labor in the economy that bring efficiency gains. This type of productivity improvement is capital saving, but can not *per se* generate sustained, balanced growth. Technical

change is also possible by investing in R&D. Unlike specialization, new technologies generated in this way are land and labor augmenting, and are the key to modern growth.

In the model, the economy has not incentives to invest in R&D until a minimum (epistemic) knowledge base is available to researchers. This is in line with ideas contained, for example, in Mokyr (2005). To make possible the accumulation of this minimum knowledge base, we assume that learning-by-doing is the implicit underlying force that leads to specialization. However, land and labor specialization is based on knowledge whose nature differs in agriculture and in manufacturing. More specifically, whereas this knowledge is *farm-specific* in agriculture, mainly concern with the acquisition of uncodified information about local conditions of soil and whether, specialization in manufacturing is the result of *general* knowledge, mainly codified, that contributes at a larger extent to the knowledge base.

Besides the aforementioned literature, our work is also related to models that neglect agriculture as a dynamic sector and a potential source of economic growth. Unlike us, Matsuyama (1991), Sachs and Warner (1995) and Rodriguez and Rodrick (1999), among many others, view the agricultural sector as a burden for economic development. Clearly this has implications for economic policy and gives support to policies that discriminate against the agricultural sector in favor of the supposedly more dynamic industrial sector. This policy bias has often led to stagnant agriculture and can be the cause of large shortfalls in domestic food production, balance of payment crisis and political instability.[1] Other related literature is the one of directed technical-change. As Acemoglu (2002, 2003), we formalize the notion that inventors decide the kind of technological improvements that they create. But unlike these papers, we focus on ideas directed to different sectors, instead of different inputs.

The rest of the paper is organized as follows. Section 2 reports some evidence on the evolution of prices and productivities in the agriculture and manufacturing sectors. Section 3 introduces the model. The predictions of our setup are analyzed in section 4. Section 5 concludes.

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[1] World Bank (1981)

2 Empirical evidence

In this section *[still incomplete]*, we include empirical evidence relative to the evolution of productivity and prices for agricultural and manufacturing activities. A lower productivity growth in agriculture, compared to manufacturing, is consistent with data over the last part of the 18th century and most part of the 19th century, that is, at early stages of the industrial revolution; see Galor and Mauntford (2003) for discussion and references. However, a striking feature common to recent empirical studies such as Bernard and Jones (1996) and Martin and Mitra (1999) is that agriculture, at least in the last 50 years, shows higher rates of total factor productivity (TFP) growth than the rest of the sectors for a large sample of countries, including both industrial and developing nations.

This is not entirely surprising from the point of view of the literature on structural change, which has already pointed out to a higher growth of TFP in farming as a possible explanation of the structural transformation observed in the last century; see, for example, Chenery and Srinivasan (1988). This changing pattern of relative TFP growth is also supported by data on the relative price of agricultural goods. In particular, evidence suggests that the relative price of agricultural goods rose over the period 1880 to 1920 and declined over the period 1920 to 1995 (Caselli and Coleman (2001) and Johnson (2002)).

Let us take a closer look to the evidence that may seem more surprising, the one related to the evolution of productivity and prices in the last 50 years. We have comparable data across sectors for the period 1959-2005. Data comes from the statistical tables provided by the US government in the Economic Report of the President (ERP 2006). Figure 1 illustrates the evolution of productivity for the farm and non-farm business sectors, which correspond to the data in tables B-99 and B49, respectively. This figure shows clearly a more rapid growth in farm productivity during the last decades relative to productivity growth in the non-farm sector.

Figure 2, on the other hand, illustrates the evolution of the price indexes across sectors, it refers to the producer price indexes (Table B-67 in ERP 2006). We can see here that industrial prices have been growing more rapidly than agricultural prices.
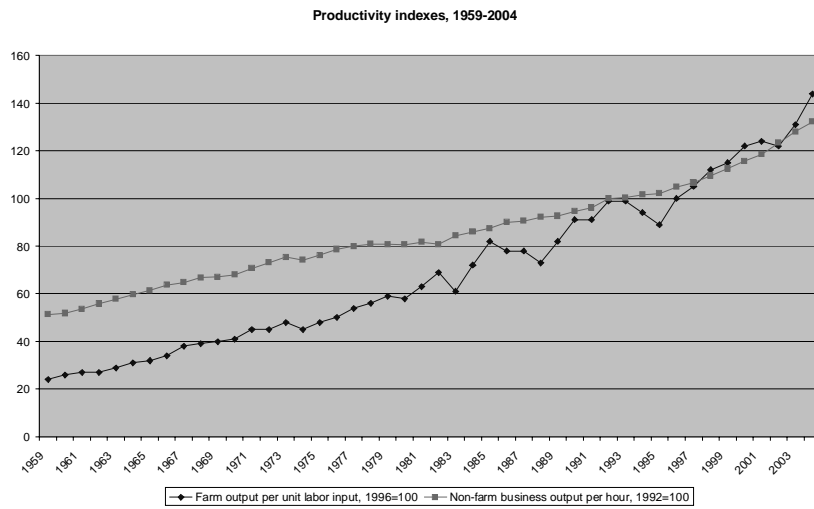
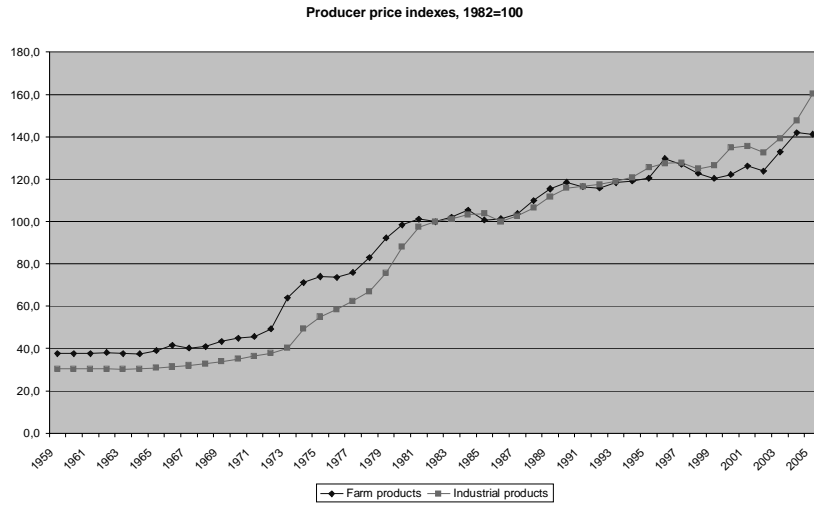Figure 1: Productivity indexes across sectors

Figure 2: Producer price indexes across sectors

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3   The Model

3.1   Households

We consider an economy composed of overlapping generations of individuals. The size of new generations grows exogenously at rate n. Individuals have preferences only over consumption of agricultural and manufactured goods. They are endowed with one unit of labor when young, and inherit land from their parents when old. These inputs are inelastically supply to the production activities.

Each period, households must decide how much to consume of each good and how much to save. Saving allows increasing the amount of consumption next period. The problem of a representative consumer is the following:

$$
\max \left\{ \left[\frac{\left(c_{1at}^{\theta} c_{1mt}^{1-\theta} \right)^{1-\sigma} - 1}{1-\sigma} \right] + \rho \left[\frac{\left(c_{2at+1}^{\theta} c_{2mt+1}^{1-\theta} \right)^{1-\sigma} - 1}{1-\sigma} \right] \right\},
$$

such that

$$
w_t = c_{1at} + p_t c_{1mt} + s_t,
$$

$$
(1 + r_{kt+1}) s_t + r_{qt} (Q/L_t) = c_{2at+1} + p_{t+1} c_{2mt+1};
$$

where $\rho, \theta \in (0,1)$; $\sigma > 0$; c_{iat} and c_{imt} are consumption at date t of an individual in period of life i of the agricultural product and the manufacturing good, respectively; r_k, w, and r_q are the rental rates of capital, labor and land, respectively; Q is the land endowment in the economy; L_t is the size of generation t; and p is the price of the manufacturing product. We introduce a subsistence-consumption level ($\bar{c}$) such that if $c_{iat} < \bar{c}$, $[(c_{iat}^{\theta} c_{imt}^{1-\theta})^{1-\sigma} - 1]/(1 - \sigma) = 0$. Assuming that all agents inherit the same amount of land, Q/L_t represents the land amount own by an individual at time t. All prices are expressed in units of the agricultural good.

First order conditions in the interior solution to this problem imply that the optimal consumption and saving decisions are

$$
\frac{c_{iat}}{c_{imt}} = \left(\frac{\theta}{1-\theta} \right) p_t,
$$

and

$$
s_t = \frac{w_t}{1 + \rho^{-1/\sigma} \left[(1 + r_{kt+1}) (p_t/p_{t+1})^{1-\theta} \right]^{-(1-\sigma)/\sigma}}.
$$

3.2 Agricultural-goods production

A relatively large number of firms produce agricultural goods (Y_a) using labor, land, and capital. At date t, capital employed is composed of a mass A_{at} of differentiated producer durables, and land and labor are specialized in M_a different uses. We assume that there is a minimum set of tools and uses with which nature endows the human kind, that is, $A_{at} \geq \bar{A}_a$ and $M_{at} \geq \bar{M}_a$, for all t. More specifically, the production technology is the following:

$$Y_{at} = \left(\int_0^{A_{at}} [x_{at}(i)]^{\alpha_a} \, di \right) \left(\int_0^{M_{at}} [q_t(i)]^{\beta} \, [l_{at}(i)]^{1-\alpha_a-\beta} \, di \right); \tag{1}$$

where $x_{at}(i)$ is the amount of equipment type i purchased in period t; and $q_t(i)$ and $l_{at}(i)$ are the amounts of land and labor allocated to field i

Increasing the mass of available types of machinery A_{at} requires the use of codified knowledge that can be only obtained in the laboratory by investing in R&D. The degree of specialization, given by M_{at}, on the other hand, is the result of learning about the form of the production function. In practice, this could involve, for example, the switch from the two-field system to the three-field system, the coexistence of irrigation and non irrigation fields, and the incorporation of new crops. We assume that this costless learning-by-doing process in agriculture generates farm-specific uncodified information that is not useful for R&D.

Farmers choose the amount of each type of capital goods that they want to buy, and the amounts of land and labor in each specialized field that they want to hire so as to maximize profits. In particular, they solve the following problem:

$$\max \left\{ \left(\int_0^{A_{at}} [x_{at}(i)]^{\alpha_a} \, di \right) \left(\int_0^{M_{at}} [q_t(i)]^{\beta} \, [l_{at}(i)]^{1-\alpha_a-\beta} \, di \right) \right.$$
$$\left. - \int_0^{A_{at}} p_{at}(i) x_{at}(i) \, di - \int_0^{M_{at}} r_{qt} \, q_t(i) \, di - \int_0^{M_{at}} w_t \, l_{at}(i) \, di \right\};$$

where $p_{at}(i)$ is the price of durable good type i .

The first order conditions supply the following inverse demand functions for the inputs equipment, land, and labor, respectively:

$$p_{at}(i) = \alpha_a \, [x_{at}(i)]^{\alpha_a-1} \left(\int_0^{M_{at}} [q_t(i)]^{\beta} \, [l_{at}(i)]^{1-\alpha_a-\beta} \, di \right), \tag{2}$$

$$r_{qt} = \beta \, [q_t(i)]^{\beta-1} \, [l_{at}(i)]^{1-\alpha_a-\beta} \left(\int_0^{A_{at}} [x_{at}(i)]^{\alpha_a} \, di \right), \tag{3}$$

$$w_t = (1 - \alpha_a - \beta) \, [l_{at}(i)]^{-\alpha_a - \beta} \, [q_t(i)]^{\beta} \left(\int_0^{A_{at}} [x_{at}(i)]^{\alpha_a} \, di \right). \tag{4}$$

Notice that firms must also decide the degree of land-labor specialization M_{at}. We assume that this is a residual decision. For a given salary, the demand function for labor gives its optimal allocation to each use, which indirectly pins down the number of specialized fields that will be operated each period. In particular, from equations (2) and (4), we find that in manufacturing

$$M_{at} = \left[\frac{w_t}{A_{at}(1 - \alpha_a - \beta)} \right]^{(1-\alpha_a)/\alpha_a} \left(\frac{L_{at}}{Q} \right)^{\beta/\alpha_a} \left(\frac{1 + r_{kt}}{\alpha_a^2} \right); \tag{5}$$

where L_{at} is the total amount of labor devoted to agriculture.

3.3 Manufacturing-goods production

There are also a large number of manufacturing firms that produce output using a mass A_{mt} of complementary types of producer durables, and labor organized in M_{mt} different tasks. As before, the economy at time *zero* is endowed with a minimum set of tools and tasks, that is, $A_{mt} \geq \bar{A}_m$ and $M_{mt} \geq \bar{M}_m$, for all t. The production technology is now the following:

$$Y_{mt} = \left(\int_0^{A_{mt}} [x_{mt}(i)]^{\alpha_m} \, di \right) \left(\int_0^{M_{mt}} [l_{mt}(i)]^{1-\alpha_m} \, di \right); \tag{6}$$

where $x_{mt}(i)$ is the amount of equipment type i purchased in period t; and $l_{mt}(i)$ is the amount of labor allocated to task i.

As in agriculture, improvements in the mass of available types of machinery A_{mt} in manufacturing requires the use of codified knowledge, and the degree of specialization M_{mt} is the result of learning about the form of the production function. However, we consider that the learning process now generates codified information that also contributes to the knowledge base useful for R&D.

Manufacturers choose the amount of each type of capital goods that they want to buy, and the amount of labor in each task so as to maximize profits. Letting $p_{mt}(i)$ be the price of durable good i, we can write their problem as:

$$\max \left\{ \left(\int_0^{A_{mt}} [x_{mt}(i)]^{\alpha_m} \, di \right) \left(\int_0^{M_{mt}} [l_{mt}(i)]^{1-\alpha_m} \, di \right) \right.$$
$$\left. - \int_0^{A_{mt}} p_{mt}(i) \, x_{mt}(i) \, di - \int_0^{M_{mt}} w_t \, l_{mt}(i) \, di \right\}.$$

Its solution implies:

$$p_{mt}(i) = \alpha_m \left[x_{mt}(i) \right]^{\alpha_m - 1} \left(\int_0^{M_{mt}} \left[l_{mt}(i) \right]^{1-\alpha_m} \, di \right), \tag{7}$$

$$w_t = (1 - \alpha_m - \beta) \left[l_{mt}(i) \right]^{-\alpha_m} \left(\int_0^{A_{mt}} \left[x_{mt}(i) \right]^{\alpha_m} di \right). \tag{8}$$

As in agriculture, manufacturers must choose the degree of labor specialization. We assume, again, that this is a residual decision. Now, equations (7) and (8) determine M_{mt} as follows:

$$M_{mt} = \left[\frac{w_t}{P^{1/(1-\alpha_m)} A_{mt}(1-\alpha_m)} \right]^{(1-\alpha_m)/\alpha_m} \left(\frac{1 + r_{kt}}{\alpha_m^2} \right). \tag{9}$$

3.4 R&D and intermediate-goods production

Technologies employ different types of differentiated capital products. The economy has initially available mass levels $\bar{A}_a$ and $\bar{A}_m$. Subsequent improvements in the varieties of intermediate goods are, however, the consequence of deliberate R&D effort. Firms in the intermediate sector invest output in R&D, and can also manufacture the capital-good varieties that result from their inventive activity investing raw capital coming from saved manufacturing output. There is free entry in the industry.

There exist institutions that guarantee that inventors can obtain patents on the new ideas that they generate. This allows them to sell producer-durable units constructed using the new designs charging monopoly prices. We assume that patents expire in one generation.[2]

In order to choose the amount to invest in R&D, firms must know how much profit they can obtain from commercializing intermediate goods. We adopt the most simple technology to manufacture capital products: a unit of capital can be converted at no cost into one unit of any variety of intermediate goods. These units fully depreciate after *one* generation. The problem of a firm that produces variety j for sector i:

$$\max_{x_{it}(j)} \left[p_{it}(j) - (1 + r_{kt}) \right] x_{it}(j);$$

where $p_{it}(j)$ is given by the inverse demand function of intermediate good $x_{it}(j)$, that is, by equations (2) and (7).

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[2]If one generation is 30 years. This implies a depreciation rate of ideas of about 10%, figure consistent with the evidence provided by Caballero and Jaffe (1993).

The optimal decision is standard in the literature. The monopolist charges a markup equal to the inverse of the elasticity of substitution between intermediate goods in final output production. More specifically,

$$p_{it}(j) = \frac{1 + r_{kt}}{\alpha_i} = p_{it}, \ \forall j. \tag{10}$$

Since the price is the same for all varieties of intermediate goods, and they enter symmetrically in final-goods production, the amount demanded of each of them will also be the same, $x_i(j) = x_i \ \forall j$. Profits then equal

$$\pi_{it}(j) = \left(\frac{1 - \alpha_i}{\alpha_i} \right)(1 + r_{kt})x_{it} = \pi_{it}, \ \text{also} \ \forall j. \tag{11}$$

Firms produce inventions directed to either agriculture and manufacturing using, respectively, the following R&D technologies:

$$A_{at+1} = \mu B_{at} R_{at}^{\lambda}, \qquad \text{with } B_{at} = A_{at}^{\phi} A_{mt}^{\gamma}, \tag{12}$$

and

$$A_{mt+1} = \mu B_{mt} R_{mt}^{\lambda}, \qquad \text{with } B_{mt} = \left(A_{mt}^{\phi} M_{mt}^{\tau} \right) A_{at}^{\gamma}; \tag{13}$$

where B_{jt} is the *knowledge base* useful to perform R&D in sector j; and R_{jt} is the amount of output investing in R&D directed to sector j.

There are several features of the R&D specifications that are worth emphasizing. First of all, both types of R&D investment display diminishing returns $(0 < \lambda < 1)$, which makes easier their coexistence in equilibrium. Second, the equations allow for intertemporal $(0 < \phi < 1)$ as well as intersectoral $(\gamma > 0)$ knowledge spillovers. Third, unlike the one in agriculture, the learning process that leads to specialization in manufacturing provides information that contributes to the R&D knowledge base $(\tau > 0)$. Finally, similar to Jones and Williams (1998), we assume that, each generation, new inventions come in packets that affect previous patents, rendering them obsolete.

Investment in each one of the two R&D technologies must be such that marginal returns are equalized. In particular, equations (12) and (13) imply that

$$\frac{R_{mt}}{R_{at}} = \left[M_{mt}^{\tau} \left(\frac{A_{mt}}{A_{at}} \right)^{\phi - \gamma} \left(\frac{\pi_{mt+1}}{\pi_{at+1}} \right) \right]^{\frac{1}{1 - \lambda}}. \tag{14}$$

This is equivalent to the following *zero*-profit condition guaranteed in equilibrium by free entry:

$$R_{it} = A_{it+1} \pi_{it+1}. \tag{15}$$

9

The LHS is the cost of investing in R&D, whereas the RHS represents the benefit.

3.5 Market clearing

The agricultural sector produces output that is used for final consumption and R&D. Manufacturing, on the other hand, produces output that can be used for final consumption, saved as capital, and invested in R&D. Hence, market clearing in goods markets requires:

$$Y_{at} = L_t c_{1at} + L_{t-1} c_{2at} + R_{at}, \tag{16}$$

and

$$Y_{mt} = L_t c_{1mt} + L_{t-1} c_{2mt} + I_t + R_{mt}; \tag{17}$$

where I_t is the amount invested in capital.

Let us now focus on input markets. Labor is supplied inelastically by consumers, therefore in equilibrium

$$L_t = \int_0^{M_{at}} l_{at}(i) \ di + \int_0^{M_{mt}} l_{mt}(i) \ di. \tag{18}$$

Capital comes from saving, and is employed to construct physical capital. Since producer durables fully depreciates after *one* generation, this implies

$$s_t L_t = I_t = \int_0^{A_{at+1}} x_{at+1}(i) \ di + \int_0^{A_{mt+1}} x_{mt+1}(i) \ di. \tag{19}$$

Finally, in the market for land,

$$\int_0^{M_{at}} q_t(i) \ di = Q.$$

4 Stages of Development in Agriculture and Manufacturing

In this section, we distinguish four stages that try to reproduce major patterns that have been observed along history. As we write this draft, we are still generating results. What follows is a just a possible outcome of the paper.

4.1 The Malthusian trap

[Incomplete]

For a while, no productivity growth may take place. Assume that the economy is near subsistence levels, and manufacturing has a very low weight in the economy. So

low that its level of labor specialization has not allowed yet the opening of the R&D activity. This means that population growth generates an increasing land-congestion problem. Hence, equations (9) and (5) imply that we can have at least two equilibria. On the one hand, it is possible a steady-state situation in which prices, A_{mt}, and A_{at} are invariant, population growth n is *zero*, and as a consequence M_{at} and M_{mt} also remain constant. This describes a situation with neither productivity growth nor increasing land-congestion problems.

On the other hand, equations (9) and (5) also allow for an equilibrium with a strictly positive population growth and increasing tasks. A rise in welfare, in this situation, could be possible even if population growth is not bounded above.

4.2   Productivity growth without mechanization

[Incomplete]

Once the degree of labor specialization starts growing in the economy, agriculture will be able to free resources that will go to manufacturing. This corresponds to a situation of productivity growth in agriculture and manufacturing without mechanization. As population and salaries grow, and the price of manufacturing goods fall, equation (9) says that M_n will increase.

It is not clear though that this capital saving technical progress is sufficient to generate perpetual growth. It will depend on how fast the degree of labor specialization rises.

4.3   R&D-based growth in manufacturing

[Incomplete]

As the mass of labor tasks grow in manufacturing, the knowledge base useful for R&D will expand. At some point, B_{mt} will be sufficiently large, and the R&D sector will open and start generating ideas directed to manufacturing.

4.4   R&D-based modern growth

[Incomplete]

After opening, the R&D sector will not start right away generating designs for agriculture. This will not occur until sufficient spillovers from manufacturing R&D has been generated. Eventually, when both sectors enter the mechanized production regime, TFP can grow faster in agriculture than in manufacturing.

To see this, combine R&D technologies (12) and (13) with the optimal R&D allocation condition, equation (14). We can obtain that

$$\frac{g_{TFP_a,t}}{g_{TFP_m,t}} = \left(\frac{A_{mt}}{A_{at}}\right)^{1+\frac{\gamma-\phi}{1-\lambda}} M_{mt}^{-\frac{\tau}{1-\lambda}} \left(\frac{\pi_{at+1}}{\pi_{mt+1}}\right)^{\frac{\lambda}{1-\lambda}}. \tag{20}$$

From there, we observe that lower intertemporal knowledge spillovers (i.e., a lower ϕ) and larger cross-sector knowledge spillovers (i.e., a higher γ) can contribute to make the growth of agricultural TFP faster than the growth of TFP in manufacturing.

It it occurs, this faster TFP growth will be only temporal. The reason is that A_{at} will get closer to A_{mt} and, in addition, the value of new designs in manufacturing increases faster than in agriculture, because of the inflow of workers. A consequence of the latter effect is that it may even be the case that eventually the ratio (20) becomes less than one.

5   Conclusion

[To be completed]

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